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<td>RACT</td>
<td>reasonably achievable control technology</td>
</tr>
<tr>
<td>RCRA</td>
<td>Resource Conservation and Recovery Act</td>
</tr>
<tr>
<td>RFP</td>
<td>request for proposal</td>
</tr>
<tr>
<td>RI/FS</td>
<td>remedial investigation/feasibility study</td>
</tr>
<tr>
<td>RLWF</td>
<td>radioactive liquid waste facilities</td>
</tr>
<tr>
<td>RTD</td>
<td>resistance temperature detector</td>
</tr>
<tr>
<td>SCC</td>
<td>stress corrosion cracking</td>
</tr>
<tr>
<td>S/CI</td>
<td>suspect/counterfeit item</td>
</tr>
<tr>
<td>SDR</td>
<td>standard dimension ratio</td>
</tr>
<tr>
<td>SEB</td>
<td>Source Evaluation Board</td>
</tr>
<tr>
<td>sec</td>
<td>second</td>
</tr>
<tr>
<td>SO</td>
<td>Secretarial Officer</td>
</tr>
<tr>
<td>SMAW</td>
<td>shielded metal arc welding</td>
</tr>
<tr>
<td>SMRF</td>
<td>special moment resisting frame</td>
</tr>
<tr>
<td>SSA</td>
<td>source selection authority</td>
</tr>
<tr>
<td>SSC</td>
<td>structure, system, and component</td>
</tr>
<tr>
<td>TEC</td>
<td>technical evaluation committee</td>
</tr>
<tr>
<td>TSCA</td>
<td>Toxic Substances Control Act</td>
</tr>
<tr>
<td>TSR</td>
<td>technical safety requirements</td>
</tr>
<tr>
<td>TxDOT</td>
<td>Texas Department of Transportation</td>
</tr>
<tr>
<td>UBC</td>
<td>Uniform Building Code</td>
</tr>
<tr>
<td>UL</td>
<td>Underwriter’s Laboratory</td>
</tr>
<tr>
<td>UPC</td>
<td>Uniform Plumbing Code</td>
</tr>
<tr>
<td>UPS</td>
<td>Uninterrupted power supply</td>
</tr>
<tr>
<td>USGS</td>
<td>U.S. Geological Society</td>
</tr>
<tr>
<td>USQ</td>
<td>unreviewed safety question</td>
</tr>
<tr>
<td>UV</td>
<td>ultraviolet</td>
</tr>
<tr>
<td>VAF</td>
<td>vertical arching factor</td>
</tr>
<tr>
<td>WBS</td>
<td>work breakdown structure</td>
</tr>
<tr>
<td>WPS</td>
<td>welding procedure specification</td>
</tr>
<tr>
<td>WQTR</td>
<td>welder qualification test record</td>
</tr>
</tbody>
</table>
PURPOSE
The purpose of this reference guide is to provide a document that contains the information required for a Department of Energy (DOE)/National Nuclear Security Administration (NNSA) technical employee to successfully complete the Construction Management Functional Area Qualification Standard (FAQS). Information essential to meeting the qualification requirements is provided; however, some competency statements require extensive knowledge or skill development. Reproducing all the required information for those statements in this document is not practical. In those instances, references are included to guide the candidate to additional resources.

SCOPE

Please direct your questions or comments related to this document to the NNSA Learning and Career Development Department.

PREFACE
Competency statements and supporting knowledge and/or skill statements from the qualification standard are shown in contrasting bold type, while the corresponding information associated with each statement is provided below it.

A comprehensive list of acronyms and abbreviations is found at the beginning of this document. It is recommended that the candidate review the list prior to proceeding with the competencies, as the acronyms and abbreviations may not be further defined within the text unless special emphasis is required.

The competencies and supporting knowledge, skill, and ability (KSA) statements are taken directly from the FAQS. Most corrections to spelling, punctuation, and grammar have been made without remark, and all document-related titles, which variously appear in roman or italic type or set within quotation marks, have been changed to plain text, also mostly without remark. Capitalized terms are found as such in the qualification standard and remain so in this reference guide. When they are needed for clarification, explanations are enclosed in brackets.

Every effort has been made to provide the most current information and references available as of August 2009. However, the candidate is advised to verify the applicability of the information provided. It is recognized that some personnel may oversee facilities that utilize predecessor documents to those identified. In those cases, such documents should be included in local qualification standards via the Technical Qualification Program.

In the cases where information about an FAQS topic in a competency or KSA statement is not available in the newest edition of a standard (consensus or industry), an older version is referenced. These references are noted in the text and in the bibliography.
Only significant corrections to errors in the technical content of the discussion text source material are identified. Editorial changes that do not affect the technical content (e.g., grammatical or spelling corrections, and changes to style) appear without remark.
TECHNICAL COMPETENCIES

1. Construction management personnel shall demonstrate familiarity level knowledge of techniques, equipment, and documentation of surveys.

   a. Discuss the mathematical basis for horizontal and vertical control.

The following is taken from the Federal Geographic Data Committee, FGDC-STD-007.4-2002.

Control surveys are performed to locate, align, and stake out construction for civil and military projects. They provide the base horizontal and vertical control used for preliminary studies, photogrammetric and topographic mapping, detailed site plan drawings for construction plans, construction stake out, construction measurement and payment, preparing as-built drawings, installation master planning mapping, and future maintenance and repair activities. Two types of survey accuracies may be specified: (1) Positional accuracy or (2) Relative closure ratio accuracy.

**Positional Accuracy**

Base control surveys should be performed to a 95 percent positional confidence level consistent with the engineering or construction application or specifications. In general, horizontal and vertical control point accuracies should be twice as accurate as positional or elevation tolerances required for features or objects on the site plans or maps. Determination and verification of 95 percent radial positional accuracies will require use of rigorous least-squares adjustment techniques.

**Relative Closure Ratio Accuracy**

The accuracy of architecture, engineering, and construction (A/E/C) control surveys may be evaluated, classified, and reported based on closure ratios for the horizontal point or the vertical elevation difference, as obtained in the field when points or benchmarks are redundantly occupied. This relative accuracy standard is applicable to most types of survey equipment and practices. Many state codes and/or state minimum technical standards require that accuracies of A/E/C surveys be evaluated and reported using survey closure ratios.

There is no simple correlation between relative closure accuracies and 95 percent radial positional accuracies; thus, determining a closure order based on a specified feature accuracy requirement is, at best, only an approximate process. Where practical and allowable, positional accuracy standards should be used instead of closure accuracy standards.

Project specifications will specify the geographic extent of data to be tested and the amount of testing (if any). Map testing should be performed within a fixed time period after delivery. Normally, a mapping organization will perform quality control tests under quality assurance oversight by the requesting agency. Accuracies of A/E/C features are reported at the 95 percent confidence level. Field observed X, Y or Z coordinate differences are converted to 95 percent confidence errors. Horizontal accuracy is tested by comparing the planimetric coordinates of well-defined ground points with coordinates of the same points from an independent source of higher accuracy. Vertical accuracy is tested by comparing the
elevations of well-defined points with elevations of the same points as determined from a source of higher accuracy.

Engineering and construction surveys are normally specified, classified, and reported based on the horizontal (linear) point closure ratios or the vertical elevation difference closures. This performance criterion is most commonly specified in Federal agency, state, and local surveying standards. These control surveys are performed to establish control, location, alignment, and grade of various types of construction.

Local accuracy standards for survey control will vary with the type of construction. Commonly specified and reported orders of horizontal closure accuracy standards are shown in table 1.

<table>
<thead>
<tr>
<th>Classification Order</th>
<th>Closure Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering and Construction Control</td>
<td>Distance (Ratio)</td>
</tr>
<tr>
<td>Second-order, Class I</td>
<td>1:50,000</td>
</tr>
<tr>
<td>Second-order Class II</td>
<td>1:20,000</td>
</tr>
<tr>
<td>Third-order, Class I</td>
<td>1:10,000</td>
</tr>
<tr>
<td>Third-order, Class II</td>
<td>1:5,000</td>
</tr>
<tr>
<td>Construction</td>
<td>1:2,500</td>
</tr>
</tbody>
</table>

N = Number of angle stations

Source: FGDC-STD-007.2-2002

Relative accuracy closure ratios for horizontal A/E/C surveys typically range from a minimum of 1:2,500 up to 1:20,000. Lower accuracies (1:2,500-1:5,000) are acceptable for earthwork, dredging, embankment, beach fill, and levee alignment stakeout and grading, and some site plan, curb and gutter, utility building foundation, sidewalk, and small roadway stakeout. Moderate accuracies (1:5,000) are used in most pipeline, sewer, culvert, catch basin, and manhole stakeouts, and for general residential building foundation and footing construction, major highway pavement, bridges, and concrete runway stakeout work. Somewhat higher accuracies (1:10,000-1:20,000) are used for aligning longer bridge spans, tunnels, and large commercial structures. For extensive bridge or tunnel projects, 1:50,000 or even 1:100,000 relative accuracy alignment work may be specified.

Orders of elevation closure ratio standards are shown in table 2. Most construction work is performed to third-order standards. These standards are applicable to most types of engineering and construction survey equipment and practices.
Table 2. Minimum elevation closure standards for vertical control surveys

<table>
<thead>
<tr>
<th>Classification Order</th>
<th>Elevation (ft)</th>
<th>Closure Standard (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First-order, Class I</td>
<td>0.013oM</td>
<td>3oK</td>
</tr>
<tr>
<td>First-order Class II</td>
<td>0.017oM</td>
<td>4oK</td>
</tr>
<tr>
<td>Second-order, Class I</td>
<td>0.025oM</td>
<td>6oK</td>
</tr>
<tr>
<td>Second-order, Class II</td>
<td>0.035oM</td>
<td>8oK</td>
</tr>
<tr>
<td>Third-order</td>
<td>0.050oM</td>
<td>12oK</td>
</tr>
<tr>
<td>Construction Layout</td>
<td>0.100oM</td>
<td>24oK</td>
</tr>
</tbody>
</table>

oM or oK = square root of distance in miles or kilometers (km)

Source: FGDC-STD-007.4-2002

b. Discuss the different types of surveying equipment commonly used on a construction project, including their applications and limitations.

The following is taken from the State of Nevada Department of Transportation Construction Manual.

Construction surveys utilize a variety of specialized instruments. Following are the two most common technologies used for construction surveys:

Total Station
The total station is an instrument that replaces the outdated transit/theodolite. It measures angles, electronically measures distances, and provides the ability of robotic survey, in which the user remotely operates the instrument from the area to be staked. It allows the user to include accurate elevation information for every staked point. The total station is limited by sight distance and radio strength, but is more accurate than global positioning systems (GPS).

Global Positioning System (GPS)
GPS is preferred because of its mobility and efficiency. Only one or two people are required to perform the survey. Because the technology uses satellites, the survey coverage area is extensive.

c. Describe the methods for verifying proper survey equipment calibration.

The following is taken from National Geodetic Survey, GPS Survey Equipment.

Basic instrumentation for a GPS network survey includes multiple sets of receivers, antennas, fixed-height tripods, and meteorological instruments. Identical equipment should be used whenever possible to minimize the effect of equipment biases. The compatibility of mixing different instrument models or brands should be demonstrated by performing a validation survey.

Survey equipment, like all scientific instrumentation, should be handled with care, maintained according to manufacturer specifications, and calibrated on a regular basis. Equipment calibrations should be performed at the start and end of a project, before and after
any maintenance, and at sufficient intervals to maintain data integrity. Any data not bracketed by successful calibrations are suspect. To prevent the invalidation of good data, frequent calibrations are recommended. The entire system of GPS equipment, personnel, and processing procedures should be proven with a validation survey as a final check to ensure all components interact properly.

Calibration for the following equipment is described below:

- Receiver
- Antenna
- Tripod
- Tribrach
- Meteorological equipment

**Receiver**
The receivers used for network surveys should record the full wavelength carrier phase and signal strength of both the L1 and L2 frequencies, and track at least eight satellites simultaneously on parallel channels. Dual frequency instruments are required for all baselines longer than 10 km.

Ensure that the receivers should have sufficient memory and battery power for the entire field campaign.

Receiver test reports are available from the Federal geodetic control subcommittee.

Ensure that the receiver contains the latest manufacturer’s firmware upgrades. A zero-baseline test can measure receiver internal noise if the performance is suspect. Consult the user’s manual for additional specifications.

**Antenna**
All antenna models used shall have undergone antenna calibration by the national geodetic survey. Consult the user’s manual for other specifications.

**Tripod**
The tripods used must facilitate precise offset measurements between the mark datum point and the antenna reference point. Fixed height tripods are preferable, due to the decreased potential for antenna centering and height measurement errors.

All tripods shall be examined for stability with each use. Ensure that hinges, clamps, and feet are secure and in good repair.

Fixed-height tripods shall be tested for stability, plumb alignment, and height verification at the start and end of each project.

**Tribrachs**
Used shall be of suitable quality and condition for high-accuracy surveys. Consult with your project coordinator for details.

The optical plummet alignment shall be tested at the start and end of each project.
**Meteorological Equipment Calibration and Care**

Meteorological equipment should be calibrated at the beginning and end of a project. Compare your instruments with standard instruments, available at National Weather Service offices.

d. Discuss the care and handling of survey equipment.

The following is taken from Integrated Publishing, Engineering, “Care and Adjustment of Surveying Equipment.”

Always exercise care in handling instruments, such as the transit, level, theodolite, or plane table. When removing an instrument from its carrying case, never grasp the telescope. Wrenching the telescope in this manner could damage a number of delicate parts. When you set up an instrument, make sure that it is securely fastened to the tripod head. In tightening the various clamp screws, leveling screws, and adjustment screws, bring them only to a firm bearing. Over tightening these screws may strip the threads, twist off the screw, bend the connecting part, or place undue stresses in the instrument. Never leave an instrument unattended while it is set on a street, near construction work, or in any other place where it can be damaged. When carrying an instrument mounted on a tripod, place the instrument and tripod on one shoulder with the tripod legs pointing forward and held together by your hand and forearm. If walking along a side hill, carry the instrument on the downhill shoulder. This leaves the uphill arm and hand free to catch yourself should you trip or stumble. Before climbing over a fence, place the instrument on the other side with the tripod legs well spread. Also, when carrying an instrument, ensure that all clamp screws are only lightly clamped so that the parts will move if the instrument is struck. Avoid carrying the instrument on your shoulder through doorways or beneath low-hanging branches; instead, carry it under your arm with the head of the instrument to the front. Every transit, theodolite, or level comes equipped with a carrying box or case. The instrument and its accessories can be stowed in the case in a manner that ensures a minimum of motion during transportation. The instrument should always be stowed in the carrying case when it is not in use. Bags are provided for carrying stakes and hubs. These are usually canvas bags equipped with a shoulder strap and closely resemble a newsboy’s bag. A newsboy’s bag, in fact, makes an excellent carrying bag for stakes and hubs. So does a Navy sea bag, equipped with a shoulder strap. Various types of leather or canvas bags and sheaths, such as chaining-pin quivers, plumb-bob sheaths, and sheaths for Abney and Locke levels, are provided for various items of equipment. Most of these can be attached to the belt. Leather pouches, also usually attachable to the belt, are available for carrying small tools, marking equipment, turning-point pins, and the like.

All surveying instruments, equipment, or tools must be thoroughly cleaned immediately after use. For example, after each use, dust off the transit or theodolite and wipe it dry before placing it back in its case. Remove all dust with a soft brush before wiping dirty components with a clean cloth. When the instrument becomes wet, you should remove it from its carrying case and dry it thoroughly at room temperature. Never leave a wet instrument stored in the carrying case. Never rub the lenses of a telescope with a rough cloth. A clean, chamois leather or a lint-free, soft cloth is suitable for this purpose. Occasionally, clean the lenses with a soft cloth that is dampened with a mixture of equal parts of water and alcohol. Remove mud and dirt from tripods, range poles, leveling rods immediately after each use. This is very important, especially when the surveying gear is made of a material that is
susceptible to rust action or decay. When lubricating instruments, you must use the right lubricant that is recommended for the local climatic condition. For instance, it is recommended that graphite be used to lubricate the moving parts of a transit when the transit is to be used in sub-zero temperatures. However, in warmer climates use a light film of oil.

e. Describe standard practices for preparing survey field notes.

The following is taken from the State of Texas, Department of Transportation TxDOT Survey Manual.

The field notes of the surveyor must contain a complete record of all measurements made during the survey with sketches and narration, where necessary, to clarify the notes. The best field survey is of little value if the notes are not complete and clear. They are the only record that is left after the field party leaves the survey site.

All field notes should be lettered legibly. Numerals and decimal points should be legible and permit only one interpretation. Notes must be kept in the regular field notebook and not on scraps of paper for later transcription. The field notebook is a permanently bound book (not loose-leaf) for recording measurements made in the field.

Field note recording takes three general forms: tabulations, sketches, and descriptions. Two, or even all three forms, are combined when necessary to make a complete record.

Tabulation
Measurements may be recorded manually in a field book or they may be recorded electronically through a data collector. Electronic data collection has the advantage of eliminating reading and recording errors.

Sketches
Sketches add much to clarify electronic data collection files and should be used as a supplemental record of the survey. They may be drawn to an approximate scale, or important details may be exaggerated for clarity. Measurements may be placed directly onto the sketch or keyed in some way to the tabular data. A very important requirement of a sketch is legibility. It should be drawn clearly and large enough to be understandable.

Descriptions
Tabulations with or without added sketches can also be supplemented with descriptions. The description may only be one or two words to clarify the recorded measurements, or it may be quite lengthy to cover and record pertinent details of the survey.

Note: Erasures are not permitted in field notebooks. Individual numbers or lines recorded incorrectly shall be lined out and the correct values added. Pages that are to be rejected are crossed out neatly and referenced to the substituted page. This procedure is mandatory since the field notebook is the book of record and it is often used as legal evidence.
f. Discuss the appropriate state requirements for preparing survey documentation, drawings, site plans, profiles, and contours.

Requirements for preparing survey documentation vary from state-to-state so a local professional surveyor should be consulted to complete this KSA. Your local Qualifying Official may be able to identify a local resource.

g. Read and interpret survey field notes.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

h. Define and discuss error closure as it applies to surveying.

The following is taken from Integrated Publishing, *Engineering*, “Linear Error of Closure.”

In a typical survey the sum of the north latitudes usually differs from the sum of the south latitudes. The difference is called the error of closure in latitude. Similarly, the sum of the east departures usually differs from the sum of the west departures. The difference is called error of closure in departure. From the error of closure in latitude and the error of closure in departure, you can determine the linear error of closure. This is the horizontal linear distance between the location of the end of the last traverse line (as computed from the measured angles and distances) and the actual point of beginning of the closed traverse.

2. Construction management personnel shall demonstrate a familiarity level of knowledge for establishing control points.

a. Select the proper instruments for establishing control points.

The following is taken from Penn State University, Department of Geography, “Chapter 5: Land Surveying and GPS.”

Surveyors have developed distinct methods, based on separate control networks, for measuring horizontal and vertical positions. In this context, a horizontal position is the location of a point relative to two axes: the equator and the prime meridian on the globe, or x and y axes in a plane coordinate system. Control points tie coordinate systems to actual locations on the ground; they are the physical manifestations of horizontal datums.

Surveyors typically measure positions in series. Starting at control points, they measure angles and distances to new locations, and use trigonometry to calculate positions in a plane coordinate system. Measuring a series of positions in this way is known as running a traverse. A traverse that begins and ends at different locations is called an open traverse.
For example, say the coordinates of point A in figure 1 are 500,000.00 East and 5,000,000.00 North. The distance between points A and P, measured with a steel tape or an electronic distance measurement (EDM), is 2,828.40 meters. The azimuth of the line AP, measured with a transit or theodolite is 45º. Using these two measurements the coordinates of point P can be calculated as follows.

\[
\begin{align*}
X_p &= X_A + (AP \times \sin \alpha) \\
Y_p &= Y_A + (AP \times \cos \alpha)
\end{align*}
\]

A traverse that begins and ends at the same point, or at two different but known points is called a closed traverse. Measurement errors in a closed traverse can be quantified by summing the interior angles of the polygon formed by the traverse. The accuracy of a single angle measurement cannot be known, but since the sum of the interior angles of a polygon is always \((n-2) \times 180\), it is possible to evaluate the traverse as a whole, and to distribute the accumulated errors among all the interior angles.

Errors produced in an open traverse, one that does not end where it started, cannot be assessed or corrected. The only way to assess the accuracy of an open traverse is to measure distances and angles repeatedly, forward and backward, and to average the results of calculations. Because repeated measurements are costly, other surveying techniques that enable surveyors to calculate and account for measurement errors are preferred over open traverses for most applications.

Closed traverses yield adequate accuracy for property boundary surveys, provided that an established control point is nearby. Surveyors conduct control surveys to extend and densify

*Source: Penn State University, Department of Geography*

**Figure 1.** An open traverse
horizontal control networks. Before survey-grade satellite positioning was available, the most common technique for conducting control surveys was triangulation.

*Source:* Penn State University, Department of Geography

**Figure 2.** The purpose of a control survey is to establish new horizontal control points (B, C, D) based on an existing control point (A)

Using a total station equipped with an EDM, the control survey team commences by measuring the azimuth alpha, and the baseline distance AB. These two measurements enable the survey team to calculate position B as in an open traverse. Before geodetic-grade GPS became available, the accuracy of the calculated position B may have been evaluated by astronomical observation.
The surveyors next measure the interior angles $\angle CAB$, $\angle ABC$, and $\angle BCA$ at point A, B, and C. Knowing the interior angles and the baseline length, the trigonometric law of sines can be used to calculate the lengths of any other side. Knowing these dimensions, surveyors can fix the position of point C.

*Source:* Penn State University, Department of Geography

**Figure 3.** Establishing a second control point (B) in a triangulation network
Having measured three interior angles and the length of one side of triangle ABC, the control survey team can calculate the length of side BC. This calculated length then serves as a baseline for triangle BDC. Triangulation is thus used to extend control networks, point by point and triangle by triangle.

*Source:* Penn State University, Department of Geography

**Figure 4.** Establishing the position of point C by triangulation
b. **Discuss the procedure for measuring angles and distances.**

The following is taken from Penn State University, Department of Geography, “Chapter 5: Land Surveying and GPS.”

*Measuring Angles*

Angles can be measured with a magnetic compass, of course. Unfortunately, the earth’s magnetic field does not yield the most reliable measurements. The magnetic poles are not aligned with the planet’s axis of rotation (an effect called magnetic declination), and they tend to change location over time. Local magnetic anomalies caused by magnetized rocks in the Earth’s crust and other geomagnetic fields make matters worse.

For these reasons land surveyors rely on transits (or their more modern equivalents, called theodolites) to measure angles. A transit consists of a telescope for siting distant target objects, two measurement wheels that work like protractors for reading horizontal and vertical angles, and bubble levels to ensure that the angles are true. A theodolite is essentially the same instrument, except that some mechanical parts are replaced with electronics.

Surveyors express angles in several ways. When specifying directions, as is done in the preparation of a property survey, angles may be specified as bearings or azimuths. A bearing is an angle less than 90° within a quadrant defined by the cardinal directions. An azimuth is
an angle between 0° and 360° measured clockwise from North. South 45° East and 135° are 
the same direction expressed as a bearing and as an azimuth. An interior angle, by contrast, is 
an angle measured between two lines of sight, or between two legs of a traverse (described 
later in this chapter).

U.S. professional organizations like the American Congress on Surveying and Mapping, the 
American Land Title Association, the National Society of Professional Land Surveyors, and 
others, recommend minimum accuracy standards for angle and distance measurements. To 
achieve this level of accuracy, surveyors must overcome errors caused by faulty instrument 
calibration; wind, temperature, and soft ground; and human errors, including misplacing the 
instrument and misreading the measurement wheels. In practice, surveyors produce accurate 
data by taking repeated measurements and averaging the results.

Measuring Distances
To measure distances, land surveyors once used 100-foot long metal tapes that are graduated 
in hundredths of a foot. Distances along slopes are measured in short horizontal segments. 
Skilled surveyors can achieve accuracies of up to one part in 10,000 (1 centimeter error for 
every 100 meters distance). Sources of error include flaws in the tape itself, such as kinks; 
variations in tape length due to extremes in temperature; and human errors such as 
inconsistent pull, allowing the tape to stray from the horizontal plane, and incorrect readings.

Since the 1980s, EDM devices have allowed surveyors to measure distances more accurately 
and more efficiently than they can with tapes. To measure the horizontal distance between 
two points, one surveyor uses an EDM instrument to shoot an energy wave toward a reflector 
held by the second surveyor. The EDM records the elapsed time between the wave’s 
emission and its return from the reflector. It then calculates distance as a function of the 
elapsed time. Typical short-range EDMs can be used to measure distances as great as 5 
kilometers at accuracies up to one part in 20,000, twice as accurate as taping.

Instruments called total stations as shown in figure 6 combine electronic distance 
measurement and the angle measuring capabilities of theodolites in one unit.
**c. Determine the proper route using known points.**

The following is taken from American Society of Civil Engineers (ASCE), *Topographic Surveying*.

Route surveys are most commonly used for levees, stream channels, highways, railways, canals, power transmission lines, pipelines, and other utilities. Route surveys consist of:

- determining ground configuration and the location of objects within and along a proposed route;
- establishing the alignment of the route;
- determining volumes of earthwork required for construction.

After the initial staking of the alignment has been closed through a set of primary control points and adjustments have been made, centerline/baseline stationing will identify all points established on the route. Differential levels are established through the area from two previously established benchmarks. Cross sections in the past were taken left and right of centerline. Today, digital terrain models or photogrammetry is used to produce cross sections for design grades. Surveys may be conducted to check these sections at intermittent stations along the centerline. Ground elevations and features will be recorded as required.

Route surveys often require layout of horizontal curves. The point of curvature (PC), point of intersection, and point of tangency (PT) should be established on centerline, identified, and staked, including offsets to the centerline. Figure 7 is a sketch of a horizontal curve. The traverse routes through the curve will be included into the closed traverse through two
primary or secondary control points for closure and adjustment. Field layout/stakeout should be no more than 100 feet (ft.) along the curve on even stationing. PCs, angle points, and or PIs should be referenced outside the clearing limits or the construction area.

Source: ASCE, Topographic Surveying

Figure 7. Horizontal curve

where

\[ \Delta = \text{Central and deflection angle} \]

PC = Point of curvature

PT = Point of tangency

T = Tangent

R = Radius

C = Long chord

M = Middle ordinate

E = External

d. **Estimate turning points.**

The following is taken from State of Texas Department of Transportation *TxDOT Survey Manual*, January 2008.
During the course of running a level loop, choose/set turning points and bench marks to accomplish the required objective and accuracy.

Balance shot distances – The rod man and instrument man must work as a team to balance the back sight and foresight distances. This can be accomplished by the use of a digital level, estimating distance by pacing, three-wire stadia difference or, when available, by observing stationing marked on the project. Balanced back sights and foresights, essential in precise leveling, will help eliminate errors caused by refraction, the curvature of the earth and an instrument that is out of adjustment and are an especially necessary procedure when establishing control bench marks.

Maximum sight distance – care should always be given to observe recommended or required distance of sight, depending on the purpose of leveling.

Control points and bench marks should always be set to the highest level of accuracy suitable for the project or a higher level if it can be justified.

Turning points may be points set either before or during the course of the survey, or natural or man-made points in the area. They must be solid, well defined (or marked) and permanent enough to remain intact until the level loop is finished. Points with a small, sharply defined top are preferred to large flat surfaces.

Turning points should be marked when used so as to insure that the rod is in the exact same place when the back sight and foresight are taken. They are also marked because turning points that are part of a closed level loop are points of known elevation that may have value during future surveys in the area.

Temporary bench marks can be turning points that remain or additional intermediate bench marks placed for added convenience.

Temporary bench marks set in trees or power poles should consist of a spike (railroad spike, boat spike, or large nail spike) set horizontally approximately 1 to 2 ft. above ground elevation, also free of above obstructions to the level rod

e. Define and discuss the following terms associated with control points:
   - Benchmark
   - Back-site
   - Temporary benchmark
   - Turning point
   - Latitudes
   - Departures
   - Instrument height
   - Bearings
   - Grid coordinates

   Benchmark
   The following is taken from the National Geodetic Society, Geodetic Glossary.
A relatively permanent, natural or artificial, material object bearing a marked point whose elevation above or below an adopted surface (datum) is known. Such a mark is sometimes further qualified as a permanent bench mark to distinguish it from a temporary bench mark.

Back-Sight
The following is taken from the National Geodetic Society, Geodetic Glossary.

(1) A sight to a previously established point of a survey, or the reading or measurement obtained by that sight. (2) (leveling) In leveling from an initial point to a final point through a sequence of intermediate points, a sight to (or the reading on) a leveling rod held on a preceding point.

The sight to, or reading on, a leveling rod on the succeeding point is called the foresight. In leveling, a back sight is sometimes called a plus sight, because its value is added to the elevation of the point on which the leveling rod is placed to obtain the elevation of the leveling instrument. But if the sight is to a mark on a wall or in the roof of a mine tunnel, with the instrument at a lower elevation than the mark, the back sight will be subtracted from the known elevation to obtain the height of the instrument. The term back sight is preferred over plus sight. Neither of these definitions requires that the point or leveling rod to which the sight is made be at a point whose coordinates have been defined or determined previously. If the sequence consists of only two points, it does not matter which is called the back sight and which the foresight.

Temporary Benchmark
The following is taken from the National Geodetic Society, Geodetic Glossary.

A bench mark established to hold, temporarily, the end of a completed section of a line of levels and to serve as a starting point from which the next section is run. Spikes and screws in poles, bolts on bridges, and chiseled marks on masonry have been used as temporary bench marks; some last for years. A temporary benchmark is also called a supplementary bench mark.

Turning Point
The following is taken from Integrated Publishing, Engineering, “Turning Points Pins and Plates.”

The point on which a leveling rod is held between a foresight and the next back sight while the instrument is being moved to the next setup is called a turning point.

Latitudes
The following is taken from the National Geodetic Society, Geodetic Glossary.

In general, the angular coordinate of a point specified as the angle from a reference plane to a suitably chosen line through that point. An angle measured northward or upward from the reference plane is considered positive; one measured southward is considered negative. The definition of northward is conventional. The reference plane in the case of the Earth is the Equator, but the reference plane can also be the plane of the ecliptic.
The length of the arc, on an ellipsoid representing the Earth and in a plane through the polar axis, between the equatorial plane and a specified point of the ellipsoid.

In plane surveying, the perpendicular distance, in a horizontal plane from an east-west reference line to the specified point.

The difference in latitudes (in this sense) of the two ends of a line is sometimes called the latitude of the line. This term also describes the perpendicular distance of the middle of a line from the east-west reference line.

*Departures*

The following is taken from the National Geodetic Society, Geodetic Glossary.

The orthogonal projection of a line onto an east-west axis of reference. The departure of a line is the difference of the meridian distances or longitudes of the ends of the line. It is east or positive, and sometimes called the easting, for a line whose azimuth or bearing is in the northeast or southeast quadrant; it is west or negative, and sometimes called the westing, for a line whose azimuth or bearing is in the southwest or northwest quadrant.

*Instrument Height*

The following is taken from Integrated Publishing, *Construction*, “Differential Leveling.”

The first step in finding the elevation point is to determine the elevation of the line of sight of the instrument. This is known as the height of instrument and is often written and referred to simply as H.I. To determine the H.I., you take a back sight on a level rod held vertically on the bench mark by a rod man. A back sight is always taken after a new instrument position is set up by sighting back to a known elevation to get the new H.I. A leveling rod is graduated upward in feet, from 0 at its base, with appropriate subdivisions in feet.

*Bearings*

The following is taken from the National Geodetic Society, Geodetic Glossary.

In general, the horizontal angle between a line from the observer to a given point, and a line from the observer along a specified direction (such as north).

Various conventions can apply. For example, the bearing can be determined either clockwise or counterclockwise from the specified direction, so that the bearing does not exceed 180°.

The horizontal angle that a line makes with the meridian of reference adjacent to the quadrant in which the line lies. Bearings are classified according to the reference meridian used, as true bearings, magnetic bearings, or grid bearings. A bearing is identified by naming the end of the meridian (north or south) from which it is reckoned and the direction (east or west) of that reckoning. Thus, a line in the northeast quadrant making an angle of 50° with the meridian will have a bearing of N. 50°E. In most survey work it is preferable to use azimuths rather than bearings.

*Grid Coordinates*

The following is taken from the National Geodetic Society, Geodetic Glossary.
A network composed of two families of lines such that a pair of lines, one from each family, intersects in no more than two points.

An example of a grid on a globe is a family of great circles intersecting each other at two points called the poles and a family of small circles concentric about the poles. The small circle equidistant from the two poles is also a great circle and is called the equator. The grid on a flat surface is most commonly composed of two families of straight lines intersecting at right angles. Another common grid in the plane consists of a pencil of straight lines radiating from a point and a family of concentric circles having that point as center. A grid differs from a coordinate system in that the grid consists of a finite number of lines intersecting in a finite number of points of the surface on which the grid lies. A coordinate system consists, in concept, of an infinite number of lines so that every point of the surface is at the intersection of two lines. The term is sometimes applied to the figure resulting by erasing all of each line except the small portions in the immediate vicinity of points of intersection. The resulting figure is an array of small crosses and is more commonly called a reseau.

3. **Construction management personnel shall demonstrate a working level knowledge of the principles and construction methods associated with grading, paving, and drainage for site preparation.**

   a. Read and interpret a site plan drawing.

   b. Read and interpret a contour map.

   c. From a site plan show how quantities of earth required for fill or removal were derived.

Elements a through c are performance-based KSAs. The Qualifying Official will evaluate their completion.

d. **Discuss field and lab soil compaction methodologies and utilization criteria.**

The following is taken from the PDH Center, Field Compaction Methods for Soils.

Compaction is the densification of sil materials by the use of mechanical energy, soil is compacted by removing air and water from its pore space. There exists a certain amount of moisture that a soil can have where a maximum unit weight is obtained. When the soil is compacted to this state it is referred to as the maximum moisture/unit weight. The maximum moisture/unit weight is used exclusively to determine the degree of compaction of the earth backfill. There are several steps to determine the degree of compaction of soil; the most widely used of those steps are described below.

**Lab Analysis**

Generally, before any soil compaction occurs, various samples of the proposed embankment or fill are analyzed in the lab. One such lab test is the proctor compaction test. The proctor compaction test is a test that compacts the soil material at various moisture contents. There are two proctor tests that are defined by the American Association of Highway Officials and American Standard Testing Material. The use of the standard or modified proctor test should
be used the discretion of the engineer. The standard test is generally used for rills requiring the minimal sub-grade compaction, such as small parking lots, and building structures and the modified proctor is used for fills that will support large loads, such as roadways, airport runways, and concrete parking aprons.

Field Compaction
Field compaction of soils is mainly done with various types of rollers. The three most common types of rollers are:
1. Sheepsfoot rollers, used mainly for clayey and silty soils
2. Smooth-drum rollers, used primarily for granular soils
3. Vibratory rollers, used primarily for granular soils

Several factors affect the degree of field compaction. Those factors are moisture type of sil and depth of fill. Soil is generally placed in lifts of 6 in. to 1 ft. high. The size and type of the compaction equipment and desired relative density is essential to determining the depth of lift. It is at the discretion of the engineer to specify the fill lifts when compacting backfill. Soil lifts should be specified as to give the required compaction with the least amount of passes of the compaction equipment.

Generally, a contractor is given a percentage of optimum compaction that must be attained in the field. This is referred to as the relative density. Relative densities range from 90 to 95 percent as compared to the modified proctor and 95 to 100 percent as compared to the standard proctor. Generally, granular fills are required to be compacted to 95 to 100 percent in the field.

e. Define the following terms as they relate to horizontal curves:
   - Point of intersection
   - Point of tangency (PT)
   - Point of curvature (PC)

The following definitions are taken from the National Geodetic Society, *Geodetic Glossary*.

Point of Intersection
The point of intersection is the point where the two tangents at the extremities of a circular arc meet. Also called the vertex of curve, or the point of intersection

Point of Tangency
The point of tangency is the point of a line where a circular curve ends and a tangent begins. The point of tangency and point of curvature are both points of tangency to a curve, their different designations being determined by the direction of progress along the line. The point of curvature is reached first.

Point of Curvature
The point of curvature is the point, on a line, where a tangent ends and a circular curve begins. It is the point where a straight line in a survey changes to a circular curve.
f. Discuss the characteristics of rigid and flexible pavement.

The following is taken from State of Texas, Department of Transportation, TxDOT, *Pavement Design Guide*.

**Rigid Pavement**

Rigid pavement structure is composed of a hydraulic cement concrete surface course, and underlying base and sub-base courses (if used). Another term commonly used is Portland cement concrete pavement (PCC), although with today’s pozzolanic additives, cements may no longer be technically classified as “Portland.”

The surface course (concrete slab) is the stiffest and provides the majority of strength. The base or sub-base layers are orders of magnitude less stiff than the PCC surface but still make important contributions to pavement drainage, frost protection and provide a working platform for construction equipment.

Rigid pavements are substantially ‘stiffer’ than flexible pavements due to the high modulus of elasticity of the PCC material resulting in very low deflections under loading. The rigid pavements can be analyzed by the plate theory. Rigid pavements can have reinforcing steel, which is generally used to handle thermal stresses to reduce or eliminate joints and maintain tight crack widths. Figure 8 shows a typical section for a rigid pavement.

*Source: TxDOT, Pavement Design Guide*

**Figure 8.** Typical section for a rigid pavement

**Flexible Pavement**

A flexible pavement structure is typically composed of several layers of material with better quality materials on top where the intensity of stress from traffic loads is high and lower
quality materials at the bottom where the stress intensity is low. Flexible pavements can be analyzed as a multilayer system under loading.

A typical flexible pavement structure consists of the surface course and underlying base and sub-base courses. Each of these layers contributes to structural support and drainage. When hot mix asphalt is used as the surface course, it is the stiffest (as measured by resilient modulus) and may contribute the most (depending upon thickness) to pavement strength. The underlying layers are less stiff but are still important to pavement strength as well as drainage and frost protection. When a seal coat is used as the surface course, the base generally is the layer that contributes most to the structural stiffness. A typical structural design results in a series of layers that gradually decrease in material quality with depth. Figure 9 shows a typical section for a flexible pavement.

![Flexible Pavement Structure](image)

Source: TxDOT, Pavement Design Guide

Figure 9. Typical section for a flexible pavement

g. Discuss the hydraulics associated with drainage to include:
   - Open channel flow
   - Flood zone determination

Open Channel Flow
The following is taken from the MoDOT Engineering Policy Guide.

Open channel flow may be classified into several different types. Flow in an open channel is said to be steady if the discharge is constant with respect to time. If the discharge is increasing or decreasing with time, the flow is said to be unsteady. In general, all open channel flow encountered in highway drainage problems is unsteady. That is, the flow rate in these channels will vary with time. Design, however, must be based on the worst condition to be expected within a reasonable period of time. This worst condition is the peak flow rate produced by the design flood. Therefore, in design, the time dependent variations of open channel flow are ignored and the channel is assumed to be operating in a steady state.

Steady state flow may be divided into two subgroups; these are: uniform flow and varied flow. Steady state uniform flow is the primary type of flow considered in open channel hydraulics and is the only type of flow to be treated in depth in this guidance on open channel flow. Channel design is based on analysis assuming uniform open channel flow. Varied flow may be subdivided into two classes as gradually varied or rapidly varied. Rapidly varied flow may take the form of either a hydraulic drop or a hydraulic jump.

The flow rate in a channel may also vary along the length of the channel. This type of flow is known as spatially varied open channel flow. That is, the flow rate varies in space. In
general, all open channel flow occurring during a runoff event is spatially varied. The best example of spatially varied flow in highway drainage design applications is the flow in a street gutter. Here the flow rate varies from zero at the high point of the pavement, to a maximum at the first down-stream inlet. The spatial variations of open channel flow are considered in the design of some highway drainage facilities

**Flood Zone Determination**

The following is taken from DOE-STD-1020-2002.

For new construction the storm water-management system can be designed according to applicable procedures and design criteria specified applicable regulations. Applicable local regulations must be considered in the design of the site storm water management system. The minimum design level for the storm water management system is the 25-year, 6-hour storm.

Once the site and facility drainage design has been developed, it should be evaluated for the design basis flood (DBFL) precipitation for each structure, system and component (SSC). The evaluation should consider the site-drainage area, natural and man-made watercourses, roof drainage, etc. The analysis shall determine the level of flooding that could occur at each SSC. The analyst may choose to evaluate the site storm water management system for the highest category DBFL (as a limiting case). If the results of this analysis demonstrate that flooding does not compromise the site SSCs, then it may be concluded that the site storm water management system is adequate. Note, that local flooding in streets, parking lots, etc. may occur due to the DBFL precipitation. This is acceptable if the effect of local flooding does not exceed the requirements of the performance goals. If however, flooding does have an unacceptable impact, increased drainage capacity and/or flood protection will be required.

Building roof design should provide adequate drainage in accordance with applicable regulations. Secondary drainage (overflow) should be provided at a higher level and have a capacity at least that of the primary drain. Limitations of water depth on a roof are specified by applicable local regulations.

Roof-drainage systems should be designed according to applicable regulations. The drainage system should be verified as part of the site analysis for the DBFL.

In the case of rainfall, a limiting check of the roof system structural design should be made. Ponding on the roof is assumed to occur to a maximum depth corresponding to the level of the secondary drainage outlet system (i.e., assuming the primary system has clogged). As part of this evaluation, the deflection of the roof due to ponding must be considered. The design of the roof should be adequate to meet the applicable codes. Design criteria for snow and rain-snow loads are defined in the model building codes and standards.

The DOE criteria specify the importance factors that should be used to scale snow loads in the design. In the design of roof systems for snow loads, the importance factor for performance categories 1 and 2 is 1.0. For performance categories 3 and 4 an importance factor of 1.2 should be used.

**h. Discuss the following elements of hydrostatics related to site preparation:**

- Hydrostatic pressure
- **Flood routing**
- **Hydraulic gradient**
- **Seepage**

**Hydrostatic Pressure**

The following is taken from *Water-Resistant Design and Construction*, by William L. Walker.

Measures must be taken to prevent hydrostatic pressure from introducing water into occupied spaces. In many coastal regions, there are areas that typically are well above the groundwater table. As a result of seasonal conditions, the water table may rise temporarily. Some soils create perched water tables, artificially keeping water locally higher than the average water table in the surrounding area. When the ground has more water than can be absorbed, it seeks relief. Often the rise can exceed 2 feet in elevation. This water will seek relief through even the smallest microscopic voids in concrete floors and walls.

There are several methods for preventing migration through walls and into a conditioned space, but the best protection is to keep the water from getting past the outside face of the wall. Two of the most common means for preventing water from getting into a wall are bentonite mats and plastic- or rubber-based impermeable sheet membranes. Some builders prefer the bentonite where the moisture levels are somewhat constant. Others rely only on the impermeable sheet membrane.

One of the inherent challenges is to prevent any punctures of the membrane. Pipes, conduit, and other requirement penetrations will need to be sealed properly. Whenever system is chose, if water does find a way in, there is likely to be a void in the system. That void must be dealt with. One proven method is to inject grout into holes that were drilled in the wall or floor slab near the apparent source of the leak. Another method involves the application of crystalline coatings that change the chemistry of the interior concrete to reduce water transmission.

Even well-intentioned maintenance procedures can result in hydrostatic introduction of water at the slab edge. Some maintenance practices include frequent pressure washing of walls and walks. The proper angle for the wand would be close to the wall so that deflected water moves away from the wall. In most cases the pressure wand is located so as to spray toward the wall, potentially degrading sealants and reflecting water into the wall cavity.

If maintenance plans are known in advance, the design team can develop a detail that will effectively prevent introduction of spray into the wall cavity.

**Flood Routing**

The following is taken from American Meteorological Society, AMS Glossary.

Flood routing, also known as storage routing or stream flow routing is a mathematical procedure for predicting the changing magnitude, speed, and shape of a flood wave as a function of time at one or more points along a waterway or channel.
Hydraulic Gradient

According to DOE Glossary of Terms Related to CERCLA, EPCRA, PPS, RCRA, & TSCA, hydraulic gradient is the change in total head with a change in distance in a given direction; the direction is that which yields a maximum rate of decrease in head.

Seepage

The following is taken from GeoEngineer, Permeability and Seepage.

Flow of water through soils is called seepage. Seepage takes place when there is difference in water levels on the two sides of the structure such as a dam or a sheet pile as shown in figure 10. Whenever there is seepage (e.g., beneath a concrete dam or a sheet pile), it is often necessary to estimate the quantity of the seepage, and permeability becomes the main parameter here.

Source: GeoEngineer, Permeability and Seepage

Figure 10. Seepage beneath a concrete dam and beneath a sheet pile

Sheet piles are interlocking walls, made of steel, timber or concrete segments. They are used as water front structures and cofferdams (temporary structure made of interlocking sheet piles, making up an impermeable wall surrounding an area, often for construction works).

i. Discuss the construction methods and requirements associated with earth work and trenching. Include the following elements in the discussion:
   - Water pollution and soil erosion
   - Noise pollution
   - Traffic control measures
   - Dust control
   - Personnel protection

Water Pollution and Soil Erosion

The following is taken from the Transportation Research Board, National Research Council, Guide to Earthwork Construction.

One of the first requirements of construction is to prevent damage to local water bodies by not permitting the construction runoff water to mix with any local stream, lake, or other nearby water body. This can best be achieved by reducing soil erosion caused by surface
runoff where possible and by preventing unavoidable soil erosion from leaving the construction site.

Normal rainfall will cause erosion of exposed soil, if not protected. During construction, it is nearly impossible to prevent rainfall from eroding the work area. Therefore, to protect the environment, all the runoff and all the eroded soil must be kept on the project site until the sediment can be removed from the runoff water. Hay bales, sedimentation basins, and silt fences have been used effectively to protect local streams and water bodies. Such installations are generally shown in the standard plans or elsewhere in the contract.

If roadway construction is in lakes or open water, use of sheetpiling or properly designed silt curtains has been very effective in keeping construction runoff from contaminating the open water. Such measures are incorporated into the project by designers and ordinarily are not left to field forces to develop.

Methods for controlling soil erosion should not be used in ways that contribute to other problems. For instance, while the use of mulching is very effective in holding seed in place until it germinates, the type of mulch must be appropriate for the area. Otherwise, a heavy rainfall could easily transport the mulch into local drainage channels, causing flooding and other damage.

**Noise Pollution**


Controlling construction noise can pose special problems for contractors. Unlike general industry, construction activities are not always stationary and in one location. Construction activities often take place outside where they can be affected by weather, wind tunnels, topography, atmosphere and landscaping. Construction noise makers, e.g., heavy earth moving equipment, can move from location to location and is likely to vary considerably in its intensity throughout a work day.

High noise levels on construction worksites can be lowered by using commonly accepted engineering and administrative controls. Normally, earplugs and other types of personal protective equipment (PPE) are used to control a worker’s exposure to noisy equipment and work areas. However, as a rule, engineering and administrative controls should always be the preferred method of reducing noise levels on worksites. Only, when these controls are proven unfeasible, earplugs as a permanent solution should be considered.

**Engineering Controls**

Engineering controls modify the equipment or the work area to make it quieter. Examples of engineering controls are: substituting existing equipment with quieter equipment; retro-fitting existing equipment with damping materials, mufflers, or enclosures; erecting barriers; and maintenance.
Administrative Controls
These are management decisions on work activities, work rotation and work load to reduce workers’ exposure to high noise levels. Typical management decisions that reduce worker exposures to noise are: moving workers away from the noise source; restricting access to areas; rotating workers performing noisy tasks; and shutting down noisy equipment when not needed.

Personal Protective Equipment
Earplugs are the typical PPE given to workers to reduce their exposure to noise. Earplugs are the control of last resort and should only be provided when other means of noise controls are infeasible. As a general rule, workers should be using earplugs whenever they are exposed to noise levels of 85 dB (A) or when they have to shout in order to communicate.

Construction Sites can be Quieter
Although many in the construction industry believe that construction sites are inherently noisy, there are many ways in which they can be made quieter.

- Sometimes a quieter process can be used. For example: Pile driving is very loud. Boring is a much quieter way to do the same work.
- New equipment is generally much quieter than old equipment. Some equipment manufacturers have gone to great lengths to make their equipment quieter. Ask equipment manufactures about the noise levels of their equipment and consider these levels when making your purchase. For example, noise-reducing saw blades can cut noise levels in half when cutting masonry blocks.
- Old equipment can be made quieter by simple modifications, such as adding new mufflers or sound absorbing materials.
- Old equipment is also much quieter when it is well maintained. Simple maintenance can reduce noise levels by as much as 50 percent.
- Noisy equipment can be sited as far away as possible from workers and residents. Noise levels drop quickly with distance from the source.
- Temporary barriers/enclosures (e.g. plywood with sound absorbing materials) can be built around noisy equipment. These barriers can significantly reduce noise levels and are relatively inexpensive.

Traffic Control Measures
The following is taken from the Occupational Safety and Health Administration, Manual on Uniform Traffic Control Devices.

All traffic control devices used on street and highway construction, maintenance, utility, or incident management (temporary traffic control) operations shall conform to the applicable specifications of this manual.

Special plan preparation and coordination with transit and other highway agencies, police and other emergency units, utilities, schools, railroads, etc., may be needed to reduce unexpected and unusual traffic operation situations.

During temporary traffic control activities, commercial vehicles may need to follow a different route from automobiles because of bridge, weight, clearance, or geometric
restrictions. Also, vehicles carrying hazardous materials may need to follow a different route from other vehicles.

Principles and procedures, which experience has shown tend to enhance the safety of motorists and workers in the vicinity of temporary traffic control areas, are included in the following listing. These principles and procedures provide a guiding philosophy of good temporary traffic control used in zone traffic control for the practitioner. They do not establish specific standards and warrants.

Traffic safety in temporary traffic control areas should be an integral and high-priority element of every project from planning through design and construction. Similarly, maintenance and utility work should be planned and conducted with the safety of motorists, pedestrians, and workers kept in mind at all times. Formulating specific plans for incident management traffic control is difficult because of the variety of situations that can arise. Nevertheless, plans should be developed in sufficient detail to provide safety for motorists, pedestrians, workers, and enforcement/emergency personnel and equipment.

The basic safety principles governing the design of permanent roadways and roadsides should also govern the design of temporary traffic control zones. The goal should be to route traffic through such areas using geometrics and traffic control devices comparable to those for normal highway situations.

A traffic control plan, in detail appropriate to the complexity of the work project or incident, should be prepared and understood by all responsible parties before the site is occupied. Any changes in the traffic control plan should be approved by an official trained in safe traffic control practices.

Traffic movement should be inhibited as little as practicable.

Traffic control in work and incident sites should be designed on the assumption that drivers will reduce their speeds only if they clearly perceive a need to do so. Reduced speed zoning should be avoided as much as practical.

Frequent and abrupt changes in geometrics—such as lane narrowing, dropped lanes, or main roadway transitions requiring rapid maneuvers—should be avoided.

Provisions should be made for the safe operation of work or incident management vehicles, particularly on high-speed, high-volume roadways.

Roadway occupancy and work completion time should be minimized to reduce exposure to potential hazards.

Pedestrians should be provided with access and safe passage through the temporary traffic control zone at all times.

Roadway occupancy should be scheduled during off-peak hours and, if necessary, night work should be considered.
Drivers and pedestrians should be guided in a clear and positive manner while approaching and traversing the temporary traffic control zone.

Adequate warning, delineation, and channelization by means of proper pavement marking, signs, or use of other devices that are effective under varying conditions of light and weather should be provided where appropriate to assure the driver and pedestrian of positive guidance before approaching and while passing through the work area.

Signs, pavement markings, channelizing devices, delineators, and other traffic control devices that are inconsistent with intended travel paths through long-term work spaces should be removed. In short-duration and mobile work spaces where retained permanent devices are inconsistent with intended travel paths, attention should be given to devices that highlight or emphasize the appropriate path.

Flagging procedures, when used, can provide positive guidance to drivers traversing the temporary traffic control area. Flagging should be employed only when all other methods of traffic control are inadequate to warn and direct drivers.

To ensure acceptable levels of operation, routine inspection of traffic control elements should be performed.

Individuals who are trained in the principles of safe traffic control should be assigned responsibility for safety at work sites. The most important duty of these individuals is to ensure that all traffic control measures implemented on the project are necessary, conform to the traffic control plan, and are effective in providing safe conditions for motorists, pedestrians, and workers.

Modification of traffic controls or working conditions may be required to expedite safe traffic movement and to promote worker safety. It is essential that the individual responsible for safety have the authority to control the progress of work on the project with respect to obtaining safe conditions, including the authority to modify conditions or halt work until applicable or remedial safety measures are taken.

Temporary traffic control areas should be carefully monitored under varying conditions of traffic volume, light, and weather to ensure that traffic control measures are operating effectively and that all devices used are clearly visible, clean, and in good repair.

When warranted, an engineering analysis should be made (in cooperation with law enforcement officials) of all accidents occurring in temporary traffic control zones. Temporary traffic control zones and accident records should be monitored to identify and analyze traffic accidents or conflicts. For example, skid marks or damaged traffic control devices may indicate the need for changes in the traffic control.

All traffic control devices should be removed when no longer needed. When work is suspended for short periods, advance warning signs that are no longer appropriate shall be removed, covered, or turned, and other inappropriate devices removed from the work area so they are not visible to drivers.
The maintenance of roadside safety requires attention during the life of the temporary traffic control zone because of the potential increase in hazards.

To accommodate run-off-the-road incidents, disabled vehicles, or emergency situations, it is desirable to provide an unencumbered roadside recovery area.

Channelization of traffic should be accomplished by pavement markings, signs, and/or lightweight channelizing devices that will yield when hit by errant vehicles.

Whenever practical, equipment, workers, private vehicles, materials, and debris should be stored in such a manner as not to be vulnerable to run-off-the-road vehicle impact.

Pedestrian paths through the temporary traffic control zone should be protected to minimize pedestrian exposure to errant vehicles.

Each person whose actions affect temporary traffic control zone safety—from upper-level management personnel through field personnel—should receive training appropriate to the job decisions each is required to make. Only those who are trained in safe traffic control practices, and who have a basic understanding of the principles and established applicable standards and regulations, should supervise the selection, placement, and maintenance of traffic control devices in work and incident management areas.

The control of traffic through work areas is an essential part of street and roadway construction, utility and maintenance operations. For these operations there must be adequate legislative authority for the implementation and enforcement of needed traffic regulations, parking controls, speed zoning, and incident management. Such statutes must provide sufficient flexibility in the application of traffic control to meet the needs of changing conditions in work areas.

Maintaining good public relations is necessary. The cooperation of the various news media in publicizing the existence of and reasons for work sites can be of great assistance in keeping the motoring public well informed.

*Dust Control*

The following is taken from the North Carolina Department of Environment and Natural Resources, Division of Pollution Prevention and Environmental Assistance, *Dust Control*.

Dust control measures are practices that help reduce surface and air movement of dust from disturbed soil surfaces. Construction sites are good candidates for dust control measures because land disturbance from clearing and excavation generates a large amount of soil disturbance and open space for wind to pick up dust particles. To illustrate this point, limited research at construction sites has established an average dust emission rate of 1.2 tons/acre/month for active construction.

These airborne particles pose a dual threat to the environment and human health. First, dust can be carried off-site, thereby increasing soil loss from the construction area and increasing the likelihood of sedimentation and water pollution. Second, blowing dust particles can contribute to respiratory health problems and create an inhospitable working environment.
Dust control measures are applicable to any construction site where dust is created and there is the potential for air and water pollution from dust traveling across the landscape or through the air. Dust control measures are particularly important in arid or semiarid regions, where soil can become extremely dry and vulnerable to transport by high winds. Also, dust control measures should be implemented on all construction sites where there will be major soil disturbances or heavy construction activity, such as clearing, excavation, demolition, or excessive vehicle traffic. Earthmoving activities are the major source of dust from construction sites, but traffic and general disturbances can also be major contributors. The particular dust control measures that are implemented at a site will depend on the topography and land cover of a given site, as well as the soil characteristics and expected rainfall at the site.

When designing a dust control plan for a site, the amount of soil exposed will dictate the quantity of dust generation and transport. Therefore, construction sequencing and disturbing only small areas at a time can greatly reduce problematic dust from a site. If land must be disturbed, additional temporary stabilization measures should be considered prior to disturbance. A number of methods can be used to control dust from a site. The following is a brief list of some control measures and their design criteria. Not all control measures will be applicable to a given site. The owner, operator, and contractors responsible for dust control at a site will have to determine which practices accommodate their needs based on specific site and weather conditions.

- **Sprinkling/Irrigation**—Sprinkling the ground surface with water until it is moist is an effective dust control method for haul roads and other traffic routes. This practice can be applied to almost any site.
- **Vegetative Cover**—In areas not expected to handle vehicle traffic, vegetative stabilization of disturbed soil is often desirable. Vegetative cover provides coverage to surface soils and slows wind velocity at the ground surface, thus reducing the potential for dust to become airborne.
- **Mulch**—Mulching can be a quick and effective means of dust control for a recently disturbed area.
- **Wind Breaks**—Wind breaks are barriers that reduce wind velocity through a site and therefore reduce the possibility of suspended particles. Wind breaks can be trees or shrubs left in place during site clearing or constructed barriers such as a wind fence, snow fence, tarp curtain, hay bale, crate wall, or sediment wall.
- **Tillage**—Deep tillage in large open areas brings soil clods to the surface where they rest on top of dust, preventing it from becoming airborne.
- **Stone**—Stone may be an effective dust deterrent for construction roads and entrances or as a mulch in areas where vegetation cannot be established.
- **Spray-on Chemical Soil Treatments**—Examples of chemical adhesives include anionic asphalt emulsion, latex emulsion, resin-water emulsions, and calcium chloride. Chemical palliatives should be used only on mineral soils. When considering chemical application to suppress dust, consideration should be taken as to whether the chemical is biodegradable or water-soluble and what effect its application could have on the surrounding environment, including water bodies and wildlife.

In areas where evaporation rates are high, water application to exposed soils may require near constant attention. If water is applied in excess, irrigation may create unwanted excess
runoff from the site and possibly create conditions where vehicles could track mud onto public roads. Chemical applications should be used sparingly and only on mineral soils (not muck soils) because their misuse can create additional surface water pollution from runoff or contaminate ground water. Chemical applications might also present a health risk if excessive amounts are used.

Because dust controls are dependent on specific site and weather conditions, inspection and maintenance are unique for each site. Generally, however, dust control measures involving application of either water or chemicals require more monitoring than structural or vegetative controls to remain effective. If structural controls are used, they should be inspected for deterioration on a regular basis to ensure that they are still achieving their intended purpose.

**Personal Protection**
The following is taken from 29 CFR 1926.95.

Protective equipment, including personal protective equipment for eyes, face, head, and extremities, protective clothing, respiratory devices, and protective shields and barriers, shall be provided, used, and maintained in a sanitary and reliable condition wherever it is necessary by reason of hazards of processes or environment, chemical hazards, radiological hazards, or mechanical irritants encountered in a manner capable of causing injury or impairment in the function of any part of the body through absorption, inhalation or physical contact.

Where employees provide their own protective equipment, the employer shall be responsible to assure its adequacy, including proper maintenance, and sanitation of such equipment.

All personal protective equipment shall be of safe design and construction for the work to be performed.

4. **Construction management personnel shall demonstrate a working level knowledge of techniques for preparing cost estimates.**

   a. **Discuss how each of the following factors contributes to the development of cost estimates for a construction project:**
      - Construction plans
      - Productivity rates
      - Specifications
      - Crew composition
      - Schedule interpretation and impacts
      - General and administrative rates
      - Material prices
      - Equipment types and rates
      - Known labor rates

**Construction Plans**
The following is taken from U.S. Department of Transportation, Federal-Aid Program Administration, Cost Estimating Guidance.
The construction estimate is the cost of physically constructing the project in the time required based on current costs for labor, materials, equipment, mobilization, bonds, and profit. The following should be considered in construction plans when preparing the construction cost estimate:

- **Contracting Method**—Innovative contracting techniques such as design-build, cost-plus-time bidding, lane rental, etc. should be taken into consideration when preparing the estimate. Design-build contracts and contracts with performance-based specifications or warranties impose a higher risk on the contractor and may increase a contractor’s bid. Any stipends or payments used to offset the cost of preliminary design for unsuccessful proposers should be included in the estimate.

- **Acquisition Strategy Analysis**—A separate value analysis on the project may be used to determine the most economical and advantageous way of packaging the contracts for advertisement. A value analysis is a systematic approach by a multi-disciplined team to identify functions of a project, establish a worth for each function, and generate alternatives that satisfy each function at the lowest life-cycle cost.

- **Surety Issues**—Obtaining bid and performance bonds for major projects are difficult, especially for smaller contractors. If bonding requirements are not reduced, then an increased amount for obtaining bonds should be included in the cost estimate.

- **Bidding Climate Impact**—Cost estimates should consider the economic impact of the major project on the local geographical area. For example, material manufacturers that would normally compete with one another may need to combine resources in order to meet the demand of the major project. Extremely large construction packages also have the potential to reduce the number of contractors that have the capacity or capability to do the work, and may need to be split up into smaller contracts to attract additional competition. Cost estimates should take into account market conditions. If the economy is experiencing a downturn and there is more competition for projects, contractors will bid with less profit. Conversely, if the market is healthy and more projects are advertised, contractors will bid projects with higher markups. In addition, the timing of the bid solicitations can also have an affect on the cost since contractors may be more competitive during the winter months when trying to build some inventory. Cost estimates should also consider controls on the use of labor.

- **Industry Capacity**—The number of potential qualified contractors that are able to bid on major projects are limited to those that have the capacity to construct the project. Contractors who bid on major projects often bid on projects throughout the country. If other major projects are being advertised concurrently, this may have a limiting effect of competition and would result in higher bids. If possible, rescheduling advertisement dates may be appropriate.

- **Price Adjustment (Price Indexing) Contract Provisions**—The price volatility of construction materials and supplies such as asphalt, fuel, cement and steel can result in significant problems for contractors in preparing bids. In some cases, prospective bidders cannot obtain firm price quotes from material suppliers for the duration of the project. This leads to price speculation and inflated bid prices to protect against possible price increases. If price adjustment provisions are used in the contract to respond to this price volatility, a portion of the risk is transferred to the contracting agency, resulting in lower bids. However, since the contracting agency may have to increase its prices paid to the contractor, a reserve amount must be set aside and included in the overall cost estimate.
- Highly Specialized Designs and Technology—Cost estimates should consider the impact of any requirement to use first-of-a-kind technology, new materials, or methods of construction.
- Context Sensitive Solutions—The implementation of context sensitive solutions into a major project may have an impact on the program cost estimate. All context sensitive solutions need to be included in the cost estimate.
- Construction Time—The impacts of construction activities (e.g. sequencing, traffic control, haul routes, accessibility, geographic locations, roads damaged by construction equipment, and ponds that may be silted as part of construction) should be considered when developing cost estimates. Also, costs associated with rush hour restrictions and night work must be considered.
- Construction Incentives—The cost for the contractor to meet quality/material and performance incentives must be included in the cost estimate.

To allow for the likelihood that additional construction work will be identified after the design has been completed and the project awarded, a contingency for cost growth during construction should be included. This is normally around 5 to 10 percent. However, some projects where the potential for scope creep and changes during construction is high have used a contingency factor approaching 15 percent. The following may also have an impact on this percentage:

- Design-Build Contracts—Design-build contracting on major projects has thus far shown very little increase from the negotiated contract amount to the final project completion and therefore may require a smaller construction contingency since the number of construction claims due to design errors is substantially reduced.
- Number of Concurrent Contracts and Contract Interfaces—On projects where multiple construction contracts are underway at the same time, close coordination of construction activities and schedules may be required. The potential for one contractor to impact another contractor's activities is higher and may result in additional delay or coordination costs during construction.
- Contractor Proposed Construction Changes—Construction contracts should include specifications to allow the contractor to propose construction changes that result in benefits to the contractor and the owner. These are sometimes referred to as value engineering change proposals. Contracts that restrict the opportunity for contractors to make changes may limit the ability to contain costs once construction starts. An increased construction contingency may be appropriate in these situations.
- Construction Time—For longer duration projects, there is a greater risk for impacts to the construction schedule and therefore, the contingency amount should be higher. Construction scheduled in winter or rainy seasons should be accounted for appropriately in the contingency amount, since there may be a higher risk in meeting construction schedules due to unforeseen weather delays. When a major project consists of two phases by different Contractors that are interdependent, a higher than normal contingency may be necessary. Also, compressed or accelerated construction schedules could potentially increase costs.
- Transportation Management Plans for Work Zones—Major projects often have complex construction traffic control and may have multiple construction contracts underway at the same time. The cost of implementing the transportation management plan for work zones must be included in the estimate. Costs may also include incident
management, public information and communication efforts, transit demand management and improvements to the local area network, which help improve safety and traffic flow through the project during construction.

- Environmental Impacts—Major projects go through a thorough National Environmental Protection Agency (NEPA) process. Due to the size and complexity of most major projects, there is often greater public and resource agency scrutiny during construction. This attention results in a greater likelihood that additional environmental mitigations may be required once construction begins.

- Other Factors—A few of the potential impacts to the construction contingency are the risks of encountering underground utilities and other obstructions, differing site conditions, contaminated soil, multi-agency involvement, etc.

- Construction Administration—This includes construction engineering, inspection, and administrative oversight during construction. The cost of a general engineering consultant for this work would be included here.

- Public Outreach—Any costs incurred by the agency with respect to public outreach should be prepared and documented as part of the project’s costs. Motorist information plans can be very extensive (and of long duration) on major projects as well as the related costs for publications and news releases.

- Management Reserve—A management reserve may be appropriate for high risk projects and projects that are sensitive to changing politics and management. A management reserve is beneficial if significant consequences could result from the project being underestimated.

*Productivity Rates*

The following is taken from DOE G 430.1-1, chapter 15.

Several good publications provide an estimate of the labor hours required for a task that the estimator should use unless adequate experience has given the estimator a more accurate base for determining labor hours required. One important item that must be remembered when using general estimating publications is that these publications are based on a national average construction project for private industry. The situation at various DOE sites may not be the same as an average construction site. Some examples of possible differences are: (1) security areas, (2) remote locations, (3) nuclear radiation areas, (4) degrees of inspection, (5) documentation, etc. For reasons like these, local productivity studies should be conducted to monitor the productivity at the specific site versus the labor hours given in the general estimating publications. If an estimate is derived using the publications, the site productivity factor must be incorporated into the estimated labor-hours. This should be done prior to multiplication of the labor-hours by the labor rate.

When estimating labor costs, the worker’s base rate plus all payroll indirect costs, such as Federal Insurance Contributions Act and payroll insurance, are multiplied by the estimated labor hours to generate the labor cost. Typically, this sum is handled as a direct labor cost. For ease of estimating, an average crew rate can be used and rounded to the nearest even dollar hourly rate.
Specifications
According to DOG G 430.1-1, appendix A, construction specifications are a deliverable of the design effort. These documents allow a contractor to procure all equipment necessary for construction.

Crew Composition
The following is taken from Principle of Applied Civil Engineering by Ying-Kit Choi.

In selecting the appropriate cost item, it is important that the cost estimator understands what equipment type, crew type, and construction method are practical. In Means data, the type and size of the construction crew are defined for each cost item. Details of the crew include total number of labor categories such as supervisor, laborers, equipment operator, type and number of equipment such as truck, loader, chain saws, tractor, hourly and daily production output, and total daily cost for each crew. This information is important in evaluating whether the crew assumed in the line item is reasonable for the work. In some situations, it is difficult to estimate the cost of work in production units, and it is necessary to estimate the cost based on the estimated production rates of an appropriate crew.

Schedule Interpretation and Impacts
According to DOE G 430.1-1 chapter 2, “Cost Estimation Package,” the schedule can play an important role in the cost estimate package since it can help identify the basis for budget cycle timing, any premiums on long-lead items to ensure their timely delivery, and the basis for escalation. The schedule used or developed with the cost estimate should be documented and will become part of the cost estimation package.

General and Administrative Rates
The following is taken from the Defense Contract Audit Agency, DCAAP 7641.90.

General and administrative (G&A) expenses represent the cost of activities that are necessary to the overall operation of the business as a whole, but for which a direct relationship to any particular cost objective cannot be shown. G&A includes the top management functions for executive control and direction over all personnel, departments, facilities, and activities of the contractor. Typically, it includes human resources, accounting, finance, public relations, contract administration, legal, and an expense allocation from the corporate home office.

The G&A rate is developed by dividing total general and administrative expenses by the selected allocation base, e.g., total cost input (i.e., total direct and indirect costs, except G&A), value added cost input (i.e., total cost input except G&A, material and subcontract costs), or single element cost input (e.g., direct labor dollars, direct labor hours, direct materials costs).

Material Prices
The following is taken from DOE G 430.1-1, chapter 15.

A material, labor, and equipment takeoff is developed from the drawing and specification review. The amount of detailed takeoff will vary with the amount of design detail. A planning estimate has minimal detail, while a Title II estimate has a great deal of detail. The
takeoffs are divided into categories or accounts, and each account has subaccounts. Each project or program should have an established code of accounts. By listing the accounts, a checklist of potential items, and activities that should be included in an estimate is formed. Each account should be considered, even when developing planning estimates, to help eliminate any omissions or oversights.

On fixed price or lump sum contracts, the material cost should be the cost a contractor will pay for the material and does not include any markup for handling by the contractor. Freight at the job site is included in the material cost. Material and equipment that is specified as government furnished equipment should be identified and kept separate from contractor furnished material.

Once the quantity takeoff is complete, the next step is to price the individual items. Several acceptable ways of pricing material are by verbal or written vendor quotations, up-to-date catalog price sheets, estimating manuals, and historical data. The current material price should be used whenever possible. If old prices are used, escalation must be added to make the prices current as of the estimate date. Escalation beyond the date of the estimate is included as a separate item.

Equipment Types and Rates
The following is taken from DOE G 430.1-1, chapter 15.

Equipment and tools are required to install the materials. Databases can be used to obtain an equipment usage relationship with the materials. Large equipment may be estimated on an activity basis or may be estimated for the duration of the project. Pricing can be obtained from verbal or written vendor quotes, estimating manuals, and from historical data. Current prices should be used whenever possible, or prices should be adjusted to reflect prices at the time of the estimate date.

Some fixed price or lump sum contract projects require special tools or equipment for completion of the work. An example of this is a heating, ventilation, and air conditioning project that might require a large crane for setting an air handling unit on the roof of a building. The cost of the crane would be considered a direct cost. Examples of construction equipment are small tools and pickup trucks. These costs would be included as an indirect cost.

On cost-plus-fixed-percentage contracts, all costs for construction equipment and small tools are considered as direct costs.

If a project has government furnished equipment and materials that the contractor must install, an additional amount of 5 to 10 percent of the value of the government furnished equipment must be added to cover the contractor’s risk, insurance, and paperwork.

Known Labor Rates
The following is taken from DOE G 430.1-1, chapter 15.

Several good publications provide an estimate of the labor hours required for a task that the estimator should use unless adequate experience has given the estimator a more accurate base
for determining labor hours required. One important item that must be remembered when using general estimating publications is that these publications are based on a national average construction project for private industry.

The situation at various DOE sites may not be the same as an average construction site. Some examples of possible differences are: (1) security areas, (2) remote locations, (3) nuclear radiation areas, (4) degrees of inspection, (5) documentation, etc. For reasons like these, local productivity studies should be conducted to monitor the productivity at the specific site versus the labor hours given in the general estimating publications. If an estimate is derived using the publications, the site productivity factor must be incorporated into the estimated labor-hours. This should be done prior to multiplication of the labor-hours by the labor rate.

When estimating labor costs, the worker’s base rate plus all payroll indirect costs, such as Federal Insurance Contributions Act and payroll insurance, are multiplied by the estimated labor hours to generate the labor cost. Typically, this sum is handled as a direct labor cost. For ease of estimating, an average crew rate can be used and rounded to the nearest even dollar hourly rate.

b. Discuss the impact of job factors on productivity rates.

The following is taken from DOE G 430.1-1, chapter 15.

Consideration must be given to all factors that affect construction. Some of these factors are:
- Availability of skilled and experienced manpower and their productivity;
- The need for overtime work;
- The anticipated weather conditions during the construction period;
- Work in congested areas or in radiation areas;
- Security requirements imposed on the work area; and
- Use of respirators and special clothing.

Special conditions may be estimated by applying a factor; for example, 10 percent was applied to the labor hours for loss of productivity due to work in a congested area. Other items may be calculated by performing a detailed takeoff. An example of this would be an activity that could only be performed over a 2-day period. Overtime would be required to complete the activity and the number of hours and rates could be calculated.

c. Evaluate time, material, and labor estimates for a construction project.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

d. Discuss the effect of escalation and inflation factors on cost estimates.

The following is taken from DOE G 430.1-1, chapter 10.

Since the duration of larger projects extends over several years, it is necessary to have a method of forecasting or predicting the funds that must be made available in the future to pay for the work. This is where predictive or forecast escalation indices are used. The current year cost estimate is, if necessary, divided into components grouped to match the available predictive escalation indices. Then each group of components is multiplied by the
appropriate predictive escalation index to produce an estimate of the future cost of the project. The future costs of these components are then summed to give the total cost of the project. Escalation accuracy for the total project increases with the number of schedule activities used in summation.

To properly apply escalation indices for a particular project, the following data are required:
- Escalation index (including issue date & index) used to prepare the estimate;
- Current performance schedule, with start and completion dates of scheduled activities; and
- Reference date the estimate was prepared.

To compare the costs of projects with differing durations, inflation/escalation costs must be considered. Escalation in cost estimating has two main uses: to convert historical costs to current costs (historical escalation index) and to escalate current costs into the future (predictive escalation index) for planning and budgeting. Historical costs are frequently used to estimate the cost of future projects. The historical escalation index is used to bring the historical cost to the present and then a predictive escalation index is used to move the cost to the future.

Associated with escalation are concepts of present and future worth. These represent methods of evaluating investment strategies like life cycle cost analyses. For example, a typical life cycle cost evaluation would be determining whether to use a higher R factor building insulation at a higher initial cost compared to higher heating and cooling costs over the life of the building resulting from a lower R factor insulation.

**Historical Escalation**
Historical escalation is generally easily evaluated. For example, the cost of concrete differed in 1981 versus 1992. The ratio of the two costs expressed as a percentage is the escalation and expressed as a decimal number is the index. Generally, escalation indices are grouped. For example, all types of chemical process piping may be grouped together and a historical escalation index determined for the group.

**Predictive Escalation**
Predictive escalation indices are obtained from commercial forecasting services, such as DRI/McGraw Hill, which supplies its most current predictions using an econometric model of the United States economy. They are the ratio of the future value to the current value expressed as a decimal. Predictive escalation indices are typically prepared for various groups and may be different for different groups. For example, the escalation index for concrete may be different from the one for environmental restoration.

**Escalation Application**
Economic escalation shall be applied to all estimates to account for the impact of broad economic forces on prices of labor, material, and equipment in accordance with the following requirements.
- Escalation shall be applied for the period from the date the estimate was prepared to the midpoint of the performance schedule.
Since economic escalation rates are revised at least annually, all estimates shall include the issue date of the escalation rates used to prepare the estimate.

Costs used for design concept shall be fully escalated and referenced as required.

*Escalation Indices*

Costs continuously change due to three factors: changing technology, changing availability of materials and labor, and changing value of the monetary unit (i.e., inflation). Cost or escalation indices have been developed to keep up with these changing costs. The use of escalation indices is recommended by DOE to forecast future project costs. The use of an established index is a quick way to calculate these costs. To ensure proper usage of an index, one must understand how it is developed and its basis.

An escalation index can be developed for a particular group of projects. The projects are divided into their elements, which can be related to current industry indices. The elements are then weighted and a composite index is developed.

DOE has developed construction escalation indices for various types of projects. These are published every February and August. A copy of the latest indices can be requested from Office of Infrastructure Acquisition.

e. Discuss the purpose of contingency in cost estimating, including an explanation of how it is calculated.

The following is taken from DOE G 430.1-1, chapter 11.

Contingency is an integral part of the total estimated costs of a project. It has been defined as a specific provision for unforeseeable elements of cost within the defined project scope. Contingency is particularly important where previous experience relating estimates and actual costs has shown that unforeseeable events which will increase costs are likely to occur.

This definition has been adopted by the American Association of Cost Engineers. DOE has elected to narrow the scope of this definition and defines contingency as follows.

Contingency covers costs that may result from incomplete design, unforeseen and unpredictable conditions, or uncertainties within the defined project scope. The amount of the contingency will depend on the status of design, procurement, and construction; and the complexity and uncertainties of the component parts of the project. Contingency is not to be used to avoid making an accurate assessment of expected cost.

It is not DOE practice to set aside contingency for major schedule changes or unknown design factors, unanticipated regulatory standards or changes, incomplete or additions to project scope definition, force majeure situations, or congressional budget cuts.

Project and operations estimates will always contain contingency. Estimators should be aware that contingency is an integral part of the estimate.

Table 3 presents the contingency allowances by type of construction estimate for the seven standard DOE estimate types, and table 4 presents the guidelines for the major components of a construction project.
Table 3. Contingency allowance guide by type of estimate

<table>
<thead>
<tr>
<th>Type of Estimate</th>
<th>Overall Contingency Allowance % of Remaining Costs Not Incurred</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. PLANNING</td>
<td>20% to 30%</td>
</tr>
<tr>
<td></td>
<td>Up to 50%</td>
</tr>
<tr>
<td></td>
<td>Standard</td>
</tr>
<tr>
<td></td>
<td>Experimental/Special Conditions</td>
</tr>
<tr>
<td>b. BUDGET (Based</td>
<td>15% to 25%</td>
</tr>
<tr>
<td>on the conceptual</td>
<td>Up to 40%</td>
</tr>
<tr>
<td>design report)</td>
<td>Standard</td>
</tr>
<tr>
<td></td>
<td>Experimental/Special Conditions</td>
</tr>
<tr>
<td>c. Title I</td>
<td>10% to 20%</td>
</tr>
<tr>
<td>d. Title II Design</td>
<td>5% to 15%</td>
</tr>
<tr>
<td>e. GOVERNMENT (BID CHECK)</td>
<td>5% to 15% adjusted to suit market conditions</td>
</tr>
<tr>
<td>f. CURRENT WORKING ESTIMATES</td>
<td>See table 4</td>
</tr>
<tr>
<td>g. INDEPENDENT ESTIMATE</td>
<td>To suit status of project and estimator’s judgment</td>
</tr>
</tbody>
</table>

Source: DOE G 430.1-1, chapter 11

Estimate types “a” through “e” in table 3 are primarily an indication of the degree of completeness of the design. Type “f,” current working estimates, found in table 3, depends on the completeness of design, procurement, and construction. Contingency is calculated on the basis of remaining costs not incurred. Type “g,” the Independent Estimate, may occur at any time, and the corresponding contingency would be used (i.e., “a,” “b,” etc.).

The following factors need to be considered to select the contingency for specific items in the estimate while staying within the guideline ranges for each type of estimate.

Project Complexity

Unforeseen, uncertain, and unpredictable conditions will exist. Therefore, using the DOE cost code of accounts for construction, the following percents are provided for planning and budget estimates. They are listed in order of increasing complexity:

- Land and Land Rights 5% to 10%
- Improvements to Land/Standard Equipment 10% to 15%
- New Buildings and Additions, Utilities, Other Structures 15% to 20%
- Engineering 15% to 25%
- Building Modifications 15% to 25%
- Special Facilities (Standard) 20% to 30%
- Experimental/Special Conditions Up to 50%
Table 4. Contingency allowances for current working estimates

<table>
<thead>
<tr>
<th>Item Contingency on Remaining Cost Not Incurred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
</tr>
<tr>
<td>a. ENGINEERING</td>
</tr>
<tr>
<td>Before detailed estimates</td>
</tr>
<tr>
<td>After detailed estimates</td>
</tr>
<tr>
<td>After detailed estimates</td>
</tr>
<tr>
<td>b. EQUIPMENT PROCUREMENT</td>
</tr>
<tr>
<td>Before Bid</td>
</tr>
<tr>
<td>Budget</td>
</tr>
<tr>
<td>Title I</td>
</tr>
<tr>
<td>Title II</td>
</tr>
<tr>
<td>After Award</td>
</tr>
<tr>
<td>Cost plus award fee contract</td>
</tr>
<tr>
<td>Fixed price contract</td>
</tr>
<tr>
<td>After delivery to site</td>
</tr>
<tr>
<td>c. CONSTRUCTION</td>
</tr>
<tr>
<td>Before Bid</td>
</tr>
<tr>
<td>Budget</td>
</tr>
<tr>
<td>Title I</td>
</tr>
<tr>
<td>Title II</td>
</tr>
<tr>
<td>After Award</td>
</tr>
<tr>
<td>Cost plus award fee contract</td>
</tr>
<tr>
<td>Fixed price contract</td>
</tr>
<tr>
<td>c. TOTAL CONTINGENCY CALCULATED</td>
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<tr>
<td></td>
</tr>
</tbody>
</table>

Source: DOE G 430.1-1, chapter 11

Considerations that affect the selection in the ranges are: state-of-the-art design, required reliability, equipment complexity, construction restraints due to continuity of operation, security, contamination, environmental, scheduling, and other items unique to the project such as nuclear and waste management permits and reviews.

Design Completeness or Status
Regardless of the complexity factors listed, the degree of detailed design to support the estimate is the more important factor. This factor is the major reason that the ranges in table 3 vary from the high of 20 to 30 percent in the planning estimate to 5 to 15 percent at the completion of Title II design. Again, parts of the estimate may have different degrees of design completion, and the appropriate contingency percent must be used. As a project progresses, the contingency range and amount of contingency decreases.
Market Conditions
Market condition considerations are an addition or a subtraction from the project cost that can be accounted for in contingency. Obviously, the certainty of the estimate prices will have a major impact. The closer to a firm quoted price for equipment or a position of construction work, the less the contingency can be until reaching 1 to 5 percent for the current working type estimate for fixed-price procurement contracts, 3 to 8 percent for fixed-price construction contracts, and 15 to 17.5 percent contingency for cost-plus contracts that have been awarded.

Special Conditions
When the technology has not been selected for a project, an optimistic/pessimistic analysis can be completed. For each competing technology, an estimate is made. The difference in these estimates of the optimistic and pessimistic alternative can be used as the contingency.

f. Prepare a cost and technical analysis of a contractor’s proposal.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

g. Discuss funding authorization limits and their impact on the cost estimating process.

The following is taken from DOE M 135.1-1A.

The Approved Funding Program (AFP), details total funding available to each AFP recipient for all programs funded from the same appropriation, which in total match the accompanying advice of allotment.

An AFP specifies operating expense, which includes capital equipment, general plant projects (GPPs) and some accelerator improvement/reactor modification projects, and line item construction project funds available for program execution and reflects all funding by obligation control levels in the DOE base table.

For appropriations that include reimbursable authority, the AFPs may include funding levels for reimbursable work.

All obligation authority available to an AFP recipient is delineated in the funds distribution system (FDS) 1540 report by budget and reporting classification and contractor identification code.

Operating expenses may include a code to designate the planned acquisition of a major item of capital equipment and may include budget reference numbers for GPPs, capital equipment, and other items.

Construction line items include a construction project number and total estimated cost for the project.

AFP line items include both new obligation authority and unobligated carryover to reflect the total obligation authority available.
Each base table obligation control level in the AFP will include a letter O, which stands for “obligation control level NOT to be exceeded.”

h. Develop recommendations for the contracting officer based on cost and technical analysis.

The following is taken from DOE G 413.3-1.

Subpart 36.203 of the Federal Acquisition Regulations specify

“an independent Government estimate of construction costs shall be prepared and furnished to the contracting officer at the earliest practicable time for each proposed contract and for each contract modification anticipated to exceed the simplified acquisition threshold.” “The estimate shall be prepared in as much detail as though the Government were competing for award.”

An independent estimate that is developed in strict accordance with this last sentence provides the Federal project director (FPD) with a basis for judging the reasonableness of the bids and an opportunity to discover previously unnoticed omissions, errors, and risk risers.

The likelihood of such valuable discoveries taking place can be increased by using a truly independent estimator whose only source of information is the same bid package that the contractors and vendors will receive and requiring that the estimator submit the same requests for information when confronted with an unclear specification or drawing.

Some degree of iteration is an unavoidable part of combining different frames of reference and should be accepted. The FPD’s and the integrated project teams focus should, therefore, focus on controlling the cost and schedule impacts of iterations, rather than attempting to eliminate the iterations. This can be done using a simple, systems engineering tool called dependence structure matrix models that show the existence of dependencies between different activities in a format that is clearer and easier to read than flow diagrams and provides information that cannot be conveyed in most critical path networks.

i. Describe the application and use of estimator tools.

The following is taken from DOE G 430.1-1, chapter 24.

Activity based costing (ABC) is a method for developing cost estimates in which the project is subdivided into discrete, quantifiable activities or a work unit. The activity must be definable where productivity can be measured in units (e.g., number of samples versus number of labor hours). After the project is broken into its activities, a cost estimate is prepared for each activity. These individual cost estimates will contain all labor, materials, equipment, and subcontracting costs, including overhead, for each activity. Each complete individual estimate is added to the others to obtain an overall estimate. Contingency and escalation can be calculated for each activity or after all the activities have been summed. ABC is a powerful tool, but it is not appropriate for all cost estimates. The following paragraphs outline the ABC method and discuss applicable uses of ABC.
**Activity Based Costing Definition**

ABC can be defined by the following equation:

\[
\frac{C}{A} = HD + M + E + S
\]

where
- \( C/A \) = Estimated cost per activity
- \( H \) = Number of labor hours required to perform the activity one time
- \( D \) = Wages per labor hour
- \( M \) = Material costs required to perform the activity one time
- \( E \) = Equipment costs to perform the activity one time
- \( S \) = Subcontracting costs to perform the activity one time

The total cost for performing the activity will be based on the number of times the activity is performed during a specific time frame.

Cost estimators have assembled large databases of activity based cost information. The R.S. Means Company updates its published cost references on a yearly basis, and they are an excellent source of ABC information for the construction industry.

**Use of Activity Based Costing Methodology**

ABC methodology is used when a project can be divided into defined activities. These activities are at the lowest function level of a project at which costs are tracked and performance is evaluated. Depending on the project organization, the activity may coincide with an element of the work breakdown structure (WBS) or may combine one or more elements of the WBS. However, the activities must be defined so there is no overlap between them. After the activity is defined, the unit of work is established. All costs for the activity are estimated using the unit of work.

The estimates for the units of work can be done by performing detailed estimates, using cost estimating relationships, obtaining outside quotes for equipment, etc. All costs, including overhead, profit, and markups should be included in the activity cost.

**Identification of Activities**

When defining an individual activity, the cost estimator must balance the need for accuracy with the amount of time available to prepare the estimate. An estimator may be able to develop an extremely accurate cost estimate by defining smaller and smaller activities; however, the amount of time required to prepare ABC estimates for each of these activities may not justify the increased accuracy. The total estimated project cost may be sufficiently accurate if 10 activities are used instead of 15. On the other hand, reliable cost information may not be accessible if the activity categories are too general. Since the activity is the basis for the estimate, it is very important that the activity be selected correctly.

ABC can be a useful cost estimating tool for non-conventional and construction projects. However, there are some activities that are more appropriately estimated using other cost estimating techniques. For example, site security may always be required at some facilities regardless of the number of employees at the facility or work being conducted at the facility.
ABC estimating is especially useful in instances where the number of activities is uncertain or may change during the estimate process.

5. Construction management personnel shall demonstrate a working level knowledge of techniques for scheduling construction projects.

a. Discuss construction project scheduling methods, including an explanation of critical path scheduling.

The following is taken from DOE G 413.3-5.

Schedule Baseline Development

The schedule baseline establishes the overall project duration and completion date and should clearly identify critical path activities and key project milestones. A tailored approach should be used to determine how much detail to include in the schedule. The number of activities should not be so few as to prevent suitable progress tracking and not so numerous that the number of activities overwhelms the system and its users—rendering the schedule logic incomprehensible and too burdensome to status. The schedule should reflect planning by appropriate technical experts as to how the activities will be accomplished.

All known project and contract requirements, major procurements, milestones, and constraints should be identified during the planning and scheduling process. Activities external to the project that could reasonably be expected to impact the project should also be considered.

The overall schedule baseline development process is described in figure 11.

Source: DOE G 413.3-5

Figure 11. Schedule baseline development process
Define Project Activities

An activity is a basic element of work that consumes time and resources and has a definable beginning and end. Activities are performed in order to produce the results and deliverables identified in the project WBS. The activities necessary to accomplish a defined scope of work are often based on historical information from similar projects that have been modified to meet the constraints and assumptions of the current effort.

The definitions of these activities should flow from the project planning and scope definition processes, and the level of definition will depend on the project lifecycle phase. Some of the major components of the activity definition process are:

- **Identification**—A list of activities should be developed based on historical site information or data from similar project environments. In some cases, generic project activity templates may facilitate the identification process. When determining the appropriate level of detail, the project team should strike a balance between the need to decompose projects into a number of activities sufficient to facilitate accurate cost estimating and scheduling, and the ability of project management and control systems to maintain effective traceability and reporting capabilities.

- **Description**—Activity descriptions should be brief but unambiguous and should include quantitative measures or reference points whenever possible. In addition, the owner of each activity should be documented as part of the description.

- **Detail**—Supporting details should be documented and included in the cost and schedule estimating files. This information, including all assumptions and constraints, will be necessary for ensuring the future traceability and defensibility of estimates, for managing change control procedures, and for performing activity resource loading and leveling procedures.

Sequence Project Activities

Sequencing involves development of chronological relationships among project activities based on the technological, organizational, and contractual requirements governing their completion. A sequence of activities is best displayed graphically in the form of a network diagram. Three common methods of network diagramming include arrow, node, and precedence diagrams.

Activities should be sequenced logically to establish the foundation for an achievable project work plan. A sequence of activities in the form of a network diagram is necessary for performing critical path, total float, and resource leveling analyses. The results of these analyses are implicitly tied to the mandatory, discretionary, and external dependencies identified by the project team and included in the network schedule.

Activity sequencing is driven by technological characteristics and requirements of the products, processes, and deliverables comprising the project scope. These may include the physical layout of a plant to be constructed, infrastructure requirements of an existing facility, or cleanup and disposal requirements of a contaminated release site. In addition to these technical requirements, administrative, organizational, regulatory, and legal requirements may drive the necessary completion dates of milestone activities. These requirements should be documented in the form of activity dependencies, constraints, and assumptions, and should be reflected in the sequencing of the network schedule.
The project team should discuss and establish a realistic sequence of events for the completion of activities based on inter-activity dependencies.

Estimate Activity Durations
Estimates of the time required to perform each project activity are based on assumed labor, equipment, efficiency and productivity, and material requirements and availability. These durations may take the form of a single point estimate describing the mean or most likely number of work periods needed to complete an activity (e.g., based on historical data), or may be defined by a range estimate that captures a continuum of durations spanning from the most optimistic to the most pessimistic as conceived by one or more subject matter experts on the project team.

Similar to the sequencing of activities, estimating activity durations is essential for developing a sound project schedule. Because of the inter-activity dependencies inherent in network scheduling, the effects of poorly defined duration estimates can be compounded through precedence relationships and milestone constraints. Successful critical path and resource leveling analyses are therefore directly dependent upon the accuracy of the duration estimating process.

Activity durations should be estimated by the project team member most familiar with the nature of a specific activity and who is responsible for ensuring its completion. The duration of most activities will be significantly influenced by the amount of resources applied to a task and the capabilities of those specific resources. These trade-offs should be considered and documented during the estimating process; however, they may be adjusted later during a resource allocation exercise. Whenever possible, duration estimates should be based on expert judgment that is supported by historical information contained in project files or commercial estimating databases.

The duration estimates provide the basis for performing critical path scheduling calculations. The basis of estimate used to develop each activity estimate should be documented in an accompanying project file. This information will be essential for maintaining the traceability and defensibility of the estimates during later project phases, especially for change control and reporting purposes.

Conduct Network Analysis
The critical path is the longest path through a network schedule that consequently defines the shortest possible duration for completing a project. This path and its duration are determined by performing forward and backward passes through the network diagram based on the defined activity sequence and estimated activity durations.

The basic scheduling computations performed on a network diagram provide the earliest and latest allowable start and finish times for each activity and as a byproduct, indicate the amount of slack or float time associated with each noncritical path. This information form the basis of the project management plan and subsequently is used for performance measurement and earned value reporting, baseline change control, milestone tracking, and schedule contingency management.
The mathematical analysis involved in calculating theoretical early and late start and finish dates for all project activities should be performed initially irrespective of resource pool limitations. The resulting dates indicate the time periods within which the activities should be scheduled provided existing resource limitations and other known constraints are met. These calculations, generally performed by scheduling software applications, require several input parameters:

- **Calendars**—Project calendars establish the periods when work will be performed. This is essential because some resources will be available only during normal business hours, while others may be available continuously, on weekends and holidays, or in some other combination.

- **Constraints**—Imposed dates and major milestones are constraints to consider. Imposed dates are driven by completion of activities and deliverables assigned by sponsors, customers, or other external entities. Major milestones are key events or deliverables established by project owners or stakeholders to meet organizational, funding, or other commitments. Both can be used to constrain the network schedule but may result in trade-offs in the form of additional resources in order to be met. Application on constraints should be used with restraint since this will limit the schedule from following the natural paths of the activities.

- **Leads and Lags**—Activities requiring significant lead or lag times should be specified in the project schedule, and these delays should be reflected in the associated network logic. Application of leads and lags should be used with restraint since this will limit the schedule from following the natural paths of the activities.

**Allocate Activity Resources**

The feasibility of a network schedule should be validated with respect to labor, equipment, and material requirements not explicitly considered in the initial critical path analysis. The process of allocation is used to distribute resources across multiple project activities within known limits and expected constraints. Some activities may be re-sequenced to compress the schedule and/or to obtain a more level distribution of resources.

Critical path computations performed during the network analysis determine the slack along each path in the project schedule. Based on the length and location of this slack, certain activities can be moved forward or backward in time without affecting the completion date of the project. Consequently, this movement can be used to develop a schedule that satisfies external constraints placed on the type and quantity of resources available during various phases of the project.

Resource allocation often entails several iterations of the basic scheduling computations and should include modification of some project activities to achieve an acceptable plan. Leveling heuristics should be used to rebalance resources based on anticipated quantity thresholds and the relative criticality of activities; however, these heuristics often produce project durations that are longer than the initial schedule.

Schedule compression is another form of resource allocation that seeks to shorten the project schedule without changing its scope. This process includes techniques such as the following:

- **Crashing**—Schedule crashing requires the analysis of trade-offs between cost and schedule to determine how the total project duration can be reduced by the greatest
amount for the least incremental cost. This technique, which is available in most automated scheduling tools, does not always produce a viable project schedule and usually results in greater total project costs.

- **Fast Tracking**—This technique involves the re-sequencing some activities in the schedule so that they are performed in parallel rather than in sequence during project execution. The negative consequences include increased project risk and some rework resulting from technical uncertainties and activity sequencing problems. The project team should evaluate the decision to fast track carefully and should be used primarily on projects with well established and proven technologies.

### Establish Schedule Contingency

Schedule contingency is an amount of time identified within the project schedule to compensate for potential for schedule risk factors such as technical data gaps, infrastructure constraints, labor productivity levels, labor availability, project complexity, stakeholder involvement, excessive scope changes, regulatory delays, and constructability issues.

The amount of contingency to be included in the baseline schedule depends on the status of project design, procurement, and construction and the complexity and uncertainty of various baseline elements.

The duration of the project critical path determines the shortest possible schedule for a given baseline. Results provided by the critical path method are accurate only when everything goes according to plan. A project, on occasion, may provide very optimistic duration estimates and plan parallel work without full considerations for the unique scheduling and work execution complexities posed by parallel activities. The project schedule therefore should contain some amount of contingency to account for the potential impacts of risk and uncertainty.

Schedule contingency should explicitly address the risks identified by the project team during the schedule development and risk management efforts, especially those factors that are likely to have the greatest impact on project execution as determined by a sensitivity analysis. The quantification of schedule contingency can be developed using the Monte Carlo simulation method. To perform such simulations, the project team should estimate a range of durations for each activity to be included in the risk analysis. These estimates should reflect the full variability of activity durations, from the most optimistic prediction to the most pessimistic. Using a computer-based simulation tool, basic scheduling calculations are performed using activity duration values sampled from the range estimates. The resulting critical path durations are recorded to determine the relative completion probabilities for a range of project finish dates.

Based on the desired level of confidence in meeting the schedule, the project team selects an appropriate amount of schedule contingency. The contingency allocation process is managed and documented through the baseline change control system, and the network schedule should be updated to reflect the most current field conditions throughout the project lifecycle.
b. Discuss each of the following elements of construction project scheduling, including the factors of each that could impact the schedule:

- Orderly delivery of equipment and materials in sequence with the installation schedule
- Construction equipment requirements
- Manpower planning and scheduling
- Bidding and award activities

Orderly Delivery of Equipment and Materials in Sequence with the Installation Schedule

The following is taken from *Project Management for Construction* by Chris Hendrickson.

Resource constrained scheduling should be applied whenever there are limited resources available for a project and the competition for these resources among the project activities is keen. In effect, delays are liable to occur in such cases as activities must wait until common resources become available. To the extent that resources are limited and demand for the resource is high, this waiting may be considerable. In turn, the congestion associated with these waits represents increased costs, poor productivity and, in the end, project delays. Schedules made without consideration for such bottlenecks can be completely unrealistic.

Resource constrained scheduling is of particular importance in managing multiple projects with fixed resources of staff or equipment. For example, a design office has an identifiable staff which must be assigned to particular projects and design activities. When the workload is heavy, the designers may fall behind on completing their assignments. Government agencies are particularly prone to the problems of fixed staffing levels, although some flexibility in accomplishing tasks is possible through the mechanism of contracting work to outside firms. Construction activities are less susceptible to this type of problem since it is easier and less costly to hire additional personnel for the (relatively) short duration of a construction project. Overtime or double shift work also provide some flexibility.

Resource oriented scheduling also is appropriate in cases in which unique resources are to be used. For example, scheduling excavation operations when one only excavator is available is simply a process of assigning work tasks or job segments on a day by day basis while insuring that appropriate precedence relationships are maintained. Even with more than one resource, this manual assignment process may be quite adequate. However, a planner should be careful to insure that necessary precedence is maintained.

Resource constrained scheduling represents a considerable challenge and source of frustration to researchers in mathematics and operations research. While algorithms for optimal solution of the resource constrained problem exist, they are generally too computationally expensive to be practical for all but small networks. The difficulty of the resource constrained project scheduling problem arises from the combinatorial explosion of different resource assignments which can be made and the fact that the decision variables are integer values representing all-or-nothing assignments of a particular resource to a particular activity. In contrast, simple critical path scheduling deals with continuous time variables. Construction projects typically involve many activities, so optimal solution techniques for resource allocation are not practical.
One possible simplification of the resource oriented scheduling problem is to ignore precedence relationships. In some applications, it may be impossible or unnecessary to consider precedence constraints among activities. In these cases, the focus of scheduling is usually on efficient utilization of project resources. To insure minimum cost and delay, a project manager attempts to minimize the amount of time that resources are unused and to minimize the waiting time for scarce resources. This resource oriented scheduling is often formalized as a problem of job shop scheduling in which numerous tasks are to be scheduled for completion and a variety of discrete resources need to perform operations to complete the tasks. Reflecting the original orientation towards manufacturing applications, tasks are usually referred to as jobs and resources to be scheduled are designated machines. In the provision of constructed facilities, an analogy would be an architectural/engineering design office in which numerous design related tasks are to be accomplished by individual professionals in different departments. The scheduling problem is to insure efficient use of the individual professionals and to complete specific tasks in a timely manner.

The simplest form of resource oriented scheduling is a reservation system for particular resources. In this case, competing activities or users of a resource pre-arrange use of the resource for a particular time period. Since the resource assignment is known in advance, other users of the resource can schedule their activities more effectively. The result is less waiting or queuing for a resource. It is also possible to inaugurate a preference system within the reservation process so that high-priority activities can be accommodated directly.

In the more general case of multiple resources and specialized tasks, practical resource constrained scheduling procedures rely on heuristic procedures to develop good but not necessarily optimal schedules. While this is the occasion for considerable anguish among researchers, the heuristic methods will typically give fairly good results. An example heuristic method is provided in the next section. Manual methods in which a human scheduler revises a critical path schedule in light of resource constraints can also work relatively well. Given that much of the data and the network representation used in forming a project schedule are uncertain, the results of applying heuristic procedures may be quite adequate in practice.

Construction Equipment Requirements
The following is taken from DOE G 430.1-1, chapter 15.

Equipment and tools are required to install the materials. Databases can be used to obtain an equipment usage relationship with the materials. Large equipment may be estimated on an activity basis or may be estimated for the duration of the project.

Pricing can be obtained from verbal or written vendor quotes, estimating manuals, and from historical data. Current prices should be used whenever possible, or prices should be adjusted to reflect prices at the time of the estimate date.

Some fixed price or lump sum contract projects require special tools or equipment for completion of the work. An example of this is a heating, ventilation, and air conditioning project that might require a large crane for setting an air handling unit on the roof of a building. The cost of the crane would be considered a direct cost.
Examples of construction equipment are small tools and pickup trucks. These costs would be included as an indirect cost.

On cost-plus-fixed-percentage contracts, all costs for construction equipment and small tools are considered as direct costs.

**Manpower Planning and Scheduling**
The following is taken from DOE G 430.1-1, chapter 15.

Several good publications provide an estimate of the labor hours required for a task that the estimator should use unless adequate experience has given the estimator a more accurate base for determining labor hours required. One important item that must be remembered when using general estimating publications is that these publications are based on a national average construction project for private industry.

The situation at various DOE sites may not be the same as an average construction site. Some examples of possible differences are: (1) security areas, (2) remote locations, (3) nuclear radiation areas, (4) degrees of inspection, (5) documentation, etc. For reasons like these, local productivity studies should be conducted to monitor the productivity at the specific site versus the labor hours given in the general estimating publications. If an estimate is derived using the publications, the site productivity factor must be incorporated into the estimated labor-hours. This should be done prior to multiplication of the labor-hours by the labor rate.

When estimating labor costs, the worker’s base rate plus all payroll indirect costs, such as Federal Insurance Contributions Act and payroll insurance, are multiplied by the estimated labor hours to generate the labor cost. Typically, this sum is handled as a direct labor cost. For ease of estimating, an average crew rate can be used and rounded to the nearest even dollar hourly rate.

**Bidding and Award Activities**
The following is taken from the DOE Acquisition Guide.

**Draft Request for Proposal (DRFP)**
The DRFP is the initial, informal document(s) that communicates the Government's intentions/needs to industry and requests questions, comments, suggestions, and corrections that improve the final product. It is a communication tool used early in competitive acquisitions to promote a clearer understanding of the Government’s requirements to industry and to obtain industry feedback on the planned acquisition. The DRFP need not include all of the sections of the request for proposal (RFP), but should contain as much as possible of the business sections necessary for industry to provide meaningful comments. As a minimum, the DRFP should include section L, “Instructions to Offerors” and section M, “Evaluation Criteria,” and the specification/statement of work.

No hard and fast rule exists as to when it is desirable to issue a DRFP; however, in the early stages of acquisition planning/procurement strategy development, the program officer(s), advisory (legal) staff and contracting officer/contract specialist are strongly encouraged to address the desirability of issuing a DRFP in advance of the final RFP. Likewise, no formal
process for comment resolution presently exists. However, a methodology should be established to ensure implementation of beneficial comments in the final RFP as well as ensuring fair disposition of all comments.

The contracting officer/contract specialist should publicize the DRFP in much the same manner as the final RFP would be publicized, using a variety of methods, such as posting announcements on the Internet using Federal Business Opportunities for Vendors at http://www.eps.gov/spg/, posting the DRFP on the DOE Industry Interactive Procurement System at http://e-center.doe.gov and those methods addressed at Federal Acquisition Regulation (FAR), 48 CFR 15.201(c), “Exchanges with Industry Before Receipt of Proposals,” and FAR 48 CFR 5.101(b), “Methods of Disseminating Information.” Publication and response times for proposed contract actions at FAR 48 CFR 5.203, “Requests for Proposals.” are not mandatory for DRFPs. The contracting officer should establish reasonable times for receipt of responses to DRFPs that reflect the nature of the product or service, the supply base, and the specifics of the individual procurement. Requirements shall be synopsized in accordance with FAR, 48 CFR 5.203, prior to issuance of the solicitation. Alternatively, the notice of availability of a DRFP and a future date when the solicitation will be issued may be included in the same synopsis.

The contracting officer/contract specialist, in conjunction with support from appropriate technical or other functional advisory staff as merited should carefully review any offeror’s question to: (1) determine whether the suggestion has merit and should be pursued; (2) develop a recommended course of action considering the impact to other processes and elements of the RFP or program; and (3) develop a proposed government response. Care must also be taken to ensure that incorporating a comment into the RFP does not give and unfair competitive advantage to an offeror.

Though not mandatory, two suggested means by which the contracting officer/contract specialist may disseminate the government’s response to industry are:

- A DRFP amendment or letter may be prepared that formally responds to the comments received. This response may group similar questions together for a single response. The amendment or letter should not attribute comments to any particular offeror. The amendment or letter should include a clear statement as to the comments disposition, i.e., accepted, rejected, deferred, etc., along with an explanation as to why that action was taken. The response should be made publicly available in the same manner as the DRFP.

- If the nature of the comment or the government response is complex, it may be beneficial for the government to convene a pre-solicitation conference to discuss the responses to the DRFP comments. Notice of the conference should be publicly announced in a manner to ensure that all interested parties/potential offerors have an opportunity to respond/attend. Minutes of the conference should be maintained, which include a written response to all of the DRFP comments received. Copies of these minutes should be publicly distributed in the same manner as the DRFP, e.g., though posting on the website.

Regardless of which response method or combination of methods is used, it is critical that all potential offerors be treated fairly and given identical information so as not to provide a basis for a perception of unfair competitive advantage by any one offeror or group of offerors.
If a private conference is requested, the contracting officer/contract specialist must take special care to ensure that either: (1) no additional information is provided during the conference which would give the offeror an unfair competitive advantage; or (2) ensure that any new information provided during the conference is provided to all potential offerors.

Pre-proposal Conferences
A pre-proposal conference is a technique to promote early exchange of information with industry after the solicitation is issued, and prior to receipt of proposals. The principal purpose of a pre-proposal conference is to provide for uniform interpretation and understanding of work statements, specifications, and other technical and administrative requirements by all prospective contractors responding to competitive solicitations.

Additionally, in conducting the pre-proposal conference, remember the following: (1) release information on a fair and equitable basis consistent with regulatory and legal restrictions; (2) establish clear ground rules for the conduct, timing, and documentation of pre-proposal conferences; (3) protect any proprietary information you may be given during this process; and (4) request legal counsel advice if any questions arise about any pre-proposal exchanges.

The contracting officer should publicize the arrangements for the conference in the solicitation. Attendees should be advised that remarks and explanations made by government personnel do not qualify, change, or otherwise amend the terms of the solicitation, and that only a formal, written amendment to the solicitation is binding. A written record of the conference proceedings should be kept. This record of proceedings, including any new material provided at the conference and questions and answers addressed should be provided to all potential offerors, regardless of whether they attend the conference.

Where possible, written questions should be requested in advance, and answers should be prepared in advance and delivered during the conference. Questions answered during the conference should be included in the record of conference proceedings.

As soon as possible after the pre-proposal conference, the contracting officer should ensure that all potential offerors receive the written record of the conference proceedings, including any new material provided, and any questions and answers addressed. If any of the terms and conditions or requirements of the solicitation were changed, a formal solicitation amendment should be issued.

Additionally, a site tour should be part of any pre-proposal conference if there is a site to tour.

Scoring Methodologies
The objective of an acquisition conducted under source selection procedures is to select the source or sources which represent the best value to the government. 48 CFR 15, “Contracting by Negotiation,” discusses source selection processes and techniques, including tradeoff processes. The tradeoff process permits tradeoffs among cost or price and non-cost factors and allows the government to accept other than the lowest priced proposal. 48 CFR 15.305, “Proposal Evaluation,” states:
Proposal evaluation is an assessment of the proposal and the offeror’s ability to perform the prospective contract successfully. An agency shall evaluate competitive proposals and then assess their relative qualities solely on the factors and sub-factors specified in the solicitation. Evaluations may be conducted using any rating method or combination of methods, including color or adjectival ratings, numerical weights, and ordinal rankings. The relative strengths, deficiencies, significant weaknesses, and risks supporting proposal evaluation shall be documented in the contract file.

The source selection authority (SSA) is required to follow the evaluation criteria and relative weighting factors set forth in the solicitation. How the SSA achieves this objective is not prescribed by the regulations. In fact, the FAR specifically states that the rating method need not be disclosed in the solicitation. The Government Accountability Office (GAO) has repeatedly held that rating plans are internal documents, and that offerors are not entitled to enforce the provisions of a rating plan that were not included in the solicitation. Beyond the implications in the FAR that a rating method will be used, there is no known regulatory requirement for creation of a proposal scoring or rating plan.

In theory, an SSA could review the proposals, identify the strengths and weaknesses of the proposals and based on his/her judgment, following the evaluation factors and weightings in the solicitation, reach a selection decision. This approach is simply not practical and SSAs normally employ the use of an advisory board, team or panel to evaluate the proposals. Scoring/rating plans have evolved as the structured means of communicating the relative standings of each offeror to the SSA. In the end however, the SSA must base the selection decision on the strengths, deficiencies, and weaknesses of the proposals submitted - not merely on the score derived through use of a proposal scoring or rating plan.

A proposal scoring or rating plan helps evaluators assess a proposal’s merit with respect to the evaluation factors and significant sub-factors in the solicitation. It uses a scale of words, colors, numbers, or other indicators to denote the degree to which proposals meet the standards for the non-cost evaluation factors. Some commonly used rating systems are adjectival, color coding, and numerical. What is important in using a rating system in proposal evaluations is not the method or combination of methods used, but rather the consistency with which the selected method is applied to all competing proposals and the adequacy of the narrative used to support the rating.

A traditional scoring or rating plan is comprised of three basic elements: (1) evaluation factors and sub-factors set forth in the solicitation; (2) a rating system (e.g., adjectival, color coding, numerical, or ordinal); and (3) evaluation standards or descriptions which explain the basis for assignment of the various rating system grades/scores.

Cost or Price Analysis
Probable cost to the government is a mandatory evaluation factor, 48 CFR 15.404-1(d) “Proposal Analysis Techniques.” Thus, this element must be evaluated in all procurements. There are two aspects of this evaluation. First, the contracting officer must ensure that the contract price, or cost and fee, is fair and reasonable. Second, in cost-reimbursement contracts the contracting officer must determine the probable cost of performance and use
that cost in the selection process. The contracting officer shall use cost or price analysis to evaluate the cost estimate or price, not only to determine whether it is reasonable, but also to determine the offeror’s understanding of the work and ability to perform the work. The contracting officer shall document the cost or price evaluation.

The term “cost or pricing data” means all facts that, as of the date of agreement on the price of a contract, a prudent buyer or seller would reasonably expect to affect price negotiations significantly. Such term does not include information that is judgmental, but does include the factual information from which a judgment was derived.

The contracting officer is required to make a price analysis on every procurement to ensure that the overall price to be included in the contract is fair and reasonable. In the competitive negotiation process, price analysis is the preferred technique for determining price reasonableness because it permits the contracting officer to make the determination without a detailed analysis of the cost and profit elements of each proposal using cost analysis techniques.

Price analysis is generally based on data obtained from sources other than the prospective contractor. This data is gathered by the government negotiating team from as many sources as possible. Generally, to assure that the price being included in the contract is reasonable, a sound price analysis will be based on several different types of data.

The contracting officer is responsible for selecting and using whatever price analysis techniques will ensure a fair and reasonable price. One or more of the following techniques may be used to perform price analysis.

Comparison of proposed prices received in response to the solicitation. In this case competition is relied on to ensure that the costs are fair and reasonable.

Comparison of previously proposed prices and previous Government and commercial contract prices with current proposed prices for the same or similar items, if both the validity and the reasonableness of the previous prices can be established. A determination must be made that ensures that the price that is being compared to the proposed price has been determined to be fair and reasonable, either through presence of adequate price competition or some other manner such as cost or price analysis.

Cost analysis is used to determine how well the proposed costs represent what the cost of the contract should be, assuming reasonable economy and efficiency. Cost analysis is: (1) the review and evaluation of the separate cost elements and profit/fee in an offeror’s or contractor’s proposal, including cost or pricing data or information other than cost or pricing data, and (2) application of judgment.

A cost analysis must performed anytime that certified cost and pricing data is required as defined in 48 CFR 15.403-(4)(a)(1). “Requiring Cost or Pricing Data.” A proposal must be analyzed to determine what costs to use in developing your negotiation objective and what price you determine to be fair and reasonable.
When using cost analysis to negotiate contracts a price analysis must also be performed as it is possible to assure that all of the specific cost elements in a proposal are reasonable and determine that the overall price is not.

In accordance with 48 CFR 15.404-1(d)(2), a cost realism analysis when awarding a cost type contract must be performed. This is a special analysis required primarily to ensure that proposed costs are not unrealistically low. In addition, this analysis provides the foundation for estimating the fee. Furthermore, a cost realism analysis may also be used on competitive fixed-priced incentive contracts or, in exceptional cases, on other competitive fixed-price type contracts when new requirements may not be fully understood by competing offerors, there are quality concerns, or past experience indicates that contractors’ proposed costs have resulted in quality or service shortfalls. Additionally, one of the criteria required for the determination of reasonableness and allocability is the determination that the cost is allocable to the contract.

Award Without Discussions

48 CFR 15 allows contracts award without discussions with the offerors if the solicitation states that the government intends to evaluate proposals and make award without discussions. Clarifications are limited exchanges between the government and offerors that may occur without jeopardizing the ability to award without discussions.

Contents of an Evaluation Report

The FAR requires that the evaluation of the relative strengths, deficiencies, and significant weaknesses of a proposal be documented in the contract file. The content of this evaluation should be in the form of a report that definitively and comprehensively reflects the government’s evaluation consistent with the evaluation criteria stated in the solicitation. Furthermore, the report should accurately reflect the deliberations of the Source Evaluation Board or the Technical Evaluation Committee (SEB/TEC), and be consistent with the rating plan. Though the content of the report is consistent for either a SEB or TEC, the report prepared by the SEB should be significantly more detailed.

The evaluation report outline below is a listing of areas that may be appropriate to address in the evaluation report. The selection and use of these areas must be consistent with the nature of the specific proposals being evaluated and the particular situation of the individual acquisition. Some of these areas may be combined as appropriate. Some of these areas will only be applicable depending on the circumstances of the acquisition, e.g., establishing the competitive range, award without discussions. The subject areas may be used, as appropriate, for both the initial evaluation report and the final evaluation report. The individual areas may be included in the main body of the report or certain areas may be more appropriate for inclusion as an attachment to the report.

Debriefings

In 48 CFR 15 procurements, contracting officers are required to offer debriefings to all unsuccessful offerors. The debriefing is the method by which the offerors obtain information to decide whether to protest and is a possible venue for heading off a protest. Debriefings need to be informative and professionally presented. They should never degenerate into debates over the propriety of the source selection process or the accuracy of the
government’s evaluation. The general approach to a debriefing should be to provide all required information, satisfy the debriefed offeror’s reasonable questions about the procurement, and provide as much information as possible without prejudicing the procurement in the event it must be reopened for any reason.

The timing of a debriefing affects both the timeframe for filing a GAO protest and also the time within which a protest will require the protested contract performance to be suspended.

When a contract is awarded on a basis other than price alone, unsuccessful offerors, upon their written request, shall be debriefed as soon as possible and furnished the basis for the selection decision and contract award.

However, the debriefing requirements only apply to procurements carried out under 48 CFR 15 requirements. There is no requirement for a debriefing for placement of an order under a schedule contract pursuant to FAR subpart 8.4, for placement of a contract using simplified acquisition procedures under 48 CFR 13, “Simplified Acquisition Procedures,” (including the test program for certain commercial items in 48 CFR 13.500, “General,” for placement of a task or delivery order under an indefinite delivery contract pursuant to 48 CFR 16.500, “Scope of Subpart,” for an contract issued pursuant to the sealed bid procedures of 48 CFR 14, “Sealed Bidding,” or at the time an option is exercised. The debriefing should provide the unsuccessful offeror with sufficient information to enable him/her to understand why the proposal was not selected and to enable the offeror to present a better proposal in a future competition. In other words, the information should be of value to the unsuccessful offeror.

c. Read and interpret the following construction project control aids:
   - GANTT Charts (bar chart)
   - Site specific electronic scheduling tools
   - Networking techniques (critical path method [CPM])
   - Percentage completion curve (S curve)
   - Labor schedules
   - Material schedules
   - Equipment schedules
   - Finance schedules

GANTT Charts
The following is taken from American Society for Quality, Quality Tools.

A GANTT chart is a bar chart that shows the tasks of a project, when each must take place and how long each will take. As the project progresses, bars are shaded to show which tasks have been completed. People assigned to each task also can be represented.

When to Use GANTT Charts
- When scheduling and monitoring tasks within a project.
- When communicating plans or status of a project.
- When the steps of the project or process, their sequence and their duration are known.
- When it’s not necessary to show which tasks depend on completion of previous tasks.
GANTT Chart Basic Procedure

Construction

- Identify tasks:
  - Identify the tasks needed to complete the project.
  - Identify key milestones in the project by brainstorming a list, or by drawing a flowchart, storyboard or arrow diagram for the project.
  - Identify the time required for each task.
  - Identify the sequence: Which tasks must be finished before a following task can begin, and which can happen simultaneously? Which tasks must be completed before each milestone?

- Draw a horizontal time axis along the top or bottom of a page. Mark it off in an appropriate scale for the length of the tasks (days or weeks).
- Down the left side of the page, write each task and milestone of the project in order. For events that happen at a point in time (such as a presentation), draw a diamond under the time the event must happen. For activities that occur over a period of time (such as developing a plan or holding a series of interviews), draw a bar that spans the appropriate times on the timeline: Align the left end of the bar with the time the activity begins, and align the right end with the time the activity concludes. Draw just the outlines of the bars and diamonds; don’t fill them in.
- Check that every task of the project is on the chart.

Using the Chart

- As events and activities take place, fill in the diamonds and bars to show completion. For tasks in progress, estimate how far along you are and fill in that much of the bar.
- Place a vertical marker to show where you are on the timeline. If the chart is posted on the wall, for example, an easy way to show the current time is with a heavy dark string hung vertically across the chart with two thumbtacks.

Site-Specific Electronic Scheduling Tools

Site-specific electronic scheduling tools are unique to each site. General information is available in element d of this competency.

Networking Techniques

The following is taken from DOE 430.1-1, chapter 12.

Like the bar chart, a network represents graphically the different work activities. The difference is that the more sophisticated network depicts the activities and their independence and interdependence. Typically, a logic network contains the activities, their durations, their interdependence, and a calculated critical path. Today networks are generated by computer and may also be time scaled.

Percentage Completion Curve

The following is taken from Project Management for Construction by Chris Hendrickson.
Since construction costs are incurred over the entire construction phase of a project, it is often necessary to determine the amounts to be spent in various periods to derive the cash flow profile, especially for large projects with long durations. Consequently, it is important to examine the percentage of work expected to be completed at various time periods to which the costs would be charged.

Consider the basic problem in determining the percentage of work completed during construction. One common method of estimating percentage of completion is based on the amount of money spent relative to the total amount budgeted for the entire project. This method has the obvious drawback in assuming that the amount of money spent has been used efficiently for production. A more reliable method is based on the concept of value of work completed which is defined as the product of the budgeted labor hours per unit of production and the actual number of production units completed, and is expressed in budgeted labor hours for the work completed. Then, the percentage of completion at any stage is the ratio of the value of work completed to date and the value of work to be completed for the entire project. Regardless of the method of measurement, it is informative to understand the trend of work progress during construction for evaluation and control.

In general, the work on a construction project progresses gradually from the time of mobilization until it reaches a plateau; then the work slows down gradually and finally stops at the time of completion. The rate of work done during various time periods (expressed in the percentage of project cost per unit time) is shown schematically in figure 12 in which ten time periods have been assumed. The solid line A represents the case in which the rate of work is zero at time $t = 0$ and increases linearly to 12.5 percent of project cost at $t = 2$, while the rate begins to decrease from 12.5 percent at $t = 8$ to 0% at $t = 10$. The dotted line B represents the case of rapid mobilization by reaching 12.5 percent of project cost at $t = 1$ while beginning to decrease from 12.5 percent at $t = 7$ to 0 percent at $t = 10$. The dash line C represents the case of slow mobilization by reaching 12.5 percent of project cost at $t = 3$ while beginning to decrease from 12.5 percent at $t = 9$ to 0 percent at $t = 10$.

Source: Project Management for Construction by Chris Hendrickson

Figure 12. Rate of work progress over project time
The value of work completed at a given time (expressed as a cumulative percentage of project cost) is shown schematically in figure 13. In each case (A, B or C), the value of work completed can be represented by an S-shaped curve. The effects of rapid mobilization and slow mobilization are indicated by the positions of curves B and C relative to curve A, respectively.

![Figure 13. Value of work completed over project time](image)

*Source: Project Management for Construction* by Chris Hendrickson

**Figure 13.** Value of work completed over project time

While the curves shown in figures 12 and 13 represent highly idealized cases, they do suggest the latitude for adjusting the schedules for various activities in a project. While the rate of work progress may be changed quite drastically within a single period, such as the change from rapid mobilization to a slow mobilization in periods 1, 2 and 3 in figure 12, the effect on the value of work completed over time will diminish in significance as indicated by the cumulative percentages for later periods in figure 13. Thus, adjustment of the scheduling of some activities may improve the utilization of labor, material and equipment, and any delay caused by such adjustments for individual activities is not likely to cause problems for the eventual progress toward the completion of a project.

In addition to the speed of resource mobilization, another important consideration is the overall duration of a project and the amount of resources applied. Various strategies may be applied to shorten the overall duration of a project such as overlapping design and construction activities or increasing the peak amounts of labor and equipment working on a site. However, spatial, managerial and technical factors will typically place a minimum limit on the project duration or cause costs to escalate with shorter durations.
Labor Schedules/Material Schedules/Equipment Schedules/Finance Schedules

The following is taken from Project Management for Construction by Chris Hendrickson.

Labor Schedules

Productivity in construction is often broadly defined as output per labor hour. Since labor constitutes a large part of the construction cost and the quantity of labor hours in performing a task in construction is more susceptible to the influence of management than are materials or capital, this productivity measure is often referred to as labor productivity. However, it is important to note that labor productivity is a measure of the overall effectiveness of an operating system in utilizing labor, equipment and capital to convert labor efforts into useful output, and is not a measure of the capabilities of labor alone. For example, by investing in a piece of new equipment to perform certain tasks in construction, output may be increased for the same number of labor hours, thus resulting in higher labor productivity.

Construction output may be expressed in terms of functional units or constant dollars. In the former case, labor productivity is associated with units of product per labor hour, such as cubic yards of concrete placed per hour or miles of highway paved per hour. In the latter case, labor productivity is identified with value of construction (in constant dollars) per labor hour. The value of construction in this regard is not measured by the benefit of constructed facilities, but by construction cost. Labor productivity measured in this way requires considerable care in interpretation. For example, wage rates in construction have been declining in the US during the period 1970 to 1990, and since wages are an important component in construction costs, the value of construction put in place per hour of work will decline as a result, suggesting lower productivity.

Because of the diversity of the construction industry, a single index for the entire industry is neither meaningful nor reliable. Productivity indices may be developed for major segments of the construction industry nationwide if reliable statistical data can be obtained for separate industrial segments. For this general type of productivity measure, it is more convenient to express labor productivity as constant dollars per labor hours since dollar values are more easily aggregated from a large amount of data collected from different sources. The use of constant dollars allows meaningful approximations of the changes in construction output from one year to another when price deflators are applied to current dollars to obtain the corresponding values in constant dollars. However, since most construction price deflators are obtained from a combination of price indices for material and labor inputs, they reflect only the change of price levels and do not capture any savings arising from improved labor productivity. Such deflators tend to overstate increases in construction costs over a long period of time, and consequently understate the physical volume or value of construction work in years subsequent to the base year for the indices.

Material Schedules

Materials management is an important element in project planning and control. Materials represent a major expense in construction, so minimizing procurement or purchase costs presents important opportunities for reducing costs. Poor materials management can also result in large and avoidable costs during construction. First, if materials are purchased early, capital may be tied up and interest charges incurred on the excess inventory of materials. Even worse, materials may deteriorate during storage or be stolen unless special care is
taken. For example, electrical equipment often must be stored in waterproof locations. Second, delays and extra expenses may be incurred if materials required for particular activities are not available. Accordingly, insuring a timely flow of material is an important concern of project managers.

Materials management is not just a concern during the monitoring stage in which construction is taking place. Decisions about material procurement may also be required during the initial planning and scheduling stages. For example, activities can be inserted in the project schedule to represent purchasing of major items such as elevators for buildings. The availability of materials may greatly influence the schedule in projects with a fast track or very tight time schedule: sufficient time for obtaining the necessary materials must be allowed. In some case, more expensive suppliers or shippers may be employed to save time.

Materials management is also a problem at the organization level if central purchasing and inventory control is used for standard items. In this case, the various projects undertaken by the organization would present requests to the central purchasing group. In turn, this group would maintain inventories of standard items to reduce the delay in providing material or to obtain lower costs due to bulk purchasing. This organizational materials management problem is analogous to inventory control in any organization facing continuing demand for particular items.

Materials ordering problems lend themselves particularly well to computer based systems to insure the consistency and completeness of the purchasing process. In the manufacturing realm, the use of automated materials requirements planning systems is common. In these systems, the master production schedule, inventory records and product component lists are merged to determine what items must be ordered, when they should be ordered, and how much of each item should be ordered in each time period. The heart of these calculations is simple arithmetic: the projected demand for each material item in each period is subtracted from the available inventory. When the inventory becomes too low, a new order is recommended. For items that are non-standard or not kept in inventory, the calculation is even simpler since no inventory must be considered. With a materials requirement system, much of the detailed record keeping is automated and project managers are alerted to purchasing requirements.

Equipment Scheduling

Typically, construction equipment is used to perform essentially repetitive operations, and can be broadly classified according to two basic functions: (1) operators such as cranes, graders, etc. which stay within the confines of the construction site, and (2) haulers such as dump trucks, ready mixed concrete truck, etc. which transport materials to and from the site. In both cases, the cycle of a piece of equipment is a sequence of tasks which is repeated to produce a unit of output. For example, the sequence of tasks for a crane might be to fit and install a wall panel (or a package of eight wall panels) on the side of a building; similarly, the sequence of tasks of a ready mixed concrete truck might be to load, haul and unload two cubic yards (or one truck load) of fresh concrete.

In order to increase job-site productivity, it is beneficial to select equipment with proper characteristics and a size most suitable for the work conditions at a construction site. In
excavation for building construction, for examples, factors that could affect the selection of excavators include:

- **Size of the job**: Larger volumes of excavation will require larger excavators, or smaller excavators in greater number.
- **Activity time constraints**: Shortage of time for excavation may force contractors to increase the size or numbers of equipment for activities related to excavation.
- **Availability of equipment**: Productivity of excavation activities will diminish if the equipment used to perform them is available but not the most adequate.
- **Cost of transportation of equipment**: This cost depends on the size of the job, the distance of transportation, and the means of transportation.
- **Type of excavation**: Principal types of excavation in building projects are cut and/or fill, excavation massive, and excavation for the elements of foundation. The most adequate equipment to perform one of these activities is not the most adequate to perform the others.
- **Soil characteristics**: The type and condition of the soil is important when choosing the most adequate equipment since each piece of equipment has different outputs for different soils. Moreover, one excavation pit could have different soils at different stratums.
- **Geometric characteristics of elements to be excavated**: Functional characteristics of different types of equipment make such considerations necessary.
- **Space constraints**: The performance of equipment is influenced by the spatial limitations for the movement of excavators.
- **Characteristics of haul units**: The size of an excavator will depend on the haul units if there is a constraint on the size and/or number of these units.
- **Location of dumping areas**: The distance between the construction site and dumping areas could be relevant not only for selecting the type and number of haulers, but also the type of excavators.
- **Weather and temperature**: Rain, snow and severe temperature conditions affect the job-site productivity of labor and equipment.

**Finance Schedules**

Financing arrangements differ sharply by type of owner and by the type of facility construction. As one example, many municipal projects are financed in the United States with tax exempt bonds for which interest payments to a lender are exempt from income taxes. As a result, tax exempt municipal bonds are available at lower interest charges. Different institutional arrangements have evolved for specific types of facilities and organizations.

A private corporation which plans to undertake large capital projects may use its retained earnings, seek equity partners in the project, issue bonds, offer new stocks in the financial markets, or seek borrowed funds in another fashion. Potential sources of funds would include pension funds, insurance companies, investment trusts, commercial banks and others. Developers who invest in real estate properties for rental purposes have similar sources, plus quasi-governmental corporations such as urban development authorities. Syndicators for investment such as real estate investment trusts as well as domestic and foreign pension funds represent relatively new entries to the financial market for building mortgage money.
Public projects may be funded by tax receipts, general revenue bonds, or special bonds with income dedicated to the specified facilities. General revenue bonds would be repaid from general taxes or other revenue sources, while special bonds would be redeemed by either special taxes or user fees collected for the project. Grants from higher levels of government are also an important source of funds for state, county, city or other local agencies.

Despite the different sources of borrowed funds, there is a rough equivalence in the actual cost of borrowing money for particular types of projects. Because lenders can participate in many different financial markets, they tend to switch towards loans that return the highest yield for a particular level of risk. As a result, borrowed funds that can be obtained from different sources tend to have very similar costs, including interest charges and issuing costs.

As a general principle, however, the costs of funds for construction will vary inversely with the risk of a loan. Lenders usually require security for a loan represented by a tangible asset. If for some reason the borrower cannot repay a loan, then the borrower can take possession of the loan security. To the extent that an asset used as security is of uncertain value, then the lender will demand a greater return and higher interest payments. Loans made for projects under construction represent considerable risk to a financial institution. If a lender acquires an unfinished facility, then it faces the difficult task of re-assembling the project team. Moreover, a default on a facility may result if a problem occurs such as foundation problems or anticipated unprofitability of the future facility. As a result of these uncertainties, construction lending for unfinished facilities commands a premium interest charge of several percent compared to mortgage lending for completed facilities.

Financing plans will typically include a reserve amount to cover unforeseen expenses, cost increases or cash flow problems. This reserve can be represented by a special reserve or a contingency amount in the project budget. In the simplest case, this reserve might represent a borrowing agreement with a financial institution to establish a line of credit in case of need. For publicly traded bonds, specific reserve funds administered by a third party may be established. The cost of these reserve funds is the difference between the interest paid to bondholders and the interest received on the reserve funds plus any administrative costs.

Finally, arranging financing may involve a lengthy period of negotiation and review. Particularly for publicly traded bond financing, specific legal requirements in the issue must be met. A typical seven month schedule to issue revenue bonds would include the various steps outlined in table 5. In many cases, the speed in which funds may be obtained will determine a project's financing mechanism.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Time of Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis of financial alternatives</td>
<td>Weeks 0-4</td>
</tr>
<tr>
<td>Preparation of legal documents</td>
<td>Weeks 1-17</td>
</tr>
<tr>
<td>Preparation of disclosure documents</td>
<td>Weeks 2-20</td>
</tr>
<tr>
<td>Forecasts of costs and revenues</td>
<td>Weeks 4-20</td>
</tr>
<tr>
<td>Bond ratings</td>
<td>Weeks 20-23</td>
</tr>
<tr>
<td>Bond marketing</td>
<td>Weeks 21-24</td>
</tr>
<tr>
<td>Bond closing and receipt of funds</td>
<td>Weeks 23-26</td>
</tr>
</tbody>
</table>

*Source: Project Management for Construction* by Chris Hendrickson
d. Describe how the project schedule is used to control cost and schedule as well as tracking it.

The following is taken from Project Management for Construction by Chris Hendrickson.

In addition to assigning dates to project activities, project scheduling is intended to match the resources of equipment, materials and labor with project work tasks over time. Good scheduling can eliminate problems due to production bottlenecks, facilitate the timely procurement of necessary materials, and otherwise insure the completion of a project as soon as possible. In contrast, poor scheduling can result in considerable waste as laborers and equipment wait for the availability of needed resources or the completion of preceding tasks. Delays in the completion of an entire project due to poor scheduling can also create havoc for owners who are eager to start using the constructed facilities.

Attitudes toward the formal scheduling of projects are often extreme. Many owners require detailed construction schedules to be submitted by contractors as a means of monitoring the work progress. The actual work performed is commonly compared to the schedule to determine if construction is proceeding satisfactorily. After the completion of construction, similar comparisons between the planned schedule and the actual accomplishments may be performed to allocate the liability for project delays due to changes requested by the owner, worker strikes or other unforeseen circumstances.

In contrast to these instances of reliance upon formal schedules, many field supervisors disdain and dislike formal scheduling procedures. In particular, the critical path method of scheduling is commonly required by owners and has been taught in universities for over two decades, but is often regarded in the field as irrelevant to actual operations and a time consuming distraction. The result is seat-of-the-pants scheduling that can be good or that can result in grossly inefficient schedules and poor productivity. Progressive construction firms use formal scheduling procedures whenever the complexity of work tasks is high and the coordination of different workers is required.

Formal scheduling procedures have become much more common with the advent of personal computers on construction sites and easy-to-use software programs. Sharing schedule information via the Internet has also provided a greater incentive to use formal scheduling methods. Savvy construction supervisors often carry schedule and budget information around with wearable or handheld computers. As a result, the continued development of easy to use computer programs and improved methods of presenting schedules have overcome the practical problems associated with formal scheduling mechanisms. But problems with the use of scheduling techniques will continue until managers understand their proper use and limitations.

A basic distinction exists between resource oriented and time oriented scheduling techniques. For resource oriented scheduling, the focus is on using and scheduling particular resources in an effective fashion. For example, the project manager's main concern on a high-rise building site might be to insure that cranes are used effectively for moving materials; without effective scheduling in this case, delivery trucks might queue on the ground and workers wait for deliveries on upper floors. For time oriented scheduling, the emphasis is on determining the completion time of the project given the necessary precedence relationships among activities.
Hybrid techniques for resource leveling or resource constrained scheduling in the presence of precedence relationships also exist. Most scheduling software is time-oriented, although virtually all of the programs have the capability to introduce resource constraints.

e. **Evaluate project baseline using resource loaded, time based CPM schedules at a level and frequency that potential problems can be identified and solved before they become real problems.**

This is a performance-based KSA. The Qualifying Official will evaluate its completion. The following information taken from *Project Management for Construction* may be helpful.

The most widely used scheduling technique is the critical path method (CPM) for scheduling, often referred to as critical path scheduling. This method calculates the minimum completion time for a project along with the possible start and finish times for the project activities. Indeed, many texts and managers regard critical path scheduling as the only usable and practical scheduling procedure. Computer programs and algorithms for critical path scheduling are widely available and can efficiently handle projects with thousands of activities.

The critical path itself represents the set or sequence of predecessor/successor activities which will take the longest time to complete. The duration of the critical path is the sum of the activities’ durations along the path. Thus, the critical path can be defined as the longest possible path through the network of project activities. The duration of the critical path represents the minimum time required to complete a project. Any delays along the critical path would imply that additional time would be required to complete the project.

There may be more than one critical path among all the project activities, so completion of the entire project could be delayed by delaying activities along any one of the critical paths. For example, a project consisting of two activities performed in parallel that each require three days would have each activity critical for a completion in three days.

Formally, critical path scheduling assumes that a project has been divided into activities of fixed duration and well defined predecessor relationships. A predecessor relationship implies that one activity must come before another in the schedule. No resource constraints other than those implied by precedence relationships are recognized in the simplest form of critical path scheduling.

To use critical path scheduling in practice, construction planners often represent a resource constraint by a precedence relation. A constraint is simply a restriction on the options available to a manager, and a resource constraint is a constraint deriving from the limited availability of some resource of equipment, material, space or labor. For example, one of two activities requiring the same piece of equipment might be arbitrarily assumed to precede the other activity. This artificial precedence constraint insures that the two activities requiring the same resource will not be scheduled at the same time. Also, most critical path scheduling algorithms impose restrictions on the generality of the activity relationships or network geometries which are used. In essence, these restrictions imply that the construction plan can be represented by a network plan in which activities appear as nodes in a network. Nodes are
numbered, and no two nodes can have the same number or designation. Two nodes are introduced to represent the start and completion of the project itself.

The actual computer representation of the project schedule generally consists of a list of activities along with their associated durations, required resources and predecessor activities. Graphical network representations rather than a list are helpful for visualization of the plan and to insure that mathematical requirements are met. The actual input of the data to a computer program may be accomplished by filling in blanks on a screen menu, reading an existing datafile, or typing data directly to the program with identifiers for the type of information being provided.

With an activity-on-branch network, dummy activities may be introduced for the purposes of providing unique activity designations and maintaining the correct sequence of activities. A dummy activity is assumed to have no time duration and can be graphically represented by a dashed line in a network. Several cases in which dummy activities are useful are illustrated in figure 14. In figure 14, the elimination of activity C would mean that both activities B and D would be identified as being between nodes 1 and 3. However, if a dummy activity X is introduced, as shown in part (b) of the figure, the unique designations for activity B (node 1 to 2) and D (node 1 to 3) will be preserved. Furthermore, if the problem in part (a) is changed so that activity E cannot start until both C and D are completed but that F can start after D alone is completed, the order in the new sequence can be indicated by the addition of a dummy activity Y, as shown in part (c). In general, dummy activities may be necessary to meet the requirements of specific computer scheduling algorithms, but it is important to limit the number of such dummy link insertions to the extent possible.

Source: Project Management for Construction by Chris Hendrickson

Figure 14. Dummy activities in a project network
The critical path scheduling can be formulated mathematically. The following is an algorithm or set of instructions for critical path scheduling assuming an activity-on-branch project network. We also assume that all precedents are of a finish-to-start nature, so that a succeeding activity cannot start until the completion of a preceding activity.

Suppose that the project network has \( n+1 \) nodes, the initial event being 0 and the last event being \( n \). Let the time at which node events occur be \( x_1, x_2, \ldots, x_n \), respectively. The start of the project at \( x_0 \) will be defined as time 0. Nodal event times must be consistent with activity durations, so that an activity's successor node event time must be larger than an activity's predecessor node event time plus its duration. For an activity defined as starting from event \( i \) and ending at event \( j \), this relationship can be expressed as the inequality constraint, \( x_j \geq x_i + D_{ij} \) where \( D_{ij} \) is the duration of activity \((i,j)\). This same expression can be written for every activity and must hold true in any feasible schedule. Mathematically, then, the critical path scheduling problem is to minimize the time of project completion \((x_n)\) subject to the constraints that each node completion event cannot occur until each of the predecessor activities have been completed:

Minimize

\[
    z = x_n
\]

Subject to

\[
    x_0 = 0 \quad \text{(start of project)}
\]

\[
    x_j - x_i - D_{ij} \geq 0 \quad \text{for each activity} \ (i,j)
\]

This is a linear programming problem since the objective value to be minimized and each of the constraints is a linear equation.

Rather than solving the critical path scheduling problem with a linear programming algorithm (such as the Simplex method), more efficient techniques are available that take advantage of the network structure of the problem. These solution methods are very efficient with respect to the required computations, so that very large networks can be treated even with personal computers. These methods also give some very useful information about possible activity schedules. The programs can compute the earliest and latest possible starting times for each activity which are consistent with completing the project in the shortest possible time. This calculation is of particular interest for activities which are not on the critical path (or paths), since these activities might be slightly delayed or re-scheduled over time as a manager desires without delaying the entire project.

6. **Construction management personnel shall demonstrate familiarity level knowledge of contract law applicable to contract specifications and drawings.**

   a. **Discuss stop-work orders, including responsibilities and authorities, and the impact of a stop-work order to project cost and schedule.**

The following is taken from 48 CFR 42.1303.
Stop-work orders may be used, when appropriate, in any negotiated fixed-price or cost-reimbursement supply, research and development, or service contract if work stoppage may be required for reasons such as advancement in the state-of-the-art, production or engineering breakthroughs, or realignment of programs.

Generally, a stop-work order will be issued only if it is advisable to suspend work pending a decision by the government and a supplemental agreement providing for the suspension is not feasible. Issuance of a stop-work order shall be approved at a level higher than the contracting officer. Stop-work orders shall not be used in place of a termination notice after a decision to terminate has been made.

Stop-work orders should include
- a description of the work to be suspended;
- instructions concerning the contractor’s issuance of further orders for materials or services;
- guidance to the contractor on action to be taken on any subcontracts; and
- other suggestions to the contractor for minimizing costs.

promptly after issuing the stop-work order, the contracting officer should discuss the stop-work order with the contractor and modify the order, if necessary, in light of the discussion.

as soon as feasible after a stop-work order is issued, but before its expiration, the contracting officer shall take appropriate action to
  - terminate the contract;
  - cancel the stop-work order (any cancellation of a stop-work order shall be subject to the same approvals as were required for its issuance); or
  - extend the period of the stop-work order if it is necessary and if the contractor agrees (any extension of the stop-work order shall be by a supplemental agreement).

b. Describe what constitutes compliance with specifications and drawings.

The following is taken from the University of Washington, Specifications.

Specifications are used for three primary purposes:
- Convey information concerning desired products from a buyer to a seller or potential seller.
- Provide a basis for competitive bidding for the delivery of products.
- Measure compliance to contracts.

There are four types of specifications generally recognized in the construction industry: proprietary product, method, end-result and performance.

Proprietary Product Specifications
A proprietary product specification is used when a generic description of a desired product or process cannot be easily formulated. It usually contains an or equivalent clause to allow for some measure of competition in providing the product. It is generally acknowledged that such a specification severely limits competition which increases cost, it provides very little
latitude for innovation and it puts substantial risk on the owner for product performance. Most agencies avoid this type of specification whenever possible.

**Method Specifications**

A method specification outlines a specific materials selection and construction operation process to be followed in providing a product. In the past, many construction specifications were written in this manner. A contractor would be told what type of material to produce, what equipment to use and in what manner it was to be used in building a structure. In its strictest sense, only the final form of the structure can be stipulated (for instance, the thickness of the pavement layers). This type of specification allows for a greater degree of competition than the proprietary product specification, but as long as the structure is built according to the materials and methods stipulated, the agency bears the responsibility for the performance.

Although widely used, method specifications have several key disadvantages. First, they tend to stifle contractor innovation. Since a contractor’s only motivation is instructional compliance, there is virtually no incentive to develop better, more efficient construction methods. Second, since they are not statistically based and 100 percent compliance is usually not possible, method specifications usually required substantial compliance, a purposely vague and undefined term that can lead to disputes. Finally, spot checks of material quality, which are often used in method specifications, do not reflect overall material quality because they are taken from subjectively determined non-random locations. Since they are not random, these spot checks have no statistical validity and therefore do not reflect overall material quality.

Despite their flaws, method specifications are still widely used on the local agency level (e.g., counties, small cities, towns, etc.). In general, this is because they are familiar, straightforward to write and can be implemented with minimal agency involvement. Local agencies often lack the expertise and resources required to use statistical specifications or warranties.

**End-Result Specifications**

An end-result specification is one in which the final characteristics of the product are stipulated, and the contractor is given considerable freedom in achieving those characteristics. In their roughest form, they specify minimum, maximum or a range of values for any given characteristic and base acceptance on conformance to these specifications. For instance, they may state a minimum layer thickness or a range of in-place air voids. However, since it is impractical to measure every square foot of constructed pavement, end-result specifications use statistical methods to estimate overall material quality based on a limited number of random samples. Therefore, end result specifications improve on methods specifications in two key areas: (1) they shift the focus away from methods and on to final product quality and (2) they do not rely on the nebulous substantial compliance because they clearly define acceptable quality.

Today, most large state and Federal contracts use statistically based end-result specifications that incorporate some elements of method specifications (usually used to guard against early failure of the product). These end-result specifications are often referred to as a quality
assurance specification. Essentially, these specifications specify the end results and also specify certain minimum construction method requirements.

End result specifications assign construction quality to the contractor, they define the desired final product, and they allow the contractor significant latitude in achieving that final product. This leads to innovation, efficiency, and lower costs. However, these specifications and their statistical sampling requirements are often too complex and resource intensive to be used at the local agency level.

*Performance Specifications*

Performance specifications are those in which the product payment is directly dependent upon its actual performance. Typical of these specifications are warranty, limited warranty and design-build-operate contracts. Contractors are held responsible for the product performance within the context of what they have control over. The contractor is given a great deal of leeway in providing the product, as long as it performs according to established guidelines. In this case, the contractor assumes considerable risk for the level of service the product provides by paying for or providing any necessary maintenance or repair within the warranty period.

*Warranty Specifications*

Warranty specifications are one type of performance specification that has begun to receive more attention. In a warranty specification, the agency specifies performance only and the contractor warrants the construction for performance over a specific amount of time (usually 2 to 7 years although some have been done up to 20 years). During the warranty period, any defects attributable to construction are repaired at the contractor’s expense.

There are two basic types of construction warranties, the second of which, performance warranties, is what is typically meant when referring to a warranty specification:

- **Materials and workmanship.** Almost all construction is covered by a short duration (usually 1 year) materials and workmanship warranty. This type of warranty assigns risk to the contractor for following agency specifications in regards to materials and workmanship. If a problem or defect is detected within the warranty period, the agency usually uses a forensic analysis to determine the cause. If it is determined that specification non-compliance caused the problem, it is repaired at the contractor's expense. Otherwise, the agency assumes repair costs. This type of warranty is almost universal, rarely collected on and is usually covered by sureties at no additional charge to the contractor.

- **Performance.** This type of warranty assigns a large portion of the pavement performance risk to the contractor. During the warranty period the agency monitors pavement performance and any unacceptable performance attributable to construction is remedied at the contractor’s expense. Because the contractor assumes greater risk he/she is allowed to control most construction aspects.

For specifying agencies, warranties represent an advancement in specifications over end result specifications because they can specify actual pavement performance rather than material characteristics that are only indicative of performance. Thus, warranty specifications are best able to align the sometimes competing influences of economic incentive, innovation,
customer requirements and quality. This alignment, when achieved, allows market forces and economics, rather than specifications alone, to drive quality.

c. **Discuss the process for making changes and modifications to contract specifications or the scope of work.**

*Changes—Fixed Price*

The following is taken from 48 CFR 52.243-1.

The contracting officer may at any time, by written order, and without notice to the sureties, if any, make changes within the general scope of the contract in any one or more of the following:

- Drawings, designs, or specifications when the supplies to be furnished are to be specially manufactured for the government in accordance with the drawings, designs, or specifications
- Method of shipment or packing
- Place of delivery

If any such change causes an increase or decrease in the cost of, or the time required for, performance of any part of the work under the contract, whether or not changed by the order, the contracting officer shall make an equitable adjustment in the contract price, the delivery schedule, or both, and shall modify the contract.

The contractor must assert its right to an adjustment under this clause within 30 days from the date of receipt of the written order. However, if the contracting officer decides that the facts justify it, the contracting officer may receive and act on a proposal submitted before final payment of the contract.

If the contractor’s proposal includes the cost of property made obsolete or excess by the change, the contracting officer shall have the right to prescribe the manner of the disposition of the property.

Failure to agree to any adjustment shall be a dispute under the disputes clause. However, nothing in this clause shall excuse the contractor from proceeding with the contract as changed.

*Changes—Time and Materials or Labor Hours*

The following is taken from 48 CFR 52.243-3.

The contracting officer may at any time, by written order, and without notice to the sureties, if any, make changes within the general scope of the contract in any one or more of the following:

- Description of services to be performed
- Time of performance
- Place of performance of the services
- Drawings, designs, or specifications when the supplies to be furnished are to be specially manufactured for the government in accordance with the drawings, designs, or specifications
- Method of shipment or packing of supplies
- Place of delivery
- Amount of government-furnished property

If any change causes an increase or decrease in any hourly rate, the ceiling price, or the time required for performance of any part of the work under the contract, whether or not changed by the order, or otherwise affects any other terms and conditions of the contract, the contracting officer will make an equitable adjustment in any one or more of the following and will modify the contract accordingly:
- Ceiling price
- Hourly rates
- Delivery schedule
- Other affected terms

The contractor shall assert its right to an adjustment under this clause within 30 days from the date of receipt of the written order. However, if the contracting officer decides that the facts justify it, the contracting officer may receive and act upon a proposal submitted before final payment of the contract.

Failure to agree to any adjustment will be a dispute under the disputes clause. However, nothing in this clause excuses the contractor from proceeding with the contract as changed.

d. Describe the difference between expressed and implied warranties and how each is addressed in contract specifications.

The following is taken from Consumer Fraud Lawyer, Types of Warranties.

Three types of warranties are enforced under the Uniform Commercial Code and products liability laws. They are:

Express Warranty
An express warranty may include statements made during sales negotiations, those written in a sales contract, those stated on tags attached to the product or sample, and more. Express warranties can be established in three ways: (1) through the supplier’s affirmation of fact to the purchaser about the goods, (2) through a description of the goods or services, or (3) through a sample or model, all of which are used in the process of sales negotiations or bargaining. An example of an express warranty is a statement like “These tires will last for 200,000 miles.” Note that puffery, or statements like “these tires will last a lifetime,” do not constitute an express warranty.

Implied Warranty
Implied warranty of merchantability – requires that minimum standards of quality be met by the products (and their containers) or services. Products must be fit for the general purposes for which they are sold. A product must be what all labeling and seller statements say it is.

Implied warranty of fitness- is made when a seller selects goods for a particular purpose for the consumer. For example, if a consumer asks a tire outfitter to recommend tires for the
snow and they select tires are not safe or appropriate for the snow, a breach of implied warranty of fitness exists.

**Extended Warranties**

Breach of extended warranty is a common culprit in warranty fraud. Warranty companies know that warranties are often the most confusing and most profitable product they can sell. For this reason, it is important to be a smart consumer when it comes to extended warranties.

Extended warranties are not necessarily insurance plans; often they are service contracts existing between the warranty company and the purchaser. While a primary warranty protects against defects and false claims made at the point of sale or present from the time of sale to a particular point in time, extended warranties continue coverage for defects or problems that occur after the point of purchase or the expiration of a primary warranty.

A manufacturer, dealer, or a third party may offer extended warranties for such products as vehicles, household appliances, home electronic systems, and much more. It is very important to be a savvy consumer to avoid becoming a casualty of warranty fraud.

e. **Describe the process for expending funds for a project as it relates to contract law.**

The following is taken from 48 CFR 32.904.

The due date for making payments on construction contracts is as follows:

The due date for making progress payments based on contracting officer approval of the estimated amount and value of work or services performed, including payments for reaching milestones in any project, is 14 days after the designated billing office receives a proper payment request.

If the designated billing office fails to annotate the payment request with the actual date of receipt at the time of receipt, the payment due date is the 14th day after the date of the contractor’s payment request, provided the designated billing office receives a proper payment request and there is no disagreement over quantity, quality, or contractor compliance with contract requirements.

The contracting officer may specify a longer period in the solicitation and resulting contract if required to afford the Government a reasonable opportunity to adequately inspect the work and to determine the adequacy of the contractor’s performance under the contract. The contracting officer must document in the contract file the justification for extending the due date beyond 14 days.

The contracting officer must not approve progress payment requests unless the certification and substantiation of amounts requested are provided as required by the clause at 48 CFR 52.232-5, “Payments Under Fixed-Price Construction Contracts.”
The due date for payment of any amounts retained by the contracting officer in accordance with the clause at 48 CFR 52.232-5, will be as specified in the contract or, if not specified, 30 days after approval by the contracting officer for release to the contractor. The contracting officer must base the release of retained amounts on the contracting officer’s determination that satisfactory progress has been made.

The due date for final payments based on completion and acceptance of all work and payments for partial deliveries that have been accepted by the government is as follows:

The later of the following two events:

- The 30th day after the designated billing office receives a proper invoice from the contractor.
- The 30th day after government acceptance of the work or services completed by the contractor. For a final invoice, when the payment amount is subject to contract settlement actions, acceptance is deemed to occur on the effective date of the contract settlement.

If the designated billing office fails to annotate the invoice with the actual date of receipt at the time of receipt, the invoice payment due date is the 30th day after the date of the contractor’s invoice, provided the designated billing office receives a proper invoice and there is no disagreement over quantity, quality, or contractor compliance with contract requirements.

For the sole purpose of computing an interest penalty that might be due the contractor the following conditions will apply:

- Government acceptance or approval is deemed to occur constructively on the 7th day after the contractor completes the work or services in accordance with the terms and conditions of the contract, unless there is a disagreement over quantity, quality, contractor compliance with a contract requirement, or the requested amount;
- If actual acceptance occurs within the constructive acceptance period, the government must base the determination of an interest penalty on the actual date of acceptance;
- The constructive acceptance requirement does not compel government officials to accept work or services, approve contractor estimates, perform contract administration functions, or make payment prior to fulfilling their responsibilities; and
- The contracting officer may specify a longer period for constructive acceptance or constructive approval in the solicitation and resulting contract, if required to afford the government a reasonable opportunity to adequately inspect the work and to determine the adequacy of the contractor’s performance under the contract. The contracting officer must document in the contract file the justification for extending the constructive acceptance or approval beyond 7 days.

Construction contracts contain special provisions concerning contractor payments to subcontractors, along with special contractor certification requirements. The Office of Management and Budget has determined that these certifications must not be construed as final acceptance of the subcontractor’s performance. The certification in 48 CFR 52.232-5(c) implements this determination; however, certificates are still acceptable if the contractor deletes paragraph (c)(4) of 48 CFR 52.232-5 from the certificate.
Paragraph (d) of the clause at 48 CFR 52.232-5, and paragraph (e)(6) of the clause at 48 CFR 52.232-27, “Prompt Payment for Construction Contracts,” provide for the contractor to pay interest on unearned amounts in certain circumstances. The government must recover this interest from subsequent payments to the contractor. Therefore, contracting officers normally must make no demand for payment. Contracting officers must—
- Compute the amount in accordance with the clause;
- Provide the contractor with a final decision; and
- Notify the payment office of the amount to be withheld.

f. Describe in general terms the process used to negotiate and establish a construction contract between the DOE and the contractor.

The following is taken from 48 CFR 16.103.

Selecting the contract type is generally a matter for negotiation and requires the exercise of sound judgment. Negotiating the contract type and negotiating prices are closely related and should be considered together. The objective is to negotiate a contract type and price (or estimated cost and fee) that will result in reasonable contractor risk and provide the contractor with the greatest incentive for efficient and economical performance.

A firm-fixed-price contract, which best utilizes the basic profit motive of business enterprise, shall be used when the risk involved is minimal or can be predicted with an acceptable degree of certainty. However, when a reasonable basis for firm pricing does not exist, other contract types should be considered, and negotiations should be directed toward selecting a contract type (or combination of types) that will appropriately tie profit to contractor performance.

In the course of an acquisition program, a series of contracts, or a single long-term contract, changing circumstances may make a different contract type appropriate in later periods than that used at the outset. In particular, contracting officers should avoid protracted use of a cost-reimbursement or time-and-materials contract after experience provides a basis for firmer pricing.

Each contract file shall include documentation to show why the particular contract type was selected. Exceptions to this requirement are:
- fixed-price acquisitions made under simplified acquisition procedures
- contracts on a firm fixed-price basis other than those for major systems or research and development
- awards on the set-aside portion

7. Construction management personnel shall demonstrate the ability to read and interpret engineering piping and instrument drawings (P&ID) at a working level.

a. Identify the symbols used on engineering piping and instrument drawings for:
- Types of valves
- Types of valve operators
- Basic types of instrumentation
- Types of system components (pumps, etc.)
- Types of lines

b. Identify the symbols used on engineering piping and instrument drawings to denote the location of instruments, indicators, and controllers.

c. Identify how valve conditions are shown on a piping and instrument drawing.

d. Determine the system flow path for a given valve lineup.

These are performance-based KSAs. The Qualifying Official will evaluate their completion.

8. Construction management personnel shall demonstrate a working level of knowledge of the application of Federal Acquisition Regulations to a construction project by successful completion of a contracting officer representative course and written examination.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

9. Construction management personnel shall demonstrate the ability to read and interpret electrical diagrams and schematics at a working level.

a. Identify the symbols used on electrical engineering drawings.

b. Identify the symbols and/or codes used on electrical engineering drawings to show the relationship between components.

c. State the conditions in which all electrical devices are shown, unless otherwise noted on the diagram or schematic.

d. Given a simple electrical schematic and initial condition, identify the power sources and/or loads and their status.

These are performance-based KSAs. The Qualifying Official will evaluate their completion.

10. Construction management personnel shall demonstrate the ability to read and interpret electronic block diagrams and logic diagrams at a working level.

a. Given an electronic block diagram, print, or schematic, identify the symbols that represent the basic components.

b. Identify the symbols on logic diagrams that represent the components.

c. Given a logic diagram and appropriate information, determine the output of each component and the logic circuit.

These are performance-based KSAs. The Qualifying Official will evaluate their completion.
11. Construction management personnel shall demonstrate the ability to read and interpret engineering fabrication, construction, and architectural drawings at a working level.

a. Given the above drawings, read and interpret the following symbology:
   - Basic dimensional and tolerance
   - Basic fabrication
   - Basic construction
   - Basic architecture

b. Given a drawing and a completed or partially completed product, compare the product against the specifications on the drawing.

KSAs a and b are performance-based KSAs. The Qualifying Official will evaluate their completion.

c. Discuss the relationship between specifications and drawings.

The following is taken from Integrated Publishing, Engineering, “Use of Drawings and Specifications.”

Construction drawings are the main basis for defining required construction activities and for measuring quantities of material. Accurate estimating requires a thorough examination of the drawings. All notes and references should be read carefully, and all details and reference drawings should be examined. The orientation of sectional views should be checked carefully. Dimensions shown on drawings or computed figures shown from those drawings should be used in preference to those obtained by scaling distances. An overall dimension shown on a drawing should be checked to see if it tallies with the sum of the partial lengths. If scaling is unavoidable, the graphic scale must be checked for possible expansion or shrinkage at a rate different from that of other parts of the drawing. The revision block should be checked for changes made to the drawings. The construction plan, the specification, and the drawing must be verified to see if they are, in fact, all talking about the same project. A list of activities and materials that are described or mentioned in the specifications will be helpful in checking quantity estimates.

d. Describe the process for resolving conflicts between specifications and drawings.

The following is taken from Integrated Publishing, Engineering, “Use of Drawings and Specifications.”

When there are inconsistencies between general drawings and details, details should be followed unless they are obviously wrong. When there are inconsistencies between drawings and specifications, the specifications should be followed. The estimator must first study the specifications and then use them with the drawings when preparing quantity estimates. The estimator should become thoroughly familiar with all the requirements stated in the specifications. Most estimators will have to read the specifications more than once to fix these requirements in their minds. If the estimator makes notes while reading the specifications, these notes will prove helpful when the drawings are examined. In the notes,
the estimator should list items of work or materials that are unusual or unfamiliar. These notes should also contain reminders for use during examination of the drawings.

12. **Construction management personnel shall demonstrate a familiarity level knowledge of the principles and concepts of natural phenomena hazards.**

a. **Discuss the impact on facilities, and the mitigating factors, associated with the following hazards:**
   - Flooding
   - Wind
   - Tornado
   - Earthquake and/or other seismic events

The following information is taken from DOE-STD-1020-2002.

*Flooding*

**Impact on Facilities**

In many ways, flood hazards differ significantly from other natural phenomena. As an example, it is often relatively easy to eliminate flood hazards as a potential contributor to damage at a site through strict siting requirements. Similarly, the opportunity to effectively use warning systems and emergency procedures to limit damage and personnel injury is significantly greater in the case of flooding than it is for seismic or extreme winds and tornadoes.

The damage to buildings and the threat to public health vary depending on the type of flood hazard. In general, structural and nonstructural damage occur if a site is inundated. Depending on the dynamic intensity of on-site flooding, severe structural damage and complete destruction of buildings can result. In many cases, structural failure may be less of a concern than the damaging effects of inundation on building contents and the possible transport of hazardous or radioactive materials.

For hazardous facilities that are not hardened against possible on-site and in-building flooding, simply inundating the site can result in a loss of function of critical components required to maintain safety and breach of areas that contain valuable or hazardous materials.

Structural damage to buildings depends on a number of factors related to the intensity of the flood hazard and the local hydraulics of the site. Severe structural damage and collapse can occur as a result of a combination of hazards such as flood stage level, flow velocity, debris or sediment transport, wave forces, and impact loads. Flood stage is quite obviously the single most important characteristic of the hazard.

In general, the consequences of flooding increases as flooding varies from submergence to rapidly moving water loaded with debris. Submergence results in water damage to a building and its contents, loss of operation of electrical components, and possible structural damage resulting from hydrostatic loads. Structural failure of roof systems can occur when drains become clogged or are inadequate, and parapet walls allow water, snow, or ice to collect.
Also, exterior walls of reinforced concrete or masonry buildings can crack and possibly fail under hydrostatic conditions.

Dynamic flood hazards can cause excessive damage to structures that are not properly designed. Where wave action is likely, erosion of shorelines or river banks can occur. Structures located near the shore are subject to continuous dynamic forces that can break up a reinforced concrete structure and at the same time undermine the foundation. Buildings with light steel frames and metal siding, wooden structures, and unreinforced masonry are susceptible to severe damage and even collapse if they are exposed to direct dynamic forces. Reinforced concrete buildings are less likely to suffer severe damage or collapse.

Mitigating Factors
As part of the flood hazard assessment that is performed for a site, the sources of flooding and the individual flood hazards are identified. A site or individual SSC may be impacted by multiple sources of flooding and flood hazards. For example, many DOE sites must consider the hazards associated with river flooding. In addition, all sites must design a storm water management system to handle the runoff due to local precipitation. Events that contribute to potential river flooding such as spring snowmelt, upstream-dam failure, etc. must be considered as part of a probabilistic flood hazard analysis.

Therefore, at a site there may be multiple DBFLs that are considered. For sites with potential for river flooding a DBFL is determined for river flooding and for local precipitation which determines the design of the site stormwater management systems. In this instance, various aspects of the design for a SSC may be determined by different flood hazards. As a result, the term DBFL is used in a general sense that applies to the multiple flood hazards that may be included in the design basis.

The flood evaluation process is illustrated in figure 15. It is divided into the consideration of regional flood hazards and local precipitation. For new construction, design practice is to construct the SSC above the DBFL, thus avoiding the flood hazard and eliminating the consideration of flood loads as part of the design. The design of the site storm water management system and structural systems for local precipitation must be adequate to prevent flooding that may damage a SSC or interrupt operations to the extent that the performance goals are not satisfied.

The basic design strategy for SSCs in performance categories 2 to 4 is to construct the SSC above the DBFL. When this can be done, flood hazards are not considered in the design basis except that possible raised ground water level must be considered. The flood criteria have been established with this basic strategy in mind. Note that local precipitation is an exception since all sites must consider this hazard in the design of the site storm water management system, roof systems, etc.

Since it may not always be possible to construct a new SSC above the DBFL level, alternate design strategies must be considered. The following lists the hierarchy of flood design strategies:

- Situate the SSC above the DBFL level,
- Modify the flood, or
- Harden the site or SSC to mitigate the effects of the DBFL such that the performance goals are satisfied, and
- Establish emergency operation plans to safely evacuate employees and secure areas with hazardous, mission-dependent, or valuable materials.

![Flood evaluation process diagram](image)

*Source: DOE-STD-1020-2002*

**Figure 15.** Flood evaluation process

**Wind**

Impact on Facilities

Wind pressures on structures can be classified as external or internal. External pressures develop as air flows over and around enclosed structures. The air particles change speed and direction, which produces a variation of pressure on the external surfaces of the structure. At sharp edges, the air particles separate from contact with the building surface, with an
attendant energy loss. These particles produce large outward-acting pressures near the location where the separation takes place. External pressures act outward on all surfaces of an enclosed structure, except on windward walls and on steep windward roofs. External pressures include pressures on windward walls, leeward walls, side walls and roof.

Internal pressures develop when air flows into or out of an enclosed structure through existing openings or openings created by airborne missiles. In some cases natural porosity of the structure also allows air to flow into or out of the building. Internal pressure acts either inward or outward, depending on the location of the opening and the wind direction. If air flows into the structure through an opening in the windward wall, a ballooning effect takes place—pressure inside the building increases relative to the outside pressure. The pressure change produces additional net outward-acting pressures on all interior surfaces. Openings in any wall or roof area where the external pressures are outward acting allow air to flow from inside the structure—pressure inside the structure decreases relative to the outside pressure. The pressure change produces net inward-acting pressure on all interior surfaces. Internal pressures combine with external pressures acting on a structure’s surface.

With systems and components, interest focuses on net overturning or sliding forces, rather than the wind pressure distribution. The magnitude of these forces is determined by wind tunnel or full-scale tests. Also, in special cases associated with aerodynamically sensitive SSCs, vortex shedding or flutter may need to be considered in design. Typical wind sensitive SSCs include stacks, poles, cooling towers, utility bridges, and relatively light-weight structures with large smooth surfaces.

Gusts of wind produce dynamic pressures on SSCs. Gust effects depend on the gust size relative to SSC size and gust frequency relative to the natural frequency of the SSC. Except for tall, slender structures, the gust frequencies and the structure frequencies of vibration are sufficiently different that resonance effects are small, but are not negligible. The size of a gust relative to the size of the SSC contributes to the magnitude of the dynamic pressure. A large gust that engulfs the entire SSC has a greater dynamic effect on the SSC than a small gust that only partially covers the SSC. In any event, wind loads may be treated as quasi-static loads by including an appropriate gust response factor in calculating the magnitude of the wind pressure. Straight wind, hurricane or tornado gusts are not exactly the same, but errors owing to the difference in gust characteristics are believed to be relatively small for those SSCs that are not wind sensitive.

The roughness of terrain surrounding SSCs significantly affects the magnitude of wind speed. Terrain roughness is typically defined in four classes: urban, suburban, open and smooth. Wind speed profiles as a function of height above ground are represented by a power law relationship for engineering purposes. The relationship gives zero wind speed at ground level. The wind speed increases with height to the top of the boundary layer, where the wind speed remains constant with height.

Mitigating Factors
The minimum wind design criteria for each performance category are summarized in table 6. The recommended basic wind speeds for straight wind, hurricanes and tornadoes are contained in table 7 for non-reactor nuclear and other hazardous facilities, reservations, and
production facilities. All wind speeds are 3 second gust, which is consistent with the ASCE 7 approach. Importance factors as given in American Society of Civil Engineers, ASCE 7 should be used where applicable.

Degrees of conservatism are introduced in the design process by means of load combinations. The combinations are given in the appropriate material national consensus design standard.

Table 6. Summary of minimum wind design criteria

<table>
<thead>
<tr>
<th>Performance Category</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wind</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hazard Annual</td>
<td>$2 \times 10^{-2}$</td>
<td>$1 \times 10^{-2}$</td>
<td>$1 \times 10^{-3}$</td>
<td>$1 \times 10^{-4}$</td>
</tr>
<tr>
<td>Probability of</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exceedance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Importance Factor</td>
<td>1.0</td>
<td>1.00</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Missile Criteria</td>
<td>N/A</td>
<td>N/A</td>
<td>2x4 timber plank 15 lb @50 mph (horiz.); max. height 30 ft.</td>
<td>2x4 timber plank 15 lb @50 mph (horiz.); max. height 50 ft.</td>
</tr>
<tr>
<td><strong>Tornado</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hazard Annual</td>
<td>N/A</td>
<td>N/A</td>
<td>(1) $2 \times 10^{-5}$</td>
<td>(1) $2 \times 10^{-6}$</td>
</tr>
<tr>
<td>Probability of</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exceedance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Importance Factor</td>
<td>N/A</td>
<td>N/A</td>
<td>1 = 1.0</td>
<td>1 = 1.0</td>
</tr>
<tr>
<td>APC</td>
<td>N/A</td>
<td>N/A</td>
<td>40 psf @ 20 psf/sec</td>
<td>125 psf @ 50 psf/sec</td>
</tr>
<tr>
<td>Missile Criteria</td>
<td>N/A</td>
<td>N/A</td>
<td>2x4 timber plank 15 lb @100 mph (horiz.); max. height 150 ft.; 70 mph (vert.)</td>
<td>2x4 timber plank 15 lb @150 mph (horiz.); max. height 200 ft.; 100 mph (vert.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 in dia. std. steel pipe 75 lb @50 mph (horiz.) max height 75 ft.; 35 mph (vert.)</td>
<td>3 in dia. std. steel pipe 75 lb @ 75 mph (horiz.) max height 100 ft.; 50 mph (vert.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3,000 lb auto @35 mph rolls and tumbles</td>
</tr>
</tbody>
</table>

Source: DOE-STD-1020-2002

Designers will need to exercise judgment in choosing the most appropriate combinations in some situations. Designs or evaluations shall be based on the load combination causing the
most unfavorable effect. For performance category 3 and 4 the load combination to be used should invoke either wind or tornado depending on which speed is specified in table 7.

Table 7. Recommended peak gust wind speeds for straight winds (for category C exposure)

<table>
<thead>
<tr>
<th>Current Performance Category</th>
<th>PC1</th>
<th>PC2</th>
<th>PC3 Wind</th>
<th>PC3 Tornado&lt;sup&gt;(2)&lt;/sup&gt;</th>
<th>PC4 Wind</th>
<th>PC4 Tornado&lt;sup&gt;(2)&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return period (yrs)</td>
<td>50</td>
<td>100</td>
<td>1000</td>
<td>50000</td>
<td>10000</td>
<td>500000</td>
</tr>
<tr>
<td>Annual Probability</td>
<td>2.00E-02</td>
<td>1.00E-02</td>
<td>1.00E-03</td>
<td>2.00E-05</td>
<td>1.00E-04</td>
<td>2.00E-06</td>
</tr>
<tr>
<td>Site</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kansas City Plant, MO</td>
<td>90</td>
<td>96</td>
<td>-</td>
<td>(3)</td>
<td>-</td>
<td>(3)</td>
</tr>
<tr>
<td>Los Alamos National Laboratory, NM</td>
<td>90</td>
<td>96</td>
<td>117</td>
<td>135</td>
<td>248</td>
<td></td>
</tr>
<tr>
<td>Mound Laboratory, OH</td>
<td>90</td>
<td>96</td>
<td>-</td>
<td>(3)</td>
<td>-</td>
<td>(3)</td>
</tr>
<tr>
<td>Pantex Plant, TX</td>
<td>90</td>
<td>96</td>
<td>-</td>
<td>195</td>
<td>-</td>
<td>248</td>
</tr>
<tr>
<td>Rocky Flats Plant, CO</td>
<td>125</td>
<td>134</td>
<td>163</td>
<td>(1)</td>
<td>199</td>
<td>(1)</td>
</tr>
<tr>
<td>Sandia National Laboratories, NM</td>
<td>90</td>
<td>96</td>
<td>117</td>
<td>135</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sandia National Laboratories, CA</td>
<td>85</td>
<td>91</td>
<td>111</td>
<td>128</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Argonne National Laboratories-East, IL</td>
<td>90</td>
<td>96</td>
<td>-</td>
<td>(3)</td>
<td>-</td>
<td>(3)</td>
</tr>
<tr>
<td>Argonne National Laboratories-West, ID</td>
<td>90</td>
<td>96</td>
<td>117</td>
<td>135</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Brookhaven National Laboratory, NY</td>
<td>125</td>
<td>128</td>
<td>178</td>
<td>(1)</td>
<td>219</td>
<td>(1)</td>
</tr>
<tr>
<td>Princeton Plasma Physics Laboratory, NJ</td>
<td>110</td>
<td>122</td>
<td>156</td>
<td>(1)</td>
<td>193</td>
<td>(1)</td>
</tr>
<tr>
<td>Idaho National Engineering Laboratory, ID</td>
<td>90</td>
<td>96</td>
<td>117</td>
<td>135</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Oak Ridge, X-10, K-25, and Y-12, TN</td>
<td>90</td>
<td>96</td>
<td>-</td>
<td>200</td>
<td>-</td>
<td>255</td>
</tr>
<tr>
<td>Fadudah Gaseous Diffusion Plant, KY</td>
<td>90</td>
<td>96</td>
<td>-</td>
<td>(3)</td>
<td>-</td>
<td>(3)</td>
</tr>
<tr>
<td>Portsmouth Gaseous Diffusion Plant, OH</td>
<td>60</td>
<td>96</td>
<td>-</td>
<td>(3)</td>
<td>-</td>
<td>(3)</td>
</tr>
<tr>
<td>Nevada Test Site, NV</td>
<td>90</td>
<td>96</td>
<td>117</td>
<td>135</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hanford Project Site, WA</td>
<td>85</td>
<td>91</td>
<td>111</td>
<td>128</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lawrence Berkeley Laboratory, CA</td>
<td>85</td>
<td>91</td>
<td>111</td>
<td>128</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lawrence Livermore National Laboratory, CA</td>
<td>85</td>
<td>91</td>
<td>111</td>
<td>128</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LLNL, Site 300, CA</td>
<td>65</td>
<td>102</td>
<td>124</td>
<td>143</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Energy Technology &amp; Engineering Center, CA</td>
<td>85</td>
<td>91</td>
<td>-</td>
<td>(3)</td>
<td>-</td>
<td>(3)</td>
</tr>
<tr>
<td>Stanford Linear Accelerator Center, CA</td>
<td>85</td>
<td>91</td>
<td>111</td>
<td>129</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Savannah River Site, SC</td>
<td>100</td>
<td>107</td>
<td>-</td>
<td>189</td>
<td>-</td>
<td>213</td>
</tr>
</tbody>
</table>

1. Although straight wind speeds govern, because the potential for a tornado strike is high, it is recommended that facilities be designed for tornado missiles using the missile speeds for the relevant performance category. Atmospheric pressure change (APC) may not be considered.
2. Tornado speed includes rotational and translational effects.
3. For non-NNSA sites tornado wind speeds need to be generated by sites from tornado hazard curves using Lawrence Livermore National Laboratory (LLNL) methodology.

Source: DOE-STD-1020-2002

Most loads, other than dead loads, vary significantly with time. When these variable loads are combined with dead loads, their combined effect could be sufficient to reduce the risk of unsatisfactory performance to an acceptably low level. When more than one variable load is considered, it is unlikely that they will all attain their maximum value at the same time.

Accordingly, some reduction in the total of the combined load effects is appropriate. This reduction is accomplished through load combination multiplication factors as given in the appropriate material national consensus standard.
Tornado

Impacts on Facilities
In addition to wind effects, tornadoes produce atmospheric pressure change effects and missile impacts from windborne debris (tornado-generated missiles). APC only affects sealed structures. Natural porosity, openings or breach of the structure envelope permit the inside and outside pressures of an unsealed structure to equalize. Openings of one sq ft per 1000 cu ft volume are sufficiently large to permit equalization of inside and outside pressure as a tornado passes. SSCs that are purposely sealed will experience the net pressure difference caused by APC. APC, when present, acts outwardly and combines with external wind pressures. The magnitude of APC is a function of the tangential wind speed of the tornado. However, the maximum tornado wind speed and the maximum APC do not occur at the same location within the tornado vortex. The lowest APC occurs at the center of the tornado vortex, whereas the maximum wind pressure occurs at the radius of maximum wind, which ranges from 150 to 500 ft from the tornado center.

The APC is approximately one-half its maximum value at the radius of maximum wind speed. With APC acting on a sealed building, internal pressure need not be considered. The rate of APC is a function of the tornado’s translational speed, which can vary from 5 to 60 miles per hour (mph). A rapid rate of pressure change can produce adverse effects on heating, ventilation, and air-conditioning systems.

High winds and tornadoes pick up and transport various pieces of debris, including roof gravel, pieces of sheet metal, timber planks, plastic pipes and other objects that have high surface area to weight ratios. These objects can be carried to heights up to 200 feet in strong tornadoes.

Steel pipes, posts, light-weight beam sections and open web steel joists having smaller area-to-weight ratios are transported by tornado winds, but occur less frequently and normally do not reach heights above 100 feet. Automobiles, storage tanks, and railroad cars may be rolled and tumbled by severe tornado winds. In extremely rare instances, large-diameter pipes, steel wide flange sections and utility poles are transported by very intense tornado winds. These latter missiles are so rare that practicality precludes concern except for SSCs having lower probabilistic performance goals than performance category 4, which are comparable to SSCs found in commercial nuclear power plants.

Effects on Structures, Systems, and Components

A structure is an element or collection of elements that provide support or enclosure of space, e.g., a building. The walls and roof make up the envelope of a structure. Wind pressures develop on the surfaces of a building envelope and produce loads on the support structure, which, in turn, transmits the loads to the foundation. The support structure also must carry dead, live, and other environmental loads.

Element failure is quite rare. More frequently the element connections are the source of failure. A properly conceived wind-force resisting structure should not fail as a result of the failure of a single element or element connection. A multiple degree of redundancy should be provided in a ductile structure that allows redistribution of load when one element or
connection of the structure is overloaded. Ductility allows the structure to undergo large deformations without sudden and catastrophic collapse. The structure also must have sufficient strength and stiffness to resist the applied loads without unacceptable deflection or collapse.

Cladding forms the surface of the structure envelope. Cladding includes the materials that cover the walls and roof of a structure. Cladding failure results in a breach of the structure envelope. A breach develops because the cladding itself fails (excessive yielding or fracture); the connections or anchorages are inadequate; or the cladding is perforated by windborne missiles. Cladding is sometimes relied upon to provide lateral support for purlins, girts or columns. Cladding may be an integral part of shear wall construction. If the cladding or its anchorage fails, this lateral support is lost, leaving the elements with a reduced load-carrying capacity.

Most cladding failures result from failure of the fasteners or the material in the vicinity of the fastener. Cladding failures initiate at locations of high local wind pressures such as wall corners, eaves, ridges, and roof corners. Wind tunnel studies and damage investigations reveal that local pressures can be one to five times larger than overall external pressures.

Breach of structure envelope resulting from cladding failure allows air to flow into or out of the building, depending on where the breach occurs. The resulting internal pressures combine with the external pressures, both overall and local, to produce a worse loading condition. If the structure envelope is breached on two sides of the building, e.g., the windward and leeward walls, a channel of air can flow through the building from one opening to the other.

The speed of flowing air is related to the wind speed outside the building. A high-speed air flow (greater than 40 mph) could collapse interior partitions, pick up small pieces of equipment or transport unconfined toxic or radioactive materials to the environment. A breach can also lead to water damage due to rain.

Systems, consisting primarily of piping, utilities, and distribution configurations, are more susceptible to wind damage when located outdoors. Electrical lines, transformers, overhead pipe bridges, steam lines, storage tanks are examples of wind vulnerable systems. Net wind forces are calculated for each element of the system. Channeling and shielding may be a factor in complex facilities. Windborne missiles also pose a threat to systems. Collapse or failure of less vulnerable SSCs could cause damage to more critical ones.

Components, consisting primarily of equipment such as fans, pumps, switch gear, are less vulnerable to wind than earthquake forces, but can be damaged if exposed to flying debris.

Mitigating Factors
For those sites requiring design for tornadoes, the criteria are based on site-specific studies. An annual exceedance probability of $1 \times 10^{-3}$, which is the same for straight wind, could be justified. A lower value is preferred because the straight wind hazard curve gives wind speeds larger than the tornado hazard curve and a lower hazard probability can be specified without placing undue hardship on the design. The basic tornado wind speed associated with an annual exceedance probability of $2 \times 10^{-5}$ is recommended for performance category 3.
The wind speed obtained from the tornado hazard curve is already converted from peak gust to fastest quarter-mile. Use an importance factor of 1.0 for performance category 3. For the use in DOE-STD-1020-2002, DOE Standard: Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities, fastest quarter-mile and 3 second gusts are deemed to be equivalent for all practical purposes.

With the wind speed given in fastest quarter-mile wind and an importance factor of 1.0, the equations in ASCE 7 should be used to obtain design wind pressures on SSCs. Exposure category C should always be used with tornado winds regardless of the actual terrain roughness. Non-conservative results will be obtained with exposure B. Tornadoes traveling over large bodies of water are waterspouts, which are less intense than land-based tornadoes. Thus, use of exposure category D also is not necessary. The velocity pressure exposure coefficient and gust effect factor are obtained from ASCE 7. External pressure coefficients are used to obtain tornado wind pressures on various surfaces of structures. Net pressure coefficients are applicable to systems and components. On structures, a distinction is made between main wind-force resisting systems and components and cladding.

If a structure is not intentionally sealed to maintain an internal negative pressure for confinement of hazardous materials, or, if openings greater than one square foot per 1000 cubic feet of volume are present, or, if openings of this size can be caused by missile perforation, then the effects of internal pressure should be considered according to the rules of ASCE 7. If a structure is sealed, then APC associated with the tornado vortex should be considered instead of internal pressures.

The maximum APC pressure occurs at the center of the tornado vortex where the wind speed is theoretically zero. A more severe loading condition occurs at the radius of maximum tornado wind speed, which is some distance from the vortex center. At the radius of maximum wind speed, the APC may be one-half its maximum value. Thus, a critical tornado load combination on a sealed building is one-half maximum APC pressure combined with maximum tornado wind pressure. A loading condition of APC alone can occur on the roof of a buried tank or sand filter, if the roof is exposed at the ground surface. APC pressure always acts outward. A rapid rate of pressure change, which can accompany a rapidly translating tornado, should be analyzed to assure that it does not damage safety-related ventilation systems. Procedures and computer codes are available for such analyses.

When using allowable stress design (ASD) methods, allowable stresses appropriate for the materials shall be used.

Since in this case, the hazard probability satisfies the performance goal, little or no additional conservatism is needed in the design. Thus, for ASD the tornado wind load combinations are modified to negate the effect of safety factors.

Careful attention should be paid to the details of construction. Continuous load paths shall be maintained; redundancy shall be built into load-carrying structural systems; ductility shall be provided in elements and connections to prevent sudden and catastrophic failures.

Two tornado missiles are specified as minimum criteria for performance category 3.
The 2x4-in. timber plank weighing 15 pounds (lbs) is assumed to travel in a horizontal direction at speeds up to 100 mph. The horizontal speed is effective up to a height of 150 ft above ground level. If carried to great heights by the tornado winds, the timber plank can achieve a terminal vertical speed of 70 mph in falling to the ground. The horizontal and vertical speeds are assumed to be uncoupled and should not be combined. Table 8 describes wall and roof structures that will resist the postulated timber missile. A second missile to be considered is a 3-in. diameter standard steel pipe, which weighs 75 lbs. Design horizontal impact speed is 50 mph; terminal vertical speed is 35 mph. The horizontal speed of the steel pipe is effective up to a height of 75 feet above ground level. Table 8 summarizes certain barrier configurations that have been successfully tested to resist the pipe missile. Although wind pressure, APC and missile impact loads can occur simultaneously, the missile impact loads can be treated independently for design and evaluation purposes. These are the minimum missile design criteria and should be reviewed for upgrading with the concurrent use of new tornado hazard assessment methodology.
Table 8. Recommended tornado missile barriers for performance category 3

<table>
<thead>
<tr>
<th>Missile Criteria</th>
<th>Recommended Missile Barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Horizontal Component:</strong></td>
<td></td>
</tr>
<tr>
<td>2x4 timber plank 15 lb @ 100 mph max. height 150 ft. above ground</td>
<td>8-in. CMU wall with one #4 rebar grouted in each vertical cell and trussed horizontal joint reinforced @ 16 in. on center Single width brick veneer attached to stud wall with metal ties 4 in. concrete slab with #3 rebar @ 6 in. on center each way in middle of slab</td>
</tr>
<tr>
<td><strong>Vertical Component:</strong></td>
<td></td>
</tr>
<tr>
<td>2x4 timber plank 15 lb @ 70 mph</td>
<td>4 in. concrete slab with #3 rebar @ 6 in. on center each way in middle of slab</td>
</tr>
<tr>
<td><strong>Horizontal Component:</strong></td>
<td></td>
</tr>
<tr>
<td>3-in. diameter steel pipe 75 lb @ 50 mph max. height 75 ft. above ground</td>
<td>12-in. CMU wall with #4 rebar in each vertical cell and grouted; #4 rebar horizontal @ 8 in. on center Nominal 12-in. wall consisting of 8-in. CMU with #4 rebar in each vertical cell and grouted; #4 rebar horizontal @ 8 in. on center; single width brick masonry on outside face; horizontal ties @ 16 in. on center 9 5- in. reinforced brick cavity wall with #4 rebar @ 8 in. on center each way in the cavity; cavity filled with 2500 psi concrete; horizontal ties @ 16 in. on center 8-in. concrete slab with #4 rebar @ 8 in. on center each way placed 1.5 in. from each face</td>
</tr>
<tr>
<td><strong>Vertical Component:</strong></td>
<td></td>
</tr>
<tr>
<td>3-in. diameter steel pipe 75 lb @ 35 mph</td>
<td>6-in. concrete slab with #4 rebar @ 12 in. on center each way 1.5 in. from inside face</td>
</tr>
</tbody>
</table>

Source: DOE-STD-1020-2002

Earthquake and/or Other Seismic Events

Impact on Facilities
For most facilities, the primary seismic hazard is earthquake ground shaking. The criteria specifically cover the design and evaluation of buildings, equipment, distribution systems, and other structures for earthquake ground shaking. Other earthquake effects that can be devastating to facilities include differential ground motion induced by fault displacement, liquefaction, and seismic-induced slope instability and ground settlement. If these latter earthquake effects cannot be avoided in facility siting, the hazard must be eliminated by site modification or foundation design. Existing facilities located on active fault traces, adjacent...
to potentially unstable slopes, or on saturated, poorly compacted cohesionless soil or fill material pose serious questions as to their usage for critical missions or handling hazardous materials.

While earthquake hazards of potential fault movement or other gross soil movement are typically avoided or mitigated, the earthquake ground shaking hazard is unavoidable. When a structure or component is subjected to earthquake shaking, its foundation or support moves with the ground or with the structural element on which it rests. If the structure or equipment is rigid, it follows the motion of its foundation, and the dynamic forces acting on it are nearly equal to those associated with the base accelerations. However, if the structure is flexible, large relative movements can be induced between the structure and its base. Earthquake ground shaking consists of a short duration of time-varying motion that has significant energy content in the range of natural frequencies of many structures. Thus, for flexible structures, dynamic amplification is possible such that the motions of the structure may be significantly greater than the ground shaking motion. In order to survive these motions, the structural elements must be sufficiently strong, as well as sufficiently ductile, to resist the seismic-induced forces and deformations. The effects of earthquake shaking on structures and equipment depend not only on the earthquake motion to which they are subjected, but also on the properties of the structure or equipment. Among the more important structural properties is the ability to absorb energy (due to damping or inelastic behavior), the natural periods of vibration, and the strength or resistance.

The response of structures to earthquake ground shaking depends on the characteristics of the supporting soil. The amplitude and frequency of the response of massive, stiff structures founded or embedded in a soil media can be significantly affected by soil-structure interaction, including spatial variation of the ground motion. For structures founded on rock media, these effects are much less pronounced. The foundation media is, in effect, another structural element of the structural system and changes the natural frequencies and mode shapes. That is, the structure plus an additional foundation element may have free vibration characteristics that differ from those of the same structure on a rigid foundation and without the additional foundation element. A significant affect of soil-structure interaction is radiation of energy from the structure into the ground (radiation damping). As a result, this foundation element must represent both the stiffness and damping of the foundation media. Spatial variation of earthquake ground motion result in reduced motion at the base of a structure from that recorded by an instrument on a small pad. These reductions are due to vertical spatial variation of the ground motion (reduced motion with depth), horizontal spatial variation of the ground motion (basemat averaging effects), and wave scattering effects (modification of earthquake waves striking a rigid structure foundation).

Earthquake ground shaking generally has lateral, vertical, and rotational components. Structures are typically more vulnerable to the lateral component of seismic motion; therefore, a lateral force-resisting system must be developed. Typical lateral force-resisting systems for buildings include moment-resisting frames, braced frames, shear walls, diaphragms, and foundations. Properly designed lateral force-resisting systems provide a continuous load path from the top of the structure down to the foundation. Furthermore, it is recommended that redundant load paths exist. Proper design of lateral force-resisting systems must consider the relative rigidities of the elements taking the lateral load and their capacities to resist load. An example of lack of consideration for relative rigidity are frames with brittle
unreinforced infill walls that are not capable of resisting the loads attracted by such rigid construction. In addition, unsymmetrical arrangement of lateral force-resisting elements can produce torsional response which, if not accounted for in design, can lead to damage. Even in symmetrical structures, propagating earthquake ground waves can give rise to torsion. Hence, a minimum torsional loading should be considered in design or evaluation.

Earthquake ground shaking causes limited energy transient loading. Structures have energy absorption capacity through material damping and hysteretic behavior during inelastic response. The capability of structures to respond to earthquake shaking beyond the elastic limit without major damage is strongly dependent on structural design details. For example, to develop ductile behavior of inelastic elements, it is necessary to prevent premature abrupt failure of connections. For reinforced concrete members, design is based on ductile steel reinforcement in which steel ratios are limited such that reinforcing steel yields before concrete crushes, abrupt bond or shear failure is prevented, and compression reinforcement includes adequate ties to prevent buckling or spalling. With proper design details, structures can be designed to withstand different amounts of inelastic behavior during an earthquake. For example, if the goal is to prevent collapse, structures may be permitted to undergo large inelastic deformations resulting in structural damage that would have to be repaired or replaced. If the goal is to allow only minor damage such that there is minimal or no interruption to the ability of the structure to function, only relatively small inelastic deformations should be permitted. For new facilities, it is assumed that proper detailing will result in permissible levels of inelastic deformation at the specified force levels, without unacceptable damage. For existing facilities, the amount of inelastic behavior that can be allowed without unacceptable damage must be estimated from the as-is condition of the structure.

Potential damage and failure of structures, systems, and components (SSCs) due to both direct earthquake ground shaking and seismic response of adjacent SSCs must be considered. The interaction of SSCs during earthquake occurrence can produce additional damage/failure modes to be addressed during seismic design or evaluation. Examples of interaction include: (1) seismic-induced failure of a relatively unimportant SSC which falls on a SSC which is important to safety or to the mission; (2) displacements of adjacent SSCs during seismic response resulting in the adjacent SSCs pounding together; (3) displacements of adjacent SSCs during seismic response resulting in failure of connecting pipes or cables; (4) flooding and exposure to fluids from vessels or piping systems ruptured as a result of earthquake motion; and (5) effects of seismic-induced fires.

The occurrence of an earthquake affects many or all SSCs in a facility. Hence, it is possible to have multiple seismic-induced failures of SSCs. These common cause effects must be considered in design or evaluation. For example, multiple failures in a tank farm can result in loss of contents greater than that held in any single tank which in turn could overflow a retention berm and/or flood adjacent SSCs. The effects of this large quantity of tank contents on SSCs must be considered.

Earthquake ground shaking also affects building contents and nonstructural features such as windows, facades, and hanging lights. It is common for the structure to survive an earthquake without serious structural damage but to have significant and expensive damage of contents. This damage could be caused by overturned equipment or shelves, fallen lights or ceilings,
broken glass, and failed infill walls. Glass and architectural finishes may be brittle relative to the main structure, and they can fail well before structural damage occurs. Windows and cladding must be specially attached in order to accommodate the relative seismic movement of the structure without damage. Building contents can usually be adequately protected against earthquake damage by anchorage to the floor, walls, or ceiling.

Facilities in which radioactive materials are handled are typically designed with redundant confinement barriers between the hazardous material and the environment. Such barriers include:

- The building shell
- Ventilation system filtering and negative pressurization that inhibits outward air flow
- Storage canisters, glove boxes, tanks, or silos for storage or handling within the building.

Release of radioactive material to the environment requires failure of two or more of these barriers. Thus, seismic design considerations for these facilities aim to prevent collapse and control cracks or openings (e.g., failed doors, failed infill walls) such that the building can function as a hazardous materials confinement barrier. Seismic design considerations also include adequate anchorage and bracing of storage canisters, glove boxes, tanks or silos and adequate support of ventilation ducting, filters, and fans to prevent their loss of function during an earthquake. Long-term storage canisters are usually very rugged, and they are not particularly vulnerable to earthquake damage.

Earthquake damage to components of a facility such as tanks, equipment, instrumentation, and distribution systems can also cause injuries, loss of function, or loss of confinement. Many of these items can survive strong earthquake ground shaking with adequate anchorage or restraint. Some items, such as large vertical tanks, must be examined in more detail to assure that there is an adequate lateral force-resisting system for seismic loads. For components mounted within a structure, there are three additional considerations for earthquake shaking. First, the input excitation for structure-supported components is the response motion of the structure (which can be amplified from the ground motion) - not the earthquake ground motion. Second, potential dynamic coupling between the component and the structure must be taken into account if the component is massive enough to affect the seismic response of the structure. Third, large differential seismic motions may be induced on components which are supported at multiple locations on a structure or on adjacent structures.

Mitigating Factors
The following paragraphs present the approach upon which the specific seismic force and story drift provisions (as applicable) for seismic design and evaluation of structures, systems, and components in each performance category is based. These provisions include the following steps:

1. Selection of earthquake loading
2. Evaluation of earthquake response
3. Specification of seismic capacity and applicable drift limits
4. Ductile detailing requirements for buildings
The above four elements taken together comprise the earthquake design and evaluation criteria. Acceptable performance can only be reached by consistent specification of all design criteria elements as shown in figure 16. In order to achieve the target performance goals, these seismic design and evaluation criteria specify seismic loading in probabilistic terms. The remaining elements of the criteria (see figure 16) are deterministic design rules which are familiar to design engineers and which have a controlled level of conservatism. This level of conservatism combined with the specification of seismic loading, leads to performance goal achievement.

Source: DOE-STD-1020-2002

**Figure 16.** DOE-STD-1020-2002 combines probabilistic and deterministic methods to achieve performance goals

Criteria are provided for each of the four performance categories 1 to 4 as defined in DOE O 420.1B, *Facility Safety*, the accompanying Guide DOE G 420.1-2, *Guide for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and NonNuclear Facilities*, and DOE-STD-1021-93, *Natural Phenomena Hazards Performance Categorization Guidelines for Structures, Systems, and Components*. The criteria for performance categories 1 and 2 are similar to those from model building codes. Criteria for performance category-3 are similar to those for the Department of Defense (DoD). Criteria for performance category-4 approach the provisions for commercial nuclear power plants.

Seismic loading is defined in terms of a site-specific design response spectrum (the design/evaluation basis earthquake, [DBE]). Either a site-specific design response spectrum developed for the site, or a generic design response spectrum that is appropriate or conservative for the site may be used. Seismic hazard estimates are used to establish the DBE per DOE-STD-1023-95, *Natural Phenomena Hazards Assessment Criteria*. 
For each performance category, a mean annual exceedance probability for the DBE, $P_H$ is specified from which the maximum ground acceleration (and/or velocity) may be determined from probabilistic seismic hazard curves.

Earthquake input excitation to be used for design and evaluation by these provisions is defined by a median amplification smoothed and broadened design/evaluation response spectrum shape. Such spectra are determined in accordance with DOE-STD-1023-95.

b. Describe the safety measures and design features commonly used as safeguards against natural hazards.

Refer to element a of this competency for a discussion of design features commonly used as safeguards against natural hazards.

c. Discuss design requirements for flooding, wind, tornado, earthquake, and seismic events.

Refer to element a of this competency for a discussion of design requirements for flooding, wind, tornado, earthquake, and seismic events.

13. Construction management personnel shall demonstrate a working level knowledge of fire protection requirements for a construction site.

a. Discuss the fire protection requirements and precautions for material storage on a construction site.

The following is taken from 29 CFR 1926.151.

*Open Yard Storage*

Combustible materials shall be piled with due regard to the stability of piles and in no case higher than 20 feet.

Driveways between and around combustible storage piles shall be at least 15 feet wide and maintained free from accumulation of rubbish, equipment, or other articles or materials.

Driveways shall be so spaced that a maximum grid system unit of 50 feet by 150 feet is produced.

The entire storage site shall be kept free from accumulation of unnecessary combustible materials. Weeds and grass shall be kept down and a regular procedure provided for the periodic cleanup of the entire area.

When there is a danger of an underground fire, that land shall not be used for combustible or flammable storage.

Method of piling shall be solid wherever possible and in orderly and regular piles. No combustible material shall be stored outdoors within 10 feet of a building or structure.
Portable fire extinguishing equipment, suitable for the fire hazard involved, shall be provided at convenient, conspicuously accessible locations in the yard area. Portable fire extinguishers, rated not less than 2A, shall be placed so that maximum travel distance to the nearest unit shall not exceed 100 feet.

*Indoor Storage*

Storage shall not obstruct, or adversely affect, means of exit.

All materials shall be stored, handled, and piled with due regard to their fire characteristics.

Non-compatible materials that may create a fire hazard, shall be segregated by a barrier having a fire resistance of at least 1 hour.

Material shall be piled to minimize the spread of fire internally and to permit convenient access for firefighting.

Stable piling shall be maintained at all times. Aisle space shall be maintained to safely accommodate the widest vehicle that may be used within the building for firefighting purposes.

A clearance of at least 36 in. shall be maintained between the top level of the stored material and the sprinkler deflectors.

Clearance shall be maintained around lights and heating units to prevent ignition of combustible materials.

A clearance of 24 in. shall be maintained around the path of travel of fire doors unless a barricade is provided, in which case no clearance is needed. Material shall not be stored within 36 in. of a fire door opening.

**b. Discuss the fire protection safety requirements for egress from areas of a construction site.**

The following is taken from 29 CFR 1926.34.

In every building or structure exits shall be so arranged and maintained as to provide free and unobstructed egress from all parts of the building or structure at all times when it is occupied. No lock or fastening to prevent free escape from the inside of any building shall be installed except in mental, penal, or corrective institutions where supervisory personnel is continually on duty and effective provisions are made to remove occupants in case of fire or other emergency.

Exits shall be marked by a readily visible sign. Access to exits shall be marked by readily visible signs in all cases where the exit or way to reach it is not immediately visible to the occupants.

Means of egress shall be continually maintained free of all obstructions or impediments to full instant use in the case of fire or other emergency.
c. Discuss the availability and location of firefighting equipment requirements on a
construction site.

The following is taken from 29 CFR 1926.150.

The contractor is responsible for the development of a fire protection program to be followed
throughout all phases of construction and demolition work, and shall provide the firefighting
equipment.

As fire hazards occur, there shall be no delay in providing the necessary equipment. Access
to all available firefighting equipment shall be maintained at all times.

All firefighting equipment provided by the contractor shall be conspicuously located.

All firefighting equipment shall be periodically inspected and maintained in operating
condition. Defective equipment shall be replaced immediately.

As warranted by the project, the contractor shall provide a trained and equipped firefighting
organization (Fire Brigade) to assure adequate protection to life.

A temporary or permanent water supply of sufficient volume, duration, and pressure required
to properly operate the firefighting equipment shall be made available as soon as combustible
materials accumulate.

Where underground water mains are to be provided, they shall be installed, completed, and
made available for use as soon as practicable.

A fire extinguisher, rated not less than 2A, shall be provided for each 3,000 square feet of the
protected building area, or major fraction thereof. Travel distance from any point of the
protected area to the nearest fire extinguisher shall not exceed 100 feet. One 55-gallon open
drum of water with two fire pails may be substituted for a fire extinguisher having a 2A
rating. A ½-inch diameter garden-type hose line, not to exceed 100 feet in length and
equipped with a nozzle, may be substituted for a 2A-rated fire extinguisher, providing it is
capable of discharging a minimum of 5 gallons per minute with a minimum hose stream
range of 30 feet, horizontally. The garden-type hose lines shall be mounted on conventional
racks or reels. The number and location of hose racks or reels shall be such that at least one
hose stream can be applied to all points in the area.

One or more fire extinguishers, rated not less than 2A, shall be provided on each floor. In
multistory buildings, at least one fire extinguisher shall be located adjacent to the stairway.
Extinguishers and water drums, subject to freezing, shall be protected from freezing. One
hundred feet, or less, of 1½-inch fire hose, with a nozzle capable of discharging water at 25
gallons or more per minute, may be substituted for a fire extinguisher rated not more than 2A
in the designated area, provided that the hose line can reach all points in the area.

If fire hose connections are not compatible with local firefighting equipment, the contractor
shall provide adapters, or equivalent, to permit connections. During demolition involving
combustible materials, charged hose lines supplied by hydrants, water tank trucks with
pumps, or some equivalent, shall be made available.
If the facility being constructed includes the installation of automatic sprinkler protection, the installation shall closely follow the construction and be placed in service as soon as applicable laws permit following completion of each story.

During demolition or alterations, existing automatic sprinkler installations shall be retained in service as long as reasonable. The operation of sprinkler control valves shall be permitted only by properly authorized persons. Modification of sprinkler systems to permit alterations or additional demolition should be expedited so that the automatic protection may be returned to service as quickly as possible. Sprinkler control valves shall be checked daily at close of work to ascertain that the protection is in service.

In all structures in which standpipes are required, or where standpipes exist in structures being altered, they shall be brought up as soon as applicable laws permit, and shall be maintained as construction progresses in such a manner that they are always ready for fire protection use. The standpipes shall be provided with Siamese fire department connections on the outside of the structure, at the street level, which shall be conspicuously marked. There shall be at least one standard hose outlet at each floor.

An alarm system, e.g., telephone system, siren, etc., shall be established by the contractor whereby employees on the site and the local fire department can be alerted for an emergency. The alarm code and reporting instructions shall be conspicuously posted at phones and at employee entrances.

Fire walls and exit stairways required for the completed buildings shall be given construction priority. Fire doors with automatic closing devices shall be hung on openings as soon as practicable.

Fire cutoffs shall be retained in buildings undergoing alterations or demolition until operations necessitate their removal.

d. Discuss the fire protection considerations specific to a construction activity that could affect nuclear safety at a defense nuclear facility.

The following is taken from DOE G 421.1-1.

A facility fire safety plan that recognizes, to the extent necessary, fire safety and nuclear criticality safety considerations must be developed. These considerations should address the possible use of water or other moderator/reflector influences, the possibility of affecting the accumulation of fissionable material, and the required presence of fire fighters in the fissionable material operations area.

A potential conflict exists between nuclear criticality safety and fire safety over the use of moderating agents such as water for fire suppression systems. An analysis is necessary to determine if a credible inadvertent criticality accident could be caused by an automatic sprinkler system or the use of fire hoses. This analysis should involve nuclear criticality safety, fire safety, and safety analysis personnel. If a credible inadvertent criticality accident is not possible, then a water sprinkler system and fire hoses should be used. However, if a credible inadvertent criticality accident is possible, then alternative fire suppression systems should be employed. There are also situations in which a water sprinkler system is
acceptable, but the use of high-pressure fire hoses is unacceptable because of the potential to rearrange items in an array.

In some situations, it is easy to make changes to equipment and operations such that the use of water is permissible. For example, revising the unit spacing of a storage array and taking steps to ensure that fissile units cannot be rearranged can make the use of water acceptable in the form of automatic sprinklers or fire hoses. In other cases, taking provisions to prohibit the accumulation of water in equipment by the use of appropriately placed and sized drainage holes, the use of an enclosure, or increasing the slope of piping, may make the use of water acceptable.

In certain situations in which nuclear criticality safety is a concern, it may be possible to use borated water as a fire suppression agent. If borated water is to be used, a dedicated source of borated water should be available, and the concentration of boron should be periodically confirmed. If the use of water is not permissible in operations with fissile nuclides, then the operating and design personnel should work with nuclear criticality safety and fire safety specialists to find a suitable alternative. From a nuclear criticality safety perspective, there are usually no restrictions on the use of dry chemicals, carbon dioxide, most foams, or inert gases as fire suppression agents in facilities that handle fissile nuclides. However, fire safety specialists will have to agree on the adequacy of these other fire suppression agents for a given facility and operation. Industrial safety specialists will also be concerned with the use of some of these alternative fire suppression agents because they will displace air and could potentially asphyxiate workers. Signs should be conspicuously displayed to alert fire fighters and workers if the use of water is not permitted and to identify what fire suppression agents are acceptable.

e. Perform construction site safety inspections of fire protection capabilities and equipment.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

14. Construction management personnel shall demonstrate a working level knowledge of construction methods and accepted construction practices for the following:
   - Structural waterproofing
   - Architectural finishes
   - Roofing systems
   - Mechanical and electrical equipment installation
   - Material protection and storage
   - Construction site tools, equipment, and materials

   a. Discuss the requirements, materials, and methods for waterproofing walls, floors, or other building elements that are subject to hydrostatic pressure, are below the water table, or may be immersed in water.

The following is taken from DOE G 430.1-1, chapter 16.

Waterproofing is defined as impervious membranes or coatings applied to walls, slabs, decks, or other surfaces subject to continuous or intermittent hydrostatic head or water
immersion. It includes membranes that are bituminous, cementitious, elastomeric, sheet metal, bentonite and similar materials, and metal oxide coatings. It includes boards or coatings required for protection of waterproofing. Dampproofing includes materials installed to provide resistance to moisture penetration through surfaces subject to high humidity, dampness, or direct water contact, but not subject to hydrostatic pressures. It includes bituminous, cementitious, or similar coatings applied to exterior walls below grade, or applied as a protective damp course. It includes silicone, acrylic, or other water repellent coatings applied to exposed surfaces of concrete, masonry, stone, cement, metal, plaster, or similar material. It also includes bituminous, laminated, or plastic vapor barriers. Insulation is defined as thermal insulation for resistance of heat transfer at exterior of structure and at enclosures of high temperature or low temperature spaces. It includes organic or inorganic insulation in the form of granules, pellets, rigid boards, fibrous batts, blankets or rolls, and spray or foam applied to walls, roofs, decks, and similar surfaces. It includes insulation applied to the perimeter of foundations and under concrete slabs on grade. Vapor barriers integral with insulation are also included.

b. Discuss the construction methods and requirements associated with the following architectural finishes. Include the following elements of fire protection, hazardous material contamination, and indoor air quality in the discussion:

- Gypsum board
- Tile
- Acoustical treatment
- Resilient flooring
- Carpet
- Resinous flooring
- Conductive flooring
- Paint
- Wall coverings
- Special coatings

Gypsum Board

The following is taken from the Gypsum Association, GA-600-2006.

Gypsum is approximately 21 percent by weight chemically combined water which greatly contributes to its effectiveness as a fire resistive barrier. When gypsum board or gypsum plaster is exposed to fire, the water is slowly released as steam, effectively retarding heat transmission. It can be compared to what happens when a blowtorch is turned on a block of ice. Although the ice is being melted, one can hold a hand on the opposite side without being burned. Even though the ice gets very thin it effectively blocks the transfer of the intense heat and one’s hand would not be burned until the ice is melted.

When gypsum-protected wood or steel structural members are exposed to a fire, the chemically combined water (being released as steam) acts as a thermal barrier until this slow process, known as calcination, is completed. The temperature directly behind the plane of calcination is only slightly higher than that of boiling water (212 °F), which is significantly lower than the temperature at which steel begins losing strength or wood ignites. Once calcination is complete, the in-place calcined gypsum continues to act as a barrier protecting the underlying structural members from direct exposure to flames.
Tile
The following is taken from American Institute of Architects, *The Graphic Standards Guide to Architectural Finishes*.

Tile is defined in American National Standards Institute (ANSI) publication ANSI A137.1, *American National Standard Specifications for Ceramic Tile*, as a ceramic surfacing unit, usually relatively thin in relation to facial area, made from clay or a mixture of clay and other ceramic materials, called the body of tile, having either a glazed or unglazed face and fired above red heat in the course of manufacture to a temperature sufficiently high to produce specific physical properties and characteristics.

Tile is further classified in the standard as follows, based on water absorption:
- Impervious tile: 0.5 percent or less
- Vitreous tile: 0.5 to 3.0 percent
- Semivitreous tile: 3.0 to 7.0 percent
- Nonvitreous tile: More than 7.0 percent

These water-absorption classifications may be useful in specifying tile because water absorption is directly related to stain resistance and may be indirectly related to durability. Lower water absorption generally indicates a denser, more thoroughly fused product and therefore also generally indicates a stronger, more durable product. Water absorption, however, is not directly correlated to strength and durability. Before specifying one or more of these water-absorption classifications, verify that the selected tile will comply with requirements and that the specified classifications do not exclude otherwise acceptable products.

Acoustical Treatment
The following is taken from American Institute of Architects, *The Graphic Standards Guide to Architectural Finishes*.

American Society for Testing and Materials, ASTM E 1264, *Standard Classification for Acoustical Ceilings*, is the principal standard referenced for specifying acoustical panels. This standard provides a method only for the generic specification of acoustical panel and tile ceilings; specifications rapidly become proprietary as most constraints for type, pattern, color, size, acoustical properties, light reflectance, and fire-resistance ratings are included.

Acoustical performance and other performance ratings include the following:
- Minimum noise reduction coefficient (NRC): A single-number rating expressed in increments of 0.05. NRC is derived from values for sound-absorption coefficients determined according to ASTM C 423, *Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method*. NRC gives an estimate of a material’s sound-absorption properties. The higher the number, the greater the material’s ability to absorb or not otherwise reflect randomly incident sound power.
- Minimum articulation class: This rating is expressed in increments of 10 and replaces noise isolation class. Articulation class measures the interzone attenuation of ceiling systems in open-plan offices in conjunction with partial-height partitions but without the use of a sound-masking system.
- Minimum ceiling attenuation class (CAC): This is expressed as a single figure. Acoustical ceiling manufacturers have tested their ceilings according to this method, which is designed to measure the sound attenuation properties of suspended ceilings installed with continuous plenum spaces. CAC indicates the degree of sound transmission from adjacent spaces, including the floor above, and from the services in the plenum above.

- Minimum light reflectance coefficients: These coefficients are listed in increments of 0.01 by manufacturers, with the top limit being 0.80.

Resistance to humidity varies among acoustical ceiling components. Most regular composition tiles and panels deteriorate when exposed to high humidity or humidity fluctuation. High-density, ceramic ceiling panels are specifically recommended for high-humidity conditions.

If acoustical ceilings are located in corrosive environments, consider the corrosive agents, their concentration, the extent of exposure (fumes, splash, or immersion), the duration of exposure, and critical variables such as temperature, pressure, ultraviolet (UV) light or potential for contact with destructive agents) and obtain test data and other evidence from manufactures about which of their products have the necessary stain-and corrosion-resistant properties for such applications.

**Resilient Flooring**

The following is taken from American Institute of Architects, *The Graphic Standards Guide to Architectural Finishes*.

Resilient flooring is made from rubber, recycled rubber, polypropylene, vinyl, recycled vinyl, or thermoplastic rubber and vinyl blends. Solid-surface tiles are rubber, recycled rubber, or recycled vinyl. These tiles are free-lay type, interlocked with male-female connections, or they are adhesively applied. Free-lay tiles are available with beveled border tiles to transition to adjacent, lower flooring surfaces. Polypropylene is used for free-lay suspended tiles. The backs of suspended tiles are formed so only portions of their surface periodically contact the substrate, which increases resiliency. Roll goods are generally vinyl and are used as free-lay mats or runners or adhesively applied with welded seams. For vinyl sheet flooring, seams are heat welded or chemically welded.

**Carpet**

The following is taken from American Institute of Architects, *The Graphic Standards Guide to Architectural Finishes*.

Carpet face-fiber types commonly used in commercial installations are nylon, polypropylene, wool, and wool blends.

Nylon is the most durable man-made fiber. It is the most popular fiber for commercial carpet. Nylon can hold bright-colored dyes, with some limitations. It has good fade resistance and cleans easily, and it is resilient and resistant to crushing. Nylon is high in static electricity build-up; however, many manufactures now produce nylon carpet fiber with an antistatic guarantee for the life of the carpet.
Polypropylene has an excellent resistance to soil. It has good fade resistance when stabilized, but colors tend to be dull. It has a low moisture-absorption rate and high chemical resistance.

Wool fibers are enormously elastic and yet have such memory that they can be stretched to 30 percent without rupture and still recover their original dimensions. Deeper, richer colors are available with wool fibers. The outer layers of fibers shed water while water vapor passes through the fibers microscopic pores, making wool a suitable carpet for areas subject to climatic extremes. Wool and wool blends are not used as frequently as synthetic fibers in commercial installations. However, they are popular for hospitality or entertainment areas, such as hotel lobbies or casinos, because wool shows less damage from cigarette burns than synthetic fibers do.

Resinous Flooring
The following is taken from General Polymers, Selecting Polymers Flooring Systems by James Hendley.

Polyurethane resins generally offer moderate adhesion, but good resistance to shrinkage. Aromatic-based systems offer fair UV resistance, while aliphatic-based types deliver excellent UV resistance.

- POLYESTERS - are fast setting, high strength, and demonstrate good resistance to acids and most solvents, but they are generally susceptible to alkali attack. Polyester resins experience a relatively high amount of shrinkage. Styrene flammability and fumes must be considered when using this product.
- VINYL ESTERS - provide ultimate performance in chemical / corrosion resistance. The products are typically formulated in high build, fast curing systems for corrosion resistance and toughness. Again, styrene flammability and fumes must be considered.
Ideally, all monolithic, non-breathing floors should be installed under the temperature and humidity conditions expected during use. If installed at low temperatures and/or high humidity, raising the temperature and/or lowering the humidity above the concrete after installation leads to disbondment, because water vapor moves to the higher temperature and lower humidity. If humidity and temperature during installation significantly differ from normal service conditions, water vapor is likely to create problems in disbondment, especially if changes are rapid.

**Conductive Flooring**

The following is taken from General Polymers, *Static Control Flooring: Trends in Technology* by Peter Song and Tom Murphy.

Static control flooring can be defined as a flooring system that can drain and/or dissipate static charges by grounding personnel, equipment or other objects contacting the floor surface or that controls the generation and accumulation of static charges. The resistance to the movement of electrons across the material’s surfaces defines static control floorings into the following two categories:

- **Conductive Floor** has a resistance of $2.5 \times 10^4 – 10^6$ ohms per 3 feet. It can drain static charge dissipating a 5,000 – volt charge to zero in 0.05 seconds.
- **Static Dissipative Floor** has a resistance of $10^6 – 10^9$ ohms per 3 feet. It adds no static electricity to the environment and drains off a 5,000 – volt charge to zero in less than 0.2 seconds.

A conductive floor material, because it has low electrical resistance, allows electrons to flow easily across its surface or through its volume. If a charged conductive floor is grounded, or coupled to another conductive object, such as a steel pipe or post that is grounded, the charge accumulated on the floor will be uniformly distributed throughout the floor and rapidly dissipated to ground. Conductive flooring prevents the build-up of a static charge, eliminating the potential of an electrostatic discharge event.

Static dissipative materials have electrical resistance between insulative and conductive materials. Like a conductive floor material, the charges generated triboelectrically on the static dissipative floor can be transferred to ground but the process of this transferring takes longer than in a conductive floor.

In terms of flooring installation, static control flooring systems can be classified into three groups:

- Permanently installed floor materials, such as tile, carpet, polymer sheet and resinous flooring;
- Periodically applied topical coatings on existing floor surfaces, like acrylics or waxes; and
- A movable island of material placed over existing floors, like a plastic, or rubbery or carpet mat.
**Paint**

The following is taken from International Correspondence Schools, *A Treatise on Architecture and Building Construction*.

The painter desirous of obtaining a correct knowledge of his trade should first acquaint himself with the nature and properties of the materials calling for his constant use, and the architect superintending the work of the painter should possess sufficient knowledge of the trade to intelligently criticize the character of the workmanship and materials.

Paint being a protective and preservative of both the structural and finishing materials of a building, edifices should be painted or varnished, according to the character of the material employed in construction, and the composition of the paint or varnish varied to suit the conditions of each case.

The utilitarian phase of painting becomes an element of architectural value, only when considered in conjunction with its decorative effect, wherein it combines the useful with the beautiful, making each administer to, and enhance the value of, the other.

The theory and practice of the painter’s art may, therefore, be considered in regard to both plain surface painting and to decorating; the former dealing with pigments-their processes of manufacture, methods of application, and combination of colors, as well as the material best suited for each particular class or part of the work, regard being had to durability and utility; while the latter discusses the character of the material painted, the combinations of colors applied, and treatment of surfaces which are to receive the color, exclusively in consideration of the decorative effect.

**Wall Coverings**

The following is taken from Wallcovering Association, *Environmental Issues and Regulations*.

The wallcoverings industry, like its counterparts in carpeting, other interior finishes, and paint, are carefully monitored by various government agencies, including Occupational Safety and Health Administration (OSHA) and Congress, to ensure that the product’s manufacture, installament and use are safe for the environment. In the wallcoverings industry, modifications where needed have been made to comply with changes made in existing environmental and safety regulations. The following information outlines how the wallcoverings industry is addressing major environmental issues.

Today, most wallcoverings are manufactured using no heavy metals such as lead, mercury, chromium or cadmium that could adversely affect the environment.

Many manufacturers are introducing and developing additional environmentally-friendly substrates in the manufacture of wallcoverings.

To save forests, designers can now select wallcoverings that use harvested wood pulp from managed forests in their production.
Wallcoverings are tested before they are put on the market for flame spread and smoke levels in case of fire. Wallcoverings on the market meet regulated standards, with many wallcoverings exhibiting extremely low flame spread and smoke development ratings.

Adhesives used in installation are environmentally sound, with many being water-based.

New products have been and are being introduced that give environmentally conscious designers and their clients additional environmentally friendly choices. The increased demand for these products by end users drives manufacturers to become even more diligent in innovating environmentally friendly products. For the newest developments when specifying a project, contact your wallcoverings supplier.

Vinyl’s toughness and durability make it the most widely used plastic in residential and contract wallcoverings. Cost-effective and durable, vinyl can also be manufactured to simulate virtually any color, pattern or texture created by man or nature. Despite the increase in vinyl production, environmental releases associated with production and disposal of vinyl have fallen. This is due in part to the fact that vinyl has been regulated for decades, ensuring that the environment is protected at each step in the life cycle of the material and the products made from it.

How does vinyl compare with other materials in environmental performance? Is it a sustainable material? The answers to these questions are clear. Vinyl’s performance is outstanding. The primary raw material in vinyl resin comes from common salt, which is in abundant supply. This means that vinyl is less reliant on petroleum resources than other plastics. The vinyl manufacturing process is highly efficient—more than 99 percent of all vinyl produced ends up in a finished product. And the energy required to make vinyl wallcoverings is only half as much as the amount needed to produce the same amount of paper wallcoverings. In addition, most vinyl wallcoverings manufacturers actively recycle scrap related to the manufacture of the product.

**Special Coatings**

The following is taken from *Construction Coatings, Widely Used Construction Coatings*.

There are many types of construction coatings that protect, waterproof and enhance the aesthetics of a structure. Traffic coatings, water repellents and elastomeric wall coatings are the most widely used.

**Traffic Coatings**

Traffic coatings are used to protect concrete decks in parking garages, warehouses and high traffic areas from chemicals, water and everyday wear and tear. Epoxy and polyurethane coatings are the most commonly used due to their chemical and abrasion resistance. Sonneborn, Conspec and Sika are leading manufacturers of these products.

**Water Repellents**

Water repellents are usually silicone or silane based products that are spray or roller applied to give water repellency to concrete and masonry. Water repellents do not let water in, but let
moisture trapped in concrete or masonry escape. Rainguard, Hydrozo, Sonneborn and Sika are among the many manufacturers of these products.

Elastomeric Wall Coatings
Elastomeric wall coatings are used to protect and enhance the appearance of the exterior of a building. Since elastomeric wall coatings stretch with thermal expansion and contraction, they are the product of choice to coat walls that are cracked. Acrylics are the work horse, but silicones are making inroads due to their longevity.

c. Discuss the construction methods and requirements of roofing systems. Include the following elements in the discussion:
   - Roofing tiles
   - Membrane roofing
   - Bituminous roofing
   - Sheet metal roofing
   - Single ply roofing
   - Roof mounted equipment
   - Water retention

Roofing Tiles
The following is taken from DOE Order 6430.1A.

Roofing tiles shall comply with Uniform Building Code (UBC) chapter 32 for roof construction and covering, UBC chapter 45 for marquee roof construction, and UBC chapter 23 for roof design and wind design.

The roofing surface color shall be considered in the energy conservation analysis.


Membrane Roofing
The following is taken from DOE Order 6430.1A.

Membrane roofing shall comply with UBC chapter 32 for roof construction and covering, UBC chapter 45 for marquee roof construction, and UBC chapter 23 for roof design and wind design.

Slope
Where a roof deck’s slope, after considering deflection and construction tolerances, is less than the slope required for the roofing, the slope shall be increased the required amount by the addition of fill, or tapered insulation in accordance with NRCA *Roofing and Waterproofing Manual*, NRCA Handbook of Accepted Roofing Knowledge, and manufacturers’ recommendations.
Roof-Mounted Equipment
Supports for equipment, such as window washing equipment, cooling towers, solar collectors, evaporative coolers, and antennae, shall be by the use of curbs or structural frames in compliance with NRCA Construction Details.

Clearances for roofing maintenance and repair under structural frames shall comply with the Width of Equipment/Height of Legs chart of NRCA Construction Details.

The weight of roof-top piping and equipment shall not be carried on any part of the roof assembly except the structural system.

The weight of equipment on roofs, the weight of equipment used during the life of the building to remove, re-install, maintain, and repair roof-mounted equipment, and the path across the roof used by that equipment to transport roof-mounted equipment shall be taken into account when establishing roof loads.

Penetrations of roofs by pipes and equipment of all types, and by curbs and legs for structural frames to support equipment, shall be minimized. Penetrations shall comply with NRCA Construction Details. Where possible, equipment shall be contained in equipment rooms and penthouses.

Walkways
Roof walkways shall be provided from points of roof access to penthouse entrances and to roof-mounted and roof-accessible equipment and devices. Walkways that are more than 30 in. above a roof or within 10 feet of a roof edge shall have guardrails that comply with UBC chapter 17 and UBC chapter 23.

Water Retention
Built-up roofs designed to pond water for the cooling of roof surfaces, designed with retarded drainage to relieve storm sewer loadings, or subjected to periodic water discharges from cooling towers or industrial processes shall have the weight of the water taken into account when establishing roof loads.

Bituminous Roofing
The following is taken from DOE Order 6430.1A.

Built-up bituminous membrane roofing shall comply with the ARMA Guide to Preparing Built-up Roofing Specifications, NRCA Roofing and Waterproofing Manual, NRCA Handbook of Accepted Roofing Knowledge, and Factory Mutual Class I.

Sheet Metal Roofing and Single-Ply Roofing
The following is taken from DOE O 6430.1A.

Sheet metal roofing shall comply with UBC chapter 32 for roof construction and covering, UBC chapter 45 for marquees roof construction, and UBC chapter 23 for roof design and wind design.
The slope of sheet metal roofing shall be as recommended by its manufacturer, and shall take into consideration deflection and construction tolerances.

The roof surface color shall be considered in the energy conservation analysis.

**Roof Mounted Equipment**
The following is taken from DOE Order 6430.1A.

Supports for equipment, such as window washing equipment, cooling towers, solar collectors, evaporative coolers, and antennae, shall be by the use of curbs or structural frames in compliance with NRCA *Construction Details*.

Clearances for roofing maintenance and repair under structural frames shall comply with the Width of Equipment/Height of Legs chart of NRCA *Construction Details*.

The weight of roof-top piping and equipment shall not be carried on any part of the roof assembly except the structural system.

The weight of equipment on roofs, the weight of equipment used during the life of the building to remove, re-install, maintain, and repair roof-mounted equipment, and the path across the roof used by that equipment to transport roof-mounted equipment shall be taken into account when establishing roof loads.

Penetrations of roofs by pipes and equipment of all types, and by curbs and legs for structural frames to support equipment, shall be minimized. Penetrations shall comply with NRCA *Construction Details*. Where possible, equipment shall be contained in equipment rooms and penthouses.

**Water Retention**
The following is taken from DOE Order 6430.1A.

Built-up roofs designed to pond water for the cooling of roof surfaces, designed with retarded drainage to relieve storm sewer loadings, or subjected to periodic water discharges from cooling towers or industrial processes shall have the weight of the water taken into account when establishing roof loads.

d. Discuss the construction methods and requirements for installing electrical and mechanical equipment. Include the following elements in the discussion:
   - Clearances
   - Maintenance access and staging space
   - Spill consequences
   - Accessibility to cranes and hoists
   - Bonding and grounding of equipment

**Clearances, Maintenance Access, and Staging Space**
The following is taken from 29 CFR 1910.303.

Electric equipment that depends on the natural circulation of air and convection principles for cooling of exposed surfaces shall be installed so that room airflow over such surfaces is not
prevented by walls or by adjacent installed equipment. For equipment designed for floor mounting, clearance between top surfaces and adjacent surfaces shall be provided to dissipate rising warm air.

Electric equipment provided with ventilating openings shall be installed so that walls or other obstructions do not prevent the free circulation of air through the equipment.

Sufficient access and working space shall be provided and maintained about all electric equipment to permit ready and safe operation and maintenance of such equipment.

Working space for equipment likely to require examination, adjustment, servicing, or maintenance while energized shall comply with the following dimensions:

- The depth of the working space in the direction of access to live parts may not be less than indicated in table 9. Distances shall be measured from the live parts if they are exposed or from the enclosure front or opening if they are enclosed;
- The width of working space in front of the electric equipment shall be the width of the equipment or 762 millimeter (mm) (30 in.), whichever is greater. In all cases, the working space shall permit at least a 90-degree opening of equipment doors or hinged panels; and
- The work space shall be clear and extend from the grade, floor, or platform to the height required by 29CFR 1910.303, “General.” However, other equipment associated with the electrical installation and located above or below the electric equipment may extend not more than 153 mm (6 in.) beyond the front of the electric equipment.

Working space required by 29 CFR 1910, “Occupational Safety and Health Standards,” may not be used for storage. When normally enclosed live parts are exposed for inspection or servicing, the working space, if in a passageway or general open space, shall be suitably guarded.

At least one entrance of sufficient area shall be provided to give access to the working space about electric equipment.

For equipment rated 1200 amperes or more and over 1.83 meter (m) (6.0 ft) wide, containing overcurrent devices, switching devices, or control devices, there shall be one entrance not less than 610 mm (24 in.) wide and 1.98 m (6.5 ft) high at each end of the working space, except that:

- Where the location permits a continuous and unobstructed way of exit travel, one means of exit is permitted; or

Where the working space required by 29 CFR 1910.303 is doubled, only one entrance to the working space is required; however, the entrance shall be located so that the edge of the entrance nearest the equipment is the minimum
Table 9. Minimum depth of clear working space at electrical equipment 600 volts or less

<table>
<thead>
<tr>
<th>Nominal voltage to ground</th>
<th>Minimum clear distance for condition(^{23})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Condition A</td>
</tr>
<tr>
<td></td>
<td>m n</td>
</tr>
<tr>
<td>0-150………………….</td>
<td>0.9 3.0</td>
</tr>
<tr>
<td>151-600………………….</td>
<td>0.9 3.0</td>
</tr>
</tbody>
</table>

Source: 29 CFR 1910.303

Notes to table 9:
1. Minimum clear distances may be 0.7 m (2.5 ft) for installations built before April 16, 1981.
2. Conditions A, B, and C are as follows:
   - Condition A—Exposed live parts on one side and no live or grounded parts on the other side of the working space, or exposed live parts on both sides effectively guarded by suitable wood or other insulating material. Insulated wire or insulated busbars operating at not over 300 volts are not considered live parts.
   - Condition B—Exposed live parts on one side and grounded parts on the other side.
   - Condition C—Exposed live parts on both sides of the work space (not guarded as provided in Condition A) with the operator between.
3. Working space is not required in back of assemblies such as dead-front switchboards or motor control centers where there are no renewable or adjustable parts (such as fuses or switches) on the back and where all connections are accessible from locations other than the back. Where rear access is required to work on deenergized parts on the back of enclosed equipment, a minimum working space of 762 mm (30 in.) horizontally shall be provided.

Switchboards, panelboards, and distribution boards installed for the control of light and power circuits, and motor control centers shall be located in dedicated spaces and protected from damage.

For indoor installation, the dedicated space shall comply with the following:
- The space equal to the width and depth of the equipment and extending from the floor to a height of 1.83 m (6.0 ft) above the equipment or to the structural ceiling, whichever is lower, shall be dedicated to the electrical installation. Unless isolated from equipment by height or physical enclosures or covers that will afford adequate mechanical protection from vehicular traffic or accidental contact by unauthorized personnel or that complies with 29 CFR 1910.303, piping, ducts, or equipment foreign to the electrical installation may not be located in this area;
- The space equal to the width and depth of the equipment shall be kept clear of foreign systems unless protection is provided to avoid damage from condensation, leaks, or breaks in such foreign systems. This area shall extend from the top of the electric equipment to the structural ceiling;
- Sprinkler protection is permitted for the dedicated space where the piping complies with 29 CFR 1910.303 and
- Control equipment that by its very nature or because of other requirements in this subpart must be adjacent to or within sight of its operating machinery is permitted in the dedicated space.
**Spill Consequences**
The following is taken from DOE Order 6430.1A.

Cryogen burns can result from direct contact with either a cryogen or uninsulated piping or equipment containing a cryogen. The large evolution of gases associated with the cryogenic spill can result in asphyxiation. Facilities that will house cryogenic storage vessels shall have collection sumps, adequate ventilation equipment for controlling vaporization pressurization and precluding asphyxiation, oxygen deficiency alarms, and rapid means of egress.

Air can contaminate the cryogen, creating a potential explosive either directly as when air mixes with liquid hydrogen or liquid methane, or indirectly by transforming an inert cryogen such as liquid nitrogen into an oxidant (a potential hazard for combustible insulation). When liquid oxygen spills on asphalt it tends to cause the asphalt to explode. When cryogen falls on concrete it tends to spall. A 6-inch layer of crushed stone shall be placed in areas where a cryogenic spill could occur.

**Accessibility to Cranes and Hoists**
The following is taken from DOE-STD-1090-2007.

DOE-STD-1090-2007, *Hoisting and Rigging Standard*, contains special provisions for hoisting and rigging operations and equipment in hostile environments where standard operating, maintenance, inspection, or test procedures cannot be followed as a result of radiation or radioactive contamination, toxic/hazardous chemicals or gases, or temperature extremes. Hostile environments are environments that have been rendered inaccessible to workers during hoisting or rigging operations due to these health hazards.

Hoisting and rigging activities can usually be accomplished where the environment will allow normal operations with access for hands-on equipment contact. In those situations, operations, maintenance, inspections, and tests shall be done according to the provision of DOE-STD-1090-2007 or other applicable regulatory requirements.


Hoisting and rigging equipment or operations shall be reviewed by a designated person to determine compliance with the requirements of DOE-STD-1090-2004 or other applicable regulatory requirements. If it is determined to be impossible or unreasonable for the requirements of DOE-STD-1090-2007 or other regulatory requirements to be met as a result of hostile environmental conditions, a hostile environment plan shall be prepared to document alternative compliance methods and procedures.

Alternate compliance methods and procedures shall be consistent with a facility’s safety basis documents.

All hoisting and rigging operations shall be consistent with DOE’s policy of as-low-as reasonably achievable (ALARA) radiation exposure per the provisions of 10 CFR 835, “Occupational Radiation Protection.”
Safety of personnel shall remain the first priority.

The following is taken from 29 CFR 1910.179.

Access to the cab and/or bridge walkway shall be by a conveniently placed fixed ladder, stairs, or platform requiring no step over any gap exceeding 12 in..

**Bonding and Grounding of Equipment**
The following is taken from DOE-STD-1090-2007.

Bonding straps shall be used to bridge locations where electrical continuity may be broken by the presence of oil on bearings, or by paint or rust at any contact point. Permanent equipment in contact with conductive floors or tabletops is not considered adequately grounded. Static grounds shall not be made to gas, steam, or air lines; dry-pipe sprinkler systems; or air terminals of lightning protection systems. Any ground that is adequate for power circuits or lightning protection is more than adequate for protection against static electricity.

e. **Discuss the methods and requirements for material protection and storage on the construction site. Include the following elements in the discussion:**
   - Theft protection
   - Moisture protection
   - Temperature protection

**Theft Protection**
The following is taken from the City of Tempe Arizona, Crime Prevention Unit, Construction Site Theft.

Construction theft is literally and figuratively big business, with industry experts estimating annual losses at roughly $1 billion. Contractors, equipment dealers, insurance companies, equipment manufacturers all suffer when job sites are vandalized or equipment and materials are stolen.

A stolen piece of equipment or material can shut the job down temporarily. Insurance costs are bound to rise.

Rental companies may refuse to rent to people who don’t properly guard their assets. Company reputations can be severely damaged through vandal actions or repeated thefts. Failure to act in a pre-emptive way to avoid theft and vandalism is irresponsible and unnecessary.

An estimated 90 percent of all equipment thefts take place between 6 p.m. Friday and 6 a.m. Monday. Holidays and week nights are next.

Owners/builders must be committed to stopping theft and vandalism on their sites
   - Build partnerships with local suppliers and scrap metal companies in the area.
   - Talk to the community and neighborhood associations you are building in for their support.
   - Work along side your local crime prevention unit within the police department
Contractors should keep excellent records, have after-hour contacts, and be willing to prosecute.

Post signs
- “Private Property”
- “Security Cameras in Use”
- “No Trespassing”
- Post signs that vehicles may be searched.
- Contractor’s and builder’s contact information.
- Rewards Program Signs—Use on gates, buildings, perimeter fencing, tool sheds, and job trailers.
- Reward Decals—These highly visible decals can be used on gang boxes, trailers, small equipment, storage sheds, and large tools.

Surveillance Cameras—The idea of being caught on video is a great deterrent to theft.
- Cost effective
  - Surveillance systems—Can be transferred from one jobsite to the next. Video streams are transferred to any location in the world using a standard computer. May include motion detection and two-way audio.
  - Remote accessibility—Can be linked to a website to give the public the ability to view the progress of a project.
  - Increase possibility of apprehension—When properly used they do result in deterrence, detection, and prosecution.
  - Security and Safety—Monitoring worksites can also be used to spot unsafe working conditions and/or procedures.

Access Control—Contractors need to take extra precautions to secure their construction sites.
- Change the padlocks on the gates and around the site several times during the construction. You never who or how many people have keys.
- Use a chain link fence to secure the perimeter of the site.
- Walk the perimeter of the site and check for breaches where someone could enter the site, then repair it.
- Have someone check out the site several times over the weekend.
- Secure storage sheds with good locks.
- Install locks as soon as possible.
- Challenge strangers on your property or job sites. Show them you are on the alert.
- Keep entrances and gates to a minimum. Lock gates when you are done for the day.
- Use a reputable security guard company.
- Wear identification badges with companies’ logo.
- Include employee search clause in contracts.
- Key control - If you store equipment keys on a key board, have someone take the keyboard home.

Equipment Security—Mark It
- Mark your equipment, metal pipe and moveable property. i.e., weld business name on property.
- Utilize the driver’s license number of a principal in the firm.
- Put numbers in two spots: hidden and obvious.
Paint your larger equipment a distinctive color and include your name or logo. Paint tools all the same color.
- Paint the last six digits of the product identification number on the roof.
- Die Stamp—Permanently mark tools and equipment with the blow of a hammer. Electric engravers can also be used.

**Record It**
- Inventory equipment frequently and store it so it is obvious if something is missing.
- Keep records. Record serial numbers and numbers you applied.
- Take color photos.

**Protect It**
- Re-key your equipment - most construction equipment is commonly keyed.
- Do not leave equipment in remote areas.
- Install anti-theft devices: fuel cutoffs, hydraulic bypasses, track locks or alarms.
- Keep equipment and supplies locked up in a securable storage shed.
- Use locking gas caps and oil caps on equipment and vehicles. Lock cabs.
- Disable vehicles with hidden switches.
- Cluster equipment. Plan to end the day with near empty tanks.
- Keep equipment and supplies locked up in a securable storage shed.
- Remove the keys from large equipment and vehicles.
- Install GPS in large construction vehicles left on site.

**Communicate**
- Talk to your new neighbors because they could be potential witnesses of future crimes.
- Advise local homeowners and businesses owners of contractors contact information.
- Offer rewards to citizens and employees. Use the silent witness program.
- Create partnerships with home owners in partially completed subdivision.
- Use an employee rewards programs—reward for not allowing crimes to occur.

**Miscellaneous**
- Conduct criminal background checks on all staff, contractors, sub-trades, and security guards.
- Zero tolerance policy on internal theft and allowing theft to occur.
- Security Guards should be visible and if possible use a marked trailer.
- Just-in-time delivery—install appliances at end of the job.
- Copper - theft of this metal is very high. Secure all metals and if possible install at the end of the job.

**Moisture Protection**

The following is taken from U.S. Environmental Protection Agency, Indoor Air Quality (IAQ) Design Tools for Schools, Moisture Control.

Newly constructed buildings give off significant amounts of moisture during their first year as a result of moisture trapped within materials such as fresh concrete, green lumber, and “wet”-applied insulations.
Keep building materials dry during construction. Building materials, especially those with moisture absorbing properties like wood, insulation, paper, and fabric, should be kept dry to prevent the growth of mold and bacteria. If moisture is present, mold will grow on any virtually any material. Some building materials such as wood may arrive at the construction site with a high moisture content or may have been wetted before arrival or during the transport process. Wet materials need to be allowed to dry as much as possible as weather permits. Cover dry materials with plastic to prevent rain damage, and if resting on the ground, use spacers to allow air to circulate between the ground and the materials.

Dry water damaged materials as quickly as possible, preferably within 24 hours. Due to the possibility of mold and bacteria growth, materials that are damp or wet for more than 48 hours may need to be discarded.

Temperature Protection
The following is taken from the Defense Technical Information Center, Automotive and Construction Equipment for Arctic use: Heating and Cold Starting.

Low-temperature problems with automotive vehicles and equipment begin to appear at about 0 ºC. Lubricants thicken, batteries lose power, and water in the fuel, oil or other fluids begins to cause problems. Diesel engines that have not been winterized become difficult to start, and they may not start at all at temperatures below -10 ºC. Gasoline engines start more reliably in the cold, but they suffer the same problems with regard to lubricants and batteries. The solution to these problems is heat. The amount of heat required and the means of applying it cannot be determined simply, as this will depend on the ambient temperature, wind speed, engine size and type, and degree of winterization of the engine. There are commercially available heaters for the following vehicle components: (1) engine block; (2) oil pan; (3) batteries; (4) fuel tanks, lines and filters; (5) transmission, differentials and transfer cases; (6) air intake; (7) combustion chamber; (8) engine compartment air; and (9) personnel and cargo compartments. Wind speed has a considerable effect on the amount of heat required to raise the temperature of a cold-soaked engine to a level at which it will start, and its effect on the cooling rate of a piece of equipment both during operation and after shutdown is significant. Heat loss experienced by a warm object in cold air varies with wind speeds. Some types of heaters used for warming cold engines are electric heaters and fuel fired heaters.

f. Describe the use and application of various tools and equipment used on a construction project. Include a discussion of specialty tools used for specific applications.

The following is taken from Houseblueprint.net, chapter 10, Construction Tools Guide.

You will need a few construction tools in order to build effectively. The following list should serve as a guide in buying the necessary tools: Shovel. Any good shovel should prove satisfactory. 8 lb. sledge.

16 02. hammer. This is about the right size for most people. For framing, a 20 02 hammer is some-times used, and a 13 02 for finishing. But most-people work better with the same hammer for all purposes, and a 16 oz. is the best all-around size. There are several good
makes, but perhaps Stanley, Maydole, Estwing, and Vaughan are among the best. It pays to get a good hammer, as it is the one of most used construction tools on the job.

26" saw. The regular-sided saw is 26" long. For framing, about 8 points to the inch is best, but good work can be done with a finer saw if only one saw is to be bought. The finish saw should have about 11 points per inch. If you can afford it, the two saws should be bought as they are used a great deal.

Hand axe. Do not get one that is too heavy. You will find this kind of construction tools very useful. Keep it sharp.

Steel tape. The 50' size is long enough for most work and is not so heavy to carry around as the 100 ft. size. But most carpenters prefer the 100 ft. tapes.

Rule. The rolling 8 or 10 ft. size is the handiest, and should always be in one’s pocket while he is working.

Steel framing square. This square has a blade 24" long and a tongue 16" long. It is used in much of the measuring and squaring in the framing of the building.

Try square. A small square that is very useful in cabinet work. An adaptation of this square is called the combination square, in which the head slips along the blade to enable one to measure in tight places, and to set off a specific distance, will be found more useful than a regular try square.

Level. A level from 2’ to 3’ long will be adequate. Bricklayers use a level, called a plumb rule that is 4’ long.

Plumb bob. A stone can be used with a string if you wish, as you measure from the string anyway.

Planes. Perhaps a 14" jack plane is the most universally used, as it will do almost any planing operation, but if you can afford two planes, get an 18" fore plane and a 6" block plane.

Chisels. A chisel 1/4" wide, one that is 3/4" wide and a large heavy chisel should be all that you really need, but other sizes are also useful.

Wrecking Bar. A 30" bar will be found better than the usual 24" size. You do not expect to use it much, but it will come in handy.

Chalk Line. Get plenty of chalk line or other strong string in long lengths, as this will aid in getting a straight building job. Whenever you want anything straight, stretch a string. Get a few pieces of chalk to go with your line.

Hoe. You will need a large hoe for mixing mortar.

Trowel, Brick Hammer. You will need these if you lay blocks or brick. They are also very useful around concrete work.
Pick. You will not need this very much unless your soil is rocky or unusually hard.

Hand Box. Make a lightweight hand box to carry your construction tools around in. This will aid in keeping them together and should prevent losing them.

Nail apron or Carpenter’s overalls. You will need something that has the right kind of pockets to carry nails in. Avoid putting too many in at one time and making the thing too heavy.

Sandpaper. When you get to the finish work, you will need sandpaper of several sizes. Garnet paper is the sharpest and cuts the fastest. You will need it in sizes of 1/2, 0, 00. Flint paper is cheaper and does not cut so fast, but the fine and very fine sizes will be very useful. When you are sanding paint, use the flint paper.

Brace and bits. You will need a brace and three or four bits. Sizes like 9/16, 3/4, and an expansion bit should give you enough so that you can get along.

Small construction tools that most people already have like pliers, screwdrivers, hack saws, wrenches, will come in very handy.

Power Saw. A small power saw will be found very helpful, and will save a great deal of labor; but one must be very careful in their use to avoid accidents. The portable electric hand saw is perhaps the most convenient for the average builder, as it can be taken to the place where the work is to be done, whereas the larger stationary models require you to bring the work to them. You can get more accurate cutting from a larger saw with an arm that permits the saw to be brought out over the work. Some radial arm saws permit you to cut almost any angle on the end of a board, like the cuts of rafters, even the complicated cheek cuts which are compound miters. You have such a few of them, however, that they can easily be cut by hand in a short time. Most of your work will require only square cutting. The little portable saws can also be set to cut compound angles, but their accuracy will depend largely on the skill of the operator and may be slightly disappointing at times. A good sharp handsaw will do a lot of cutting in an hour if worked by a determined and sinewy hand.

Power Jointer. A 6" power jointer will save a lot of hand planing. You can use it to straighten some boards, plane others smooth, to help in fitting doors, making thresholds, etc. This will also be used in the cupboard work.

Electric Drill. The 1/2" size will be large enough to bore holes for electric wiring and plumbing. It can also be used to bore holes in brick or concrete if you use carboloy drill bits.

Here is just a word of caution for builders regarding power construction tools, particularly these small portable electric hand saws. Treat them with respect and learn how to use them safely. Always keep the guard in place, looking before you turn on the switch to see that everything is ready for the saw to start. No amount of saving you may hope to make can compensate for the loss of a hand, a leg, or even of a finger, and they are not hard to saw off.

Many accidents result from falls. When you work at any height, take special precaution to see that all ladders are strong and in good condition, and that they rest squarely on the ground. If you build scaffolds be sure that they are substantial, well braced, and equipped
with a strong hand rail. A fall can end your building work in a hurry. Select scaffold planks that do not have knots near the middle, testing them for strength by placing them on low supports and springing them up and down.

Construction tools can be handled safely, but it takes constant vigilance and a certain amount of information as to what is safe practice and what is dangerous. Never take a chance. If a thing is at all dangerous, instead of doing it that way figure out a safe way of accomplishing the result you desire. You cut off a finger only once and it is gone forever. Take time to be safe. Never remove the guard from portable hand saws. The switch should work freely and turn off automatically as soon as you release it. Be sure the saw is grounded electrically. They usually come with a triple plug or with a small wire insulated in green which should be connected to a ground somewhere. If you have an outlet with the triple plug, it is probably properly grounded. Arrange the boards so they will not bind or pinch the blade and cause the saw to jerk out of control. Keep the blade sharp and avoid cutting into nails or cement. Do not use the saw where you do not have good footing, or where something is liable to slip.

The electric hand saw saves a lot of work, but remember that a bad accident could stop the entire job very suddenly. Never use a cord that is frayed, or not otherwise in first class condition. These construction tools use a large current, so the cord must be larger than an ordinary lamp cord. Always pull the cord from the outlet before attempting to change the saw blade or making major adjustments, as an accidental start at the wrong time might be a serious mistake.

One cause of accidents is hurry. Work with your construction tools as fast as you can without hurrying. That feeling of urgency that makes people step too heavily on the gas sometimes carries over into the building work. Take enough time to be safe, for it will pay in the long run.

g. Discuss the characteristics, material strength properties, and service applications for the materials used on a construction project. Include the following elements in the discussion:
- Sand and aggregate
- Construction lumber
- Concrete
- Back-fill material
- Shoring

Sand
The following is taken from the Bureau of Mines, Minerals Yearbook.

Sand and gravel is a granular, unconsolidated, and usually rounded agglomeration of particles of rocks and minerals, resulting primarily from the natural disintegration and abrasion of rocks through weathering or erosion. Most sand and gravel is used for construction purposes, mainly as aggregate in concrete, as road base material in the construction and repair of highways, railways, and runways; and as aggregate in asphaltic concrete for paving highways, streets, etc.
Aggregate

The following is taken from U.S. Geological Society (USGS), Natural Aggregates—Foundation of America’s Future.

Natural aggregates, which consist of crushed stone and sand and gravel, are among the most abundant natural resources and a major basic raw material used by construction, agriculture, and industries employing complex chemical and metallurgical processes. Despite the low value of the basic products, natural aggregates are a major contributor to and an indicator of the economic wellbeing of the Nation.

Aggregates have an amazing variety of uses. Imagine our lives without roads, bridges, streets, bricks, concrete, wallboard, and roofing tiles or without paint, glass, plastics, and medicine. Every small town or big city and every road connecting them were built and are maintained with aggregates. More than 90 percent of asphalt pavements and 80 percent of concrete are aggregates. Paint, paper, plastics, and glass also require sand, gravel, or crushed stone as a constituent.

When ground into powder, limestone is used as an important mineral supplement in agriculture, medicine, and household products. Aggregates are also being used more and more to protect our environment. Soil erosion-control programs, water purification, and reduction of sulfur dioxide emissions generated by electric power plants are just a few examples of such uses.

Construction Lumber

The following is taken from Woodbin Woodworking, Softwood Lumber Grading.

Lumber intended for general construction purposes may be subdivided into stress-graded, nonstress-graded, and appearance lumber. For stress-graded and nonstress-graded lumber, the structural integrity of the wood is the primary requirement in the grading process. With appearance lumber, the appearance or visual quality of the piece is most important and structural integrity is of secondary importance. The term "yard lumber" is often applied to the nonstress-graded and appearance lumber that is sold by retail lumberyards. This is the type of lumber that many woodworkers utilize. With such lumber, grading is done on the better side of a piece after drying and surfacing, and grades are designated by specifying the allowable size and number of defects (e.g., knotholes). This contrasts with hardwoods where most grades are determined from the poorer side of each piece on the basis of a specified number of clear cuttings. Another distinction is that hardwoods are typically graded prior to drying and surfacing.

Nonstress-Graded Lumber (Common)

With nonstress-graded lumber, pieces are graded primarily for serviceability but appearance is also considered, especially in the higher grades. Imperfections such as knots and knotholes are allowed to become larger and more frequent as the grade drops. The primary product is boards that are less than 2 in. in nominal thickness and 2 in. or more in nominal width. The standard 3/4" thick board found in retail lumber yards is an example familiar to most woodworkers. Common nominal widths are 2-, 3-, 4-, 6-, 8-, 10-, and 12-in.. Lengths are usually from 6- to 18-feet in increments of 2 feet. Boards may be sold square-edged, tongue-
and-grooved, or shiplapped. Three to five different Common grades may be applied to boards in this group depending upon the species and the lumber manufacturing association involved. In descending order of quality, the grades are No. 1 (Construction), No. 2 (Standard), No. 3 (Utility), No. 4 and No. 5. The first three grades are most commonly available in retail lumber yards.

Common Lumber Grades
No. 1 (Construction)—Moderate-sized tight knots. Paints well. Used for siding, cornice, shelving, paneling, some furniture.

No. 2 (Standard)—Knots larger and more numerous. Paints fair. Similar uses as No. 1.

No. 3 (Utility)—Splits and knotholes present. Does not take paint well. Used for crates, sheathing, subflooring, small furniture parts.

No. 4 (Economy)—Numerous splits and knotholes. Large waste areas. Does not take paint well. Used for sheathing, subflooring, concrete form work.

No. 5 (Economy)—Larger waste areas and coarser defects. Unpaintable. Applications are similar to No. 4.

Concrete
The following is taken from the Portland Cement Association, Cement and Concrete Basics.

Aggregates are inert granular materials such as sand, gravel, or crushed stone that, along with water and Portland cement, are an essential ingredient in concrete. For a good concrete mix, aggregates need to be clean, hard, strong particles free of absorbed chemicals or coatings of clay and other fine materials that could cause the deterioration of concrete. Aggregates, which account for 60 to 75 percent of the total volume of concrete, are divided into two distinct categories-fine and coarse. Fine aggregates generally consist of natural sand or crushed stone with most particles passing through a 3/8-inch sieve. Coarse aggregates are any particles greater than 0.19 inch, but generally range between 3/8 and 1.5 in. in diameter. Gravels constitute the majority of coarse aggregate used in concrete with crushed stone making up most of the remainder.

Once processed, the aggregates are handled and stored in a way that minimizes segregation and degradation and prevents contamination. Aggregates strongly influence concrete's freshly mixed and hardened properties, mixture proportions, and economy. Consequently, selection of aggregates is an important process. Although some variation in aggregate properties is expected, characteristics that are considered when selecting aggregate include:

- Grading
- Durability
- Particle shape and surface texture
- Abrasion and skid resistance
- Unit weights and voids
- Absorption and surface moisture
Grading refers to the determination of the particle-size distribution for aggregate. Grading limits and maximum aggregate size are specified because grading and size affect the amount of aggregate used as well as cement and water requirements, workability, pumpability, and durability of concrete. In general, if the water-cement ratio is chosen correctly, a wide range in grading can be used without a major effect on strength. When gap-graded aggregate are specified, certain particle sizes of aggregate are omitted from the size continuum. Gap-graded aggregate are used to obtain uniform textures in exposed aggregate concrete. Close control of mix proportions is necessary to avoid segregation.

Particle shape and surface texture influence the properties of freshly mixed concrete more than the properties of hardened concrete. Rough-textured, angular, and elongated particles require more water to produce workable concrete than smooth, rounded compact aggregate. Consequently, the cement content must also be increased to maintain the water-cement ratio. Generally, flat and elongated particles are avoided or are limited to about 15 percent by weight of the total aggregate. Unit-weight measures the volume that graded aggregate and the voids between them will occupy in concrete. The void content between particles affects the amount of cement paste required for the mix. Angular aggregate increase the void content. Larger sizes of well-graded aggregate and improved grading decrease the void content. Absorption and surface moisture of aggregate are measured when selecting aggregate because the internal structure of aggregate is made up of solid material and voids that may or may not contain water. The amount of water in the concrete mixture must be adjusted to include the moisture conditions of the aggregate. Abrasion and skid resistance of an aggregate are essential when the aggregate is to be used in concrete constantly subject to abrasion as in heavy-duty floors or pavements. Different minerals in the aggregate wear and polish at different rates. Harder aggregate can be selected in highly abrasive conditions to minimize wear.

**Back-fill Material**

The following is taken from Keystone Retaining Wall Systems, Backfill Soil Specifications.

The successful performance of reinforced soil wall structures is largely attributable to the quality of the soils involved and the contractor’s experience with soils and structural fill construction. Many wall performance problems can be traced back to the quality, strength, moisture, and density of the in-situ or compacted backfill soils.

The US Bureau of Public Roads introduced the first soil classification system in 1928 attempting to classify soils based on engineering behavior with designations of A-1, A-2, etc. After this system had been use for about 15 years, American Association of State Highway Officials reviewed and adopted a similar system with designations of A-1-a, A-2-4, etc. In 1952, the Unified Soil Classification System with designations of GW, SM, ML, CL, etc. was adopted by the US Corps of Engineers and the Bureau of Reclamation. Table 10 provides a quick summary of the “granular” materials for use in structures:
Table 10. Granular backfill soil parameters

<table>
<thead>
<tr>
<th>Group</th>
<th>Backfill Classification</th>
<th>Top Size 100% passing</th>
<th>#40 Sieve % passing</th>
<th>#200 Sieve % passing</th>
<th>Plasticity Index (PI)</th>
<th>Liquid Limit (LL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASHTO</td>
<td>MSE Select</td>
<td>4&quot; max</td>
<td>-</td>
<td>≤ 60%</td>
<td>≤ 15%</td>
<td>≤ 6</td>
</tr>
<tr>
<td>AASHTO</td>
<td>A-1-a</td>
<td>3&quot; (tested)</td>
<td>-</td>
<td>≤ 30%</td>
<td>≤ 15%</td>
<td>≤ 6</td>
</tr>
<tr>
<td>AASHTO</td>
<td>A-1-b</td>
<td>3&quot; (tested)</td>
<td>-</td>
<td>≤ 50%</td>
<td>≤ 25%</td>
<td>≤ 6</td>
</tr>
<tr>
<td>AASHTO</td>
<td>A-2-f</td>
<td>3&quot; (tested)</td>
<td>-</td>
<td>n/a</td>
<td>≤ 35%</td>
<td>40 max</td>
</tr>
<tr>
<td>AASHTO</td>
<td>A-2-6</td>
<td>3&quot; (tested)</td>
<td>-</td>
<td>n/a</td>
<td>≤ 35%</td>
<td>40 max</td>
</tr>
<tr>
<td>ASTM-USC</td>
<td>GW,GP</td>
<td>-</td>
<td>≤ 50%</td>
<td>-</td>
<td>≤ 5%</td>
<td>NP</td>
</tr>
<tr>
<td>ASTM-USC</td>
<td>GM,GC</td>
<td>-</td>
<td>≤ 50%</td>
<td>-</td>
<td>12-50%</td>
<td>4-20</td>
</tr>
<tr>
<td>ASTM-USC</td>
<td>SW,SP</td>
<td>-</td>
<td>≥ 50%</td>
<td>-</td>
<td>≤ 5%</td>
<td>NP</td>
</tr>
<tr>
<td>ASTM-USC</td>
<td>SM,SC</td>
<td>-</td>
<td>≥ 50%</td>
<td>-</td>
<td>12-50%</td>
<td>4-20</td>
</tr>
<tr>
<td>ASTM-USC</td>
<td>ML,CL</td>
<td>-</td>
<td>-</td>
<td>≥ 50%</td>
<td>&quot;A&quot;line</td>
<td>50 max</td>
</tr>
</tbody>
</table>

Source: Keystone Retaining Wall Systems, Backfill Soil Specifications

The amount of fine material (fine sand, silt and clay) as defined by the #40 and #200 sieves is generally a good indicator of favorable engineering and construction properties. The properties of the fine material as defined by its Atterberg limits (PI and liquid limit [LL]) has also been a good indicator of a soil’s engineering and construction properties. These soils properties should be clearly defined and limited by specification for any wall installation that is counted on to serve a structural purpose such as supporting a parking lot, building or roadway.

Table 11. Recommended backfill parameters (Geogrid)

<table>
<thead>
<tr>
<th>Designation</th>
<th>Top Size 100% passing</th>
<th>#40 Sieve % passing</th>
<th>#200 Sieve % passing</th>
<th>Plasticity Index (PI)</th>
<th>Liquid Limit (LL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select Backfill</td>
<td>2&quot;</td>
<td>≤ 60%</td>
<td>≤ 15%</td>
<td>≤ 6</td>
<td>-</td>
</tr>
<tr>
<td>Semi-Select Backfill</td>
<td>2&quot;</td>
<td>-</td>
<td>≤ 35%</td>
<td>≤ 10</td>
<td>≤ 40</td>
</tr>
<tr>
<td>Tolerable Silt/Clay</td>
<td>2&quot;</td>
<td>-</td>
<td>≤ 65%</td>
<td>≤ 20</td>
<td>≤ 40</td>
</tr>
<tr>
<td>Unacceptable Silt/Clay</td>
<td>2&quot;</td>
<td>-</td>
<td>≥ 65%</td>
<td>&gt; 20</td>
<td>&gt; 50</td>
</tr>
</tbody>
</table>

Source: Keystone Retaining Wall Systems, Backfill Soil Specifications

Note: It is easy to consider poor site soils for economic reasons but is not so easy to construct with such soils or to expect high performance from marginal soils even though a design can be done on paper. Construction management personnel shall demonstrate a familiarity level knowledge of the chemical fundamentals of corrosion.

Shoring

Shoring is the provision of a support system for trench faces used to prevent movement of soil, underground utilities, roadways, and foundations. Shoring or shielding is used when the location or depth of the cut makes sloping back to the maximum allowable slope impractical.
Shoring systems consist of posts, wales, struts, and sheeting. There are two basic types of shoring, timber and aluminum hydraulic. Figure 17 provides an illustration of timber shoring.

![Timber Shoring Diagram]

Source: OSHA Technical Manual

**Figure 17. Timber Shoring**

**Hydraulic Shoring**

The trend today is toward the use of hydraulic shoring, a prefabricated strut and/or wale system manufactured of aluminum or steel. Hydraulic shoring provides a critical safety advantage over timber shoring because workers do not have to enter the trench to install or remove hydraulic shoring. Other advantages of most hydraulic systems are that they:

- Are light enough to be installed by one worker;
- Are gauge-regulated to ensure even distribution of pressure along the trench line;
- Can have their trench faces preloaded to use the soil’s natural cohesion to prevent movement; and
- Can be adapted easily to various trench depths and widths.

All shoring should be installed from the top down and removed from the bottom up. Hydraulic shoring should be checked at least once per shift for leaking hoses and/or cylinders, broken connections, cracked nipples, bent bases, and any other damaged or defective parts. Figure 18 provides an illustration of typical aluminum hydraulic shoring installations.
Pneumatic Shoring

Pneumatic shoring works in a manner similar to hydraulic shoring. The primary difference is that pneumatic shoring uses air pressure in place of hydraulic pressure. A disadvantage to the use of pneumatic shoring is that an air compressor must be on site.

- **Screw Jacks.** Screw jack systems differ from hydraulic and pneumatic systems in that the struts of a screw jack system must be adjusted manually. This creates a hazard because the worker is required to be in the trench in order to adjust the strut. In addition, uniform “preloading” cannot be achieved with screw jacks, and their weight creates handling difficulties.

- **Single-Cylinder Hydraulic Shores.** Shores of this type are generally used in a water system, as an assist to timber shoring systems, and in shallow trenches where face stability is required.

*Source:* OSHA Technical Manual

**Figure 18.** Shoring variations: Typical aluminum hydraulic shoring installations
Underpinning. This process involves stabilizing adjacent structures, foundations, and other intrusions that may have an impact on the excavation. As the term indicates, underpinning is a procedure in which the foundation is physically reinforced. Underpinning should be conducted only under the direction and with the approval of a registered professional engineer. Figure 19 illustrates shoring variations.

Source: OSHA Technical Manual

Figure 19. Shoring variations

15. Construction Management personnel shall demonstrate a familiarity level knowledge of the chemical fundamentals of corrosion.

a. Explain the general corrosion process for iron and steel when exposed to water.

The following is taken from DOE-HDBK-1015/1-93.

The oxidation and reduction half-reactions in the corrosion of iron are as follows.

\[
\begin{align*}
Fe & \rightarrow Fe^{2+} + 2e \quad \text{(oxidation)} \\
H_2O + e & \rightarrow H^+ + H_2O \quad \text{(reduction)}
\end{align*}
\]

The overall reaction is the sum of these half-reactions.

\[
Fe + 2H_2O \rightarrow Fe^{2+} + 2H + 2 H_2O
\]

The \(Fe^{2+}\) ions readily combine with \(OH^-\) ions at the metal surface, first forming \(Fe(OH)_2\), which decomposes to \(FeO\).

\[
Fe^{2+} + 2OH \rightarrow Fe(OH)_2 \rightarrow Fe + H_2O
\]

Ferrous oxide (FeO) then forms a layer on the surface of the metal. Below about 1000 °F, however, FeO is unstable and undergoes further oxidation.
2Fe+H₂O → Fe₂O₃+2H

Atomic hydrogen then reacts to form molecular hydrogen, and a layer of ferric oxide (Fe₂O₃) builds up on the FeO layer. Between these two layers is another layer that has the apparent composition Fe₃O₄. It is believed that Fe₃O₄ is a distinct crystalline state composed of O²⁻, Fe²⁺ and Fe³⁺ in proportions so that the apparent composition is Fe₃O₄. These three layers are illustrated in figure 20.

Source: DOE-HDBK-1015/1-93

Figure 20. Simplified schematic diagram of oxide corrosion film on the surface of a metal

Once the oxide film begins to form, the metal surface is no longer in direct contact with the aqueous environment. For further corrosion to occur, the reactants must diffuse through the oxide barrier. It is believed that the oxidation step occurs at the metal-oxide interface. The Fe²⁺ ions and electrons then diffuse through the oxide layer toward the oxide-water interface. Eventually, Fe²⁺ ions encounter OH⁻ ions and form FeO. The electrons participate in the reduction reaction with hydronium ions. These latter reactions are believed to take place predominately at the oxide-water interface, but some reaction may occur within the oxide layer by the diffusion of H⁺, OH⁻, and H₂O into the layer.

Regardless of the exact diffusion mechanism, the oxide layer represents a barrier to continued corrosion and tends to slow the corrosion rate. The exact effect of this layer on the corrosion rate depends on the uniformity and tenacity of the film. If the film is loosely attached, develops defects, or is removed, the metal surface is again exposed to the environment and corrosion occurs more readily.
b. Discuss the conditions that can cause galvanic corrosion.

The following is taken from DOE-HDBK-1015/1-93.

Galvanic corrosion is the corrosion that results when two dissimilar metals with different potentials are placed in electrical contact in an electrolyte.

Of all the different types of corrosion, galvanic corrosion corresponds most closely to electrochemical cells because galvanic corrosion occurs when two electrochemically dissimilar metals are joined together (in electrical contact) in a conducting medium (electrolyte). It may also take place with one metal with heterogeneities (dissimilarities) (for example, impurity inclusions, grains of different sizes, difference in composition of grains, differences in mechanical stress); abnormal levels of pH; and high temperatures. A difference in electrical potential exists between the different metals and serves as the driving force for electrical current flow through the corrodant or electrolyte. This current results in corrosion of one of the metals. The larger the potential difference, the greater the probability of galvanic corrosion. Galvanic corrosion only causes deterioration of one of the metals. The less resistant, active metal becomes the anodic corrosion site. The stronger, nobler metal is cathodic and protected. If there were no electrical contact, the two metals would be uniformly attacked by the corrosive medium as if the other metal were absent. Two locations susceptible to galvanic corrosion is a piping transition from one metal to another and a sacrificial anode (such as zinc).

c. Discuss the following types of specialized corrosion:
   - Pitting corrosion
   - Stress corrosion cracking
   - Crevice corrosion

The following definitions are taken from DOE-HDBK-1015/1-93.

Pitting Corrosion

Pitting corrosion occurs where the anodic site becomes fixed in a small area and the formation of holes (deep attack) in an otherwise unaffected area takes place.

To illustrate pitting attack, consider a special type of galvanic cell called a differential aeration cell such as the one illustrated in figure 21. This particular differential aeration cell is showing current flow as a result of depolarization of one electrode (cathode) by oxygen. In this type of cell, two iron electrodes are exposed to a dilute solution of an electrolyte. Air (or oxygen) is bubbled around one electrode, and nitrogen is bubbled around the other. A current flows through the wire connecting the two electrodes. The difference in potential is a result of the difference in oxygen concentration at the two electrode surfaces. At the electrode exposed to nitrogen, electrons are given up by the iron as it is oxidized. These electrons readily flow through the external circuit to the electrode exposed to oxygen. At this depolarized electrode they can participate in a reduction reaction. As a result, oxidation occurs at the electrode exposed to nitrogen and reduction occurs at the aerated electrode. Oxidation at one electrode and reduction at the other creates a potential and a flow of current through the connecting wire. Note that loss of metal occurs at the electrode that is deficient in oxygen.
Stress Corrosion Cracking

Stress corrosion cracking (SCC) is a type of intergranular attack corrosion that occurs at the grain boundaries under tensile stress. SCC occurs in susceptible alloys when the alloy is exposed to a particular, specific environment if the alloy is in a stressed condition. Stress corrosion cracking appears to be relatively independent of general uniform corrosion processes. Thus, the extent of general corrosion can be essentially nil, and stress cracking can still occur. Most pure metals are immune to this type of attack.

According to the most widely accepted theory, stress corrosion cracking is caused by a process called chemisorption. Unlike relatively weak physical absorption, such as hydrogen gas on platinum metal, chemisorption may be thought of as the formation of a compound between the metal atoms on the surface as a monomolecular layer of the chemisorbed substance, such as Cl\(^{-}\), OH\(^{-}\), Br\(^{-}\), and some other ions. The formation of this chemisorbed layer greatly reduces the attraction between neighboring metal atoms. A defect initially present then grows as the metal atoms separate under stress, more chemisorption occurs, and the process continues. In very severe cases, the time required for this cracking to occur is only a matter of minutes.

Many stainless steels are susceptible to stress corrosion cracking. Stainless steels containing 18 percent chromium and 8 percent nickel are susceptible to cracking in environments containing chloride ions and in concentrated caustic environments (that is, in environments where the hydroxyl ion concentration is high). On the other hand, these types of stainless
steels do not exhibit any tendency to crack when they are exposed to water environments containing nitrate, sulfite, and ammonium ions.

SCC is of great concern because it can readily crack metal of appreciable thickness. If the environment is severe enough, cracking can occur in a very short period of time. The crack can then lead to a serious failure of the component, or the system, and all the attendant results (for example, contamination, loss of coolant, and loss of pressure).

The most effective means for preventing SCC are proper design, reducing stress, removing critical environmental contributors (for example, hydroxides, chlorides, and oxygen), and avoiding stagnant areas and crevices in heat exchangers where chlorides and hydroxides might become concentrated. Low alloy steels are less susceptible than high alloy steels, but they are subject to SCC in water containing chloride ions. Nickel based alloys are not affected by chloride or hydroxide ions.

Two types of SCC are of major concern to a nuclear facility.

Chloride Stress Corrosion Cracking (Stainless Steels)
The three conditions that must be present for chloride stress corrosion to occur are as follows.

- Chloride ions are present in the environment
- Dissolved oxygen is present in the environment
- Metal is under tensile stress

Austenitic stainless steel is a non-magnetic alloy consisting of iron, chromium, and nickel, with a low carbon content. This alloy is highly corrosion resistant and has desirable mechanical properties. One type of corrosion which can attack austenitic stainless steel is chloride stress corrosion. Chloride stress corrosion is a type of intergranular corrosion.

Chloride stress corrosion involves selective attack of the metal along grain boundaries. In the formation of the steel, a chromium-rich carbide precipitates at the grain boundaries leaving these areas low in protective chromium, and thereby, susceptible to attack. It has been found that this is closely associated with certain heat treatments resulting from welding. This can be minimized considerably by proper annealing processes.

This form of corrosion is controlled by maintaining low chloride ion and oxygen content in the environment and the use of low carbon steels. Environments containing dissolved oxygen and chloride ions can readily be created in auxiliary water systems. Chloride ions can enter these systems via leaks in condensers or at other locations where auxiliary systems associated with the nuclear facility are cooled by unpurified cooling water. Dissolved oxygen can readily enter these systems with feed and makeup water. Thus, chloride stress corrosion cracking is of concern, and controls must be used to prevent its occurrence.

Caustic Stress Corrosion Cracking

Caustic stress corrosion, or caustic embrittlement, is another form of intergranular corrosion cracking. The mechanism is similar to that of chloride stress corrosion. Mild steels (steels with low carbon and low alloy content) and stainless steels will crack if they are exposed to concentrated caustic (high pH) environments with the metal under a tensile stress. In stress
cracking that is induced by a caustic environment, the presence of dissolved oxygen is not necessary for the cracking to occur.

Caustic stress corrosion cracking was first encountered in the operation of riveted steam boilers. These boilers were found to fail on occasion along riveted seams. Failure was attributed to caustic-induced cracking at the highly stressed regions near and under the rivets. Boiler water could easily flow into the crevices which existed under the rivets.

Radiative heating would cause the water in the crevices to boil. As steam was formed, it would escape from the crevice. More boiler water would then flow into the crevice, boil, and pass from the crevice as steam. The net result of this continuing process was concentration of caustic under the rivet. The combination of high stress and high caustic concentrations eventually led to destructive cracking of the boiler vessel.

Where the rate of steam generation (boiling) is high, it is more difficult to eliminate the problem of solute concentration in regions of the boiler. Caustic stress corrosion may concentrate in such regions as the water evaporates rapidly, but sufficient concentration of caustic by such a mechanism to induce stress cracking is considered unlikely.

Available data indicates that caustic concentrations greater than 10,000 parts per million (ppm), and probably up to 50,000 ppm, are required to induce caustic stress cracking. The pH of such a solution is on the order of 14. An alkaline environment is produced and controlled by use of a solution having some properties of a buffer, that is, one that tends to retard or slow a reaction or tends to force it in one direction or the other.

*Crevice Corrosion*

Crevice corrosion is a type of pitting corrosion that occurs specifically within the low flow region of a crevice. In iron that is exposed to water, a similar action can occur if adjacent areas of the metal surface become exposed to solutions with different oxygen concentrations. For example, the solution in a crevice exchanges slowly with the bulk of the solution outside the crevice. Oxygen in the solution inside the crevice will be depleted initially by the corrosion reaction.

This reaction alone does not produce a protective film on the metal. Because of restricted flow into the crevice, replenishment of oxygen will be very slow; therefore, the solution inside the crevice will have a low oxygen concentration relative to that outside the crevice as shown in figure 22. The two adjacent areas then establish a concentration cell with electrons flowing from the region of low oxygen concentration to the region of high concentration. Thus, metal goes into solution (oxidation) inside the crevice, and reduction occurs outside the crevice.

Metal ions diffuse out of the crevice, more metal dissolves, and the process continues. This results in the formation of a pit inside the crevice.
16. Construction management personnel shall demonstrate a familiarity level knowledge of chemical safety fundamentals.

a. Discuss the hazards associated with the use of corrosives (acids and alkalies).

The following discussions are taken from DOE-HDBK-1015/2-93.

Acids

Acids are compounds of hydrogen and one or more other elements that dissociate or break down to produce hydrogen ions when dissolved in water or certain other solvents.

Acids are corrosive in any form, and in high concentrations destroy body tissue and cause severe burns on contact with the skin. The eyes are very susceptible, and permanent damage or loss of sight may result from contact with acids. The inhalation of excessive concentrations of vapor or mist is extremely irritating to the respiratory system and to mucous membranes in particular.

Accidental swallowing of concentrated acids may result in severe irritation of, and damage to, the throat and stomach which, in some cases, may prove fatal. Some of these materials are specifically poisonous as well as irritating. In lower concentrations, repeated skin contact may result in inflammation.

Concentrated aqueous solutions of acids are not in themselves flammable. The potential hazard is the danger of their mixture with other chemicals or combustible materials which may result in fire or explosion. Acids also react with many metals resulting in the liberation of hydrogen, a highly flammable gas, which upon ignition in air may cause an explosion.
Some of the acids are strong oxidizing agents and can react destructively and violently when in contact with organic or other oxidizable materials.

Personnel exposure requiring immediate action usually involves direct contact of the acid with the body or eyes of the individual, inhalation of acid vapors or decomposition products, and ingestion of acid. The initial treatment in all cases of local contact is immediate removal of the acid with a large amount of water. This treatment must be prolonged until all traces of acid have been removed, usually a minimum washing time of 15 minutes.

**Alkalies**

Alkalies (bases) are corrosive caustic substances that dissociate in water and yield hydroxyl ions. Alkalies include: ammonia, ammonium hydroxide; calcium hydroxide and oxide; potassium, potassium hydroxide and carbonate; sodium, sodium hydroxide; carbonate, peroxide and silicate; and trisodium phosphate.

The alkalies, whether in solid form or concentrated liquid solution, are more destructive to tissue than most acids. Alkali dusts, mists, and sprays may cause irritation of the eyes and respiratory tract and lesions of the nasal septum. Strong alkalies combine with tissue, causing severe burns, frequently deep ulceration, and ultimate scarring. Severe burns result not only from contact with solid alkalies, but also from solutions of these compounds. Potassium and sodium hydroxide are the most active materials in this group. Even dilute solutions of the stronger alkalies tend to soften the epidermis (skin) and emulsify or dissolve the skin fats. Exposure to atmospheres contaminated with alkalies may result in damage to the upper respiratory tract and to lung tissue, depending upon the severity of the exposure. The effects of inhalation may vary from mild irritation of the nasal mucous membranes to severe inflammation of the lungs.

Ingestion causes severe damage to mucous membranes or deeper tissues with which contact is made. Perforation of these tissues may follow, or there may be severe and extensive scar formation. Death may result if penetration into vital areas occurs.

Even though alkalies are not flammable and will not support combustion, much heat is evolved when the solid material is dissolved in water. Therefore, cold water must be used to dissolve solid alkalies, otherwise the solution may boil, and splatter corrosive liquid over a wide area.

**b. Describe the general safety precautions necessary for the handling, storage, and disposal of corrosives.**

The following is taken from DOE-HDBK-1015/2-93.

Safety in handling hazardous chemicals depends to a great extent upon effective employee education, proper safety practices, intelligent supervision, and the use of safe equipment. Workers should be thoroughly informed of the hazards that may result from improper handling. Each employee should know what to do in an emergency and should be fully informed about proper first-aid measures. Hazards from spills and leaks should be minimized by an adequate supply of water for washing-down. Drainage of hard-surfaced or diked areas
should be directed to minimize the exposure of personnel and equipment. Adequate ventilation should be provided in areas where chemical mist or dust is present.

Alkalies are much more injurious to the eyes than acids because strong acids tend to precipitate a protein barrier, which prevents further penetration into the tissue. The alkalies do not do this.

They continue to soak into the tissue as long as they are allowed to remain in contact with the eye. The end result of a corrosive burn to the eye (alkali or acid) is usually a scar on the cornea and possible permanent damage.

Speed in removing corrosives is of primary importance. If the chemical enters the eyes, they should be copiously irrigated with water for at least 15 minutes, and a physician should be consulted immediately. In case of contact with skin or mucous membranes, the safety shower should be used immediately. Clothing can be removed under the shower. Contaminated skin areas should be washed with very large quantities of water for 1 to 2 hours, or until medical help arrives. The ready availability of water, particularly safety showers and eye-washing baths, greatly minimizes the possibility of severe, extensive damage. Contaminated clothing and shoes should be thoroughly washed and decontaminated before re-use.

The use of personal protective equipment is not intended as a substitute for adequate control measures, but because corrosives can cause extensive damage to the body this equipment must be available as needed. During handling operations where spills or splashes are possible, whole body protection (eyes, head, body, hands, and feet) may be necessary. All personal protective equipment should be carefully cleaned and stored following use, and any equipment that cannot be decontaminated should be discarded.

For the protection of the eyes, chemical safety goggles should be worn. Face shields should be worn if complete face protection is necessary. Eyewash fountains and safety showers must be available at any location where eye and/or skin contact may occur. Protection against mist or dust can be provided by proper respiratory protective equipment. The wearing of protective clothing is also advisable to avoid skin contact. This may consist of rubber gloves, aprons, shoes or boots, and cotton coveralls which fit snugly. Safety shoes or boots made of rubber, chlorobutadiene, or other chemical-resistant materials with built-in steel toecaps are recommended for workers handling drums or in process areas where leakage may occur.

Containers should be stored in rooms with trapped floor drains. Curbs or a drained gutter, covered with an appropriate grill, should be constructed at door openings where floor drains are not provided.

Tanks should be entered for cleaning or repairing only after these have been drained, flushed thoroughly with water, ventilated, and sampled. Workers entering tanks should be monitored by someone on the outside of the tank. A supplied-air respirator or self-contained breathing apparatus, together with rescue harness and lifeline, should be on hand for rescue purposes.

Removal from exposure is the primary, and most important, step where exposure by inhalation is involved. The individual should be made as warm and comfortable as possible, and a physician should be called immediately.
c. Discuss the general safety precautions to be taken during the use, handling, and storage of compressed gases, specifically including: hydrogen, oxygen, and nitrogen.

The following is taken from DOE-STD-1015/2-93.

Compressed and liquified gases are widely useful due to properties including high heat output in combustion for some gases, high reactivity in chemical processing with other gases, extremely low temperatures available from some gases, and the economy of handling them all in compact form at high pressure or low temperature. These same properties, however, also represent hazards if the gases are not handled with full knowledge and care. Practically all gases can act as simple asphyxiants by displacing the oxygen in air. The chief precaution taken against this potential hazard is adequate ventilation of all enclosed areas in which unsafe concentrations may build up. A second precaution is to avoid entering unventilated areas that might contain high concentrations of gas without first putting on a breathing apparatus with a self-contained or hose-line air supply. A number of gases have characteristic odors which can warn of their presence in air. Others, however, like the atmospheric gases, have no odor or color. Warning labels are required for compressed and liquified gas shipping containers. Similar warning signs are placed at the approaches to areas in which the gases are regularly stored and used. Some gases can also have a toxic effect on the human system through inhalation via high vapor concentrations, or by liquified gas coming in contact with the skin or the eyes. Adequate ventilation of enclosed areas serves as the chief precaution against high concentrations of gas. In addition, for unusually toxic gases, automatic devices can be purchased or built to constantly monitor the gas concentration and set off alarms if the concentration approaches a danger point. Precautions against skin or eye contact with liquified gases that are toxic or very cold, or both, include thorough knowledge and training for all personnel handling such gases, the development of proper procedures and equipment for handling them, and special protective clothing and equipment (for example, protective garments, gloves, and face shields). With flammable gases, it is necessary to guard against the possibility of fire or explosion. Ventilation, in addition to safe procedures and equipment to detect possible leaks, represents a primary precaution against these hazards. If fire breaks out, suitable fire extinguishing apparatus and preparation will limit damage. Care must also be taken to keep any flammable gas from reaching any source of ignition or heat (such as sparking electrical equipment, sparks struck by ordinary tools, boiler rooms, or open flames). Oxygen poses a combustible hazard of a special kind. Although oxygen does not ignite, it lowers the ignition point of flammable substances and greatly accelerates combustion. It should not be allowed closer than 10 feet to any flammable substance, including grease and oil, and should be stored no closer than 10 feet to cylinders or tanks containing flammable gases. Proper storage and handling of containers avoids many possible incidents. Hazards resulting from the rupture of a cylinder or other vessel containing gas at high pressure are protected against by careful and secure handling of containers at all times. Cylinders should not be dragged or rolled across the floor; they should be moved by a hand truck. Also, when they are upright on a hand truck, floor, or vehicle, they should be chained securely to keep them from falling over. Moreover, cylinders should not be heated to the point at which any part of their outside surface exceeds a temperature of 125 ºF, and they should never be heated with a torch or other open flame. Initial protection against the possibility of vessel rupture is provided by the demanding requirements and recommendations that compressed gas containers fulfill in their construction, testing, and retesting.
d. Discuss the safety precautions for working with cryogenic liquids.

The following is taken from DOE-STD-1015/2-93.

Most cryogenic liquids are colorless, odorless, and tasteless when vaporized to a gas. As liquids, most have no color (except liquid oxygen which is light blue). However, whenever the cold liquid and vapor are exposed to the atmosphere a warning appears. As the boil-off gases condense moisture in the air, a fog forms that extends over an area larger than the vaporizing gas. Many cryogenic liquids are inert gases, and may inert an enclosed space. Inert gases will not support life.

Both the liquid and its boil-off vapor can rapidly freeze human tissue and can cause many common materials such as carbon steel, plastic, and rubber to become brittle or fracture under stress. Liquids in containers and piping at temperatures at or below the boiling point of liquefied air (-318 ºF) can cause the surrounding air to condense to a liquid.

Extremely cold liquified gases (helium, hydrogen, and neon) can even solidify air or other gases to which they are directly exposed. In some cases, plugs of ice or foreign material will develop in cryogenic container vents and openings and cause the vessel to rupture. If a plug forms, contact the supplier immediately. Do not attempt to remove the plug; move the vessel to a remote location.

All cryogenic liquids produce large volumes of gas when they vaporize. For example, 1 volume of saturated liquid nitrogen at 1 atmosphere vaporizes to 696.5 volumes of nitrogen gas at room temperature at 1 atmosphere.

When vaporized in a sealed container, cryogenic liquids produce enormous pressures. If 1 volume of liquid helium at 1 atmosphere is warmed to room temperature and vaporized in a totally enclosed container, it has the potential to generate a pressure of more than 14,500 pounds per square inch gauge (psig).

Because of this high pressure, cryogenic containers are usually protected with two pressure-relief devices, a pressure-relief valve and a frangible (easily broken) disk.

Many safety precautions that must be taken with compressed gases also apply to liquified gases. However, some additional precautions are necessary because of the special properties exhibited by fluids at cryogenic temperatures.

The properties of cryogenic liquids affect their safe handling and use. Table 1 presents information to help determine safe handling procedures. None of the gases listed are corrosive at ambient temperatures, and only carbon monoxide is toxic.

- Always handle cryogenic liquids carefully. They can cause frostbite on skin and exposed eye tissue. When spilled, they tend to spread, covering a surface completely and cooling a large area. The vapors emitted by these liquids are also extremely cold and can damage tissues. The vapor boil-off may inert the immediate vicinity.
- Stand clear of boiling or splashing liquid and its vapors. Boiling and splashing occurs when a warm container is charged or when warm objects are inserted into a liquid. These operations should always be performed slowly to minimize boiling and
splashing. If cold liquid or vapor comes in contact with the skin or eyes, first aid should be given immediately.

- Never allow an unprotected part of the body to touch uninsulated pipes or vessels that contain cryogenic fluids. The extremely cold metal will cause the flesh to stick fast to the surface and tear when withdrawn. Touching even nonmetallic materials at low temperatures is dangerous.

Tongs, or a similar device, should be used to withdraw objects immersed in a cryogenic liquid. Materials that are soft and pliable at room temperature become hard and brittle at extremely low temperatures and will break easily.

Workers handling cryogenic liquids should use eye and hand protection to protect against splashing and cold-contact burns. Safety glasses are also recommended. If severe spraying or splashing is likely, a face shield or chemical goggles should be worn. Protective gloves should always be worn when anything that comes in contact with cold liquids and their vapors is being handled. Gloves should be loose fitting so that they can be removed quickly if liquids are spilled into them. Trousers should remain outside of boots or work shoes.

Table 12. Safety properties of cryogenic fluids

<table>
<thead>
<tr>
<th>Source: DOE-HDBK-1015/2-93</th>
</tr>
</thead>
<tbody>
<tr>
<td>e. Explain the difference between an inflammable material and a combustible material.</td>
</tr>
</tbody>
</table>

The following is taken from 29 CFR 1910.106, “Flammable and Combustible Liquids.”

Inflammable material, also called flammable material, has a flash point below 100 °F and a vapor pressure not exceeding 40 absolute pressure (psia) at 100 °F. Combustible liquids are those with flash points at or above 100 °F, but below 200 °F.
f. **Describe the general safety precautions regarding the use, handling, and storage of inflammable and combustible liquids.**

The following is taken from 29 CFR 1910.106.

Flammable or combustible liquids shall be stored in tanks or closed containers.

(a) Except as provided in subdivisions (b) and (c) of this subdivision, all storage shall comply with paragraph (d) (3) or (4) of this section.

(b) The quantity of liquid that may be located outside of an inside storage room or storage cabinet in a building or in any one fire area of a building shall not exceed:

- (1) 25 gallons of Class IA liquids in containers
- (2) 120 gallons of Class IB, IC, II, or III liquids in containers
- (3) 660 gallons of Class IB, IC, II, or III liquids in a single portable tank.

(c) Where large quantities of flammable or combustible liquids are necessary, storage may be in tanks which shall comply with the applicable requirements of paragraph (b) of this section.

(iii) Separation and protection. Areas in which flammable or combustible liquids are transferred from one tank or container to another container shall be separated from other operations in the building by adequate distance or by construction having adequate fire resistance.

Drainage or other means shall be provided to control spills. Adequate natural or mechanical ventilation shall be provided.

(iv) Handling liquids at point of final use. (a) Flammable liquids shall be kept in covered containers when not actually in use.

(b) Where flammable or combustible liquids are used or handled, except in closed containers, means shall be provided to dispose promptly and safely of leakage or spills.

(c) Class I liquids may be used only where there are no open flames or other sources of ignition within the possible path of vapor travel.

(d) Flammable or combustible liquids shall be drawn from or transferred into vessels, containers, or portable tanks within a building only through a closed piping system, from safety cans, by means of a device drawing through the top, or from a container or portable tanks by gravity through an approved self-closing valve. Transferring by means of air pressure on the container or portable tanks shall be prohibited.

g. **Describe the information on a material safety data sheet (MSDS) and discuss the uses for material safety data sheets on a construction project.**

The following is taken from OSHA, Recommended Formats for Material Safety Data Sheets.

OSHA’s hazard communication standard specifies certain information that must be included on MSDSs, but does not require that any particular format be followed in presenting this
information. In order to promote consistent presentation of information, OSHA recommends that MSDSs follow the 16-section format established by the ANSI standard for preparation of MSDSs.

By following this recommended format, the information of greatest concern to workers is featured at the beginning of the data sheet, including information on chemical composition and first aid measures. More technical information that addresses topics such as the physical and chemical properties of the material and toxicological data appears later in the document. While some of this information (such as ecological information) is not required by the hazard communication standard, the 16-section MSDS is becoming the international norm. The 16 sections are:

- Identification
- Hazard(s) identification
- Composition/information on ingredients
- First-aid measures
- Fire-fighting measures
- Accidental release measures
- Handling and storage
- Exposure controls/personal protection
- Physical and chemical properties
- Stability and reactivity
- Toxicological information
- Ecological information
- Disposal considerations
- Transport information
- Regulatory information
- Other information

17. **Construction management personnel shall demonstrate a familiarity level knowledge of the basic principles and concepts of geoscience as applied to soil, erosion, foundations, and earth embankments.**

   a. **Identify and describe examples of shallow and deep foundations.**

   **Shallow Foundations**

   The following is taken from the U.S. Department of Housing and Urban Development, *Design Guide for Frost-Protected Shallow Foundations*.

   A frost protected shallow foundation (FPSF) is a practical alternative to deeper, more-costly foundations in cold regions with seasonal ground freezing and the potential for frost heave. Figure 23 shows an FPSF and a conventional foundation. An FPSF incorporates strategically placed insulation to raise the frost depth around a building, thereby allowing foundation depths as shallow as 16 in., even in the most severe climates.
The frost protected shallow foundation technology recognizes the thermal interaction of building foundations with the ground. Heat input to the ground from building effectively raises the frost depth at the perimeter of the foundation. This effect and other conditions that regulate frost penetration into the ground are illustrated in figure 24.


**Figure 23.** Schematic of FPSF and conventional foundation systems

**Source:** U.S. Department of Housing and Urban Development, Design Guide for Frost-Protected Shallow Foundations

Figure 24. Frost penetration into the ground under various conditions
It is important to note that the frost line rises near a foundation if the building is heated. This effect is magnified when insulation is strategically placed around the foundation. The FPSF also works on an unheated building by conserving geothermal heat below the building.

Deep Foundations
The following is taken from Washington State, Department of Transportation, Geotechnical Services Division, Foundation Design.

Deep foundations such as shafts or piles are required where the depth to the bearing layer is large, or the depth of scour is anticipated to be great. Shafts are drilled in place using large augers, typically 3 to 12 feet in diameter, and may extend to more than 100 feet in depth. Where soils are very soft or weak, steel casing is often advanced as the hole is excavated to prevent the side walls of the hole from collapsing. Drilling slurry may be used in lieu of casing for this purpose if the soils are not too weak. Once the excavation is completed, the hole is filled with concrete and reinforced with steel to form the shaft. Shafts may also be used in relatively dense soils if there is not adequate room to construct a spread footing. In general, it is usually attempted to support each bridge column with a single shaft, to avoid the need to construct a structural cap (i.e., platform or footing which transfers the load from the bridge column to the deep foundation units), reducing the room required for the foundation and decreasing costs. Alternatively, pile foundations can be used in deep relatively soft or weak soils. Piles are driven into the ground using a pile hammer attached to a crane. Groups of piles are usually used to support a foundation, and are cast into a pile cap near the ground surface which transfers load from the bridge column to the pile group. The capacity of each pile can be determined directly during foundation installation knowing the size of the pile hammer and the resistance of the pile to penetration during pile driving. Shaft capacity on the other hand, must be determined by estimating the strength of the soil or rock around the foundation.

b. Discuss the basic elements of embankment design.

The following is taken from the State of Texas, Department of Transportation, Hydraulic Design Manual, Embankment Protection.

The best slope protection type for a given situation depends on the conditions where the installation is to be made, availability of protection material, cost of the various types, and protection desired.

The major reservoir sponsors can help decide which to use for a given situation.

Rock Riprap
Consider the following elements of rock riprap:
- size – Rock riprap consists of loose rock that is dumped on the slope and distributed. The size of the rock should be large enough that it withstands the forces of wind and water directed at the slope.
- placement – The rock is placed on a bedding of sand, engineering fabric pinned to the slope, or both a bedding of sand and engineering fabric pinned to the slope. Bedding
is primarily for the purpose of keeping the embankment material in place as the embankment is saturated and drained.

- keyed rock riprap – An effective rock riprap variation is keyed riprap. This is rock that has been placed and distributed on bedding upon the slope and then slammed with a very heavy plate to set the rock riprap in place (i.e., to key the rock together). Rock riprap is considered a rough slope when computing wave runup on the slope.

- rock riprap design – Once the wind effects are known, the weight of the median stone and the total thickness of the riprap blanket can be established.

Source: State of Texas, Department of Transportation, Hydraulic Design Manual, Embankment Protection

**Figure 25.** Rock riprap specifications

**Soil-Cement Riprap**

Soil-cement riprap consists of layers of soil cement on the slope placed in prescribed lifts. Figure 26 shows completed soil-cement slope protection. This type of protection provides excellent slope protection. However, inspection and maintenance is necessary, especially at the reservoir water surface elevation that exists most of the time.
**Articulated Riprap**

This type of riprap is usually fabricated so that the individual elements are keyed together, and connecting cables or strands run in two directions to hold the units together. Articulated riprap is usually placed on a filter bed, engineering fabric, or both. The riprap is so named because it is flexible—can move as a unit with the slope and still remain intact. There are several commercial sources of articulated riprap. Consider each for price, performance, and experience.

**Concrete Riprap**

Concrete usually consists of slope paving of 4 to 6 in. (100 to 150 mm) in thickness. Concrete riprap ordinarily is not recommended for embankment slope protection for highways within a reservoir. This is because the hydrostatic head that can exist in the embankment after it is wet cannot be relieved adequately through the concrete riprap. The riprap bulges and falls because it does not have the structural integrity necessary to withstand the hydrostatic head of the trapped water.

Concrete riprap can be useful for short sections when placed on a bed of coarse filter material with numerous drain holes located in the riprap, and in an area where the embankment does not have standing water on the slope. There should not be constant differentials in the water surface that might cause prolonged periods of wetting and drying of the embankment.

**Vegetation**

The use of vegetation with large, strong root systems is a common and economical way to protect slopes. This type of protection can be useful on embankment slopes in a reservoir where wind effects are mild.


---

**Figure 26.** Soil cement riprap specifications
c. Define erosion and describe the characteristics and effects of water and wind erosion.

Erosion

The following is taken from the State of Texas, Department of Transportation, *Hydraulic Design Manual*, Soil Erosion Control Considerations.

Understanding erosion is necessary as a basis for adequate control measures. Erosion is caused by rainfall, which displaces soil particles on inadequately protected areas and by water running over soil, carrying some soil particles away in the process. The rate of soil particle removal is proportional to the intensity and duration of the rainfall and to the volume and characteristics of the water flow and soil properties. Deposition of water-borne sediment occurs when the velocity decreases and the transport capacity of the flowing water becomes insufficient to carry all of its sediment load.

![Diagram of soil erosion forces](image)


**Figure 27.** Typical forces in soil erosion

Effects of Water Erosion

The following is taken from Iowa State University, Extension Program, Soil Erosion and Water Quality.

Water quality is affected significantly by soil erosion. Increased levels of nitrogen and phosphorus, along with higher sediment loads, are the leading contributors to reduced water quality. Nitrogen and phosphorus move from fields to surface water when sediment is transported through runoff and soil erosion. As a result of the nitrogen- and phosphorus-enriched sediments, eutrophication—the growth of algae and other aquatic plants—occurs, decreasing dissolved oxygen levels.
Effects of Wind Erosion

The following is taken from the U.S. Department of Agriculture, Agricultural Research Service, Wind Erosion.

Wind erosion is a serious problem in many parts of the world and is worse in arid and semiarid regions. Areas most susceptible to wind erosion on agricultural land not only include parts of North America, but also much of North Africa and the Near East; parts of southern central, and eastern Asia; the Siberian Plains; Australia; northwest China; and southern South America.

Wind erosion is the dominant problem on about 30 million hectares (74 million acres) of land in the United States. About 2 million hectares (5 million acres) are moderately to severely damaged each year. Wind erosion physically removes from the field the most fertile portion of the soil. Some soil from damaged land enters suspension and becomes part of the atmospheric dust load. Dust obscures visibility and pollutes the air, causes automobile accidents, fouls machinery, and imperils animal, plant, and human health.

d. Describe the types of tests used to determine the strength and dynamic properties of soils.

The following is taken from 29 CFR 1926, subpart P, appendix A, “Soil Classification.”

Manual Tests
Manual analysis of soil samples is conducted to determine quantitative as well as qualitative properties of soil and to provide more information in order to classify soil properly.

Plasticity
Mold a moist or wet sample of soil into a ball and attempt to roll it into threads as thin as 1/8-inch in diameter. Cohesive material can be successfully rolled into threads without crumbling. For example, if at least a two inch length of 1/8-inch thread can be held on one end without tearing, the soil is cohesive.

Dry Strength
If the soil is dry and crumbles on its own or with moderate pressure into individual grains or fine powder, it is granular (any combination of gravel, sand, or silt). If the soil is dry and falls into clumps which break up into smaller clumps, but the smaller clumps can only be broken up with difficulty, it may be clay in any combination with gravel, sand or silt. If the dry soil breaks into clumps which do not break up into small clumps and which can only be broken with difficulty, and there is no visual indication the soil is fissured, the soil may be considered unfissured.

Thumb Penetration
The thumb penetration test can be used to estimate the unconfined compressive strength of cohesive soils. Type A soils with an unconfined compressive strength of 1.5 tons per square foot can be readily indented by the thumb; however, they can be penetrated by the thumb only with very great effort. Type C soils with an unconfined compressive strength of 0.5 tons
per square foot can be easily penetrated several in. by the thumb, and can be molded by light finger pressure.

This test should be conducted on an undisturbed soil sample, such as a large clump of spoil, as soon as practicable after excavation to keep to a minimum the effects of exposure to drying influences. If the excavation is later exposed to wetting influences (rain, flooding), the classification of the soil must be changed accordingly.

Other Strength Tests
Estimates of unconfined compressive strength of soils can also be obtained by use of a pocket penetrometer or by using a hand-operated shearvane.

Drying Test
The basic purpose of the drying test is to differentiate between cohesive material with fissures, unfissured cohesive material, and granular material. The procedure for the drying test involves drying a sample of soil that is approximately one inch thick and six in. in. diameter until it is thoroughly dry:

If the sample develops cracks as it dries, significant fissures are indicated.

Samples that dry without cracking are to be broken by hand. If considerable force is necessary to break a sample, the soil has significant cohesive material content. The soil can be classified as a unfissured cohesive material and the unconfined compressive strength should be determined.

If a sample breaks easily by hand, it is either a fissured cohesive material or a granular material. To distinguish between the two, pulverize the dried clumps of the sample by hand or by stepping on them. If the clumps do not pulverize easily, the material is cohesive with fissures. If they pulverize easily into very small fragments, the material is granular.

e. Describe the unified soil classification system.

Table 13 is taken from the American Society for Testing and Materials, ASTM D2488-9a, Standard Practice for Description and Identification of Soils.
Table 13. Unified soil classification system

<table>
<thead>
<tr>
<th>MAJOR DIVISION</th>
<th>GROUP SYMBOL</th>
<th>LETTER SYMBOL</th>
<th>GROUP NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRAVEL AND GRAVELY SOILS MORE THAN 50% OF COARSE FRACTION RETAINED ON NO. 4 SIEVE</td>
<td>GRAVEL WITH ≥ 15% FINES</td>
<td>GM</td>
<td>Silty GRAVEL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SC</td>
<td>Clayey GRAVEL</td>
</tr>
<tr>
<td></td>
<td>SAND WITH ≥ 15% FINES</td>
<td>SW</td>
<td>Well-graded SAND</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SP</td>
<td>Poorly graded SAND</td>
</tr>
<tr>
<td></td>
<td>SAND WITH &lt; 15% FINES</td>
<td>SW-SM</td>
<td>Well-graded SAND with silt</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SW-SC</td>
<td>Well-graded SAND with clay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SP-SM</td>
<td>Poorly graded SAND with silt</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SP-SC</td>
<td>Poorly graded SAND with clay</td>
</tr>
<tr>
<td>FINE GRAINED SOILS CONTAINS MORE THAN 50% FINES</td>
<td>SILT AND CLAY</td>
<td>ML</td>
<td>Inorganic SILT with low plasticity</td>
</tr>
<tr>
<td></td>
<td>LIQUID LIMIT LESS THAN 50%</td>
<td>CL</td>
<td>Lean inorganic CLAY with low plasticity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OL</td>
<td>Organic SILT with low plasticity</td>
</tr>
<tr>
<td></td>
<td>LIQUID LIMIT GREATER THAN 50%</td>
<td>MH</td>
<td>Elastic inorganic SILT with moderate to high plasticity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CH</td>
<td>Fat inorganic CLAY with moderate to high plasticity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OH</td>
<td>Organic SILT or CLAY with moderate to high plasticity</td>
</tr>
<tr>
<td></td>
<td>HIGHLY ORGANIC SOILS</td>
<td>PT</td>
<td>PEAT soils with high organic contents</td>
</tr>
</tbody>
</table>

NOTES

Sample descriptions are based on visual field and laboratory observations using classification methods of ASTM D2488. Where laboratory data are available, classifications are in accordance with ASTM D2487, Standard Practice for Classification of Soils for Engineering Purposes.

Solid lines between soil descriptions indicate change in interpreted geologic unit. Dashed lines indicate stratigraphic change within the unit.

Fines are material passing the U.S. Std. #200 Sieve.

Source: American Society for Testing and Materials, ASTM D2488-9a
f. Discuss the applicability of active, passive, and at-rest pressures to earth retaining structures.

The following discussions are taken from the U.S. Department of Transportation, *Geotechnical Engineering Circular No.4, Ground Anchors and Anchored Systems*.

**Active and Passive Pressures**

Active and passive horizontal earth pressures may be considered in terms of limiting horizontal stresses within the soil mass, and, for purposes of this discussion, a smooth (i.e., zero wall friction) wall retaining ground with a horizontal backslope is considered (figure 28); this case defines Rankine conditions. Consider an element of soil in the ground under a vertical effective stress, $\sigma_v$ (figure 29). In considering the potential movements of a retaining wall, the element may be brought to failure in two distinct ways that are fundamentally important in the context of retaining wall design. The horizontal soil stress may be increased until the soil element fails at B, when the stress reaches its maximum value $\sigma_h^{\text{max}}$. This scenario will occur when significant outward movement of the wall increases the lateral earth pressure in the soil at the base of the wall (see figure 28).

Similarly, the horizontal stress may be reduced until failure at A, when the stress reaches its minimum value $\sigma_h^{\text{min}}$. This scenario models the outward movement which reduces the lateral earth pressures behind the wall (see figure 28).

![Figure 28. Mobilization of Rankine active and passive horizontal pressures](image-url)
Source: U.S. Department of Transportation, *Geotechnical Engineering Circular No.4, Ground Anchors and Anchored Systems*

**Figure 29.** Limiting active and passive horizontal pressures

The geometry of figure 15 gives the following two relationships:

\[
\frac{\sigma_{h\min}'}{\sigma'_v} = K_A = \frac{1 - \sin \phi'}{1 + \sin \phi'} = \tan^2 (45 - \phi'/2)
\]

\[
\frac{\sigma_{h\max}'}{\sigma'_v} = K_P = \frac{1 + \sin \phi'}{1 - \sin \phi'} = \tan^2 (45 + \phi'/2)
\]

where \(K_A\) is the active earth pressure coefficient and \(K_P\) is the passive earth pressure coefficient. The definitions of \(K_A\) and \(K_P\) are consistent with a Rankine analysis for a cohesionless (i.e., \(c=0\)) retained soil.

For a cohesive soil defined by effective stress strength parameters \(\phi'\) and \(c'\), the active and passive earth pressure coefficients are:

\[
K_A = \tan^2 (45 - \phi'/2) - \frac{2c'}{\sigma_v} \tan (45 - \phi'/2)
\]

\[
K_P = \tan^2 (45 + \phi'/2) + \frac{2c'}{\sigma_v} \tan (45 + \phi'/2)
\]
For the undrained case with $\phi = 0$ and $c = S_u$, the total stress active and passive earth pressure coefficients are:

$$K_{AT} = 1 - \frac{2S_u}{\sigma_v}$$

$$K_{PT} = 1 + \frac{2S_u}{\sigma_v}$$

where $\sigma_v$ is the total vertical stress.

*At-Rest Pressure*

Sand or clay, normally consolidated in the ground under the natural condition of no lateral deformation and under an incremental application of vertical load, experience a condition referenced as the earth pressure at rest. The value of the coefficient of the earth pressure at rest, $K_o$, is found to be in close agreement with the empirical equation:

$$K_o = \frac{\sigma_h}{\sigma_v} = 1 - \sin \phi'$$

For normally consolidated clay, $K_o$ is typically in the range of 0.55 to 0.65; for sands, the typical range is 0.4 to 0.5. For lightly overconsolidated clays, $K_o$ may reach a value up to 1; for heavily overconsolidated clays, $K_o$ values may range up to or greater than 2.

In the context of anchored wall design using steel soldier beams or sheet-pile wall elements, design earth pressures based on at-rest conditions are not typically used. Using at-rest earth pressures implicitly assumes that the wall system undergoes no lateral deformation. This condition may be appropriate for use in designing heavily preloaded, stiff wall systems, but designing to this stringent (i.e., zero wall movement) requirement for flexible anchored wall systems for highway applications is not practical.

18. Construction management personnel shall demonstrate a familiarity level knowledge of the basic concepts of hydrology.

a. Define hydrology as it applies to construction management and engineering.

The following is taken from U.S. Geological Society, Hydrology Primer.

Hydrology is the science that encompasses the occurrence, distribution, movement and properties of the waters of the earth and their relationship with the environment within each phase of the hydrologic cycle. The hydrologic cycle is a continuous process by which water is purified by evaporation and transported from the earth's surface (including the oceans) to the atmosphere and back to the land and oceans. All of the physical, chemical and biological processes involving water as it travels its various paths in the atmosphere, over and beneath the earth's surface and through growing plants, are of interest to those who study the hydrologic cycle. There are many pathways the water may take in its continuous cycle of
falling as rainfall or snowfall and returning to the atmosphere. It may be captured for millions of years in polar ice caps. It may flow to rivers and finally to the sea. It may soak into the soil to be evaporated directly from the soil surface as it dries or be transpired by growing plants. It may percolate through the soil to groundwater reservoirs (aquifers) to be stored or it may flow to wells or springs or back to streams by seepage. They cycle for water may be short, or it may take millions of years. People tap the water cycle for their own uses. Water is diverted temporarily from one part of the cycle by pumping it from the ground or drawing it from a river or lake. It is used for a variety of activities such as households, businesses and industries; for irrigation of farms and parklands; and for production of electric power. After use, water is returned to another part of the cycle: perhaps discharged downstream or allowed to soak into the ground. Used water normally is lower in quality, even after treatment, which often poses a problem for downstream users. The hydrologist studies the fundamental transport processes to be able to describe the quantity and quality of water as it moves through the cycle (evaporation, precipitation, streamflow, infiltration, groundwater flow, and other components). The engineering hydrologist, or water resources engineer, is involved in the planning, analysis, design, construction and operation of projects for the control, utilization, and management of water resources. Water resources problems are also the concern of meteorologists, oceanographers, geologists, chemists, physicists, biologists, economists, political scientists, specialists in applied mathematics and computer science, and engineers in several fields.

Hydrologists apply scientific knowledge and mathematical principles to solve water-related problems in society: problems of quantity, quality and availability. They may be concerned with finding water supplies for cities or irrigated farms, or controlling river flooding or soil erosion. Or, they may work in environmental protection: preventing or cleaning up pollution or locating sites for safe disposal of hazardous wastes. Persons trained in hydrology may have a wide variety of job titles. Some specialize in the study of water in just one part of the hydrologic cycle: hydro meteorologists (atmosphere); glaciologists (glaciers); geomorphologic (landforms); geochemists (groundwater quality); and hydro geologists (groundwater). Engineers who study hydrology include those in agricultural, civil, environmental, hydraulic, irrigation and sanitary engineering. Scientists and engineers in hydrology may be involved in both field investigations and office work. In the field, they may collect basic data, oversee testing of water quality, direct field crews and work with equipment. Many jobs require travel, some abroad. A hydrologist may spend considerable time doing field work in remote and rugged terrain. In the office, hydrologists do many things such as interpreting hydrologic data and performing analyses for determining possible water supplies. Much of their work relies on computers for organizing, summarizing and analyzing masses of data, and for modeling studies such as the prediction of flooding and the consequences of reservoir releases or the effect of leaking underground oil storage tanks. The work of hydrologists is as varied as the uses of water and may range from planning multimillion dollar interstate water projects to advising homeowners about backyard drainage problems.

b. **Describe the flow of subsurface groundwater.**

The following is taken from U.S.Geological Society, Hydrology Primer.
Groundwater, pumped from beneath the earth's surface, is often cheaper, more convenient and less vulnerable to pollution than surface water. Therefore, it is commonly used for public water supplies. Groundwater provides the largest source of usable water storage in the United States. Underground reservoirs contain far more water than the capacity of all surface reservoirs and lakes, including the Great Lakes. In some areas, groundwater may be the only option. Some municipalities survive solely on groundwater.

Hydrologists estimate the volume of water stored underground by measuring water levels in local wells and by examining geologic records from well-drilling to determine the extent, depth and thickness of water-bearing sediments and rocks. Before an investment is made in full-sized wells, hydrologists may supervise the drilling of test wells. They note the depths at which water is encountered and collect samples of soils, rock and water for laboratory analyses. They may run a variety of geophysical tests on the completed hole, keeping and accurate log of their observations and test results. Hydrologists determine the most efficient pumping rate by monitoring the extent that water levels drop in the pumped well and in its nearest neighbors. Pumping the well too fast could cause it to go dry or could interfere with neighboring wells. Along the coast, over pumping can cause saltwater intrusion. By plotting and analyzing these data, hydrologists can estimate the maximum and optimum yields of the well.

Polluted groundwater is less visible, but more insidious and difficult to clean up, than pollution in rivers and lakes. Groundwater pollution most often results from improper disposal of wastes on land. Major sources include industrial and household chemicals and garbage landfills, industrial waste lagoons, tailings and process wastewater from mines, oil field brine pits, leaking underground oil storage tanks and pipelines, sewage sludge and septic systems. Hydrologists provide guidance in the location of monitoring wells around waste disposal sites and sample them at regular intervals to determine if undesirable leachate-contaminated water containing toxic or hazardous chemicals--is reaching the groundwater. In polluted areas, hydrologists may collect soil and water samples to identify the type and extent of contamination. The chemical data then are plotted on a map to show the size and direction of waste movement. In complex situations, computer modeling of water flow and waste migration provides guidance for a clean-up program. In extreme cases, remedial actions may require excavation of the polluted soil. Today, most people and industries realize that the amount of money invested in prevention is far less than that of cleanup. Hydrologists often are consulted for selection of proper sites for new waste disposal facilities. The danger of pollution is minimized by locating wells in areas of deep groundwater and impermeable soils. Other practices include lining the bottom of a landfill with watertight materials, collecting any leachate with drains, and keeping the landfill surface covered as much as possible. Careful monitoring is always necessary.

19. Construction management personnel shall demonstrate a familiarity level knowledge of DOE’s design and construction processes.

a. Discuss the following elements of the Department design process:
   - Congressional project approval process
   - Actual preparation of a conceptual design report
   - Architect/engineer selection process
Design approval process

Congressional Project Approval Process
The following is taken from U.S. Code Title 40, subtitle II, part A, chapter 33, section 3307, Congressional Approval of Proposed Contracts.

Resolutions Required Before Appropriations May Be Made—The following appropriations may be made only if the Committee on Environment and Public Works of the Senate and the Committee on Transportation and Infrastructure of the House of Representatives adopt resolutions approving the purpose for which the appropriation is made:

- An appropriation to construct, alter, or acquire any building to be used as a public building which involves a total expenditure in excess of $1,500,000, so that the equitable distribution of public buildings throughout the United States with due regard for the comparative urgency of need for the buildings is ensured.
- An appropriation to lease any space at an average annual rental in excess of $1,500,000 for use for public purposes.
- An appropriation to alter any building, or part of the building, which is under lease by the Federal government for use for a public purpose if the cost of the alteration will exceed $750,000.

Transmission to Congress of Prospectus of Proposed Project—To secure consideration for the approval, the Administrator of General Services shall transmit to Congress a prospectus of the proposed facility, including:

- a brief description of the building to be constructed, altered, or acquired, or the space to be leased, under this chapter;
- the location of the building or space to be leased and an estimate of the maximum cost to the Government of the facility to be constructed, altered, or acquired, or the space to be leased;
- a comprehensive plan for providing space for all Government officers and employees in the locality of the proposed facility or the space to be leased, having due regard for suitable space which may continue to be available in existing Government-owned or occupied buildings, especially those buildings that enhance the architectural, historical, social, cultural, and economic environment of the locality;
- with respect to any project for the construction, alteration, or acquisition of any building, a statement by the Administrator that suitable space owned by the Government is not available and that suitable rental space is not available at a price commensurate with that to be afforded through the proposed action;
- a statement by the Administrator of the economic and other justifications for not acquiring a building identified to the Administrator under section 3303 (c) of this title as suitable for the public building needs of the Government;
- a statement of rents and other housing costs currently being paid by the Government for federal agencies to be housed in the building to be constructed, altered, or acquired, or the space to be leased; and
- with respect to any prospectus for the construction, alteration, or acquisition of any building or space to be leased, an estimate of the future energy performance of the building or space and a specific description of the use of energy efficient and
renewable energy systems, including photovoltaic systems, in carrying out the project.

**Actual Preparation of a Conceptual Design Report**
The following is taken from DOE O 413.3A.

Following approval of critical decision-0, Approval of Mission Need, the project team will commence development of the alternative strategies that will satisfy the mission requirements identified in the program.

These alternative strategies will culminate in the proposed path forward for the project, the conceptual design. The activities that support the development of the conceptual design are funded through the program office and these costs will eventually be collected and included in the project’s total project cost. Title 50 U.S. Code for projects authorized by annual National Defense Authorization Acts requires that any time during the development of the conceptual design or the conceptual design report the cost will exceed the $3M notification threshold, Congress must be officially notified. Until the approval of critical decision-1, approval of preliminary baseline range, there is no capital funding authorized for the project, i.e., all funds expended will be program funds. In view of the Congressional notification requirement, the project must keep track of the costs that are allowed for the conceptual design.

As a minimum, the conceptual design should develop the following: the scope required to satisfy the program mission requirements, the project feasibility and attainment of specified performance levels, reliable cost and schedule range estimates, project criteria and design parameters, and identification of requirements and features.

**Architect/Engineer Selection Process**
The following is taken from 48 CFR 936.602-70, “DOE Selection Criteria.”

Contracting officers or architect-engineer evaluation boards shall apply the evaluation criteria contained in 48 CFR 936.602-70, as appropriate, and any special criteria developed for individual selections. When special and additional criteria are to be used, they shall be set forth in a public announcement and a written justification for their use shall be placed in the DOE file maintained for the project.

General qualifications, including:
- reputation and standing of the firm and its principal members;
- experience and technical competence of the firm in comparable work;
- past record in performing work for DOE, other government agencies, and private industry, including projects or contracts implemented with no overruns; performance from the standpoint of cost including cost overruns (last 5 years); the nature, extent, and effectiveness of contractor’s cost reduction program; quality of work; and ability to meet schedules, including schedule overruns (last 5 years) (where applicable);
- the volume of past and present workloads;
- interest of company management in the project and expected participation and contribution of top officials;
• adequacy of central or branch office facilities for the proposed work, including facilities for any special services that may be required;
• geographic location of the home office and familiarity with the locality in which the project is located;

In addition to these requirements, consider the architect-engineer firm’s experience in energy efficiency, pollution prevention, waste reduction, and the use of recovered and environmentally preferable materials and other criteria at 48 CFR 36.602–1, “Selection Criteria.”

**Design Approval Process**
The following is taken from DOE G 413.3-1.

The department’s directives contain multiple requirements and recommendations pertaining to project reviews, two of which are specifically aimed at ensuring that the design outputs satisfy project requirements. They are:

• Beginning at continuing decision-1 and continuing through the life of the project, as appropriate, design reviews are performed by individuals external to the project to determine if a product (drawings, analysis, or specifications) is correct and will perform its intended functions and meet requirements. Design reviews must be conducted for all projects and must involve a formalized, structured approach to ensure the reviews are comprehensive, objective, and documented;
• Design verification is a documented process for ensuring that the design and the resulting items will comply with the project requirements. Design verification should be performed by technically knowledgeable persons separate from those who performed the design.

Other DOE O 413.3A requirements that touch on the subject without specifically indicating that reviews should verify that the design satisfies the requirements are:

• The integrated project team reviews and comments on project deliverables (e.g., drawings, specifications, procurement, and construction packages);
• Contractors performing design for project must at a minimum conduct a preliminary and final design review, in accordance with the project execution plan. For nuclear projects, the design review will include a focus on safety and security systems.

DOE O 413.3A also specifies that the Acquisition Executive designates the design authority for the project at critical decision 1. The design authority (aka the engineering technical authority) is the individual who formally signs off on the design drawings, calculations, and specifications. The design authority is typically not a DOE employee or official. This role and responsibility for assuring the technical adequacy of the design is normally delegated to the management and operating contractor.

**b. Discuss the Department’s construction process following a project’s certification for construction. Include in the discussion the difference between direct hire and indirect hire construction contracts, and the role of Department construction management and engineering personnel in the construction process.**

The following is taken from U.S. Department of Defense, DoD 1400.25M.
**Direct Hires**

In the case of direct hires, the responsibility for recruitment should be vested in the construction contractors. However, the agreement may provide for assistance from DOE through its existing facilities. This can take the form of DOE’s assistance in obtaining qualified applicants and referring them to the contractor for selection. In such cases, the contractor keeps the management right to decide the number of employees needed and to accept or reject any applicant so referred for a position.

**Indirect hires**

DOE through its existing facilities, is responsible for recruiting construction workers. DOE refers qualified applicants to the contractor for selection. The contractors have the right to accept or reject any applicant so referred. Additionally, the contractor should be permitted, with DOE’s consent, to recruit qualified personnel.

20. **Construction management personnel shall demonstrate a familiarity level knowledge of basic electrical equipment.**

a. **Discuss the basic purpose of a transformer.**

The following is taken from U.S. Department of the Interior, *Transformer: Basics, Maintenance, and Diagnostics*.

A transformer has no internal moving parts, and it transfers energy from one circuit to another by electromagnetic induction. External cooling may include heat exchangers, radiators, fans, and oil pumps.

Radiators and fans are evident in figure 30. The large horizontal tank at the top is a conservator. Transformers are typically used because a change in voltage is needed. Power transformers are defined as transformers rated 500 kVA and larger.

![Figure 30. Typical generator step-up transformer](image)

Larger transformers are oil-filled for insulation and cooling; a typical generator step-up transformer may contain several thousand gallons of oil. One must always be aware of the possibility of spills, leaks, fires, and environmental risks this oil poses.

Source: U.S. Department of the Interior, *Transformer: Basics, Maintenance, and Diagnostics*
Transformers smaller than 500 kVA are generally called distribution transformers. Pole-top and small, pad-mounted transformers that serve residences and small businesses are typically distribution transformers. Generator step-up transformers, used in reclamation power plants, receive electrical energy at generator voltage and increase it to a higher voltage for transmission lines.

Conversely, a step-down transformer receives energy at a higher voltage and delivers it at a lower voltage for distribution to various loads.

**b. Discuss the applications of alternating current (AC) and direct current (DC) generators and motors on a construction project.**

**AC Generators**
According to the Northern Tool and Equipment Generator Buyer’s Guide, portable AC generators can be put to work on construction sites that have no electrical service to provide clean, reliable power to operate saws, drills, air compressors, heaters, paint sprayers and other AC-powered tools.

**DC Generators**
According to *Electric Power Systems Technology* by Stephen Fardo, DC generator use has declined rapidly since the development of the low-cost silicon rectifier. However, DC there are still certain applications where DC generators are used such as large earth-moving equipment on a construction site.

**AC Motors**

AC motors are widely used to drive machinery for a wide variety of applications. The principle of operation for all AC motors relies on the interaction of a revolving magnetic field created in the stator by AC current, with an opposing magnetic field either induced on the rotor or provided by a separate DC current source. The resulting interaction produces usable torque, which can be coupled to desired loads throughout the facility in a convenient manner.

**DC Motors**
The following is taken from the Electric Motors Reference Center, DC Motors.

Industrial applications use DC motors because the speed-torque relationship can be varied to almost any useful form for DC motor and regeneration applications in either direction of rotation. Continuous operation of DC motors is commonly available over a speed range of 8:1. Infinite range (smooth control down to zero speed) for short durations or reduced load is also common.

DC motors are often applied where they momentarily deliver three or more times their rated torque. In emergency situations, DC motors can supply over five times rated torque without stalling (power supply permitting).
Dynamic braking or regenerative braking can be obtained with DC motors on applications requiring quick stops, thus eliminating the need for, or reducing the size of, a mechanical brake.

DC motors feature a speed, which can be controlled smoothly down to zero, immediately followed by acceleration in the opposite direction -- without power circuit switching. And DC motors respond quickly to changes in control signals due to the DC motor’s high ratio of torque to inertia.

c. Discuss application of the following as backup power supplies:
   - Uninterrupted power supply (UPS) inverters
   - Diesel generators
   - Motor generators
   - Auto transfer switches

**UPS Inverters**

The following is taken from Digital Transmission Systems, *Technical Specifications for the Supply of an Uninterruptible Power System Composed of Three-Phase Modules in Parallel Configuration*.

The UPS inverter design enables the tolerances of different output parameters (i.e., voltage, distortion rates, frequency) to be maintained. Each inverter consists of a three-phase frequency converter fitted with

- A power converter bridge with insulated gate bipolar-type transistors
- A parallel series filter
- Control and command electronics

The operating principle is based on pulse width modulation. The oscillator provides the frequency reference and is synchronized with the main’s frequency when this is within tolerance. It operates autonomously when the main is out of tolerance or absent.

It is also possible to desynchronize its operating when, for example, the UPS supply is provided by a generator set, the stability of which is incompatible with the load requirements. In cases of sharp current build, and before the inverter voltage exceeds its tolerance, the load is transferred to the mains without interruption (automatic by-pass). Once returned to a normal state, the load is automatically supplied by the inverters. In the case of a non-discriminated short-circuit, the inverters must be shut off by their electronic protection without any deterioration. After the inverter has stopped after full battery discharge, the UPS will restart automatically when the mains supply is restored.
**Diesel Generators**

The following is taken from Diesel Generator Engine.

Diesel generator engines are basically designed to meet the power requirements of small- and medium-sized companies and heavy usage needs for larger industries. The generator is an innovative product which brings affordable and clean standby power that can be easily accessed by millions of industries, small businesses, and homes. The easy installation of generators and the reduced cost of back up power have made generators in demand from different areas of usage. There are a number of modern diesel generator engines that are specifically engineered to fulfill emergency power requirements. These types of units constantly monitor the electrical current, and they automatically start up when the power is interrupted or is shut off. There are some specific high-power diesel generator engines that can supply emergency power to all the important and selected loads during a critical process of the industries. These power units are used in almost all types of industries and commercial sectors, whether big or small, which have uninterrupted power requirements, and these needs are fulfilled through this backup diesel generator engine.

**Motor Generators**

The following is taken from Encyclopedia Britannica, Motor Generator.

A motor generator is an electric motor coupled to an electric generator to convert electric power from one from to another. The motor operates from the available electric power source, and the generator provides power of the characteristics desired for the load. For example, a set may be designed to convert commercially available alternating current to direct current, as in some welding applications; or it may provide high-frequency alternating current power for induction heating. Such a combination has been termed a dynamotor. In some sets, there may be more than one coupled generator. Motor generator is also used to denote an electric generator and a driving motor, such as a gasoline or diesel engine.

**Auto Transfer Switches**

The following is taken from DOE-HDBK-1013/2-02.

The transfer switch has five positions that alter the mode of operation. The indication is provided by a deviation meter.

AUTO. This is the normal position of the transfer switch. It places the controller in the automatic mode of operation. Also, the deviation meter indicates any deviation between controlled variable and setpoint.

0 - 100 (AUTO side). In this position, the controller is still in automatic mode. However, the deviation meter now indicates the approximate value of the controlled variable. The deviation meter deflects full down for zero variable value, and full up for 100 percent variable value.

MAN. This position places the controller in the manual mode of operation. Controller output is now varied by adjusting the manual output adjust knob. This adjustment is indicated on the output meter. The deviation meter indicates any deviation between controlled variable and setpoint.
0 - 100 (MAN side). The controller is still in the manual mode of operation, and the deviation meter indicates controlled variable value as it did in the 0-100 (AUTO side) position.

BAL. In many cases, controller output signals of the automatic mode and manual mode may not be the same. If the controller were directly transferred from automatic to manual or manual to automatic, the controller output signal could suddenly change from one value to another. As a result, the final control element would experience a sudden change in position or bump. This can cause large swings in the value of the process variable and possible damage to the final control element.

d. Discuss the types and function of electrical switchgear used on a construction project.

The following is taken from Institute of Electrical and Electronics Engineers (IEEE) Std. 141-1993.

“Switchgear” is a general term that describes switching and interrupting devices, either alone or in combination with other associated control, metering, protective, and regulating equipment, which are assembled in one or more sections.

A power switchgear assembly consists of a complete assembly of one or more of the above noted devices and main bus conductors, interconnecting wiring, accessories, supporting structures, and enclosure. Power switchgear is applied throughout the electric power system of an industrial plant, but is principally used for incoming line service and to control and protect load centers, motors, transformers, motor control centers, panelboards, and other secondary distribution equipment.

Outdoor switchgear assemblies can be of the non-walk-in or walk-in variety. Switchgear for industrial plants is generally located indoors for easier maintenance, avoidance of weather problems, and shorter runs of feeder cable or bus duct. In outdoor applications the effect of external influences, principally the sun, wind, moisture, and local ambient temperatures, should be considered in determining the suitability and current-carrying capacity of the switchgear.

In many locations, the use of lighter colored (non-metallic) paints will minimize the effect of solar energy loading so as to avoid derating of the equipment in outdoor locations.

Classifications
An open switchgear assembly is one that does not have an enclosure as part of the supporting structure. Since open switchgear assemblies are rarely used in industrial installations, consideration will be given to metal-enclosed assemblies only.

An enclosed switchgear assembly consists of a metal-enclosed supporting structure with the switchgear enclosed on the top and all sides with sheet metal. Access within the enclosure is provided by doors or removable panels.
Metal-enclosed switchgear is universally used throughout industry for utilization and primary distribution voltage service, for AC and DC applications, and for indoor and outdoor locations.

Types of Metal-Enclosed Switchgear
Specific types of metal-enclosed switchgear used in industrial plants are defined as (1) metal clad switchgear, (2) low-voltage power circuit breaker switchgear, and (3) interrupter switchgear. The metal-enclosed bus will also be discussed because it is frequently used in conjunction with power switchgear in modern industrial power systems.

Metal-clad switchgear is metal-enclosed power switchgear characterized by the following necessary features:

- The main circuit switching and interrupting device is of the removable type arranged with a mechanism for moving it physically between connected and disconnected positions, and equipped with self-aligning and self-coupling primary and secondary disconnecting devices.
- Major parts of the primary circuit, such as the circuit switching or interrupting devices, buses, potential transformers, and control power transformers, are enclosed by grounded metal barriers. Specifically included is an inner barrier in front of, or as a part of, the circuit interrupting device to ensure that no energized primary circuit components are exposed when the unit door is opened.
- All live parts are enclosed within grounded metal compartments. Automatic shutters prevent exposure of primary circuit elements when the removable element is in the test, disconnected, or fully withdrawn position.
- Primary bus conductors and connections are covered with insulating material throughout. For special configurations, insulated barriers between phases and between phase and ground may be specified.
- Mechanical interlocks are provided to ensure a proper and safe operating sequence.
- Instruments, meters, relays, secondary control devices, and their wiring are isolated by grounded metal barriers from all primary circuit elements, with the exception of short lengths of wire associated with instrument transformer terminals.
- The door through which the circuit-interrupting device is inserted into the housing may serve as an instrument or relay panel and may also provide access to a secondary or control compartment within the housing.

Auxiliary frames may be required for mounting associated auxiliary equipment, such as potential transformers, control power transformers, etc.

All metal-clad switchgear is metal-enclosed, but not all metal-enclosed switchgear can be correctly designated as metal-clad.

Low-Voltage Power Circuit Breaker Switchgear
Metal-enclosed power circuit breaker switchgear of 1000 V and below is metal-enclosed power switchgear, including the following equipment as required:

- Power circuit breakers of 1000 V and below (fused or unfused)
- Non-insulated bus and connections (insulated and isolated bus is available)
- Instrument and control power transformers
- Instruments, meters, and relays
- Control wiring and accessory devices
- Cable and busway termination facilities
- Shutters to automatically cover line-side contacts when the circuit breaker is withdrawn

The power circuit breakers of 1000 V and below are contained in individual grounded metal compartments and controlled either remotely or from the front of the panels. The circuit breakers are usually of the drawout type, but may be stationary (fixed or plug-in). When drawout-type circuit breakers are used, mechanical interlocks must be provided to ensure a proper and safe operating sequence.

Interrupter Switchgear
Metal-enclosed interrupter switchgear is metal-enclosed power switchgear, including the following equipment as required:
- Interrupter switches or circuit switchers
- Power fuses (if required)
- Non-insulated bus and connections
- Instrument and control power transformers
- Control wiring and accessory devices

The interrupter switches and power fuses may be of the stationary or removable type. For the removable type, mechanical interlocks are provided to ensure a proper and safe operating sequence.

e. Identify and discuss the application of the different types of circuit breakers.

The following is taken from DOE-HDBK-1011/4-92.

The purpose of a circuit breaker is to break the circuit and stop the current flow when the current exceeds a predetermined value without causing damage to the circuit or the circuit breaker.

Circuit breakers are commonly used in place of fuses and sometimes eliminate the need for a switch. A circuit breaker differs from a fuse in that it trips to break the circuit and may be reset, while a fuse melts and must be replaced.

Air circuit breakers (ACBs) are breakers where the interruption of the breaker contacts takes place in an air environment. Oil circuit breakers use oil to quench the arc when the breaker contacts open.

Low-Voltage ACBs
A low-voltage ACB is one which is suited for circuits rated at 600 volts or lower. One of the most commonly used low-voltage ACBs is the molded case circuit breaker.

A cutaway view of the molded case circuit breaker is shown in figure 31.
A circuit can be connected or disconnected using a circuit breaker by manually moving the operating handle to the on or off position. All breakers, with the exception of very small ones, have a linkage between the operating handle and contacts that allows a quick make (quick break contact action) regardless of how fast the operating handle is moved. The handle is also designed so that it cannot be held shut on a short-circuit or overload condition. If the circuit breaker opens under one of these conditions, the handle will go to the trip-free position. The trip-free position is midway between the on and off positions and cannot be re-shut until the handle is pushed to the off position and reset.

A circuit breaker will automatically trip when the current through it exceeds a predetermined value. In lower current ratings, automatic tripping of the circuit breaker is accomplished by use of thermal tripping devices. Thermal trip elements consist of a bimetallic element that can be calibrated so that the heat from normal current through it does not cause it to deflect. An abnormally high current, which could be caused by a short-circuit or overload condition, will cause the element to deflect and trip the linkage that holds the circuit breaker shut. The circuit breaker will then be opened by spring action. This bimetallic element, which is responsive to the heat produced by current flowing through it, has an inverse-time characteristic. If an extremely high current is developed, the circuit breaker will be tripped very rapidly.

For moderate overload currents, it will operate more slowly. Molded case breakers with much larger current ratings also have a magnetic trip element to supplement the thermal trip element. The magnetic unit utilizes the magnetic force that surrounds the conductor to operate the circuit breaker tripping linkage.
When the separable contacts of an air circuit breaker are opened, an arc develops between the two contacts. Different manufacturers use many designs and arrangements of contacts and their surrounding chambers. The most common design places the moving contacts inside of an arc chute. The construction of this arc chute allows the arc formed as the contacts open to draw out into the arc chute. When the arc is drawn into the arc chute, it is divided into small segments and quenched. This action extinguishes the arc rapidly, which minimizes the chance of a fire and also minimizes damage to the breaker contacts.

Molded case circuit breakers come in a wide range of sizes and current ratings. There are six frame sizes available: 100, 225, 400, 600, 800, and 2,000 amps. The size, contact rating, and current-interrupting ratings are the same for all circuit breakers of a given frame size. The continuous current rating of a breaker is governed by the trip element rating. The range of voltage available is from 120 to 600 volts, and interrupting capacity ranges as high as 100,000 amps.

Much larger air circuit breakers are used in large commercial and industrial distribution systems. These circuit breakers are available in much higher continuous current and interrupting ratings than the molded case circuit breaker. Breakers of this type have current ratings as high as 4,000 amps, and interrupting ratings as high as 150,000 amps.

Most large air circuit breakers use a closing device, known as a stored energy mechanism, for fast, positive closing action. Energy is stored by compressing large powerful coil springs that are attached to the contact assembly of a circuit breaker. Once these springs are compressed, the latch may be operated to release the springs, and spring pressure will shut the circuit breaker.

Circuit breaker closing springs may be compressed manually or by means of a small electric motor. This type of circuit breaker can be classified as either a manually or electrically operated circuit breaker.

When a large air circuit breaker is closed, the operating mechanism is latched. As the circuit breaker is closed, a set of tripping springs or coils are compressed, and the circuit breaker may then be tripped by means of a trip latch. The trip latch mechanism may be operated either manually or remotely by means of a solenoid trip coil.

Circuit breakers may be operated either manually or electrically. Electrically operated circuit breakers are used when circuit breakers are to be operated at frequent intervals or when remote operation is required.

21. Construction management personnel shall demonstrate a familiarity level knowledge of basic electrical equipment operation.

a. Discuss the various types of batteries used in electrical systems. Include the following elements of battery operation in the discussion:
   - Capacity
   - Voltage applications
   - Battery life expectancy
   - Environmental requirements for safe battery operation
Capacity

Current Capacity

The following is taken from George Washington University, School of Engineering and Applied Sciences, Current Carrying Capacity of Copper Conductors.

Current carrying capacity is defined as the amperage a conductor can carry before melting either the conductor or the insulation.

Heat, caused by an electrical current flowing through a conductor, will determine the amount of current a wire will handle. Theoretically, the amount of current that can be passed through a single bare copper wire can be increased until the heat generated reaches the melting temperature of the copper.

Amp-Hour Capacity

The following is taken from All About Circuits, Battery Ratings.

A battery with a capacity of 1 ampere-hour (Ah) should be able to continuously supply a current of 1 A to a load for exactly 1 hour, or 2 A for 1/2 hour, or 1/3 amp for 3 hours, etc., before becoming completely discharged. In an ideal battery, this relationship between continuous current and discharge time is stable and absolute, but real batteries don’t behave exactly as this simple linear formula would indicate. Therefore, when amp-hour capacity is given for a battery, it is specified at either a given current, given time, or assumed to be rated for a time period of 8 hours (if no limiting factor is given).

For example, an average automotive battery might have a capacity of about 70 Ah, specified at a current of 3.5 A. This means that the amount of time this battery could continuously supply a current of 3.5 A to a load would be 20 hours (70 Ah/3.5 A). But if a lower-resistance load were connected to that battery, drawing 70 A continuously, the battery should hold out for exactly 1 hour (70 Ah/70 A), but this might not be true in real life. With higher currents, the battery will dissipate more heat across its internal resistance, which has the effect of altering the chemical reactions taking place within. Chances are, the battery would fully discharge some time before the calculated time of 1 hour under this greater load.

Voltage Applications

The following is taken from Transtronics, Sealed Lead Acid Battery Applications.

Battery Voltage

There is much confusion about battery voltage because a battery has more than one voltage and often the literature is lax in defining which voltage is being discussed at the time. Also, measurements of a battery’s voltage, particularly float voltage, require time for the battery to stabilize.

- Float voltage - Battery voltage at zero current. You must wait about 20 minutes for the battery to stabilize at this voltage.
- Nominal voltage - The voltage by which a battery is referred to. For example, a 12-volt battery is made of 6 cells and has a float voltage of about 12 V.
- Charge voltage - The voltage a battery goes to while being charged.
• Discharge voltage - The voltage of a battery while discharging. This voltage is determined by the charge state and the current flowing.

Charge voltage is usually stated as the battery capacity in ampere-hours divided by 5 (Ah/5). Thus, a 10 Ah battery would use a 2 A charge rate to specify the battery charge voltage. This voltage varies with the charge state of the battery, that is, it is higher when the battery has a full charge.

In a similar manner discharge voltage is usually specified at a current that is capacity in Ah divided by 20. A 10 Ah battery would have a load of 0.5 A on it while measuring this voltage.

Battery Efficiency
Energy efficiency is calculated on the amount of power used from the battery while discharging divided by the amount of power delivered to the battery while charging, multiplied by 100 to yield a percentage. A lead-acid battery has an efficiency of only 75 to 85 percent. The energy lost appears as heat and warms the battery. Keeping the charge and discharge rate of a battery low helps keep a battery cool and improves the battery life.

The energy losses don’t include losses in the charging circuit that may have an efficiency of anywhere from 60 percent to 80 percent. Thus, the overall- total efficiency is the product of these efficiencies and ends up being 45 to 68 percent.

Battery Capacity
Battery capacity refers to the total amount of energy stored within a battery. Rated capacity is in Ah, which is the product of the current times the number of hours to total discharge. The capacity is normally compared with a time of 20 hours and a temperature of 68 °F (20 °C).

There are five factors that dictate the capacity of a given battery:
1. Size
2. Temperature
3. Cut off voltage
4. Discharge rate
5. History

Choosing Battery Capacity
Specifying battery capacity involves a bit more than multiplying the load current by the backup time in hours. You must first de-rate the battery for capacity tolerance, temperature, and discharge rate.

1. Multiply the average load current by the backup hours of operation you need.
2. Add 15 percent to cover loss of capacity from tolerance and un-cycled batteries.
3. For every 10 °C (18 °F) below room temperature (72 °F) that your worst case low temperature is, add 10 percent.
4. If your backup time is less than 20 hours, add 10 percent for every time you have to double your back-up time to equal more than 20 hours. For example, 20 minutes would have to be doubled 6 times to equal more than 20 hours. Thus you would have to add 60 percent on to your required capacity.
5. Add 40 percent to provide for an economic life cycle. A battery with 60 percent of its capacity left is considered worn out.

_Battery Life Expectancy_

The following is taken from Dataweek, Battery Selection and Life Expectancy.

The formula for determining battery life expectancy is reasonably complex, requiring proprietary data that factor in a number of variables to determine the required capacity to deliver an expected run time. In addition to variables such as voltage, background current, and pulse profiles, the formula also factors in how the required temperature range will affect both the battery voltage, and, most important, the self-discharge rate of the battery.

Temperature has a significant impact on battery performance and life expectancy. If the application is designed for cold temperatures, such requirements can prove problematic for certain battery chemistries, since a cold electrolyte becomes less active, leading to higher internal resistance, which may lead to battery failure. When subjected to extremely high temperatures, certain battery chemistries and mechanical sealing techniques start to fail, affecting both short-term performance and long-term reliability.

The self-discharge rate of a cell is governed by its electrolyte composition, its production processes, and its construction. As a general rule, the greater the cell’s internal surface area, the greater the self-discharge rate will be. In addition, high-rate spiral cells with large surface areas have inherently higher self-discharge rates compared to bobbin-type cells of equal size that utilize the same chemistry.

A lesser-known fact that impacts battery self-discharge involves impurity levels in the electrolyte. Through years of study and fine-tuning of the electrolyte production processes, experienced battery manufacturers have found ways to lower battery self-discharge rates by reducing electrolyte impurities and parasitic reactions to nominal levels.

Battery life is also affected by impedance. Unfortunately, battery impedance is not a nice stable number, but rather one that varies by time, temperature, and the mechanical environment it must operate within.

Impedance is measured by the internal resistance developed not only in the electrolyte, but also in the cathode and anode. Impedance can also rise as a result of electrolyte loss. Even though the coin cell’s seal remains intact, being in an elevated temperature environment can cause the electrolyte to simply diffuse through the seal.

_Environmental Requirements for Safe Battery Operation_

The following is taken from DOE-HDBK-1011/2-92.

Because batteries store large amounts of energy, there are certain hazards that are associated with battery operation. These hazards must be fully understood to ensure safe operation of batteries. Hazards include shorted cells, gas generation, and battery temperature.
**Shorted Cell**

Cell short circuits can be caused by several conditions, which include the following: faulty separators; lead particles or other metals forming a circuit between the positive and negative plates; buckling of the plates; or excessive sediments in the bottom of the jar. The primary cause of some of these occurrences is overcharging and over discharging of the battery, which causes sediment to build up due to flaking of active material and buckling of cell plates.

Overcharging and over discharging should be avoided at all costs. Short circuits cause a great reduction in battery capacity. With each shorted cell, battery capacity is reduced by a percentage equal to one over the total number of cells.

**Gas Generation**

A lead-acid battery cannot absorb all the energy from the charging source when the battery is nearing the completion of the charge. This excess energy dissociates water by way of electrolysis into hydrogen and oxygen. Oxygen is produced by the positive plate, and hydrogen is produced by the negative plate. This process is known as gassing.

Gassing is first noticed when cell voltage reaches 2.30–2.35 volts per cell and increases as the charge progresses. At full charge, the amount of hydrogen produced is about one cubic foot per cell for each 63 ampere-hours input. If gassing occurs and the gases are allowed to collect, an explosive mixture of hydrogen and oxygen can be readily produced. It is necessary, therefore, to ensure that the area is well ventilated and that it remains free of any open flames or spark-producing equipment.

As long as battery voltage is greater than 2.30 volts per cell, gassing will occur and cannot be prevented entirely. To reduce the amount of gassing, charging voltages above 2.30 volts per cell should be minimized (e.g., 13.8 volts for a 12-volt battery).

**Battery Temperature**

The operating temperature of a battery should preferably be maintained in the nominal band of 60 °F–80 °F. Whenever the battery is charged, the current flowing through the battery will cause heat to be generated by the electrolysis of water. The current flowing through the battery (I) will also cause heat to be generated (P) during charge and discharge as it passes through the internal resistance (R_i), as illustrated using the formula for power in the equation below.

\[
P = I^2R_i
\]

Higher temperatures will give some additional capacity, but they will eventually reduce the life of the battery. Very high temperatures, 125 °F and higher, can actually do damage to the battery and cause early failure.

Low temperatures will lower battery capacity but also prolong battery life under floating (i.e., slightly charging) operation or storage. Extremely low temperatures can freeze the electrolyte, but only if the battery is low in specific gravity.
b. Discuss the basic operation of alternating current (AC) and direct current (DC) generators.

The following is taken from DOE-HDBK-1011/3-92.

The elementary AC generator (figure 32) consists of a conductor, or loop of wire, in a magnetic field that is produced by an electromagnet. The two ends of the loop are connected to slip rings, and they are in contact with two brushes. When the loop rotates it cuts magnetic lines of force, first in one direction and then the other.

*Source: DOE-HDBK-1011/3-92*

**Figure 32.** Simple AC generator

The induced voltages add in series, making slip ring X (in figure 32) positive (+) and slip ring Y negative (-). The potential across resistor R will cause a current to flow from Y to X through the resistor. This current will increase until it reaches a maximum value when the coil is horizontal to the magnetic lines of force. The horizontal coil is moving perpendicular to the field and is cutting the greatest number of magnetic lines of force. As the coil continues to turn, the voltage and current induced decrease until they reach zero, where the coil is again in the vertical position (figure 33). In the other half revolution, an equal voltage is produced, but the polarity is reversed (figure 33). The current flow through R is now from X to Y (figure 32).
Figure 33. Developing a sine wave voltage

The periodic reversal of polarity results in the generation of a voltage, as shown in figure 33. The rotation of the coil through 360° results in an AC sine wave output.

**DC Generator**

The following is taken from DOE-HDBK-1011/2-92.

A basic DC generator has four basic parts: (1) a magnetic field; (2) a single conductor, or loop; (3) a commutator; and (4) brushes (figure 34). The magnetic field may be supplied by either a permanent magnet or an electromagnet. For now, we will use a permanent magnet to describe a basic DC generator.
c. Discuss the basic operation of the various types of alternating current (AC) and direct current (DC) motors. Include in the discussion the following elements of motor operation as applicable to alternating current (AC) or direct current (DC) motors:

- Starting current vs. running current
- Current vs. load characteristics
- Applications for different types of motors

Starting Current vs. Running Current

The following is taken from DOE-HDBK-1011/2-92.

At the moment a DC motor is started, the armature is stationary and there is no counter electromotive force (CEMF) being generated. The only component to limit starting current is the armature resistance, which in most DC motors is a very low value (approximately 1 ohm or less) as shown in this equation:

\[ I_a = \frac{E_t - E_{CEMF}}{R_a} \]

where
- \( I_a \) = armature current
- \( E_t \) = terminal voltage
- \( E_{CEMF} \) = counter EMF
- \( R_a \) = armature resistance

To reduce a very high starting current, an external resistance must be placed in series with the armature during the starting period. To show why this is essential, consider a 10-
horsepower (hp) motor with an armature resistance of 0.4 ohms. If the motor were supplied by a 260 volt DC source, the resulting current would be as shown in the equations below.

\[ I_a = \frac{E_t - E_{CEMF}}{R_a} \]

\[ I_a = \frac{260 \text{VDC} - 0}{0.4 \Omega} \]

\[ I_a = 650 \text{ amps} \]

where

\( V_{DC} = \text{volt DC} \)

This large current is approximately twelve times greater than actual full-load current for this motor. This high current would, in all probability, cause severe damage to the brushes, commutator, or windings. Starting resistors are usually incorporated into the motor design to limit starting current to 125–200 percent of full-load current.

The amount of starting resistance necessary to limit starting current to a more desirable value is calculated using the following equation:

\[ R_s = \frac{E_t}{I_s} = R_a \]

where

\( R_s = \text{starting resistance} \)
\( E_t = \text{terminal voltage} \)
\( I_s = \text{desired armature starting current} \)
\( R_a = \text{armature resistance} \)

The starting resistors are used in a DC motor by placing them in the starting circuit of the motor controller that is used to start the DC motor. Starting resistors are normally of variable resistances, with the value of resistance in the circuit at any time being either manually or automatically controlled. The maximum amount of resistance will always be inserted when the motor is first started. As the speed of the motor increases, CEMF will begin to increase, decreasing armature current. The starting resistors may then be cut out, in successive steps, until the motor reaches full running speed.

**Current vs. Load Characteristics**

The following is taken from *Industrial Motor Control* by Stephen L. Herman and Walter N. Alerich.

In general, the higher the inrush current, the lower the slip at which the motor can carry full load, and the higher the efficiency. The lower the inrush current, the higher the slip at which the motor can carry full load, and the lower the efficiency.
An increase in line voltage decreases the slip. A decrease in line voltage increases the slip. An increase in line voltage decreases the heating of the motor. A decrease in line voltage increases the heating of the motor.

Applications for Different Types of Motors

AC Motor
The following is taken from Hyperphysics, AC Motor.

In an AC motor, a current is passed through the coil, generating a torque on the coil. Since the current is alternating, the motor will run smoothly only at the frequency of the sine wave. It is called a synchronous motor. More common is the induction motor, where electric current is induced in the rotating coils rather than supplied to them directly.

One of the drawbacks of this kind of AC motor is the high current that must flow through the rotating contacts. Sparking and heating at those contacts can waste energy and shorten the lifetime of the motor. In common AC motors, the magnetic field is produced by an electromagnet powered by the same AC voltage as the motor coil. The coils that produce the magnetic field are sometimes referred to as the stator, while the coils and the solid core that rotates are called the armature. In an AC motor, the magnetic field is sinusoidally varying, just as the current in the coil varies.

DC Motor
The following is taken from EC&M Magazine, Direct Current Motor Basics.

DC motors consist of rotor-mounted windings (armature) and stationary windings (field poles). In all DC motors, except permanent magnet motors, current must be conducted to the armature windings by passing current through carbon brushes that slide over a set of copper surfaces called a commutator, which is mounted on the rotor. The commutator bars are soldered to armature coils. The brush/commutator combination makes a sliding switch that energizes particular portions of the armature, based on the position of the rotor. This process creates north and south magnetic poles on the rotor that are attracted to or repelled by north and south poles on the stator, which are formed by passing DC through the field windings. This magnetic attraction and repulsion causes the rotor to rotate.

The greatest advantage of DC motors may be speed control. Since speed is directly proportional to armature voltage and inversely proportional to the magnetic flux produced by the poles, adjusting the armature voltage and/or the field current will change the rotor speed. Today, adjustable frequency drives can provide precise speed control for AC motors, but they do so at the expense of power quality, as the solid-state switching devices in the drives produce a rich harmonic spectrum. The DC motor has no adverse effects on power quality.

Power supply, initial cost, and maintenance requirements are the negatives associated with DC motors. Rectification must be provided for any DC motors supplied from the grid. Rectification can also cause power quality problems. The construction of a DC motor is considerably more complicated and expensive than that of an AC motor, primarily due to the commutator, brushes, and armature windings. An induction motor requires no commutator or
brushes, and most use cast squirrel-cage rotor bars instead of true windings. Maintenance of the brush/commutator assembly is significant compared to that of induction motor designs.

d. Discuss the basic operation of the various types of transformers. Include in the discussion the following elements of transformer operation and design:

- Theory of operation
- Purpose of the transformer
- Transformer ratings
- Transformer cooling requirements

Theory of Operation
The following descriptions and definitions are taken from DOE-HDBK-1011/4-92.

Theory of Operation
A transformer works on the principle that energy can be transferred by magnetic induction from one set of coils to another set by means of a varying magnetic flux. The magnetic flux is produced by an AC source.

The coil of a transformer that is energized from an AC source is called the primary winding (coil), and the coil that delivers this AC to the load is called the secondary winding (coil) (figure 35). In figure 35, the primary and secondary coils are shown on separate legs of the magnetic circuit so that we can easily understand how the transformer works. Actually, half of the primary and secondary coils are wound on each of the two legs, with sufficient insulation between the two coils and the core to properly insulate the windings from one another and the core. A transformer wound such as in figure 35, will operate at a greatly reduced efficiency due to the magnetic leakage. Magnetic leakage is the part of the magnetic flux that passes through either one of the coils, but not through both. The larger the distance between the primary and secondary windings, the longer the magnetic circuit and the greater the leakage.

Source: DOE-HDBK-1011/4-92

Figure 35. Core type transformer
Purpose of the Transformer
According to DOE-HDBK-1011/4-92, transformers are used extensively for AC power transmissions and for various control and indication circuits.

Transformer Ratings
The following is taken from PowerVolt, How to Determine Power Supply Transformer Ratings.

The transformer ratings depend upon the type of filter and rectifier configuration used. The commonly used filter types are inductor and capacitor input filters. However, due to increased weight and cost considerations, the inductor filter is not very popular. In most power supplies, a voltage regulator is used, which provides extra ripple reduction so that an inductor-capacitor filter is not required. As a result, a capacitive filter is sufficient for a majority of the applications and is very popular among power supply designers.

The current drawn from the transformer secondary winding varies with the type of rectifier circuit used. The most commonly used single-phase circuits are
- Half-wave (single diode)
- Full wave center tap (two diodes)
- Full wave bridge (four diodes)
- Dual complementary rectifier

The half-wave rectifier is simple and less costly than the other types. However, very high current spikes during the capacitive charging interval and the unidirectional DC current in the transformer secondary winding require a larger transformer core to avoid saturation. Consequently, the half-wave rectifier is not very popular, and the only time it may be worth considering is for power levels below 1 watt.

Transformer Cooling Requirements
The following is taken from Transformers and Motors by George Patrick Shultz.

All transformers must be equipped with some method for cooling. Heat decreases the transformer’s efficiency and reduces the unit’s life expectancy. Operating the transformer below rated temperature allows for a great kilovolt ampere capacity to be delivered to the load.

Dry-Type Transformers
For dry-type transformers, no particular check is necessary if conditions for ventilation have been provided for the area in which the transformer is to be installed. In this event, the ventilation system of the room should be inspected to make sure it is operating properly. Transformer radiator vents should be clear of any obstructions that may prevent the heat from escaping.

Forced Air
If the cooling system consists of forced air for maintaining the temperature of the transformer, the motors should be checked for proper lubrications and operation. These motors will often be controlled by thermostats that also need to be inspected and tested to
determine if the motors operate within the preset temperature ranges. Manufacturers’ specifications are to be followed for making these tests. When located in closed vaults, means should be provided to exchange the air in the vaults.

Water-Cooled Systems

Water-cooled systems must be tested for leaks and proper operations. To make these tests, the cooling coils should be removed from the transformer if water is to be used to provide the pressure. Care must be taken not to damage the coils when removing or replacing them. If the coils are to be checked in the transformer, air or the type of coolant oil used by the transformer can be used to make the pressure checks.

If the coils are removed from the transformer, the total water cooling system can be checked. The coils are filled with water under pressure of 80 to 100 pounds per square inch (psi) and they are checked for leaks. The coils remain under pressure for at least 1 hour to assure that no leaks will develop. A drop in pressure would indicate a leak.

A very small amount of moisture, 0.06 percent, will reduce the dielectric strength of the oil by 50 percent. Moisture content beyond this point does not cause the dielectric strength of the oil to deteriorate much more.

Associated equipment with the water-cooled system also needs to be checked, including the water pump, pressure gauges, temperature gauges, and the alarm system. In addition, make sure there is a water source with an adequate flow and pressure.

e. Identify and discuss the operation of the different types of electrical switchgear.

See competency 20, element “d” for an explanation of the different types of electrical switchgear.

22. Construction management personnel shall demonstrate a familiarity level knowledge of instrumentation and control systems.

a. Describe the functions that temperature, pressure, level, flow, position, and radiation detectors provide.

Temperature Detectors

The following is taken from DOE-HDBK-1013/1-92.

Although the temperatures that are monitored vary slightly depending on the details of facility design, temperature detectors are used to provide three basic functions: indication, alarm, and control. The temperatures monitored may normally be displayed in a central location, such as a control room, and may have audible and visual alarms associated with them when specified preset limits are exceeded. These temperatures may have control functions associated with them so that equipment is started or stopped to support a given temperature condition or so that a protective action occurs.

Because temperature is one of the most important parameters of a material, many instruments have been developed to measure it. One type of detector used is the resistance temperature
detector (RTD). The RTD is used at many DOE nuclear facilities to measure temperatures of the process or materials being monitored.

**Pressure Detectors**
The following is taken from DOE-HDBK-1013/1-92.

Although the pressures that are monitored vary slightly depending on the details of facility design, all pressure detectors are used to provide up to three basic functions: indication, alarm, and control. Since the fluid system may operate at both saturation and subcooled conditions, accurate pressure indication must be available to maintain proper cooling. Some pressure detectors have audible and visual alarms associated with them when specified preset limits are exceeded. Some pressure detector applications are used as inputs to protective features and control functions.

**Level Detectors**
The following is taken from DOE-HDBK-1013/1-92.

The different types of level detectors and their functions are summarized below.

In the gauge glass method, a transparent tube is attached to the bottom and top (top connection not needed in a tank open to atmosphere) of the tank that is monitored. The height of the liquid in the tube will be equal to the height of water in the tank.

The operation of the ball float is simple. The ball floats on top of the liquid in the tank. If the liquid level changes, the float will follow and change the position of the pointer attached to the rotating shaft.

The operation of the chain float is similar to the ball float except in its method of positioning the pointer and its connection to the position indication. The float is connected to a rotating element by a chain with a weight attached to the other end to provide a means of keeping the chain taut during changes in level.

The magnetic bond mechanism consists of a magnetic float that rises and falls with changes in level. The float travels outside of a non-magnetic tube which houses an inner magnet connected to a level indicator. When the float rises and falls, the outer magnet will attract the inner magnet, causing the inner magnet to follow the level within the vessel.

The conductivity probe consists of one or more level detectors, an operating relay, and a controller. When the liquid makes contact with any of the electrodes, an electric current will flow between the electrode and ground. The current energizes a relay which causes the relay contacts to open or close depending on the state of the process involved. The relay in turn will actuate an alarm, a pump, a control valve, or all three.

The differential pressure (DP) detector uses a DP detector connected to the bottom of the tank that is being monitored. The higher pressure in the tank is compared to a lower reference pressure (usually atmospheric). This comparison takes place in the DP detector.
Flow Detectors

The following is taken from DOE-HDBK-1013/1-92.

Flow detectors operate on the principle of placing a restriction in the line to cause a DP head. The DP, which is caused by the head, is measured and converted to a flow measurement. Industrial applications of flow detectors incorporate a pneumatic or electrical transmitting system for remote readout of flow rate. Generally, the indicating instrument extracts the square root of the differential pressure and displays the flow rate on a linear indicator. There are two elements in a flow meter; the primary element is the restriction in the line, and the secondary element is the DP measuring device.

The flow-path restriction, such as an orifice, causes a DP across the orifice. This pressure differential is measured by a mercury manometer or a DP detector. From this measurement, flow rate is determined from known physical laws.

Position Detectors

The following is taken from DOE-HDBK-1018/2-93.

Operators require indication of the position of certain valves to permit knowledgeable operation of the plant. For such valves, remote valve position indication is provided in the form of position lights that indicate if valves are open or closed. Remote valve position indication circuits use a position detector that senses stem and disk position or actuator position. One type of position detector is the mechanical limit switch, which is physically operated by valve movement.

Other types of position detectors are magnetic switches or transformers that sense movement of their magnetic cores, which are physically operated by valve movement. Local valve position indication refers to some visually discernable characteristic of the valve that indicates valve position. Rising stem valve position is indicated by the stem position. Nonrising stem valves sometimes have small mechanical pointers that are operated by the valve actuator simultaneously with valve operation. Power actuated valves typically have a mechanical pointer that provides local valve position indication. On the other hand, some valves do not have any feature for position indication.

Radiation Detector

The following is taken from DOE-HDBK-1013/2-92.

The Geiger-Müller or G-M detector is a radiation detector that operates in region V, or G-M region, as shown in figure 36. G-M detectors produce larger pulses than other types of detectors. However, discrimination is not possible, since the pulse height is independent of the type of radiation. Counting systems that use G-M detectors are not as complex as those using ion chambers or proportional counters.
The number of electrons collected by a gas-filled detector varies as applied voltage is increased. Once the voltage is increased beyond the proportional region, another flat portion of the curve is reached; this is known as the G-M region. The G-M region has two important characteristics:

1. The number of electrons produced is independent of applied voltage.
2. The number of electrons produced is independent of the number of electrons produced by the initial radiation.

This means that the radiation producing one electron will have the same size pulse as radiation producing hundreds or thousands of electrons. The reason for this characteristic is related to the way in which electrons are collected.

When a gamma produces an electron, the electron moves rapidly toward the positively charged central wire. As the electron nears the wire, its velocity increases. At some point its velocity is great enough to cause additional ionizations. As the electrons approach the central wire, the additional ionizations produce a larger number of electrons in the vicinity of the central wire.

b. Describe the basic operation of process control systems used in the following applications:
   - Temperature measurement
   - Flow measurement
   - Pressure measurement
   - Level measurement
   - Position measurement

**Temperature Measurement**

The following is taken from DOE-HDBK-1122-2009.
Temperature measurements are made to determine the amount of heat flow in an environment. To measure temperature it is necessary to establish relative scales of comparison. Three temperature scales are in common use today. The general temperature measurements we use on a day-to-day basis in the United States are based on the Fahrenheit scale. In science, the Celsius scale and the Kelvin scale are used.

The Fahrenheit scale, named for its developer, was devised in the early 1700’s. This scale was originally based on the temperatures of human blood and salt-water, and later on the freezing and boiling points of water. Today, the Fahrenheit scale is a secondary scale defined with reference to the other two scientific scales. The symbol °F is used to represent a degree on the Fahrenheit scale.

About thirty years after the Fahrenheit scale was adopted, Anders Celsius, a Swedish astronomer, suggested that it would be simpler to use a temperature scale divided into one hundred degrees between the freezing and boiling points of water. For many years his scale was called the centigrade scale. In 1948 an international conference of scientists re-named it the Celsius scale in honor of its inventor. The Celsius degree, °C, was defined as 1/100 of the temperature difference between the freezing point and boiling point of water.

In the 19th century, an English scientist, Lord Kelvin, established a more fundamental temperature scale that used the lowest possible temperature as a reference point for the beginning of the scale. The lowest possible temperature, sometimes called absolute zero, was established as 0 K (zero Kelvin). This temperature is 273.15°C below zero, or -273.15°C. Accordingly, the Kelvin degree, was chosen to be the same as a Celsius degree so that there would be a simple relationship between the two scales.

Note that the degree sign (°) is not used when stating a temperature on the Kelvin scale. Temperature is stated simply as Kelvin (K). The Kelvin was adopted by the 10th Conference of Weights and Measures in 1954, and is the SI unit of thermodynamic temperature. Note that the degree Celsius (°C) is the SI unit for expressing Celsius temperature and temperature intervals. The temperature interval one degree Celsius equals one kelvin exactly. Thus, 0°C = 273.15 K by definition.

Flow Measurement
The following is taken from DOE-HDBK-1013/1-92.

Head flow meters operate on the principle of placing a restriction in the line to cause a differential pressure head. The differential pressure, which is caused by the head, is measured and converted to a flow measurement. Industrial applications of head flow meters incorporate a pneumatic or electrical transmitting system for remote readout of flow rate. Generally, the indicating instrument extracts the square root of the differential pressure and displays the flow rate on a linear indicator.

There are two elements in a head flow meter; the primary element is the restriction in the line, and the secondary element is the differential pressure measuring device.
The flow path restriction, such as an orifice, causes a differential pressure across the orifice. This pressure differential is measured by a mercury manometer or a differential pressure detector. From this measurement, flow rate is determined from known physical laws.

The head flow meter actually measures volume flow rate rather than mass flow rate. Mass flow rate is easily calculated or computed from volumetric flow rate by knowing or sensing temperature and/or pressure. Temperature and pressure affect the density of the fluid and, therefore, the mass of fluid flowing past a certain point. If the volumetric flow rate signal is compensated for changes in temperature and/or pressure, a true mass flow rate signal can be obtained. In thermodynamics it is explained that temperature and density are inversely proportional, while pressure and density are directly proportional.

**Pressure Measurement**
The following is taken from DOE-HDBK-1013/1-92.

Although the pressures that are monitored vary slightly depending on the details of facility design, all pressure detectors are used to provide up to three basic functions: indication, alarm, and control. Since the fluid system may operate at both saturation and subcooled conditions, accurate pressure indication must be available to maintain proper cooling. Some pressure detectors have audible and visual alarms associated with them when specified preset limits are exceeded. Some pressure detector applications are used as inputs to protective features and control functions.

**Level Measurement**
The following is taken from DOE-HDBK-1013/1-92.

There are three major reasons for using level measurement:
- Level measurements may be taken at locations far from the main facility.
- The level to be controlled may be a long distance from the point of control.
- The level being measured may be in an unsafe/radioactive area.

The basic components of a differential pressure level instrument are
- A differential pressure (D/P) transmitter that consists of a diaphragm with the high pressure and low pressure inputs on opposite sides. As the differential pressure changes, the diaphragm will move. The transducer changes this mechanical motion into an electrical signal.
- An amplifier that amplifies the electrical signal generated by the transducer and sends it to the level indicator.
- A level indicator that displays the level indication on a monitor.

**Position Measurement**
The following is taken from DOE-HDBK-1013/1-92.

Position indicating instrumentation is used in nuclear facilities to provide remote indication of control rod position with respect to the fully inserted position, and remote indication of the open or shut condition of important valves. This remote indication is necessary for the monitoring of vital components located within inaccessible or remote areas. Remote position
indication can be used at any DOE facility, not only nuclear facilities, where valve position indication is required for safety.

Potentiometer valve position indicators provide an accurate indication of position throughout the travel of a valve or control rod. The extension is physically attached to a variable resistor. As the extension moves up or down, the resistance of the attached circuit changes, changing the amount of current flow in the circuit. The amount of current is proportional to the valve position.

A limit switch is a mechanical device that can be used to determine the physical position of equipment. For example, an extension on a valve shaft mechanically trips a limit switch as it moves from open to shut or shut to open. The limit switch gives on/off output that corresponds to valve position. Normally, limit switches are used to provide full open or full shut indications.

Reed switches are more reliable than limit switches, due to their simplified construction. The switches are constructed of flexible ferrous strips (reeds) and are placed near the intended travel of the valve stem or control rod extension.

When using reed switches, the extension used is a permanent magnet. As the magnet approaches the reed switch, the switch shuts. When the magnet moves away, the reed switch opens. This on/off indicator is similar to mechanical limit switches. By using a large number of magnetic reed switches, incremental position can be measured. This technique is sometimes used in monitoring a reactor’s control rod position.

c. **Discuss the requirements specific to instrumentation and control system components that are important to safety.**

The following is taken from the National Research Council, *Digital Instrumentation and Control Systems in Nuclear Power Plants.*

Safety systems in nuclear power plants must reliably satisfy their functional requirements. To help achieve this goal safety systems are designed to be single-failure proof, i.e., no single failure is to prevent safety systems actuation if needed, nor shall a single failure cause a spurious activation. Various forms or redundancy are commonly used to achieve this design goal.

There are two approaches to providing redundant components: active redundancy and standby redundancy. In active redundancy, the outputs of multiple identical components or strings of components, operating in parallel, are compared or selected in some way to determine which outputs will actually be used. If the individual components are each highly reliable and fail independently, then a correct output can be assured with high probability.

The second type of redundant design uses standby redundancy. In this scheme, one or more spares are available to replace failed components. An example of standby redundancy is switching to an alternate or backup power supply when loss of electrical power is detected. Combinations of active and standby redundancy can also be used.
d. Describe the operation of the following types of actuators used in process control systems:

- Pneumatic
- Hydraulic
- Solenoid
- Electric motor

The following descriptions are taken from DOE-HDBK-1013/2-92.

**Pneumatic**
A pneumatic actuator operates by a combination of force created by air and spring force. The actuator positions a control valve by transmitting its motion through the stem.

A rubber diaphragm separates the actuator housing into two air chambers. The upper chamber receives supply air through an opening in the top of the housing. The bottom chamber contains a spring that forces the diaphragm against mechanical stops in the upper chamber. Finally, a local indicator is connected to the stem to indicate the position of the valve.

The position of the valve is controlled by varying supply air pressure in the upper chamber. This results in a varying force on the top of the diaphragm. Initially, with no supply air, the spring forces the diaphragm upward against the mechanical stops and holds the valve fully open. As supply air pressure is increased from zero, its force on top of the diaphragm begins to overcome the opposing force of the spring. This causes the diaphragm to move downward and the control valve to close. With increasing supply air pressure, the diaphragm will continue to move downward and compress the spring until the control valve is fully closed. Conversely, if supply air pressure is decreased, the spring will begin to force the diaphragm upward and open the control valve. Additionally, if supply pressure is held constant at some value between zero and maximum, the valve will position at an intermediate position. Therefore, the valve can be positioned anywhere between fully open and fully closed in response to changes in supply air pressure.

A positioner is a device that regulates the supply air pressure to a pneumatic actuator. It does this by comparing the actuator’s demanded position with the control valve’s actual position. The demanded position is transmitted by a pneumatic or electrical control signal from a controller to the positioner. The controller generates an output signal that represents the demanded position. This signal is sent to the positioner. Externally, the positioner consists of an input connection for the control signal, a supply air input connection, a supply air output connection, a supply air vent connection, and a feedback linkage. Internally, it contains an intricate network of electrical transducers, air lines, valves, linkages, and necessary adjustments. Other positioners may also provide controls for local valve positioning and gauges to indicate supply air pressure and control air pressure (for pneumatic controllers).

**Hydraulic**
Pneumatic actuators are normally used to control processes requiring quick and accurate response, as they do not require a large amount of motive force. However, when a large amount of force is required to operate a valve (for example, the main steam system valves), hydraulic actuators are normally used. Although hydraulic actuators come in many designs, piston types are most common.
A typical piston type hydraulic actuator consists of a cylinder, piston, spring, hydraulic supply and return line, and stem. The piston slides vertically inside the cylinder and separates the cylinder into two chambers. The upper chamber contains the spring, and the lower chamber contains hydraulic oil.

The hydraulic supply and return line is connected to the lower chamber and allows hydraulic fluid to flow to and from the lower chamber of the actuator. The stem transmits the motion of the piston to a valve. Initially, with no hydraulic fluid pressure, the spring force holds the valve in the closed position. As fluid enters the lower chamber, pressure in the chamber increases. This pressure results in a force on the bottom of the piston opposite to the force caused by the spring. When the hydraulic force is greater than the spring force, the piston begins to move upward, the spring compresses, and the valve begins to open. As the hydraulic pressure increases, the valve continues to open. Conversely, as hydraulic oil is drained from the cylinder, the hydraulic force becomes less than the spring force, the piston moves downward, and the valve closes. By regulating the amount of oil supplied or drained from the actuator, the valve can be positioned between fully open and fully closed.

**Solenoid**

An electric solenoid actuator consists of a coil, armature, spring, and stem. The coil is connected to an external current supply. The spring rests on the armature to force it downward. The armature moves vertically inside the coil and transmits its motion through the stem to the valve. When current flows through the coil, a magnetic field forms around the coil. The magnetic field attracts the armature toward the center of the coil. As the armature moves upward, the spring collapses and the valve opens. When the circuit is opened and current stops flowing to the coil, the magnetic field collapses. This allows the spring to expand and shut the valve.

A major advantage of solenoid actuators is their quick operation. Also, they are much easier to install than pneumatic or hydraulic actuators. However, solenoid actuators have two disadvantages. First, they have only two positions: fully open and fully closed. Second, they do not produce much force, so they usually only operate relatively small valves.

**Electric Motor**

Electric motor actuators vary widely in their design and applications. Some electric motor actuators are designed to operate in only two positions (fully open or fully closed). Other electric motors can be positioned between the two positions. An electric motor actuator’s major parts include an electric motor, a clutch and gear box assembly, a manual hand wheel, and a stem connected to a valve.

The motor moves the stem through the gear assembly. The motor reverses its rotation to either open or close the valve. The clutch and clutch lever disconnect the electric motor from the gear assembly and allow the valve to be operated manually with the hand wheel. Most electric motor actuators are equipped with limit switches, torque limiters, or both. Limit switches de-energize the electric motor when the valve has reached a specific position. Torque limiters de-energize the electric motor when the amount of turning force has reached a specified value. The turning force normally is greatest when the valve reaches the fully...
open or fully closed position. This feature can also prevent damage to the actuator or valve if
the valve binds in an intermediate position.

23. Construction management personnel shall demonstrate a familiarity level knowledge
of the construction and operation of basic mechanical components.

a. Describe the function, construction, and operation of the following types of
pumps:
   - Centrifugal pump
   - Positive displacement pump
   - Single stage and multiple stage pumps
   - Submersible pumps

*Centrifugal Pump*

The following is taken from DOE-HDBK-1018/1-93.

Centrifugal pumps basically consist of a stationary pump casing and an impeller mounted on
a rotating shaft. The pump casing provides a pressure boundary for the pump and contains
channels to properly direct the suction and discharge flow. The pump casing has suction and
discharge penetrations for the main flow path of the pump and normally has small drain and
vent fittings to remove gases trapped in the pump casing or to drain the pump casing for
maintenance.

Figure 37 is a simplified diagram of a typical centrifugal pump that shows the relative
locations of the pump suction, impeller, volute, and discharge. The pump casing guides the
liquid from the suction connection to the center, or eye, of the impeller. The vanes of the
rotating impeller impart a radial and rotary motion to the liquid, forcing it to the outer
periphery of the pump casing where it is collected in the outer part of the pump casing called
the volute. The volute is a region that expands in cross-sectional area as it wraps around the
pump casing. The purpose of the volute is to collect the liquid discharged from the periphery
of the impeller at high velocity and gradually cause a reduction in fluid velocity by
increasing the flow area. This converts the velocity head to static pressure. The fluid is then
discharged from the pump through the discharge connection.
Centrifugal pumps can also be constructed in a manner that results in two distinct volutes, each receiving the liquid that is discharged from a 180° region of the impeller at any given time. Pumps of this type are called double volute pumps (they may also be referred to as split volute pumps). In some applications, the double volute minimizes radial forces imparted to the shaft and bearings due to imbalances in the pressure around the impeller. A comparison of single and double volute centrifugal pumps is shown on figure 38.

Source: DOE-HDBK-1018/1-93.

Figure 37. Centrifugal pump

Source: DOE-HDBK-1018.1-93.

Figure 38. Single and double volutes
**Positive Displacement Pump**
The following is taken from DOE-HDBK-1018.1-93.

A positive displacement pump is one in which a definite volume of liquid is delivered for each cycle of pump operation. This volume is constant regardless of the resistance to flow offered by the system the pump is in, provided the capacity of the power unit driving the pump or the pump component strength limits are not exceeded. The positive displacement pump delivers liquid in separate volumes with no delivery in between, although a pump having several chambers may have an overlapping delivery among individual chambers, which minimizes this effect. The positive displacement pump differs from centrifugal pumps, which deliver a continuous flow for any given pump speed and discharge resistance.

Positive displacement pumps can be grouped into three basic categories based on their design and operation. The three groups are reciprocating pumps, rotary pumps, and diaphragm pumps.

**Single Stage and Multiple Stage Pumps**
The following is taken from DOE-HDBK-1018.1-93.

A pump stage is defined as that portion of a centrifugal pump consisting of one impeller and its associated components. Most centrifugal pumps are single-stage pumps, containing only one impeller. A pump containing seven impellers within a single casing would be referred to as a seven-stage pump, or generally, as a multi-stage pump.

**Submersible Pumps**
The following is taken from Pumps-in-Stock.com, Submersible Pumps.

Few items provide as quick a return on investment and as long a work life as submersible pumps. Their compact and streamlined design makes them ideal for wells and other jobs where space is limited.

Submersibles have the advantage of being able to work in the water source being pumped. As a result the submersible is not subject to the suction lift limitations of other typical pumps. No suction hose is required helping to save money and time while eliminating a potential source of problems. The pump is limited only by the discharge head it is capable of producing.

The pumps can also be classified by motor size and voltage requirements. Smaller units, with 1/3 and 1/2 horsepower 115 volt motors are ideal for homeowner use or light duty jobs. Experienced dewatering contractors will often choose pumps with 230/240 volt 3 phase motors as they provide the higher performance and cost less to run over time.

The pump motors use a vertical drive shaft to turn an impeller and generate the velocity needed to create the discharge pressure. Water flows in through the bottom and is discharged out the top of the pump casing. Submersible trash pumps use a vortex design that allows the pump to handle some solids without passing them through the casing.
Combining electricity and water obviously brings a certain element of risk. Further, it is difficult and often impossible to know if there is a problem once the pump is submerged. As a result the pump should provide some built-in protections to ensure safety and guard against damage to the equipment.

A high quality pump will have its motor housed in a watertight compartment and equip it with thermal overload sensors that shut down the motor to prevent damage from over heating. Pumps should also be used with protected circuits.

Maintenance is minimal and generally consists of periodically inspecting the electrical cord and the mechanical seal lubricant. There are none of the concerns common with engine driven pumps such as noise, fuel or emissions.

Control boxes and float switches are available for unattended operation of submersible pumps. The boxes provide protection against voltage fluctuations and incorrect phasing while float switches turn the pump on and off according to fluctuating water levels. A number of different accessories are available but care should be taken that they meet the electrical requirements of the pump.

b. Describe the basic construction and operation of the following types of valves:

- Gate valve
- Globe valve
- Butterfly valve
- Check valve
- Relief and safety valves

The following descriptions are taken from DOE-HDBK-1018/2-93.

**Gate Valve**

A gate valve is a linear motion valve used to start or stop fluid flow. However, it does not regulate or throttle flow. The name “gate” is derived from the appearance of the disk in the flow stream.

The disk of a gate valve is completely removed from the flow stream when the valve is fully open. This characteristic offers virtually no resistance to flow when the valve is open. Hence, there is little pressure drop across an open gate valve. When the valve is fully closed, a disk-to-seal ring contact surface exists for 360 degrees, and good sealing is provided. With the proper mating of a disk to the seal ring, very little or no leakage occurs across the disk when the gate valve is closed.

On opening the gate valve, the flow path is enlarged in a highly nonlinear manner with respect to percent of opening. This means that flow rate does not change evenly with stem travel. Also, a partially open gate disk tends to vibrate from the fluid flow. Most of the flow change occurs near shutoff with a relatively high fluid velocity causing disk and seat wear and eventual leakage if used to regulate flow. For these reasons, gate valves are not used to regulate or throttle flow.

A gate valve can be used for a wide variety of fluids and provides a tight seal when closed. The major disadvantages to the use of a gate valve are listed below:
- It is not suitable for throttling applications.
- It is prone to vibration in the partially open state.
- It is more subject to seat and disk wear than a globe valve.
- Repairs, such as lapping and grinding, are generally more difficult to accomplish.

**Globe Valve**

A globe valve is a linear motion valve used to stop, start, and regulate fluid flow. The globe valve disk can be totally removed from the flow path or it can completely close the flow path. The essential principle of globe valve operation is the perpendicular movement of the disk away from the seat. This causes the annular space between the disk and seat ring to gradually close as the valve is closed. This characteristic gives the globe valve good throttling ability, which permits its use in regulating flow. Therefore, the globe valve may be used for stopping and starting fluid flow and for regulating flow.

When compared to a gate valve, a globe valve generally yields much less seat leakage. This is because the disk-to-seat ring contact is more at right angles, which permits the force of closing to tightly seat the disk.

Globe valves can be arranged so that the disk closes against or in the same direction of fluid flow. When the disk closes against the direction of flow, the kinetic energy of the fluid impedes closing but aids opening of the valve. When the disk closes in the same direction of flow, the kinetic energy of the fluid aids closing but impedes opening. This characteristic is preferable to other designs when quick-acting stop valves are necessary.

Globe valves also have drawbacks. The most evident shortcoming of the simple globe valve is the high head loss from two or more right angle turns of flowing fluid. Obstructions and discontinuities in the flow path lead to head loss. In a large high-pressure line, the fluid dynamic effects from pulsations, impacts, and pressure drops can damage trim, stem packing, and actuators. In addition, large valve sizes require considerable power to operate and are especially noisy in high-pressure applications.

Other drawbacks of globe valves are the large openings necessary for disk assembly, the heavier weight compared to other valves of the same flow rating, and the cantilevered mounting of the disk to the stem.

**Butterfly Valve**

A butterfly valve is a rotary motion valve that is used to stop, regulate, and start fluid flow. Butterfly valves are easily and quickly operated because a 90 degree rotation of the handle moves the disk from a fully closed to a fully opened position. Larger butterfly valves are actuated by hand wheels connected to the stem through gears that provide mechanical advantage at the expense of speed.

Butterfly valves possess many advantages over gate, globe, plug, and ball valves, especially for large valve applications. Savings in weight, space, and cost are the most obvious advantages. The maintenance costs are usually low because there are a minimal number of moving parts and there are no pockets to trap fluids.
**Check Valve**
Check valves are designed to prevent the reversal of flow in a piping system. These valves are activated by the flowing material in the pipeline. The pressure of the fluid passing through the system opens the valve, while any reversal of flow will close the valve. Closure is accomplished by the weight of the check mechanism, by back pressure, by a spring, or by a combination of these means. The general types of check valves are swing, tilting-disk, piston, butterfly, and stop.

**Relief and Safety Valves**
Relief and safety valves prevent equipment damage by relieving accidental over-pressurization of fluid systems. The main difference between a relief valve and a safety valve is the extent of opening at the set point pressure.

A relief valve gradually opens as the inlet pressure increases above the set point. A relief valve opens only as necessary to relieve the over-pressure condition. A safety valve rapidly pops fully open as soon as the pressure setting is reached.

A safety valve will stay fully open until the pressure drops below a reset pressure. The reset pressure is lower than the actuating pressure set point. The difference between the actuating pressure set point and the pressure at which the safety valve resets is called lowdown. Lowdown is expressed as a percentage of the actuating pressure set point.

c. Discuss the function and application of the following types of filters/strainers used in mechanical fluid flow systems and ventilation systems:

- Cartridge filters
- Pre-coated filters
- Bucket strainers
- Deep-bed filters
- HEPA filters
- Particulate filters
- Duplex strainers

The following definitions are taken from DOE-HDBK-1018/2-93.

**Cartridge Filters**
Cartridge filters are shaped like cylinders and usually consist of a fiber yarn wound around a perforated metal core. The liquid being filtered is forced through the yarn, which is approximately one-half inch thick, and then through the perforations in the metal core to the filter outlet, which can be at either end. A cartridge filter may include several cartridges, with the exact number depending on the liquid flow rate that must be handled.

**Precoated Filters**
A precoated filter eliminates the problem of physically handling radioactive materials because the filter material (called the medium) can be installed and removed remotely. Inside the filter housing is a bundle of septums (vertical tubes on which the filter medium is deposited). The septums in some filters are approximately one inch in diameter and three feet long and are usually made of perforated or porous metal (normally stainless steel). There may be several hundred of these septums in a filter. Septums in other filters are
approximately three in. in diameter and three feet long and are made of porous stone or porous ceramic material. There are usually less than 100 of these larger septums in a filter.

**Bucket Strainers**

Bucket strainers are strainers that basically look like a bucket. The fluid enters the top and leaves the bottom, and the strainer can be pulled out like a bucket and cleaned prior to being reinstalled and reused in the system.

**Deep-Bed Filters**

A deep-bed filter is based on a support screen (decking) that is mounted a few in. above the bottom of the tank. The screen is perforated to allow water to flow through it. A coarse, aggregate layer of crushed rock (or large lumps of charcoal) is placed on top of the screen, and the deep bed itself (two to four feet of granular anthracite or charcoal) is placed on top of the aggregate. The filter is sized so that there is one to two feet of “free board” above the deep bed.

**High Efficiency Particulate Air (HEPA) Filters**

A HEPA filter is a throwaway, extended-media, dry type filter with a rigid casing enclosing the full depth of the pleats. The filter shall exhibit a minimum efficiency of 99.97 percent when tested at an aerosol of 0.3 micrometers diameter.

**Duplex Strainers**

A duplex strainer is a strainer consisting of two sides with a basket in each side. Only one side is placed in service at a time. These are commonly used in fuel oil and lubricating oil lines where it is essential to maintain an uninterrupted flow of oil. The flow may be diverted from one basket to the other while one is being cleaned.

d. **Discuss the causes of water hammer and pressure spiking.**

The following discussions are taken from DOE-HDBK-1012/3-92.

**Water Hammer**

Water hammer is a liquid shock wave resulting from the sudden starting or stopping of flow. It is affected by the initial system pressure, the density of the fluid, the speed of sound in the fluid, the elasticity of the fluid and pipe, the change in velocity of the fluid, the diameter and thickness of the pipe, and the valve operating time.

**Pressure Spike**

A pressure spike is the resulting rapid rise in pressure above static pressure caused by water hammer. The highest pressure spike attained will be at the instant the flow changed.

e. **Describe the operation of a compressed air system, including a discussion of the basic function of each of the following components:**

- Compressor
- Moisture separator
- Intercooler
- After cooler
- Receiver
Air dryer

Compressor

The following is taken from DOE-HDBK-1018/2-93.

Air compressors of various designs are used widely throughout DOE facilities in numerous applications. Compressed air has numerous uses throughout a facility including the operation of equipment and portable tools. Three types of designs include reciprocating, rotary, and centrifugal air compressors.

Reciprocating Compressors

The reciprocating air compressor, illustrated in figure 39 is the most common design employed today.

![Diagram of reciprocating air compressor](image)

**Source:** DOE-HDBK-1018/2-93.

**Figure 39.** Reciprocating air compressor

The reciprocating compressor normally consists of the following elements.
- The compressing element, consisting of air cylinders, heads and pistons, and air inlet and discharge valves;
- A system of connecting rods, piston rods, crossheads, and a crankshaft and flywheel for transmitting the power developed by the driving unit to the air cylinder piston;
- A self-contained lubricating system for bearings, gears, and cylinder walls, including a reservoir or sump for the lubricating oil, and a pump, or other means of delivering...
oil to the various parts. On some compressors a separate force-fed lubricator is installed to supply oil to the compressor cylinders;

- A regulation or control system designed to maintain the pressure in the discharge line and air receiver (storage tank) within a predetermined range of pressure;
- An unloading system, which operates in conjunction with the regulator, to reduce or eliminate the load put on the prime mover when starting the unit.

A section of a typical reciprocating single-stage, single-acting compressor cylinder is shown in figure 40.

![Diagram of a single-acting air compressor cylinder](image)

Source: DOE-HDBK-1018/2-93

**Figure 40.** Single-acting air compressor cylinder

Inlet and discharge valves are located in the clearance space and connected through ports in the cylinder head to the inlet and discharge connections. During the suction stroke the compressor piston starts its downward stroke and the air under pressure in the clearance space rapidly expands until the pressure falls below that on the opposite side of the inlet valve (figures 40B and 40C). This difference in pressure causes the inlet valve to open into the cylinder until the piston reaches the bottom of its stroke (figure 40C).

During the compression stroke the piston starts upward, compression begins, and at point D has reached the same pressure as the compressor intake. The spring-loaded inlet valve then closes. As the piston continues upward, air is compressed until the pressure in the cylinder becomes great enough to open the discharge valve against the pressure of the valve springs.
and the pressure of the discharge line (figure 40E). From this point, to the end of the stroke (figures 40E and 40A), the air compressed within the cylinder is discharged at practically constant pressure.

Rotary Compressors
The rotary compressor is adaptable to direct drive by induction motors or multicylinder gasoline or diesel engines. The units are compact, relatively inexpensive, and require a minimum of operating attention and maintenance. They occupy a fraction of the space and weight of a reciprocating machine of equivalent capacity. Rotary compressor units are classified into three general groups, slide vane-type, lobe-type, and liquid seal ring-type.

The rotary slide vane-type, as illustrated in figure 41, has longitudinal vanes, sliding radially in a slotted rotor mounted eccentrically in a cylinder.

![Rotary slide vane air compressor](image)

Source: DOE-HDBK-1018/2-93

**Figure 41.** Rotary slide vane air compressor

The centrifugal force carries the sliding vanes against the cylindrical case with the vanes forming a number of individual longitudinal cells in the eccentric annulus between the case and rotor. The suction port is located where the longitudinal cells are largest. The size of each cell is reduced by the eccentricity of the rotor as the vanes approach the discharge port, thus compressing the air.

The rotary lobe-type, illustrated in figure 42, features two mating lobe-type rotors mounted in a case. The lobes are gear driven at close clearance, but without metal-to-metal contact. The suction to the unit is located where the cavity made by the lobes is largest. As the lobes rotate, the cavity size is reduced, causing compression of the vapor within. The compression continues until the discharge port is reached, at which point the vapor exits the compressor at a higher pressure.
The rotary liquid seal ring-type, illustrated in figure 43, features a forward inclined, open impeller, in an oblong cavity filled with liquid. As the impeller rotates, the centrifugal force causes the seal liquid to collect at the outer edge of the oblong cavity.

Source: DOE-HDBK-1018/2-93

Figure 42. Rotary lobe air compressor

Due to the oblong configuration of the compressor case, large longitudinal cells are created and reduced to smaller ones. The suction port is positioned where the longitudinal cells are

Source: DOE-HDBK-1018/2-93

Figure 43. Rotary liquid seal air compressor
the largest, and for the discharge port, where they are smallest, thus causing the vapor within
the cell to compress as the rotor rotates. The rotary liquid seal compressor is frequently used
in specialized applications for the compression of extremely corrosive and exothermic gasses
and is commonly used in commercial nuclear plants as a means of establishing initial
condenser vacuum.

Centrifugal Compressors
The centrifugal compressor, originally built to handle only large volumes of low pressure gas
and air, has been developed to enable it to move large volumes of gas with discharge
pressures up to 3,500 psig. However, centrifugal compressors are now most frequently used
for medium volume and medium pressure air delivery. One advantage of a centrifugal pump
is the smooth discharge of the compressed air.

The centrifugal force utilized by the centrifugal compressor is the same force utilized by the
centrifugal pump. The air particles enter the eye of the impeller, designated D in figure 44.

Source: DOE-HDBK-1018/2-93.

Figure 44. Simplified centrifugal pump

As the impeller rotates, air is thrown against the casing of the compressor. The air becomes
compressed as more and more air is thrown out to the casing by the impeller blades. The air
is pushed along the path designated A, B, and C in figure 44. The pressure of the air is
increased as it is pushed along this path. Note in figure 44 that the impeller blades curve
forward, which is opposite to the backward curve used in typical centrifugal liquid pumps.
Centrifugal compressors can use a variety of blade orientation including both forward and
backward curves as well as other designs. There may be several stages to a centrifugal air
compressor, as in the centrifugal pump, and the result would be the same; a higher pressure
would be produced. The air compressor is used to create compressed or high pressure air for
a variety of uses. Some of its uses are pneumatic control devices, pneumatic sensors, pneumatic valve operators, pneumatic motors, and starting air for diesel engines.

**Moisture Separator**
The following is taken from Flowserve, Moisture Separator Drains.

Moisture separators are used to remove as much moisture from the steam as possible before it goes to the turbine. In boiling water reactors the steam going to the turbines is close to saturated conditions. In pressurized water reactors the steam going to the low-pressure turbines also passes through moisture separators. If moisture in the form of water droplets enters the turbine it causes erosion damage to the turbine blades. The condensate that accumulates in the moisture separators is drained off to be used in feed water heaters or forwarded to the condenser.

**Intercooler**
The following is taken from DOE-HDBK-1018/2-93.

If a compressor is multi-staged, there may be an intercooler, which is usually located after the first stage discharge and before the second stage suction. The principle of the intercooler is the same as that of the aftercoolers. The result is drier, cooler, compressed air.

**Aftercooler**
The following is taken from DOE-HDBK-1018/2-93

Coolers used on the discharge of a compressor are called aftercoolers. Their purpose is to remove the heat generated during the compression of the air. The decrease in temperature promotes the condensing of any moisture present in the compressed air. This moisture is collected in condensate traps that are either automatically or manually drained.

**Receiver**
The following is taken from Plant Services, The Compressed Air Receiver: The Endless Question.

Classic purposes for an air receiver are

- Pressure stabilization: A receiver delivers or stores short-term demand that either exceeds or is less than compressor capacity. A pressure change of one atmosphere (less than 15 pounds per square inch [psi]) accommodates a free air volume equal to that of the receiver.
- Compressor control: Receivers with ample volume reduce and slow pressure changes in response to intermittent compressed air use. Compressor controls, normally responding to pressure, smoothly regulate output without frequent ranging through their full control span.
- Pulsation dampening: An ample receiver reduces the probability of excess compressor power or shortened service life resulting from resonant response to the frequency of compressor delivery. Providing a receiver near the compressor discharge dampens pressure pulses from positive displacement compressor (rotary or reciprocating) to a small fraction of their original value.
Separation: A receiver, with its reduction in flow velocity, encourages finely divided particles of liquid lubricant or condensate to drop out of the air stream. Separated liquids drain from the receiver rather than traveling with the compressed air or gas to yield adverse downstream effects.

Air Dryer
The following is taken from GlobalSpec, Compressed Air Dryers.

Compressed air dryers are used to remove water and other contaminants from compressed air. Compressed air dryers use technologies such as refrigeration, desiccant adsorption, and membrane filtration to remove contaminants, particularly water, from the air. Major groupings include refrigerant (which removes the water by cooling the air) force condensation, and desiccant (which adsorbs the water in the air with granular material such as activated alumina, silica gel and molecular sieves). Other technologies include membrane and in-line compressed air dryers. The air can be dried in single or multiple stages to prevent tool corrosion and other problems associated with water.

Important specifications to consider when searching for compressed air dryers include drying capacity, maximum pressure, minimum output dewpoint, motor power, and operating temperature. Drying capacity is the maximum volume of air through dryer; typically given at 100 psig. The maximum pressure refers to the maximum rated inlet pressure of dryer. Dew point is a measure of dryness; it describes how much water vapor is present and tells us how cold the compressed air can get before liquid water will form. Motor horsepower is a reference value often used to approximate dryer size; pressure and capacity are the differentiating specifications. The operating temperature is the full-required range of ambient operating temperature.

f. Describe the basic operation of pressure regulating, temperature control, and flow control valves in a process system.

The following is taken from Hydraulic Power System Analysis by Arthur Akers, Max Gassman, and Richard John Smith.

Power at any point in a hydraulic system can be determined by multiplying the fluid flow by the pressure drop across a section of the machine. Flow is produced by an appropriate hydraulic pump. Pressure is the result of restriction in the system caused by fluid viscosity, system geometry, and power output. Because the hydraulic pumps that are used in fluid power systems are of the positive displacement type, pressure will develop up to a preset regulated value. This desired pressure value is controlled by an appropriately designed pressure regulating valve.

All hydraulic power systems must have at least one of these valves. The function of this valve is to establish the maximum pressure that will develop in the system. The pressure developed in a system will at all times be large enough to overcome circuit resistance and provide desired output power. Without a pressure regulating valve system pressure could rise until failure of machine parts occurs.
Flow Control Valves
The following is taken from DOE-HDBK-1018/2-93.

A flow control valve is a mechanical device that controls the flow of fluid and pressure within a system or process. A valve controls system or process fluid flow and pressure by performing any of the following functions:

- Stopping and starting fluid flow
- Varying (throttling) the amount of fluid flow
- Controlling the direction of fluid flow
- Regulating downstream system or process pressure
- Relieving component or piping over pressure

There are many valve designs and types that satisfy one or more of the functions identified above. A multitude of valve types and designs safely accommodate a wide variety of industrial applications.

Regardless of type, all valves have the following basic parts: the body, bonnet, trim (internal elements), actuator, and packing.

g. Describe the basic operation of a heat exchanger used in a process system.

The following is taken from DOE-HDBK-1012/2-92.

The transfer of thermal energy between fluids is one of the most important and frequently used processes in engineering. The transfer of heat is usually accomplished by means of a device known as a heat exchanger. Common applications of heat exchangers in the nuclear field include boilers, fan coolers, cooling water heat exchangers, and condensers.

The basic design of a heat exchanger normally has two fluids of different temperatures separated by some conducting medium. The most common design has one fluid flowing through metal tubes and the other fluid flowing around the tubes. On either side of the tube, heat is transferred by convection. Heat is transferred through the tube wall by conduction.

Heat exchangers may be divided into several categories or classifications. In the most commonly used type of heat exchanger, two fluids of different temperature flow in spaces separated by a tube wall. They transfer heat by convection and by conduction through the wall. This type is referred to as an ordinary heat exchanger, as compared to the other two types classified as regenerators and cooling towers.

An ordinary heat exchanger is single-phase or two-phase. In a single-phase heat exchanger, both of the fluids (cooled and heated) remain in their initial gaseous or liquid states. In two-phase exchangers, either of the fluids may change its phase during the heat exchange process. The steam generator and main condenser of nuclear facilities are of the two-phase, ordinary heat exchanger classification.

h. Describe the basic design and operation of a typical heating, ventilation, and air conditioning (HVAC) system.

The following is taken from Hvachome. What is HVAC?
The primary use of HVAC is to regulate room temperature, humidity, and air flow, ensuring that such elements remain within their acceptable ranges. Effective control of such factors minimizes health-related risks. A very humid atmosphere impairs the body’s ability to regulate body temperature as it prevents the evaporation of sweat. High humidity also decreases physical strength, which usually leads to fatigue. An unhealthy surrounding can also affect people’s thinking abilities. Hypothermia, heat stroke, and hyperpyrexia, among others, are some of the illnesses that may also occur.

Three Functions of HVAC

Heating is significant in maintaining adequate room temperature especially during colder weather conditions. There are two classifications of heating: local and central. The latter is more commonly used because it is more economical. Furnace or boiler, heat pump, and radiator make up the heating system.

Ventilation, on the other hand, is associated with air movement. There are many types of ventilation, but they all function similarly. Ventilation is necessary to allow carbon dioxide to go out and oxygen to get in, making sure that people are inhaling fresh air. Stagnant air causes the spreading of sickness, usually airborne, and allergies. But it is also essential to maintain an efficient ventilation system, especially in the attics. Insufficient ventilation usually promotes the growth of bacteria and fungi such as molds because of high humidity. It will also decrease the effectiveness of rafter and roof sheathing insulation because of water vapor condensation.

The air-conditioning system controls the heat as well as ventilation. They often come in different sizes. Most air conditioners have large air ducts, so it is better to check out the building first to see if they can be installed. Or else, you can use the split system or remote coils. It is necessary, though, that air ducts are properly cleaned. Pathogens thrive in dirty air ducts. Return-air grills are also vulnerable to chemical, microbiological, and radiological elements. Thus, HVAC return-air grill height should be that it is not accessible but visible for any observation.

24. Construction management personnel shall demonstrate a familiarity level knowledge of mechanical system/component installation.

a. Discuss the following elements and components of mechanical system piping design. Include a discussion of construction methods used in the installation of each component:
   - Pipe hangers
   - Piping supports
   - Snubbers
   - Piping insulation and vapor barriers
   - Piping installation
   - Piping anchors
   - Piping material
   - Field routing of piping
   - Expansion joints
Pipe Hangers and Piping Supports
The following is taken from GlobalSpec, Pipe Hangers and Pipe Supports.

Pipe hangers and pipe supports include clevis hangers, beam clamps, pipe clamps, brackets, pipe straps and other accessories that hold or support pipes in place. Pipe hangers can be used as anchor points to control expansion. In a piping system, devices such as valves, heavy flanges and pumps should be supported independently. Typically, a pipe hanger is suspended from a beam or other structural support above the pipes. By contrast, a pipe support rests or is secured to a floor or other structural support below the pipes. A pipe clamp can be attached in any direction, typically to a wall or other upright structural support. A pipe strap can support pipe and in some cases provide additional strength to the pipe wall, as in a temporary repair. A pipe bracket is a plate or tube that holds pipe in place. An industrial pipe hanger is designed for long service in harsh conditions, such as extreme temperatures, corrosive environments, and heavy vibrations.

Specifications for pipe hangers and pipe supports include pipe size, maximum recommended load, weight, and material of construction. Most products are made of fiberglass, steel, or stainless steel. Some pipe hangers and pipe supports are corrosion-resistant, non-conductive, or flame-retardant. Others conform to iron pipe size dimension standards or are available in special colors. Products with custom sizes are also commonly available.

Snubbers
The following is taken from HVAC Principles and Application Manual, Thomas E. Mull.

The main intent of snubbers is to prevent non-structural items in a building, such as HVAC equipment, from becoming lethal missiles in the event of an earthquake. Earthquakes can cause equipment to break loose and fall from a ceiling or slide across a floor when the ground shakes a building and its contents. In addition to the lethal missile problem, it is also important to keep building mechanical systems in operation during and after an earthquake. The attachment (or seismic restraint) of equipment must have sufficient strength to transmit the forces during an earthquake, or it must provide sufficient isolation to allow for the induced motion of the equipment.

There are two general methods for restraining equipment such as HVAC and other mechanical equipment. The first method is to rigidly attach the equipment to the building structure to prevent any movement. In such an arrangement, the supporting members used to attach the equipment to the building structure must be strong enough to withstand the forces that would be expected in the event of an earthquake. Rigidly attaching equipment to the building structure has some disadvantages. The second method is the isolation approach, in which equipment is provided with sufficient space and the support has sufficient flexibility to reduce the possibility of excessive motion of the equipment. This method usually employs restraints to limit the travel of the equipment.

Piping Insulation and Vapor Barriers
Piping Insulation
The following is taken from Integrated Publishing, Engineering, Pipe Insulation.
The main purpose of insulating pipelines is to prevent heat passage from steam or hot-water pipes to the surrounding air or from the surrounding air to cold-water lines. In some cold regions, insulation also prevents water from freezing in a pipe, especially when the pipe runs outside a building. Thus, hot-water lines are insulated to prevent loss of heat from the hot water, while potable waterlines are insulated to prevent absorption of heat in drinking water. Insulation also subdued noise made by the flow of water inside pipes, such as water closet discharges.

Vapor Barrier
The following is taken from Building Science Digest, BSD-106, *Understanding Vapor Barriers*.

The function of a vapor barrier is to retard the migration of water vapor. Where it is located in an assembly and its permeability is a function of climate, the characteristics of the materials that comprise the assembly and the interior conditions. Vapor barriers are not typically intended to retard the migration of air. That is the function of air barriers.

Confusion on the issue of vapor barriers and air barriers is common. The confusion arises because air often holds a great deal of moisture in the vapor form. When this air moves from location to location due to an air pressure difference, the vapor moves with it. This is a type of migration of water vapor. In the strictest sense air barriers are also vapor barriers when they control the transport of moisture-laden air.

*Piping Installation*
The following is taken from DOE-HDBK-1132-99.

The following design guidelines should be considered in the physical routing and design of piping systems. These guidelines are a compilation of design, construction, startup, and operating experiences.

**General**
Where continuous services are required, service headers should be looped and appropriately valved to maintain service during routine maintenance or system modification.

Service piping should be extended from horizontal service headers. Piping should be located outside of hazardous areas whenever possible to reduce personnel exposure during maintenance.

Adjacent facility walls and floors should not be penetrated in cases where routine maintenance or alterations of service piping would result in undesirable curtailment or interruption of operations in other adjacent facilities.

**Clearances**
Adequate clearances should be provided between pipe and other piping systems, ductwork, structural steel and concrete, equipment, and cable trays to permit interference-free erection and allow for maintenance and in-service inspection and reduces the possibility of impact during a seismic event.
Proper clearances will allow for the removal of valves and other equipment. Piping should not be routed across floors, walkways, or working spaces if that location could be a hazard.

Overhead clearance to the bottom of piping or pipe racks should address the following guidelines:
- 7 feet, 6 in. over walkways inside buildings,
- 15 feet elevated yard piping and/or pipe racks over roadways,
- 22 feet over railroad tracks.

Vents and Drains
Vents and drains facilitate the filling, hydrostatic testing, and draining of piping systems. The following guidelines provide the piping system with adequate venting and draining:
- Where possible, the piping system should be designed with only one high point and one low point; vent and drain connections should be provided at these locations.
- Liquid systems 2.5 in. and larger in diameter should be vented and drained at all high and low points. Liquid systems 2 in. and smaller in diameter should be vented and drained at the highest and lowest points in the system. Piping of this size self-purges any intermediate high and low points.
- In steam, air, and gas systems, the blowdown connections at all low points may serve as drains and the branch connections off the top of piping headers may serve as vents.
- Vent and drain connections are not required when their function is filled by system branch connections, equipment vents, and drains or instrument connections.

Lined Pipe
Special considerations should be given to the design of piping systems lined with materials such as rubber, cement, glass, or epoxy. The following guidelines should be considered in the fabrication and erection of such piping systems:
- Maximum spool lengths of lined pipe vary among suppliers.
- The method of joining may be flanged, mechanical joint, screwed, or welded prior to lining. Welding after the lining is installed is generally not permitted.
- When using butterfly valves, consider a potential interference between the valve disk and lining material, which decreases the inside diameter of the pipe.

Freeze Protection
In cold climates external piping should be provided with freeze protection. Preventing piping systems from freezing can eliminate costly repairs and system outages. Freeze protection typically consists of either steam or electric heat tracing. Economic considerations dictate which method is selected.

Avoid routing piping along the inside of exterior building walls or uninsulated siding in cold climates. Where possible, route piping near radiant heat sources to prevent freezing.

Review the location of steam relief valve vent stacks to ensure that the condensing vapor does not cause ice to form on nearby equipment, walkways, or roads.

Consider local area frost penetration when designing underground piping.
Piping at Pumps
Piping configurations at pumps require special considerations to ensure the safe and effective operation of the pump.

Proper piping layout permits the suction and the discharge pipes to be supported independently of the pump so that little load is transmitted to the pump casing.

Reductions in pipe size at the pump should be made with an eccentric reducer flat side up.

Startup strainers necessary near pumps should have adequate space for installation.

Expansion Joints
Metallic or rubber bellows-type expansion joints should be used in the design of piping systems in the following instances:
- To absorb the thermally induced dimensional changes in the piping system;
- To minimize the stresses and moments in the system;
- To minimize the loads imposed on equipment nozzles;
- To reduce the recurring problem of rotating equipment misalignment due to nozzle loads, particularly at pumps;
- Where space is inadequate for a conventional flexible piping arrangement;
- Where a conventional piping arrangement would result in excessive pressure drop in the system;
- Where the economics favor the expansion joint over a conventional piping arrangement;
- To compensate for differential expansion of a pipe within a pipe or at flued heads.

Piping Containing Radioactive Materials
The routing of piping containing radioactive materials should consider the reduction of exposure levels to ALARA.

Piping that contains radioactive materials should not be routed through corridors. If necessary, shielding should be provided for the entire exposed run.

Piping that contains radioactive materials should be routed close to the floor, along walls, and away from the normal access areas to facilitate cleanup in case of failure.

Equipment or components in the room may be used as a shield. Piping that contains low or moderately radioactive material can be used to shield piping that contains highly radioactive material.

Shielded pipe chases or trenches should be used wherever possible.

Multiple blockouts may be used for piping containing low or moderately radioactive material. It is recommended that piping containing highly radioactive material should have individual pipe penetrations.

Pipe penetrations should be located so that no direct lines of sight exist from any source of radiation in a compartment to personnel in an adjacent compartment or corridor.
Isolation valves should be provided where radioactive material passes through compartments or rooms.

Piping that contains radioactive material should be routed so that no direct lines-of-sight exist through doorways or labyrinths.

In occupied areas, wall, ceiling, and floor penetrations should be provided shielding from piping containing radioactive materials.

Valves requiring frequent operation may be fitted with remote mechanical reach rods.

Remote valve operators should be located externally to the compartment housing the valve.

Stagnant or low-point pockets should be avoided in any radioactive piping system.

Restricting orifices or metering plates in piping systems containing radioactive materials should be located in vertical runs. They can be located in horizontal runs if drains are provided on both sides of the instrument.

The piping system should be designed to preclude solids from settling in the piping.

Process lines should be free-draining to prevent fluid accumulation in traps. In cases where low points or traps cannot be prevented by design, a drain and collection system should be provided at each low point.

Encasement piping should drain into the process pit in which it terminates. Encasement piping for process lines connecting valve pits or diversion boxes should be equipped with leak detection systems. In cases where more than one pipeline terminates in a valve pit or diversion box, the leak detection system should be designed with the capability of identifying which line is leaking.

Primary process piping and encasement piping should be provided with capabilities for periodic pressure testing. The design should restrict the use of freeze plugs for pressure testing.

Transfer lines terminating at a tank should be provided with pressure testing capabilities.

Primary and secondary piping should be supported and anchored. Supports should be adequate to carry the weight of the lines and maintain proper alignment.

Pipe guides and anchors should be provided to keep pipes in accurate alignment; direct the expansion movement; and prevent buckling, swaying, and undue strain. Spider-type supports should be provided inside the encasement piping to permit leak detection.

Process piping carrying radioactive material should be buried underground or otherwise shielded to provide radiation protection.

Process piping should be equipped with valves at appropriate locations to facilitate maintenance within ALARA guidelines.
Piping and equipment containing radioactive material should be designed for ease of decontamination during operations and for ease of decommissioning after the building life cycle.

Valves
Valves should be located in systems to provide proper isolation for maintenance tasks, normal operations, and reduced radiation exposure.

Consideration should also be given to provide future expansion of the system without major system outages.

Particular attention to valve installation and positioning is recommended to avoid head and knee injuries, eye injuries (due to the presence of valve stems in the horizontal plane at eye level), and dripping hazards.

Valve access is best accomplished in the natural routing of pipe from point to point, avoiding the use of vertical loops and pockets. Control valves should be located adjacent to walkways wherever possible. (Access platforms should be provided where valves are otherwise inaccessible.)

Only infrequently operated valves should be located so that the bottom of the hand wheel is more than 6 feet, 6 in. above a floor or platform.

A minimum of 4 in. of knuckle clearance is recommended around hand wheels.

Chain-wheel operators can be used as long as they do not present a hazard to operating personnel.

Control valves should be located near the operating equipment to be observed while on local manual control.

Control valve manifolds should have a minimum of at least three diameters of straight pipe both upstream and downstream of the control valve.

Concentric reducers are recommended to make size reductions at the control valve.

*Piping Anchors*
The following is taken from DOE-HDBK-1132-99.

Primary and secondary piping should be supported and anchored. Supports should be adequate to carry the weight of the lines and maintain proper alignment.

Pipe guides and anchors should be provided to keep pipes in accurate alignment; direct the expansion movement; and prevent buckling, swaying, and undue strain. Spider-type supports should be provided inside the encasement piping to permit leak detection.

*Piping Material*
The following is taken from DOE-HDBK-1132-99.
Selection of an appropriate corrosion/erosion allowance is vital to the service life of the system. Consideration of effects of temperature and fluid velocities is very important in selecting and sizing the system properly. For example, carbon steel piping may be acceptable for sulfuric acid when the concentrations are above 93 percent, flow rates are below 3 feet/sec, and the temperature is below 122 °F.

Piping systems that perform safety-related functions are to be designed and fabricated to more rigorous standards than other fluid service piping.

In accordance with ASME B31.3, Process Piping, Category M Fluid Service may be designated for design, material and component selection, fabrication and erection, and examination and inspection of these systems. Certified material test reports for material and components provide additional assurance for these piping systems.

Field Routing of Piping
Refer to the discussion about piping installation in this KSA for a discussion of routing of piping.

Expansion Joints
The following is taken from DOE-HDBK-1132-99.

Metallic or rubber bellows-type expansion joints should be used in the design of piping systems in the following instances:
- to absorb the thermally induced dimensional changes in the piping system;
- to minimize the stresses and moments in the system;
- to minimize the loads imposed on equipment nozzles;
- to reduce the recurring problem of rotating equipment misalignment due to nozzle loads, particularly at pumps;
- where space is inadequate for a conventional flexible piping arrangement;
- where a conventional piping arrangement would result in excessive pressure drop in the system;
- where the economics favor the expansion joint over a conventional piping arrangement;
- to compensate for differential expansion of a pipe within a pipe or at flued heads.

b. Discuss the following types of piping connections and their application to different piping sizes and uses:
- Threaded connections
- Flanged connections
- Socket welded connections
- Butt welded connections
- Re-weldable joints
- Bayonet joints
- Compression joints

Threaded Connections
The following is taken from Industrial Maintenance by Michael E. Brumbach, Jeffrey A. Clade.
The American Standard Pipe and the American Standard Pipe Thread were formed in 1862 in an effort to standardize the sizes of pipes and the threads on pipes. This was to ensure that all piping systems that were installed and threaded were of the same dimensions. If this had not been accomplished, there would be different types of threads, which would cause the fitting of one manufacturer and the fitting from another not to be interchangeable. The standard thread that is used on piping today is known as a V-thread. The angles of the threads are at 60º. The threads are tapered to provide a watertight seal to keep fluid contained within the piping system. The taper of the threads is 1/32 inch per inch of length.

The seven threads closest to the end of the pipe should be perfect threads. The crest and the root of the thread should be clean, with a definite sharpness. The taper will begin on the next two or three threads. For these two or three threads, the crest of the thread is slightly rounded, while the root of the thread still remains sharp. The remaining threads are referred to as the starting threads and therefore do not provide any sealing capabilities.

**Flanged Connections**
The following is taken from American Ductile Iron Pipe, Flanged Pipe Description, Details and Accessories.

Flanged pipe is generally specified for aboveground service for air, water, sewage, oil and other liquids where rigid, restrained joints are needed. It is widely used in industrial piping systems, water treatment plants and sewage treatment plants, and for other interior piping.

Long runs of flanged pipe should normally include design provisions for thermal expansion and contraction, such as flexible joints or couplings at strategic intervals.

Pipe may be furnished with one end flanged and the other end with Fastite bell, mechanical joint bell, restrained joint bell, plain end, grooved or shouldered end, or with other type end as may be required.

The underground use of the flanged joint is generally not recommended due to the rigidity of the joint.

**Socket-Welded Connections**
The following is taken from *Engineering Drawing and Design* by David A. Madsen.

The socket-welded connection is used on pipe 2 in. and smaller. It forms a reliable leak-proof connection. The pipe has plain end preparation and slips into the fitting. One exterior weld is required, thus no weld material protrudes into the pipe. Since the pipe is slipped inside the fitting, the connection is self-aligning. Socket welding small diameter pipe is less expensive than other welded systems.

**Butt-Welded Connections**
The following is taken from *Engineering Drawing and Design* by David A. Madsen.

Butt welding is the most common method of joining pipes used in industry today. It is used on steel pipe 2 in. in diameter and more to create permanent systems.
Butt-welded pipe and fitting provide a uniform wall thickness throughout the system. The smooth inside surface creates gradual direction changes, thus generating little turbulence. One circumferential weld is required to join two pieces of pipe. The weld is strong, leak-proof, and relatively maintenance free. Pipe joined in this manner is self-contained, withstands high temperature and pressure is easy to insulate, and requires less space for construction and hanging than do other methods.

Pipe and fittings joined by butt welding are prepared with a beveled end. This type of end preparation provides space for the welding operation.

**Re-Weldable Joints**
According to DOE Order 6430.1A, re-weldable joints featuring an outer can welded to sealed closure rings may be used where periodic but infrequent disassembly is required.

**Bayonet Joints**
The following is taken from H₂ Safety Best Practices, Glossary.

The bayonet joint is a high-performance joint originally developed by Dr. Herrick L. Johnston (J.C. Daunt and H.L. Johnston (1949). The bayonet joint is used for lines that must be dismantled frequently or for applications in which a low heat in leak at the joint is required. The bayonet joint consists of a male portion that telescopes within the female portion. The clearance between the male and female portions is made such that no liquid can flow into the space, and gaseous convection is suppressed.

**Compression Joints**
The following is taken from Creative Homemaker, Projects Online: Forming a Compression Joint.

A compression joint makes use of special fittings to make a watertight seal on a plumbing line that may need to be taken apart at some future time, or on a line that is in a place where it is either unsafe or too difficult to make a soldered joint. Faucet and toilet water-supply line connections are typically made with compression fittings. These special fittings are a compression nut and a compression ring (ferrule). As the name suggests, while the compression nut is being tightened, it presses against a rubber, plastic, brass, or copper compression ring, making the ring sit tightly against the copper tubing and the nut. This type of joint works particularly well with copper tubing because copper is softer and more malleable than other pipe materials.

c. Describe the basic construction methods and precautions associated with the installation of the following types of mechanical components:

- Large pumps
- Heat exchangers
- Air conditioning units
- Compressors
- Tanks and pressure vessels
**Large Pumps**

The following is taken from *Integrated Engineering/Construction Projects: Proposal to Completion* by Edward Dansker.

The size of the pumps in a plant can range from fractional horse-power to several hundred-horse power. A pump with a 1800 horsepower (HP) turbine could weight in the area of 14 tons. This is a large size for a pump. One top 3 tons is closer to the average. Because of the volatile nature of the vapors and liquids in a petroleum-based process plant, the ambient atmosphere can also have volatile characteristics, possible as the result of slight leaks in the piping systems, or from exhaust systems that sometimes expel volatile vapors and gases. Therefore, the electric motors used to drive the pumps must be impervious to this volatile atmosphere.

The motor’s design is based on very strict specifications and is specified to be explosion proof, or totally enclosed fan cooled, when used in such a volatile service or area. Similar precautions extend to the electrical wiring connecting the pump to its power source, using special fittings and cable that would preclude any electric sparking during pump operations. Motors 10 HP and larger are normally delivered to the site separate from the pump, and usually from a different vendor. This is another situation requiring coordinated planning and scheduling.

The task of setting the pumps and their drivers is performed by millwrights. This is a very exacting operation and requires craftsmen skilled in the use of extremely accurate and sensitive tools and gauges.

The field engineer will provide the millwright with the center line of the pump that is the center of the pump drive shaft. The center line in the other direction can be the center of either the suction or discharge nozzle. The field engineer will also provide an elevation mark related to the center of either the suction or discharge nozzle, or to the center of the drive shaft. These base lines are usually scratched onto the pump foundation, so that they are permanent, and they are set to a very close tolerance. Because the elevation of the center of the suction or discharge nozzles of the pump is above the elevation of the pump foundation, the elevation mark placed on the foundation must be some fixed dimension below the center of the nozzle. This amount is determined by the field engineer and the millwright foreman. With these reference lines now established, the millwright will set the pump base, line up and level its drive shaft, and then connect the pump drivers to the drive shaft. Before the motor is connected to the drive shaft, the millwright will turn it over to be assured that the motor is rotating in the correct direction.

A pump operating at about 3600 revolutions per minute can cause a great amount of vibration, not only to itself, but to the piping and instrumentation systems connected to it, if it has not been exactly lined and leveled. In the normal running of a pump there will always be some vibration. But such normal vibration is tolerable. More important though, is the fact that the pump cannot tolerate the weight of the piping that is connected to its suction and discharge nozzles. These weights can induce loads and pressures on the pump that may interfere with its operation, and possible cause physical damage. For this reason the piping connected to the pumps must be stress relieved. The piping must be so supported that its weight will not be transmitted to the pump. This is accomplished by the use of special pipe
hangers and supports that will not only keep the pump free of the piping weight, but will also assist the flanged connections to it to remain tight.

As with all other equipment supported on concrete foundations, when a pump has finally been adjusted to its correct location, it is then fixed in lace with grout. Note that one method commonly used to level the pump base is by the use of leveling nuts placed on the pump foundation anchor bolts. With the pump base place on these anchor bolts, the proper elevation of the pump base can be obtained by turning the leveling nuts until the pump base reaches its specified elevation.

Heat Exchangers
The following is taken from DOE-HDBK-1018/1-93.

Although heat exchangers come in every shape and size imaginable, the construction of most heat exchangers fall into one of two categories: tube and shell, or plate. As in all mechanical devices, each type has its advantages and disadvantages.

Tube and Shell
The most basic and the most common type of heat exchanger construction is the tube and shell, as shown in figure 45.

Source: DOE-HDBK-1018/1-93

Figure 45. Tube and shell heat exchanger
This type of heat exchanger consists of a set of tubes in a container called a shell. The fluid flowing inside the tubes is called the tube side fluid and the fluid flowing on the outside of the tubes is the shell side fluid. At the ends of the tubes, the tube side fluid is separated from the shell side fluid by the tube sheet(s). The tubes are rolled and press-fitted or welded into the tube sheet to provide a leak tight seal. In systems where the two fluids are at vastly different pressures, the higher pressure fluid is typically directed through the tubes and the lower pressure fluid is circulated on the shell side. This is due to economy, because the heat exchanger tubes can be made to withstand higher pressures than the shell of the heat exchanger for a much lower cost. The support plates shown on figure 45 also act as baffles to direct the flow of fluid within the shell back and forth across the tubes.

Plate
A plate type heat exchanger, as illustrated in figure 46, consists of plates instead of tubes to separate the hot and cold fluids.

Source: DOE-HDBK-1018/1-93

Figure 46. Plate heat exchanger

The hot and cold fluids alternate between each of the plates. Baffles direct the flow of fluid between plates. Because each of the plates has a very large surface area, the plates provide each of the fluids with an extremely large heat transfer area. Therefore a plate type heat exchanger, as compared to a similarly sized tube and shell heat exchanger, is capable of
transferring much more heat. This is due to the larger area the plates provide over tubes. Due to the high heat transfer efficiency of the plates, plate type heat exchangers are usually very small when compared to a tube and shell type heat exchanger with the same heat transfer capacity. Plate type heat exchangers are not widely used because of the inability to reliably seal the large gaskets between each of the plates. Because of this problem, plate type heat exchangers have only been used in small, low pressure applications such as on oil coolers for engines. However, new improvements in gasket design and overall heat exchanger design have allowed some large scale applications of the plate type heat exchanger. As older facilities are upgraded or newly designed facilities are built, large plate type heat exchangers are replacing tube and shell heat exchangers and becoming more common.

**Air Conditioning Units**

The following is taken from Consulting-Specifying Engineer, Understanding NFPA’s Standard 90A for Air Conditioning and Ventilation Systems.


Divide the work. Architects and structural engineers on the project team will define the massing, compartmentalization, interior construction details, means of egress, function of the ceiling and raised floor plenums, and fire and smoke separations for inclusion in the project’s code-compliance drawings.

Critical to successful building systems integration, all project changes must be documented in the code-compliance drawings so team members can continually reassess impacts on their systems. Even a subtle change in design can compromise the HVAC system and its life safety features, not to mention initiating a change order that affects contract values and schedules.

Define the HVAC system. Defining ingredients that make up the HVAC system is crucial to 90A compliance. Screen requirements for outdoor air intakes, flame-spread and smoke-developed product index ratings; access panel requirements in ductwork; flexible duct connector length restrictions; and protection for exposed fan inlets are all details that need to be documented in project specifications.

Taking it a step further, 90A requires drawing of fan arrangements for proper inspection and maintenance, identifying specific locations of air outlets, inlets and light fixtures used as return air paths, and indicating fan rooms used as an extension of ceiling plenums or used as a return air path.

Seemingly insignificant details can affect the HVAC system design. For example, the need to provide access panels in return and exhaust system ductwork affects the integrity of the ductwork itself, i.e., one needs to estimate how much more duct leakage will occur and provide fan capacity accordingly.

Integrate all the systems. Superimposing HVAC infrastructure on architectural and structural systems is where the fun begins. Protection of duct, pipe and conduit penetrations in fire-rated walls and partitions, floors, roof-ceiling assemblies, shafts and smoke barriers is a focus...
of 90A. The standard includes a handy diagram outlining a couple dozen of the most common penetrations in these building components.

Next, make sure that fan rooms comply with all requirements. This is particularly important for rooms that house fan systems serving multiple floors with ducts routed into vertical shafts. Standard 90A dictates which ducts can share shaft space with each other. For example, kitchen exhaust duct risers cannot be installed in the same shaft as supply and return air duct risers. Note: When this situation is met in an existing building, there are techniques that can be implemented to achieve separation without having to reconstruct shafts and duct risers, including special duct wraps for kitchen exhaust duct risers.

Requirements for fire and smoke dampers and combination fire/smoke dampers in smoke barriers are also outlined in 90A as well. Fire dampers need to be installed in the plane of the wall, partition or floor and must be rated for dynamic conditions. Smoke dampers can be installed up to 2 feet away from the smoke barrier (the concept is that the duct itself provides some protection from the passage of smoke). Access panels must be provided in the ductwork of all fire and smoke dampers and combination fire/smoke dampers, and they must be installed immediately adjacent to the device.

Additionally, there may be cases where project architects and structural engineers choose to extend a fire-rated shaft below the elevation of a floor slab in order to protect a duct riser. When the shaft is extended down into the ceiling plenum of the floor below, a fire damper can be installed in its vertical plane, instead of having to install it in the floor slab, making installation and maintenance easier.

The 90A standard also lists specific requirements for the provision of smoke dampers in an air-handling unit (AHU), as opposed to smoke dampers out in the duct distribution portion of the system as discussed above. Smoke dampers are required in HVAC systems with a capacity greater than 15,000 cubic feet per minute (cfm) in order to isolate the AHU from duct distribution. The smoke damper on the return side of the system should be installed upstream of its fan. The smoke damper on the supply side of the system should be installed downstream of its supply fan. Exceptions include systems located on the floor that they serve exclusively, as well as systems positioned on a roof that control only the floor immediately below.

Finally, 90A defines a need for duct-mounted smoke detectors downstream of all filters, but upstream of all branch takeoffs for supply fans with capacities greater than 2,000 cfm. The same goes for those of return fans with a capacity greater than 15,000 cfm. Additionally, duct-mounted smoke detectors also are required in each return duct inlet that serves more than one story for systems with a capacity of greater than 15,000 cfm. These smoke detectors also should be able to sense smoke on a particular floor of multi-story building. Duct-mounted smoke detectors, however, are not required in a return air system if the spaces served by the HVAC system are protected by ceiling-mounted smoke detectors. Duct-mounted smoke detectors are also not required downstream of exhaust fans.

Sequence of operation. Once all system components have been furnished and installed, engineers need to help clients and contractors understand how life safety systems work. The 90A standard requires smoke dampers installed at the AHU to close automatically when the
HVAC system is not in operation. Activation of any duct-mounted smoke detector noted above shall automatically stop the fans associated with the HVAC system and close the smoke dampers, unless the system is intended to function as part of an engineered smoke control system.

Last but not least, acceptance testing is required in order for all parties to confirm that the systems have been installed and are operating according to design requirements. A form of commissioning, acceptance testing must occur even if the owner chooses not to have any other elective commissioning performed on other building systems.

Compressors
Refer to KSA 22e. for a discussion on the construction of compressors.

The following is taken from DOE-HDBK-1018/2-93.

Hazards of Compressed Air

People often lack respect for the power in compressed air because air is so common and is often viewed as harmless. At sufficient pressures, compressed air can cause serious damage if handled incorrectly. To minimize the hazards of working with compressed air, all safety precautions should be followed closely.

Small leaks or breaks in the compressed air system can cause minute particles to be blown at extremely high speeds. Always wear safety glasses when working in the vicinity of any compressed air system. Safety goggles are recommended if contact lenses are worn. Compressors can make an exceptional amount of noise while running. The noise of the compressor, in addition to the drain valves lifting, creates enough noise to require hearing protection. The area around compressors should normally be posted as a hearing protection zone.

Pressurized air can do the same type of damage as pressurized water. Treat all operations on compressed air systems with the same care taken on liquid systems. Closed valves should be slowly cracked open and both sides should be allowed to equalize prior to opening the valve further. Systems being opened for maintenance should always be depressurized before work begins.

Great care should be taken to keep contaminants from entering air systems. This is especially true for oil. Oil introduced in an air compressor can be compressed to the point where detonation takes place in a similar manner as that which occurs in a diesel engine. This detonation can cause equipment damage and personnel injury.

Tanks and Pressure Vessels

Tanks
The following is taken from DOE-HDBK-1132-99.

Shop-fabricated tanks should be a maximum of 12 feet in diameter to permit rail shipment with a preferred ratio of overall length to diameter of 2D to 4D. The maximum ratio of length to diameter is 6D.
Lube oil storage tanks should be located in a fire-rated room fitted with a sliding fire door or outside if the tanks are over 5,000 gallons. The door entrance can be elevated to create a diked area within the room capable of containing the volume of lube oil stored in the tank. All lube oil equipment should be located within this room. The room should include a sump, sump pump, and associated warning devices. Underground tanks should be double-lined with a low-point sump having a fluid detection device. The sump should be pumped to an oily water separator.

Condensate storage tanks are usually located outdoors, as close as possible to their points of connection to the condensate system. Elevation of these tanks should provide sufficient net positive suction head at any connected pump suction. If these tanks are located within a radiological area, they should be placed in a diked area to control contamination.

*Pressure Vessels*

The following is taken from American Society of Mechanical Engineers, *Boiler and Pressure Vessel Code*.

Section VIII, Division 1 of the ASME *Boiler and Pressure Vessel Code*, provides requirements applicable to the design, fabrication, inspection, testing, and certification of pressure vessels operating at either internal or external pressures exceeding 15 psig.

Such pressure vessels may be fired or unfired. Specific requirements apply to several classes of material used in pressure vessel construction, and also to fabrication methods such as welding, forging, and brazing.

It contains mandatory and nonmandatory appendices detailing supplementary design criteria, nondestructive examination, and inspection acceptance standards. Rules pertaining to the use of the U, UM and UV code symbol stamps are also included.

Section VIII, Division 2, Alternative Rules

This division of section VIII provides requirements applicable to the design, fabrication, inspection, testing, and certification of pressure vessels operating at either internal or external pressures exceeding 15 psig. Such vessels may be fired or unfired.

This pressure may be obtained from an external source or by the application of heat from a direct or indirect source, or any combination thereof.

These rules provide an alternative to the minimum requirements for pressure vessels under division 1 rules. In comparison to the division 1 requirements, division 2 requirements on materials, design, and nondestructive examination are more rigorous; however, higher design stress intensity values are permitted.

Section VIII, Division 3, High Pressure Vessels

This division of section VIII provides requirements applicable to the design, fabrication, inspection, testing, and certification of pressure vessels operating at either internal or external pressures generally above 10,000 psi.
Such vessels may be fired or unfired. This pressure may be obtained from an external source, a process reaction, by the application of heat from a direct or indirect source, or any combination thereof.

Division 3 rules cover vessels intended for a specific service and installed in a fixed location or relocated from work site to work site between pressurizations.

The operation and maintenance control is retained during the useful life of the vessel by the user who prepares or causes to be prepared the design specifications.

Division 3 does not establish maximum pressure limits for either section VIII, divisions 1 or 2, nor minimum pressure limits for this division. Rules pertaining to the use of the UV3 code symbol stamps are also included.

Division 2 rules cover only vessels to be installed in a fixed location for a specific service where operation and maintenance control is retained during the useful life of the vessel by the user who prepares or causes to be prepared the design specifications.

These rules may also apply to human occupancy pressure vessels typically in the diving industry. Rules pertaining to the use of the U2 and UV code symbol stamps are also included.

25. Construction management personnel shall demonstrate a familiarity level knowledge of the systems for industrial waste treatment, storm drains, and sanitary waste treatment.

a. Describe the basic design for a sanitary waste treatment system.

The following is taken from DOE-HDBK-1132-99.

Radioactive liquid waste facilities (RLWFs) store, treat, and dispose of radioactive liquid wastes generated by facilities and activities. This waste includes low-level, high-level, and transuranic-contaminated waste. An RLWF may be a separate facility or an adjunct to another facility. RLWFs may include waste treatment activities that separate solid and liquid waste constituents with provisions for disposing of noncontaminated waste.

Design Considerations
The design of RLWFs should consider the features described below. Design requirements vary significantly depending on waste characteristics, waste management techniques, and site characteristics.

- The use of multiple barriers should be emphasized when necessary to restrict the movement of radioactive liquid waste that has the potential for human contact or for reducing groundwater quality below requirements.
- Measurement and analysis capability should be provided to determine the volume and radioactivity of wastes fed to collection tank(s). Provisions should be made for analyzing liquids prior to transfer. Each transfer line should be identified individually. Instrumentation and control systems should be used to provide monitoring and control capabilities associated with confinement, nuclear criticality safety, and/or radiation protection.
- Individual lines should be used for each waste stream fed to central collection tanks, where necessary, to prevent chemical reactions or introduction of contaminants such as complexing agents that could interfere with waste decontamination. The use of traps in radioactive liquid waste lines should be avoided, and piping should be designed to minimize entrapment and build-up of solids in the system. Bypasses that would allow waste streams to be routed around collection tanks should be avoided. The radioactive liquid waste treatment system should contain no bypasses or drains through which waste may inadvertently be released directly to the environment.
- Basic liquid waste treatment concepts include volume reduction, immobilization of radioactive material, change of composition, and removal of radioactive material from waste. The waste treatment concept(s) for a particular application should be selected on a case-by-case basis. To the extent practical, features should be included to allow volume reduction and/or waste solidification (immobilization) to forms required for long-term isolation.
- Provisions should be made to adjust liquid waste characteristics prior to treatment to minimize adverse chemical reactions in the treatment system.
- Recirculating closed-loop cooling systems should be used for facilities and equipment associated with the storage or treatment of high-heat, high-level radioactive liquid waste.
- Provisions should be made for the continuous monitoring and recording of radioactivity, flow volume, pH, and other parameters required for material control and proper waste treatment operations while each volume of industrial waste is being received by an on-site treatment plant. This monitoring allows optimum control of waste treatment operations and helps prevent unintended off-site releases.
- Liquid process wastes containing radioactive or other hazardous material should be collected and monitored near the source of generation before batch transfer through appropriate pipelines or tank transfer to a liquid waste treatment plant or area. Radiation, liquid level, or conductivity detectors should be provided in collection systems. Monitoring not only provides information useful for planning efficient waste treatment operations, but also can serve as an indicator of unintended fluctuations in process operations.
- The airborne radioactive waste sources typically associated with RLWFs and radioactive solid waste facilities that should be considered during the design include but are not limited to radioactive liquid waste process vessel vents, high-level liquid radioactive waste collection and storage tank vents, airborne effluents from process system vents, and fission product gases. Effluent system designs should preclude the holdup or collection of fissile material or other material capable of sustaining a chain reaction in portions of the system that are not geometrically favorable. Nuclear criticality safety should be considered in the design of airborne effluent systems.
- Provisions should be made to handle combustible gasses generated during waste handling and/or storage.
- Consideration should be given to condensation and deposition of aerosols formed in vent lines.

b. Discuss the following methods of waste water treatment:
   - Primary
   - Secondary
   - Tertiary
The following is taken from Ohio State University, Wastewater Treatment Principles and Regulations.

*Primary Treatment*

Primary treatment is the second step in treatment and separates suspended solids and greases from wastewater. Waste-water is held in a quiet tank for several hours allowing the particles to settle to the bottom and the greases to float to the top. The solids drawn off the bottom and skimmed off the top receive further treatment as sludge. The clarified wastewater flows on to the next stage of wastewater treatment. Clarifiers and septic tanks are usually used to provide primary treatment.

*Secondary Treatment*

Secondary treatment is a biological treatment process to remove dissolved organic matter from wastewater. Sewage microorganisms are cultivated and added to the wastewater. The microorganisms absorb organic matter from sewage as their food supply. Three approaches are used to accomplish secondary treatment; fixed film, suspended film and lagoon systems.

*Tertiary Treatment*

The following is taken from the Water Encyclopedia, Wastewater Treatment and Management.

Tertiary wastewater treatment is additional treatment that follows primary and secondary treatment processes. It is employed when primary and secondary treatment cannot accomplish all that is required. For example, phosphorus removal may be needed for wastewaters that are discharged to receiving waters that are likely to become eutrophic, or enriched with nutrients. (Cultural or human-enhanced eutrophication often is associated with nitrogen and phosphorous in effluent.) Water reclamation is achieved in varying degrees, but only a few large-scale plants are reclaiming water to near-pristine quality.

c. Discuss the functions of the following components:
   - Clarifier
   - Trickling filters
   - Pumping station
   - Wet well

*Clarifier*

The following is taken from Water Treatment Plant, Water Clarifier/Clarification.

Clarifiers are used for the purpose of clarification of wastewater. Clarification is the widely accepted and the oldest used method in the effective treatment of water and wastewater. This operation includes removal of sediment, floating material and turbidity from raw wastewater. There are two types of clarifier. One is circular center feed clarifier that operates with the effluent entering through a center stilling well. It ensures proper residence time of the water in the clarifier to allow for the settling of the solids. The water rises and exits through a wall mounted weir. Other type of clarifier is the circular peripheral flow clarifier. It operates with the water flow entering the system at the periphery. The water flow is distributed evenly and spirals down around the annulus of the clarifier. It is done by means of a specially designed
baffle skirt. This configuration provides maximum settling of solids toward the sludge pick-up.

**Trickling Filter**
The following is taken from Water/Wastewater Distance Learning, Trickling Filters.

A trickling filter consists of a bed of highly permeable media on whose surface a mixed population of microorganisms is developed as a slime layer. The word "filter" in this case is not correctly used for there is no straining or filtering action involved. Passage of wastewater through the filter causes the development of a gelatinous coating of bacteria, protozoa and other organisms on the media. With time, the thickness of the slime layer increases preventing oxygen from penetrating the full depth of the slime layer. In the absence of oxygen, anaerobic decomposition becomes active near the surface of the media. The continual increase in the thickness of the slime layer, the production of anaerobic end products next to the media surface, and the maintenance of a hydraulic load to the filter, eventually causes sloughing of the slime layer to start to form. This cycle is continuously repeated throughout the operation of a trickling filter. For economy and to prevent clogging of the distribution nozzles, trickling filters should be preceded by primary sedimentation tanks equipped with scum collecting devices.

Primary treatment ahead of trickling filters makes available the full capacity of the trickling filter for use in the conversion of non-settleable, colloidal and dissolved solids to living microscopic organisms and stable organic matter temporarily attached to the filter medium and to inorganic matter temporarily attached to the filter medium and to inorganic matter carried off with the effluent. The attached material intermittently sloughs off and is carried away in the filter effluent. For this reason, trickling filters should be followed by secondary sedimentation tanks to remove these sloughed solids and to produce a relatively clear effluent.

**Pumping Station**
The following is taken from Automated Environmental Systems, Packaged Pumping Stations.

A pumping station is a mechanical device installed in a sewer or water system or other liquid-carrying pipeline to move a liquid to a higher level. Sewer pipes are generally gravity driven. Wastewater flows slowly downhill until it reaches a certain low point. Then pumping, or lift, stations are sited at this low point and push the wastewater back uphill to a high point where gravity can once again take over the process.

The pump station discharge pipe is a continuous main through which sewage or effluent is pumped and running full and at a pressure greater than atmospheric, to a final destination.

The pumping station itself is usually an underground structure that the foul (or surface water) sewage is discharged into. The types vary but in smaller systems these comprise of a wet well, into which the sewage is discharged, and the wet well also houses submersible pumps which pump the sewage to its destination. In a larger station there may be a separate dry well, adjacent to the wet well, which houses the pumps. On some pumping stations the pumps may be housed above ground near the wet well.
In more recent times, a packaged pumping station provides an efficient and economical way of installing a drainage system. They are suitable for mechanical building services collection and pumping of liquids like surface water, wastewater or sewage from areas where drainage by gravity is not possible. A package pumping station is an integrated system, built in a housing manufactured from strong, impact-resistant polyethylene or glass-reinforced plastic. The unit is supplied with internal pipework fitted, pre-assembled ready for installation into the ground, after which the submersible pumps and control equipment are fitted. Features may include controls for fully automatic operation; a high-level alarm indication, in the event of pump failure; and possibly a guide-rail/auto-coupling/pedestal system, to permit easy removal of pumps for maintenance/repair.

Compared to the conventional alternative of a concrete well and separate pump system, a packaged system offers the potential for reducing the cost and time involved with civil work and site labor.

Submersible pumps became popular in the early 1960s, when a guide-rail system was developed to lift the submersible pump out of the pump station for repair, and ended the dirty and sometimes dangerous task of sending people into the sewage or wet pit. Growth of the submersible pump for sewage pumping since has been dramatic, as an increasing number of specifiers and developers learned of their advantages.

**Wet Well**

According to the City of Batavia, Wastewater Terminology, a wet well is a compartment or tank in which wastewater is collected. The suction pipe of a pump may be connected to the wet well or a submersible pump may be located in the wet well.

d. **Discuss the methods and requirements for solid waste disposal associated with sanitary waste treatment systems.**

The following is taken from Encarta. Solid Waste Disposal.

Disposal of solid wastes on land is by far the most common method in the U.S. and probably accounts for more than 90 percent of the nation’s municipal refuse. Incineration accounts for most of the remainder, whereas composting of solid wastes accounts for only an insignificant amount. Selecting a disposal method depends almost entirely on costs, which in turn are likely to reflect local circumstances.

**Landfill**

Sanitary landfill is the cheapest satisfactory means of disposal, but only if suitable land is within economic range of the source of the wastes; typically, collection and transportation account for 75 percent of the total cost of solid waste management. In a modern landfill, refuse is spread in thin layers, each of which is compacted by a bulldozer before the next is spread. When about 3 m (about 10 feet) of refuse has been laid down, it is covered by a thin layer of clean earth, which also is compacted. Pollution of surface and groundwater is minimized by lining and contouring the fill, compacting and planting the cover, selecting proper soil, diverting upland drainage, and placing wastes in sites not subject to flooding or high groundwater levels. Gases are generated in landfills through anaerobic decomposition of organic solid waste. If a significant amount of methane is present, it may be explosive;
proper venting eliminates this problem. Restrictions may be placed on disposal of paints, electronics, and other products that may contain certain toxic or hazardous materials.

**Incinerators**

In incinerators of conventional design, refuse is burned on moving grates in refractory-lined chambers; combustible gases and the solids they carry are burned in secondary chambers. Combustion is 85 to 90 percent complete for the combustible materials. In addition to heat, the products of incineration include the normal primary products of combustion—carbon dioxide and water—as well as oxides of sulfur and nitrogen and other gaseous pollutants; nongaseous products are fly ash and unburned solid residue. Emissions of fly ash and other particles are often controlled by wet scrubbers, electrostatic precipitators, and bag filters.

**Composting**

Composting operations of solid wastes include preparing refuse and degrading organic matter by aerobic microorganisms. Refuse is presorted, to remove materials that might have salvage value or cannot be composted, and is ground up to improve the efficiency of the decomposition process. The refuse is placed in long piles on the ground or deposited in mechanical systems, where it is degraded biologically to a humus with a total nitrogen, phosphorus, and potassium content of 1 to 3 percent, depending on the material being composted. After about three weeks, the product is ready for curing, blending with additives, bagging, and marketing.

**Resource Recovery**

Numerous thermal processes, now in various stages of development, recover energy in one form or another from solid waste. These systems fall into two groups: combustion processes and pyrolysis processes. A number of companies burn in-plant wastes in conventional incinerators to produce steam. A few municipalities produce steam in incinerators in which the walls of the combustion chamber are lined with boiler tubes; the water circulated through the tubes absorbs heat generated in the combustion chamber and produces steam.

Pyrolysis, also called destructive distillation, is the process of chemically decomposing solid wastes by heat in an oxygen-reduced atmosphere. This results in a gas stream containing primarily hydrogen, methane, carbon monoxide, carbon dioxide, and various other gases and inert ash, depending on the organic characteristics of the material being pyrolyzed.

**Recycling**

The practice of recycling solid waste is an ancient one. Metal implements were melted down and recast in prehistoric times. Today, recyclable materials are recovered from municipal refuse by a number of methods, including shredding, magnetic separation of metals, air classification that separates light and heavy fractions, screening, and washing. Another method of recovery is the wet pulping process: Incoming refuse is mixed with water and ground into a slurry in the wet pulper, which resembles a large kitchen disposal unit. Large pieces of metal and other nonpulpable materials are pulled out by a magnetic device before the slurry from the pulper is loaded into a centrifuge called a liquid cyclone. Here the heavier noncombustibles, such as glass, metals, and ceramics, are separated out and sent on to a glass- and metal-recovery system; other, lighter materials go to a paper-fiber-recovery system. The final residue is either incinerated or is used as landfill.
e. **Discuss the construction and installation requirements for sewers and force mains.**

The following is taken from Sandia National Laboratories, Construction Standard Specification: Sanitary Sewer Systems.

**Pipes and Fittings**

Pipe and fitting materials shall be polyvinyl chloride (PVC), unless otherwise indicated as ductile iron or vitrified clay on the contract drawings. Each pipe and fitting shall be marked with a permanent label which allows identification of class and type of material. In addition, pipe shall conform to the following requirements:

- Sanitary sewer pipe and fittings of nominal pipe diameters 8in. and larger and all sanitary sewer main lines shall be constructed of PVC, vitrified clay, or ductile iron pipe. Building sewer branch lines and other service lines of nominal pipe diameters 6 in. and smaller shall be constructed of PVC or ductile iron pipe or as indicated on the contract drawings.


- Cast-iron pipe and fittings, when specified, shall be hub and spigot type conforming to ASTM A 74, *Standard Specification for Cast Iron Soil Pipe and Fittings*.

- Ductile iron pipe and fittings for sewer shall conform to ASTM A 746, *Standard Test Method for Brittleness Temperature of Plastics and Elastomers by Impact*. Ductile iron pipe shall have an asphaltic lining unless otherwise specified.

- PVC pipe shall meet the requirements of ASTM D 3034, *Standard Specification for Type PSM Poly(Vinyl Chloride) (PVC) Sewer Pipe and Fittings*, for pipe sizes 6 in. through 15in. diameter. Minimum wall classification shall be standard dimension ratio (SDR) 35 or SDR 26, as required. Only solid wall pipe will be acceptable.

- PVC pipe which will be used only for sanitary sewer service lines shall conform to ASTM D 2665, *Standard Specification for Poly(Vinyl Chloride) (PVC) Plastic Drain, Waste, and Vent Pipe and Fittings*, for schedule 40 pipe. Pipe for this purpose shall be solvent-welded joined, per manufacturer’s recommendations.

**Joints**

Joint materials shall be furnished with the sewer pipe. Gaskets shall be stored in accordance with ASTM C 443, *Standard Specification for Joints for Concrete Pipe and Manholes, Using Rubber Gaskets*. In addition, the joints shall conform to the following requirements:


- Cast-iron pipe hub and spigot joints shall have neoprene compression gaskets and shall conform to ASTM C 564, *Standard Specification for Rubber Gaskets for Cast Iron Soil Pipe and Fittings*.

- Ductile iron pipe for sewer shall have push-on rubber gasket joints and shall conform to American Water Works Association, (AWWA) C111, *Rubber-Gasket Joints for Ductile-Iron Pressure Pipe and Fittings*.

- All joints will be assembled in accordance with manufacturer’s published recommendations. If a lubricant is required to facilitate assembly, it shall have no detrimental effect on the gasket or on the pipe when subjected to prolonged exposure. Proper jointing may be verified by rotation of the spigot by hand or with a strap wrench. If unusual joining resistance is encountered or if the insertion mark does not reach the flush position, disassemble the joint components and repeat the assembly steps. Note that fitting bells may permit less insertion depth than pipe bells. When mechanical equipment is used to assemble joints, care should be taken to prevent over insertion.


**Pipe Laying**

The depth of sewer pipe mains shall be a minimum of 3 feet from top of finished grade to the top of sewer pipe, unless otherwise indicated on the contract drawings.

Pipe shall be laid on a smoothly graded, prepared subgrade soil foundation true to alignment and grade as indicated on the applicable contract drawings. Bell holes shall be hand-excavated so that the bottom of the pipe is in continuous contact with the surface of the prepared subgrade material. When joined in the trench, the pipe invert shall form a true and straight line.

Sewer pipe shall be laid according to the pipe manufacturer’s written recommendations or installation handbooks. If conflicts occur between these specifications and the manufacturer’s instructions, these specifications shall govern.

Vitrified clay pipe shall also be laid in accordance with ASTM C 12, *Standard Practice for Installing Vitrified Clay Pipe Lines*, for Class C bedding.

Vitrified clay pipe joints shall be made up using furan-based cement mortar. Before joining, the mortar shall be applied in the base of the bell so that when the pipe sections are joined, the joint will be completely filled with mortar, and the excess mortar will be pushed out into the bore of the pipe. A burlap bag, stuffed so that it fits tightly into the bore of the pipe, shall be drawn past the joint to wipe the excess mortar away, leaving a smooth interior surface at the joint.

For PVC, the reference mark (a distinct circumferential line) is placed on the pipe’s spigot by the manufacturer to indicate the correct depth of spigot penetration into the pipe gasket joint.
If the pipe is seated too deeply or too shallowly, the pipe may buckle or separate due to thermal expansion/contraction. Spigot penetration shall be within ¼ inch of the manufacturer’s recommended mark.

PVC pipe connection to manholes: The contractor shall install an appropriately sized press seal gasket, such as PS-10 by Press Seal Gasket Corporation, Large Diameter Waterstops for Concrete Manhole Adapters by Fernco, or approved equal. The gasket shall be installed per manufacturer’s directions.

Approved backfill material shall be spaded and tamped into the haunch area under each side of the pipe so that all void spaces underneath the pipe are filled with compacted backfill material.

Pipe laying shall proceed upstream with the spigot ends pointing in the direction of flow. Pipe shall not be laid in standing water or when trench or weather conditions are deemed unsuitable.

Approved backfill material shall be placed in the trench along the side of the pipe and compacted by hand up to the top of the pipe. Approved backfill material shall be placed and compacted a minimum of 12 in. above the top of the pipe.

Pipe coupons shall not be left inside the sewer main when the direct-tapping method is used. All pipe coupons shall be returned to the SDR.

**Cleanouts**

Single and two-way cleanouts shall be constructed at the locations indicated and as detailed on the contract drawings. Cleanouts and extensions to grade shall be constructed on 6 inch and smaller lines at the minimum spacing and at the locations required by the Uniform Plumbing Code (UPC), section 406, unless otherwise specified on the contract drawings.

**Septic Systems**

Septic systems, including septic tank, distribution box, drain field (or seepage pit), shall comply with UPC requirements. In addition, the following requirements shall be met:

- Access holes (with covers) shall be extended to grade and furnished with manhole covers.
- Septic tanks shall be placed on a sand bed (with a minimum thickness of 1 inch) 90 percent compacted earth.
- A minimum of six guard posts shall be installed above grade around the septic tank perimeter.

The contractor shall also be required to:

- Complete the liquid waste disposal (LWD) permit application and pay the application fee.
- Obtain all necessary state inspections relating to the LWD permit.
- Complete, as a contract deliverable, the LWD permit application.
- Submit the completed LWD permit to the SDR.
- Have a state plumbing license.
Cleaning

Prior to laying pipe, each interior pipe section shall be cleaned of all soil and debris.

After laying backfill, all interior pipes shall be free of all foreign material such as soil, cement mortar, joint compounds, etc. If large amounts of material have accumulated, the SDR may require flushing of the pipe. If flushing is required, any outlets into existing lines shall be blocked so that no foreign material is discharged into existing lines.

Location of Water and Sewer Lines

Mains: Water and sewer mains running parallel shall be laid at least 10 feet apart horizontally with the water main at a higher elevation than the top of the sewer line. Water and sewer mains shall be laid in separate trenches in all cases. Where water and sewer mains are laid closer than 10 feet or where they are crossing, the bottom of the water main shall be at least 18 in. higher than the top of the sewer line, otherwise the sewer line shall be of pressure class pipe, or shall be encased in concrete as indicated on the contract drawings, within 10 feet either side of the water main.

Service Lines: Water and sewer service lines shall not be laid in the same trench, unless the bottom of the water line, at all points, is at least 12 in. above the top of the sewer line, and the water line shall be laid on a solid shelf excavated at one side of the common trench. Where water and sewer service lines cross, the water line shall be at least 12 in. higher than the sewer.

The following is taken from the Kansas Rural Water Association, cleaning Wastewater Force Mains.

A force main is a pipeline to transfer wastewater from a lower to higher elevation. Force mains are installed to prevent excessive excavation depths and expensive sewer pipeline construction costs. A simple description is that a force main is a wastewater pipeline, with a pump forcing the wastewater to the treatment facility. Typically, a sewer force main is made of either ductile iron pipe or it may also be made of PVC or other poly materials.

f. Discuss the installation and construction requirements for storm drain and sewer main piping that pass under a security barrier.

Storm Drain

The following is taken from the State of Connecticut, Department of Transportation, Storm Drainage Systems.

The design of any storm drainage system involves the accumulation of basic data, familiarity with the project site, and a basic understanding of the hydrologic and hydraulic principles and drainage policy associated with that design.

The designer should be familiar with land use patterns, the nature of the physical development of the area(s) to be served by the storm drainage system, the stormwater management plans for the area and the ultimate pattern of drainage (both overland and by storm drains) to some existing outfall location. Furthermore, there should be an understanding of the nature of the outfall since it usually has a significant influence on the
storm drainage system. In environmentally sensitive areas, there may be water quality requirements to consider as well.

Actual surveys of these and other features are the most reliable means of gathering the required data. Photogrammetric mapping has become one of the most important methods of obtaining the large amounts of data required for drainage design, particularly for busy urban roadways with all the attendant urban development. Existing topographic maps, available from the U. S. Geological Survey, the Natural Resource Conservation Service, many municipalities, and private developers are also valuable sources of the kind of data needed for a proper storm drainage design. Developers and governmental planning agencies should be consulted regarding plans for the area in question.

Often, in rapidly growing urban areas, the physical characteristics of an area to be served by a storm drainage system may change drastically in a very short time. In such cases, the designer is to anticipate these changes and consider them in the storm drainage design. Comprehensive stormwater management plans and floodplain ordinances should be reviewed when they are available.

Preliminary sketches or schematics, featuring the basic components of the intended design, are useful to the designer. Such sketches should indicate watershed areas and land use, existing drainage patterns, plan and profile of the roadway, street and driveway layout with respect to the project roadway, underground utility locations and elevations, locations of proposed retaining walls, bridge abutments and piers, logical inlet and manhole locations, preliminary lateral and trunk line layouts and a clear definition of the outfall location and characteristics. This sketch should be reviewed with the traffic staging plans and soils recommendations for areas which are incompatible with required construction staging. With this sketch or schematic, the designer is able to proceed with the detailed process of storm drainage design calculations, adjustments and refinements. Unless the proposed system is very simple and small, the designer should not ignore a preliminary plan as described above. Upon completion of the design, documentation of the overall plan is facilitated by the preliminary schematic.

Consideration and planning should be directed toward avoidance of utilities and deep cuts. In some cases, traffic must be maintained or temporary bypasses constructed and temporary drainage provided for during the construction phase.

Further consideration should be given to the actual trunk line layout and its constructibility. For example, will the proposed location of the storm drain interfere with in-place utilities or disrupt traffic? Some instances may dictate a trunk line on both sides of the roadway with very few laterals while other instances may call for a single trunk line. Such features are usually a function of economy but may be controlled by other physical features.

Except in unusual circumstances, storm drains should discharge to a single outfall. A storm drain which branches, thereby distributing the discharge, should be avoided. Storm drain pipes should not decrease in size in a downstream direction regardless of the available pipe gradient.
g. Discuss the hydraulics associated with the following:
   - Runoff into storm sewers
   - Open channels
   - Street drainage

Runoff into Storm Sewers
The following is taken from Carnegie Mellon University, Urban Watersheds.

Water runoff that is channeled into sewers can enter either separated or combined sewer systems. While these systems help to prevent flooding of roads and parking areas, there can still be problems for waterways.

In a separate sewer system, sanitary wastes (from toilets, washers, and sinks) are carried through sanitary sewers to a wastewater treatment plant. Separate storm sewers carry runoff from streets. Since the storm sewers discharge water directly into a river, any contaminants in the runoff enter the waterway.

They may also carry untreated waste from sanitary sewers that are improperly connected to storm sewers.

In a combined sewer system, both sanitary wastes and storm runoff are collected in the same pipe and carried to a wastewater treatment plant. Treated water is then released to a water body. However, after a heavy rainfall, the wastewater volume can exceed the capacity of the treatment plant. When this happens, combined sewer systems are designed to overflow and discharge excess wastewater directly into a waterway. These overflows contain contaminated runoff, untreated waste, and debris.

One solution that can help prevent sewer overflow is reducing the amount of storm water runoff by taking advantage of natural processes. These processes include tree planting, green space development and use of porous pavements in parking lots and walkways which allow water to filter into the ground instead of going into sewers.

Open Channels
The following is taken from the U.S. Department of Agriculture, Natural Resources Conservation Services, Open Channel Hydraulics.

Open channel flow is the flow of water in a channel, conduit or waterway while in contact with the atmosphere. It does not include flow in pipes under pressure although most of the principles also apply to that condition.

Flow is measured in terms of volume over time, such as cubic feet per second or gallons per minute.

The discharge (flow) and the stage (depth) of water in an open channel at any time is the result of a combination of discharge, channel, and downstream factors. Each of these has a varied effect on the design condition and should be considered in all situations needing stage-discharge data.
Discharge
Discharge is affected by meteorological and watershed factors. It varies with time as storm runoff is accumulated down a watershed drainage. The shape of a watershed and the location of tributaries will direct runoff from different points in the watershed to the outlet or measuring point at different time, also varying the flow rates. Watershed tributary slopes will cause variation in flows as well. This combined variation is depicted in a hydrograph of flow rate over time rising and falling and represents unsteady flow. Design applications generally pick the maximum flow rate or a series of flows and assume that they do not vary with time within a design reach. Flows that do not vary with time are called steady flow.

Critical Flow
Critical flow is an important discharge factor affecting the stage discharge relationships. Flow at any point in a channel has two energy components, potential and kinetic energy. The potential energy is the depth of water. Kinetic energy is the energy due to the velocity of flow. The sum of the two components constitutes the specific energy, $H_e$ and is given by the equation:

$$H_e = d + \frac{v^2}{2g}$$

where
- $H_e =$ specific energy in feet
- $D =$ depth of water in feet
- $v =$ mean velocity of low in feet/second
- $g =$ acceleration due to gravity in feet/second

Critical flow is the term used to define a dividing point between subcritical and super critical flow. There are two conditions that describe critical flow.

- The discharge is maximum for a given specific energy head.
- The specific energy head is minimum for a given discharge.

The general equation for critical flow in a channel is:

$$\frac{Q^2}{g} = \frac{a^3}{T} \text{ or } Q = a\sqrt{\frac{ga}{T}}$$

where
- $Q =$ discharge in cubic feet per second
- $a =$ cross-section are of flow in square feet
- $T =$ top width of water surface in feet.

If the channel flow is less than the value given in this equation, it is subcritical. Flow greater than this value is supercritical. Flow rates near critical flow are unstable, resulting in wide changes in depth from minor changes in energy. Channel designs should avoid conditions near critical. This may be avoided by consideration of critical slope, $S_c$, which is the slope that will sustain a given discharge in a given channel at uniform critical depth.
Critical slope is:

\[ Sc = 14.56 \frac{n^2 d_m}{r^3} \]

where

- \( Sc \) = critical slope in feet per foot
- \( N \) = Manning’s coefficient
- \( D_m \) = mean depth in feet
- \( r \) = hydraulic radius in feet

Unstable flow conditions may be avoided by design of channel slopes either less than 0.7 \( S_c \) or greater than 1.3 \( S_c \).

Channel factors are the physical characteristics at the point of interest. These include shape, slope, roughness, and other local physical conditions.

Shape

Shape factors are areas, depth, wetted, perimeter, and top width. Area \((a)\) is the cross-sectional area of flow in square feet. Depth \((d)\) is the depth of water flow from channel bottom to water surface in feet. Wetted perimeter \((p)\) is the length of the cross section boundary in contact with the water. Top width \((T)\) is the length of water surface across the cross section. Mean depth \((d_m)\) is determined by the formula:

\[ d_m = \frac{a}{T} \]

Hydraulic radius \((r)\) is computed as:

\[ r = \frac{a}{p} \]

Slope

Channel slope is the slope of the channel bottom through the stream reach being studied or designed. It is measured feet per foot or percent.

Roughness

Roughness is a factor sued to estimate resistance to the flow of water. Local conditions contributing to roughness include the degree of channel meandering in the area and the amount and type of obstructions in the channel. These channel characteristics are factors in computing flows by Manning’s equation. The Manning’s \( n \) coefficient is one measure of roughness.
Downstream Conditions

Downstream conditions can have a large effect on flow and flow depth. Restrictions or obstructions downstream such as a dam, culvert, bridge, rock outcrop or channel encroachment can cause backwater conditions upstream into the cross-section being measured. Under these conditions, the slope of water surface determine the flow, not the channel bottom slopes. Where backwater conditions are suspected, a further analysis of water surface profiles would be required. Downstream conditions will affect water surface levels upstream when the flow is subcritical. Supercritical flows affect stages downstream but do not control upstream flows.

Street Drainage

The following is taken from Street Storm Water Conveyance Capacity by James Guo.

Water flowing on a street imposes a momentum impulse on vehicles and pedestrians. With a concept similar to the hydroplaning analysis, the hyperbolic relationship between water velocity (V) and depth (D) in a gutter flow has been adopted as a control of runoff discharge for street drainage designs. Both the VD product and discharge reduction methods have been developed from field experience. For instance, since 1968, the Storm Water Drainage Design Criteria Manual recommended by the City and County of Denver in the State of Colorado has adopted a set of discharge reduction factors for determining the street hydraulic conveyance capacity. Since 1991, the Hydrologic Criteria and Drainage Design Manual published by Clark County for the 800-square mile Las Vegas area in the State of Nevada has suggested that the VD product of a street gutter flow be less than six for a minor event and eight for a major event when estimating the average street hydraulic conveyance capacity (ASHCC).

The approach of discharge reduction is an explicit method using a set of empirical factors derived from field experience. On the other hand, the approach of VD products provides an implicit procedure that involves an iterative design process to convert the permissible VD product to a discharge reduction. Regardless of the inconsistency in predictions and inadequate understanding in theory, both methods have been adopted as empirical guidance for street drainage designs because of the increasing concerns about the safety of storm water flowing on streets.

Street curbs and gutters are designed to intercept storm water safely until the water spread becomes too wide and the flow velocity becomes too high. The momentum impulse and the capacity per unit width in a gutter flow can be directly related to its VD product. Therefore, the VD product can serve as a criterion to consistently determine the ASHCC on a steep and wide street. Derivations also mathematically relate discharge reduction factors to VD products and further lead to the developments of discharge reduction factors as a function of street slope and water spread width. With these modifications, a specified permissible VD product can be converted to its equivalent discharge reduction factor for a direct estimation of ASHCC without iterations.
26. Construction management personnel shall demonstrate a familiarity level knowledge of the following laws and DOE Order related to environmental protection, safety and health:

- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
- Resource Conservation and Recovery Act (RCRA)
- National Environmental Policy Act (NEPA)
- Clean Water Act (CWA)
- Clean Air Act (CAA)
- Toxic Substances Control Act (TSCA)
- DOE Order 5480.4, Environmental Protection, Safety, and Health Protection Standards

a. Discuss the purpose, scope, and application of the listed Acts and DOE Order. Include in this discussion the key terms, essential elements, and personnel responsibilities and authorities.

**CERCLA**

In 1980, Congress enacted CERCLA. CERCLA’s most basic purposes are to provide funding and enforcement authority for cleaning up the thousands of hazardous waste sites created in the U.S. in the past which are now abandoned and inactive, and to respond to hazardous substance spills.

Following is a listing of some of the key terms and essential elements of CERCLA.

**Applicable relevant and appropriate requirements** (ARARs) are any standard, requirement, criteria, or limitation under any federal environmental law, and any promulgated standard, requirement, criteria, or limitation under a state environmental or facility siting law that is more stringent than any federal standard.

**Environment** is defined broadly to include any surface water, groundwater, drinking water supply, land surface, subsurface strata, and ambient air.

**Hazardous substance** is defined as a substance that is listed or designated under other environmental statutes, including hazardous and characteristic wastes under RCRA, hazardous substances defined in the CWA, hazardous air pollutants listed under the CAA, and hazardous chemical substances or mixtures listed under TSCA.

**Joint and several liability** is the legal instrument within CERCLA that gives the Environmental Protection Agency (EPA) the ability to sue a few potentially responsible parties at major Superfund sites and obtain a judicial decision that each is individually responsible for all cleanup costs at the site.

**National Contingency Plan** (NCP) is the primary guidance document for the implementation of CERCLA response actions. The actions include response to oil spills and other hazardous substances.

**National Priorities List** is the national ranking of inactive hazardous waste sites across the country that the EPA has determined to be in need of some type of response action.
**Record of decision** documents all facts, analyses, and site-specific determinations in sufficient detail to explain how the remedy is protective of human health and the environment, how it meets ARARs, and how it will attain permanent solutions to the maximum extent possible.

**Release or threat of release** is the discharge of a certain quantity of a hazardous substance into the environment. Release of any quantity is adequate to trigger a CERCLA response action.

**Remedial investigation/feasibility study (RI/FS)** is the field assessment of site conditions and the evaluation of alternatives to the extent necessary to select a remedy. The RI/FS can be expensive and time consuming at most national plan list sites.

**Removal actions** are performed to deal with environmental emergencies. CERCLA loosely defines a removal to include providing alternate drinking water supply or the erection of a fence around a hazardous waste site. In short, just about any action that diminishes the threat to human health or the environment from a hazardous waste site and that can be done quickly qualifies as a removal.

**RCRA**

RCRA is a regulatory statute designed to provide “cradle to grave” control of hazardous waste by imposing management requirements on generators and transporters of hazardous waste, and upon owners and operators of treatment, storage and disposal facilities.

RCRA applies mainly to active facilities, and does not address the serious problem of abandoned and inactive sites. RCRA amended the Solid Waste Disposal Act, therefore, the two terms are sometimes used synonymously.

Subtitle A of RCRA declares that, as a matter of national policy, the generation of hazardous waste is to be reduced or eliminated as expeditiously as possible, and land disposal should be the least favored method for managing hazardous wastes. In addition, all waste that is generated must be handled so as to minimize the present and future threat to human health and the environment.

The Federal Facilities Compliance Act amends RCRA to waive the sovereign immunity previously afforded to federal facilities. Federal facilities are now subject to the federal, state, interstate, and local substantive and procedural requirements of RCRA.

Following is a listing of some of the key terms and essential elements of RCRA.

**Abandoned materials** are materials that are disposed of, burned, or incinerated, or that are accumulated, stored, or treated (but not recycled) before, or in lieu of, being abandoned by being disposed of, burned, or incinerated.

**Cradle to grave** is the basic structure for RCRA subtitle C that follows a substance from identification through disposal.
Disposal is the means of discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into or on any land or water so that such solid waste or hazardous waste, or any constituent thereof, may enter the environment or be emitted into the air or discharged into any waters, including groundwater.

Facility is defined as all contiguous land, structures, other appurtenances, and improvements on the land, used for treating, storing, or disposing of hazardous waste. A facility may consist of several treatment, storage, or disposal operational units.

Generator is defined as any person, by site, whose act or process produces hazardous waste identified or listed in RCRA, or whose act first causes a hazardous waste to become subject to regulation.

Listed waste is defined as waste that meets the criteria set forth in 261.3(a) (2) and in 261, subpart D of RCRA.

Operator is defined as any person responsible for the overall operation of a facility.

Recycled materials are materials that are recycled, or accumulated, stored, or treated before recycling. Recycled materials include materials that are burned to recover energy or used to produce fuels, reclaimed materials, and materials that are accumulated speculatively, such as scrap metal.

Section 261.4 (a) exclusions are domestic sewage, industrial wastewater discharges, irrigation return flows, nuclear source or by-products, materials subjected to in situ mining, pulping liquors, spent sulfuric acid used to produce virgin sulfuric acid, secondary materials that are reclaimed and returned to the original process, spent wood preserving solutions, certain EPA hazardous wastes, and certain non-wastewater splash condenser dross residues from high-temperature metals recovery units.

Solid waste is defined as any discarded material that is not excluded by section 261.4 (a), or that is not excluded by variance granted under sections 260.30 and 260.31 (RCRA 261.2). A discarded material is any material that is abandoned, recycled, or considered inherently waste-like. Solid waste is hazardous waste if it is not excluded by 261.4(b) (see the solid waste definition for these exclusions) and it meets the following exclusions: (1) it meets any of the characteristics of hazardous wastes identified in subpart C; (2) it is listed in subpart D; (3) it is a mixture of a solid waste and a hazardous waste; and, (4) it is used oil that contains more than 1000 parts per million (ppm) total halogens.

Storage is defined as the holding of hazardous waste for a temporary period, at the end of which the hazardous waste is treated, disposed of, or stored elsewhere.

Transporter is defined as a person engaged in the offsite transportation of hazardous waste by air, rail, highway, or water.

NEPA

NEPA establishes national environmental policy and goals for the protection, maintenance, and enhancement of the environment, and provides a process for implementing these goals.
within federal agencies. Section 102 requires federal agencies to incorporate environmental considerations in their planning and decision-making through a systematic interdisciplinary approach. Specifically, all federal agencies are to prepare detailed statements assessing the environmental impact of and alternatives to major federal actions significantly affecting the environment. These statements are commonly referred to as environmental impact statements (EIS).

Following is a listing of some of the key terms and essential elements of NEPA.

**Categorical exclusion** is the method by which an agency identifies a category of actions that do not individually or cumulatively have a significant effect on the human environment and which have been found to have had no such effect in past instances. DOE has determined that these classes of actions do not individually or cumulatively have a significant effect on the human environment.

**Environmental assessment (EA)** is a screening process document used to determine whether an agency must prepare an EIS or make a finding of no significant impact (FONSI). The Council on Environmental Quality’s (CEQ) regulations describe an EA as a concise public document that also serves to aid an agency’s compliance with NEPA when no EIS is necessary and to facilitate preparation of an EIS when one is necessary. An EA should include a brief discussion of the need for the proposal, alternatives, the environmental impacts of the proposed action and alternatives, and a listing of agencies and persons consulted.

**Environmental impact statement (EIS)** describes the environmental impacts of the proposed action, any adverse environmental impacts which cannot be avoided, the reasonable alternative to the proposed action, the relationship between local short term uses of man’s environment and the maintenance and enhancement of long-term productivity, and any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented. It is prepared when it is determined that a proposed federal action does not fall within a designated categorical exclusion or does not qualify for a FONSI.

**Finding of no significant impact** is one of two alternative results of an EA, the other being that an agency must prepare an EIS.

**Major federal actions** include actions with effects that may be major and that are potentially subject to federal control and responsibility. “Major” reinforces but does not have a meaning independent of “significantly.” The term “significantly,” as used in NEPA, requires consideration of context and intensity. Context means that the significance of an action must be analyzed in several contexts such as society as a whole, the affected region, the affected interests, and the locality. Intensity means the severity of impact.

**Mitigation measures** are used to reduce adverse impacts, and must be included in the EIS. These measures must be implemented by the lead agency once a decision is made. CEQ lists five generic mitigation measures.
The CWA was enacted to improve the quality of surface water. The CWA is comprised of the following five elements: (1) a system of minimum national effluent standards for each industry; (2) water quality standards; (3) a discharge permit program where these standards are translated into enforceable limitations (i.e., the National Pollutant Discharge Elimination System program); (4) provisions for special problems such as toxic chemicals and oils spills; and, (5) a revolving construction loan program for publicly-owned treatment works.

Following is a listing of some of the key terms and essential elements of CWA.

Best management practices are the comprehensive and detailed formal processes outlined in the Act, and are, in many cases, inapplicable to situations where discharge limits are yet to be promulgated. In such cases, the regulations authorize the permit issuer to establish discharge limits based on the exercise of professional or engineering judgment.

Discharge as defined in the CWA includes any leaking, pumping, pouring, emitting, emptying, or dumping of oil. It excludes: discharges in compliance with a permit under section 402 of the CWA; discharges resulting from circumstances identified, reviewed, and made a part of the public record with respect to a permit issued or modified under section 402 of the CWA and subject to condition in such permit; or continuous or anticipated intermittent discharges from a point source, identified in a permit or permit application under section 402 of the CWA, that are caused by events occurring within the scope of relevant operating or treatment systems.

Effluent limits are included in the discharge permit. They are based on published limits for a specific pollutant or on professional judgment for those pollutants without a published limit.

National Pollutant Discharge Elimination System is a system of requirements to obtain permits for the commencement or continuation of any discharge of pollutants to surface waters. It defines for each individual discharger his permissible level of release into waters of the United States.

Navigable water is defined as the waters of the United States, including the territorial seas. They include: all waters that are currently used or were used in the past or may be susceptible to use in interstate or foreign commerce, including all waters that are subject to the ebb and flow of the tide; interstate waters, including interstate wetlands; all other waters, such as intrastate lakes, rivers, streams (including intermittent streams), mudflats, sandflats, and wetlands, the use, degradation, or destruction of which would affect or could affect interstate or foreign commerce; all impoundments of waters otherwise defined as navigable water under this section; tributaries of water identified in this definition, including adjacent wetlands; and wetlands adjacent to water identified in this definition.

Point source includes any discernible, confined, and discrete conveyance from which pollutants are or may be discharged.

Pollutant as defined in section 502(6) of the CWA includes only the materials specifically listed in that section. The definition is nevertheless quite broad and has been broadly
interpreted to include virtually all waste material, whether or not that material has value at the time it is discharged.

Publicly Owned Treatment Works (POTW) is typically a municipal water treatment facility that treats and disposes of domestic, “municipal,” and commercial waste water. Industrial facilities that discharge into POTWs are regulated not by requirements governing direct discharges, but rather by comparable treatment requirements, called pretreatment standards, adopted pursuant to section 307(b) of the CWA.

Water quality standards are mechanisms provided in the CWA by which discharge limitations are tightened to protect or maintain adequate water quality in specific bodies of water.

CAA

The purposes of the CAA are: (1) to protect and enhance the quality of the nation’s air resources so as to promote the public health and welfare and the productive capacity of its population; (2) to initiate and accelerate a national research and development program to achieve the prevention and control of air pollution; (3) to provide technical and financial assistance to state and local governments in connection with the development and execution of their air pollution prevention and control programs; and, (4) to encourage and assist the development and operation of regional air pollution prevention and control programs.

Following is a listing of some of the key terms and essential elements of the CAA.

Attainment and nonattainment areas are areas that did not meet the statutory deadline in 1975 for attainment of air quality standards. As a result, the law was amended to extend deadlines for specific standards. Areas that were not in compliance with one or more air quality standard(s) were classified by EPA as nonattainment areas.

Best achievable control technology is the maximum degree of emission reduction achievable taking into account economic, energy, and environmental factors.

Criteria pollutants are sulfur dioxide, carbon monoxide, particulate matter, nitrogen dioxide, photochemical oxidants, and lead.

Hazardous air pollutants are asbestos, benzene, beryllium, coke oven emissions, inorganic arsenic, mercury, radionuclides, and vinyl chloride. Other chemicals are under consideration for inclusion in this list.

Maximum achievable control technology refers to the requirement that EPA must promulgate standards requiring the installation of technology that will result in the maximum degree of reductions it determines is achievable.

National Ambient Air Quality Standards are the primary standards designed to protect health, and secondary standards designed to protect public welfare. Standards exist for carbon monoxide, nitrogen dioxide, sulfur dioxide, particulate matter, hydrocarbons, ozone, and lead.
**New Source Performance Standards** are emission standards set by EPA that reflect the degree of emission reduction achievable through the technology that the agency determines has been adequately demonstrated to be the best taking into consideration several factors for these sources.

**New sources** are those sources that contribute significantly to air pollution that did not exist when the Act was implemented. These new sources are subject to more stringent levels of control under the Act than existing sources because Congress concluded that it would be more cost effective to require high levels of technological performance at new sources than to retrofit existing sources with state of the art control technologies.

**Prevention of significant deterioration** is a permit program that is designed to prevent significant deterioration of air quality in attainment areas.

**Reasonably achievable control technology** (RACT) is part of the requirement that Step Implementation Plans must provide for all reasonably available control measures for major sources as expeditiously as practicable with adoption, at a minimum, of RACT for existing sources.

**Step Implementation Plan** is a system used by each state under sections 107 and 10 of the CAA to ensure that the air quality within its borders is maintained at a level consistent with the national ambient air quality standard program.

**TSCA**

The TSCA has two main regulatory features: (1) the acquisition of sufficient information by EPA to identify and evaluate potential hazards from chemical substances, and (2) regulation of the production, use, distribution, and disposal of such substances where necessary. The main provisions of the Act include pre-manufacture notification, an inventory list, reporting requirements, and testing requirements. Additionally, TSCA specifically regulates polychlorinated biphenyl, chlorofluorocarbons, and asbestos.

Following is a listing of some of the key terms and essential elements of TSCA.

**Chemical substance** includes any organic or inorganic substance of a particular molecular identity, including any combination of such substances occurring in whole or in part as a result of a chemical reaction or occurring in nature and any element of uncombined radical. Statutory exclusions from this definition are: (1) any mixture; (2) any commercial pesticide; (3) tobacco and certain tobacco products; (4) any nuclear source material or by-product; (5) any pistol, firearm, revolver, shells, and cartridges; and (6) any commercial food, food additive, drug, cosmetic, or device.

**Manufacture** is defined by TSCA to include not only the traditional notions of manufacture and production, but also the importation of TSCA-regulated chemical substances or mixtures.

**New chemical review** is required under TSCA, whereby any person intending to manufacture or import a chemical substance first must determine whether it is listed on the TSCA inventory. If the chemical substance is not listed on the inventory, the manufacturer or importer must determine whether the chemical substance is excluded from regulation or
whether it is exempt from requirements. If the chemical substance is neither excluded nor exempted, the prospective manufacturer or importer must comply with the pre-manufacture notice requirements before commencing those activities.

PCB is the abbreviation for polychlorinated biphenyl.

Pre-manufacture notice is a notice that a manufacturer is required to submit regarding its intention to manufacture a chemical substance not on the TSCA inventory or before manufacturing a chemical for a significant new use.

Process means the preparation of a chemical substance or mixture, after its manufacture, for distribution in commerce in the same form or physical state as, or in a different form or physical state from, that in which it was received by the persons so preparing such a substance or mixture, or as part of an article containing the chemical substance or mixture.

Processor is defined as any person who processes a chemical substance or mixture.

DOE Order 5480.4, Environmental Protection, Safety, and Health Protection Standards [Note: DOE Order 5480.4 has been canceled.]

The purpose of this DOE Order is: to specify and provide requirements for the application of the mandatory environmental, safety, and health (ES&H) standards applicable to all DOE and DOE contractor operations; to provide a listing of reference ES&H standards; and to identify the sources of the mandatory and reference ES&H standards. This Order is to be followed during facility design, construction, operation, modification, and decommissioning. The Order applies to all departmental elements and contractors performing work for DOE.

Following is a listing of some of the key terms and essential elements of DOE Order 5480.4.

Departmental elements are the offices, sites, or other entities with DOE that are impacted by this Order.

Mandatory ES&H standards are those standards required either by federal or state law or DOE Order. The sources of these standards are listed throughout the Order.

Noncompliance is a temporary or permanent release from the requirements of a statute, code, directive, regulation, Order, or manual. Depending of the origin of the ES&H standards, noncompliance with a requirement of these standards is referred to as an exemption, variance, exception, interim order, waiver, or deviation.

b. Discuss the contractor's responsibilities for environmental safety and health protection, as stated in the listed documents.

CERCLA

CERCLA requires compliance with federal health and safety standards by contractors and subcontractors as a condition of contracts awarded by the president. Additionally, the NCP provides for the protection of the health and safety of employees in response actions.
Section 300.150 of the NCP requires that response actions comply with the provisions for response action worker safety and health in 29 CFR 1910.120, “Hazardous Waste Operations and Emergency Response.” The contractor on a response action must assure that an occupational safety and health program is made available for the protection of workers at the response site. In addition, contractors must comply with any applicable provisions of the Occupational Safety and Health Act and state health and safety laws.

Federal OSHA requirements include such items as construction standards, general industry standards, and the general duty requirement of section 5(a)(1). Finally, the NCP states that all governmental agencies and private employers are directly responsible for the health and safety of their own employees.

**RCRA**
Employee protection, or occupational safety and health, is covered under section 6971 (f) of subchapter VII, Miscellaneous Provisions, which states a contractor must meet OSHA requirements. As part of meeting OSHA requirements, a contractor must also identify any hazardous waste generation, treatment, storage, or disposal facility or site where cleanup is planned or underway; provide information identifying the hazards to which persons working at a hazardous waste generation, treatment, storage, or disposal facility or site or otherwise handling hazardous waste may be exposed, the nature and extent of the exposure, and methods to protect workers from such hazards; and provide information about incidents or worker injury or harm at a hazardous waste generation, treatment, storage, or disposal facility or site. The contractor is also responsible for reporting this information to the lead regulatory agency.

**NEPA**
NEPA does not specifically address health and safety issues. However, under section 4331 (c), subchapter I, Policies and Goals, NEPA broadly states that each person should enjoy a healthful environment and that each person has a responsibility to contribute to the preservation and enhancement of the environment. Usually, any work related to NEPA is covered by the provisions set forth in CERCLA, RCRA, and/or OSHA for health and safety concerns.

**CWA**
The CWA does not specifically address health and safety issues. Under section 1251 (a) and (b), subchapter, Research and Related Programs, Congress states that its policy is to prevent, reduce, and eliminate pollution being discharged to the Nation’s waters. Work related to the CWA is covered by the provisions set forth in CERCLA, RCRA, and/or OSHA for health and safety concerns.

**CAA**
As relating to the environment and health and safety, the intent of Congress in writing the CAA was to protect and enhance the quality of the Nation’s air resources so as to promote the public health and welfare and the productive capacity of the populace. Regarding health and safety, the CAA mandates the specification of air quality standards for certain hazardous air pollutants. Any project defined as a source of air emissions must meet the applicable
permitting standards for the location of the project. Such permit standards are site and contaminant specific.

**TSCA**

Regarding health and safety issues, TSCA is slightly different in that it clearly states that the EPA administer is not deemed to be exercising statutory authority to prescribe or enforce standards or regulations affecting occupational safety and health as specified under OSHA. Work related to the TSCA is covered by the provisions set forth in CERCLA, RCRA, and/or OSHA for health and safety concerns.

**DOE Order 5480.4, Environmental Protection, Safety, and Health Protection Standards**

This Order is applicable in all situations where, under the contractual arrangements for the work to be performed, DOE has authority to establish and enforce environmental protection, safety, and health protection program requirements. The Order applies to all DOE contractor operations and must meet all regulatory health and safety requirements unless specifically exempted by a legally binding contract.

c. **Determine the potential implications resulting from violations and describe the procedure for communicating the results to the contractor and to Department management.**

The following is taken from the National Safety Council, *Fundamentals of Industrial Hygiene*.

Noncompliance may be found in the establishment. In that case, citations may be issued and civil penalties may be proposed. In order of significance, these are the types of violations or conditions normally considered.

**Imminent Danger**

An imminent danger is a condition where there is reasonable certainty a hazard exists that can be expected to cause death or serious physical harm immediately or before the hazard can be eliminated through regular procedures. If the employer fails to abate such conditions immediately, the compliance officer, through his or her area director, can go directly to the nearest Federal district court for legal action as necessary.

**Serious Violations**

A serious violation has a substantial probability that death or serious physical harm could result and that the employer knew, or should have known, of the hazard. An example is the absence of point-of-operations guards on punch presses or saws. A serious penalty may be adjusted downward based on the employer’s good faith, history of previous violations, and the size of the business.

**Willful Violations**

A willful violation exists where the evidence shows either an intentional violation of any standard, rule, or order or an indifference to requirements. The determination of whether to issue a citation for a willful or repeated violation often raises difficult issues of law and policy and requires the evaluation of complex situation.
Criminal/Willful Violations
An employer who willfully violates any standard, rule, or order, if that violation caused death to any employee, will on conviction be punished by a fine or by imprisonment for not more than 6 months, or both. If the conviction is for a violation committed after a first conviction, the punishment will be a fine or imprisonment for not more than 1 year, or both.

Repeated Violations
An employer may be cited for a repeated violation if that employer has been cited previously for a substantially similar condition and the citation has become a final order. Generally, similar conditions can be demonstrated by showing that in both situations the identical standard was violated.

Repeated Versus Willful
Repeated violations differ from willful violations in that they may result from an inadvertent, accidental, or ordinarily negligent act. If a repeated violation also meets the criteria for willfulness, but not clearly so, a citation for a repeated violation is normally issued.

Egregious Citations
Cases under consideration for treatment as egregious must be classified as willful and meet one of the following criteria:
- The violations resulted in a worker fatality, a worksite catastrophe, or a large number of injuries or illnesses.
- The violations resulted in persistently high rates of worker injuries or illnesses.
- The employer has an extensive history of prior violations of the act.
- The employer has intentionally disregarded its safety and health responsibilities.
- The employer’s conduct, taken as a whole, amounts to clear bad faith in the performance of his or her duties.
- The employer has committed a large number of violations so as to undermine significantly the effectiveness of any safety and health program in place.

Other-Than-Serious Violations
Other-than-serious violations are those that have a direct relationship to job safety and health but probably would not cause death or serious physical harm, such as tripping hazards. A non-serious penalty may be adjusted downward depending on the severity of the hazard, the employer’s good faith, his or her history of previous violations, and the size of the business.

De Minimis
A de minimis violation is a condition that has no direct or immediate relationship to job safety and health.

If respirators and other personal protective equipment are not properly fitted or are not worn and the affected employee is exposed to a toxic agent above the PEL, a citation will be issued, classified as serious.

Employers may be cited for an other-than-serious violation if, for example, they have not established written operating procedures governing the use of respirators, have not trained
and instructed employees in their proper use, or have not regularly cleaned and disinfected the respirators even though such respirators are properly fitted and worn.

d. Discuss the application of the listed environmental protection Acts to a construction project during the conceptual, execution, acceptance, and close-out phases of the project.

Elements “a” through “c” of this competency provide the information necessary to discuss the application of the listed Acts and how they apply to the various phases of a project.

As an example, construction of a remedial action project will be briefly reviewed from the perspective of the environmental protection acts. During conceptual planning for a construction project, all of the listed environmental protection acts must be evaluated for their applicability to the proposed project. If the remedial action project is performed under CERCLA, then all the other environmental laws must be reviewed to determine whether they are applicable or relevant and appropriate requirements. If wastes are generated, they must be evaluated to assess whether they are hazardous wastes and thus must be treated, stored or disposed of according to RCRA. For water or wastes treated onsite, all air emissions and effluent discharges must meet the requirements of the CAA and CWA. A NEPA EA or EIS will be required for any remediation project on federal land. As part of project execution, mitigation measures may have to be designed and implemented to protect critical habitat, and emissions and effluents will have to be monitored to ensure regulatory compliance. Prior to project acceptance and close-out, project completion reports that include chemical-specific data on emissions and effluents will have to be provided to the regulatory agencies to document that the project was executed and completed in accordance with the applicable environmental acts.

27. Construction management personnel shall demonstrate a working level knowledge of the quality assurance processes and procedures applicable to construction management in 10 CFR 830.120, Quality Assurance Requirements.

    a. Discuss the purpose, scope, and application of 10 CFR 830.120. Include in this discussion key terms, essential elements, and personnel responsibilities and authorities.

**Objectives**

   The objectives of 10 CFR 830.120 are

   ▪ to achieve quality assurance (QA) for all work based upon the following principles:
     o that quality is assured and maintained through a single, integrated, effective quality assurance program (i.e., management system)
     o that management support for planning, organization, resources, direction, and control is essential to QA
     o that performance and quality improvement require thorough, rigorous assessment and corrective action
     o that workers are responsible for achieving and maintaining quality
     o that environmental, safety, and health risks and impacts associated with work processes can be minimized while maximizing reliability and performance of work products
to establish quality process requirements to be implemented under a QA program (QAP) for the control of suspect/counterfeit items and safety issue corrective actions.

Applicability

DOE/NNSA elements. Primary DOE organizations, including NNSA organizations, must follow this regulation when performing their work.

b. Discuss the quality assurance measures required for each of the following elements of a project:
   - Design configuration control
   - Procurement control
   - Instructions, procedures, and drawings
   - Document control
   - Identification, control, and traceability of materials, parts, and components
   - Control of special processes
   - Inspection
   - Test control
   - Calibration and control of test and measurement equipment
   - Handling, storage, shipping, and preservation of material, parts, or components
   - Nonconformity of material, parts, or components
   - Corrective action
   - Quality assurance records
   - Audits


**Design Configuration Control**

A design process should be established that provides appropriate control of design inputs, outputs, verification, configuration and design changes, and technical and administrative interfaces.

The completed design should be recorded in design output documents such as drawings, specifications, test/inspection plans, maintenance requirements, and reports. As-built drawings and shop drawings should be maintained after production or construction to show actual configuration. The administrative interface process should clearly indicate responsibilities for design output documents, including the requirements for document control, configuration management, and records management.

**Procurement Control**

The procurement process should ensure that items and/or services provided by suppliers meet the requirements and expectations of the end user. The procurement process should be planned and controlled to ensure that

- The end user’s requirements are accurately, completely, and clearly communicated to the supplier;
- Supplier, designer, and end-user requirements are met during the production phase;
- The proper product is delivered on time and maintained until use.
Procurement processes should prevent introduction of suspect/counterfeit items (S/CIs) and provide a method to detect them before they are released for use.

The selection of procurement requirements should be commensurate with the importance of the end use of the purchased item or service. Management controls exist for DOE procurement and subcontracts through applicable DOE Orders, the Department of Energy Acquisition Regulation (the DEAR) in 48 CFR subchapters A through H, and the Federal Acquisition Regulation (FAR) in 48 CFR 970, “DOE Management and Operating Contracts” et. seq. The requirements in the QA Rule and Order should not be interpreted to require the development of redundant procurement management systems, but rather to ensure that existing procurement management systems adequately respond to end-user requirements.

The procurement process of DOE nuclear facility contractors must include a determination of the applicability of 10 CFR 830, “Nuclear Safety Management,” to the supplier or subcontractor. (10 CFR 830.121 states “The quality assurance plan must: Describe how the contractor responsible for the nuclear facility ensures that subcontractors and suppliers satisfy the criteria of 10 CFR 830.122.”) If applicable, procurement documents and contracts for items and services provided to facilities covered by 10 CFR 830 should include a statement informing the supplier or subcontractor that it is subject to 10 CFR 830 and of the potential for enforcement actions under 10 CFR 820. Suppliers and subcontractors are not required by 10 CFR 830 to submit their QAPs to DOE for review and approval; rather, it is left to the contractor to determine the methods for ensuring that procured items and services meet requirements and perform as expected.

Instructions, Procedures, and Drawings
Procedures, work instructions, or other appropriate means used to define work processes should be documented and controlled. The scope and detail of documentation should be commensurate with the complexity and importance of the work, the skills required to perform the work, the hazards and risks or consequences of quality problems in the product, process, or service, and the need to meet regulatory and contract requirements. Control of processes, skills, hazards, and equipment should be clearly specified, understood, and fully documented. This serves as the point of integration for integrated safety management and quality assurance into an integrated management approach.

Document Control
A document control system should be in place to control the preparation, review, approval, issue, control, and revision of documents. Documents are required by organizations, projects, or programs to control policy and administrative and/or technical information. A document may describe work to be done, data to be used at different locations or by different people, or, in changing situations, data to be controlled from time to time for reference purposes. The document control system should be established to supply the documents necessary for personnel to safely and correctly perform their assigned responsibilities. Document control systems ensure that the mechanisms developed to implement the safety management functions are properly prepared, controlled, and available for use.
Identification, Control, and Traceability of Materials, Parts, and Components

The identification and control process should apply from manufacture or receipt through delivery, installation, or use. The process should also provide for the identification and configuration control of installed or replacement items consistent with specified requirements. Physical identification of items is preferred. Suitable identification information includes the unique part, lot, heat, model, version, or serial numbers on the item or in records traceable to the item, or both.

Control of Special Processes

Note: 10 CFR 830.120 or DOE G 414.1-2A, Quality Assurance Management System Guide for Use with 10 CFR 830 Subpart A, Quality Assurance Requirements, and DOE O 414.1C, Quality Assurance, does not include any requirements related to the control of special processes. There may be site-specific requirements associated with this. The local qualifying official will evaluate the completion of this competency.

Inspection and Test Control

Inspections and tests are accomplished to verify that physical and functional aspects of items, services, and processes meet requirements and are fit for acceptance and use. Performance expectations, inspections, and tests should be identified/considered early in the design process and/or specified in the design output and procurement documents.

Before beginning work, personnel should check items to ensure they are correct and suitable for their intended applications. Personnel should check their process output to verify that it meets or exceeds specified requirements.

Inspection or test planning should be performed. Appropriate sections of approved codes or standards may be used for acceptance requirements and inspection or test methods. In planning for inspections/tests, personnel should consider provisions for the following:

- Identification of characteristics to be examined
- Required qualifications of individuals who perform the examinations
- Descriptions of examination methods, including equipment and calibration requirements
- Acceptance and rejection criteria
- Suitable environmental conditions
- Shelf life and maintenance
- Required safety measures
- Mandatory hold points, when applicable

Inspections or tests should be performed by technically qualified personnel who have the authority to access appropriate information and facilities to verify acceptance. These qualified personnel should be independent of the activities being inspected or tested and should have the freedom to report the results of the inspections/tests. Inspection/test results should be evaluated and verified by qualified personnel of the design organization to document that requirements have been satisfied.
**Calibration and Control of Test and Measurement Equipment**

Measuring and test equipment (M&TE) used for inspections, tests, monitoring, and data collection should be calibrated, maintained, and controlled using a documented process. M&TE should be checked before use to ensure that it is of the proper type, range, accuracy, and precision, and that it is uniquely identified and traceable to its calibration data. Procedures should be established for testing, retesting, adjusting, and recalibrating M&TE. M&TE should be calibrated to standards traceable to the National Institute of Standards and Technology or other nationally recognized standards when appropriate. If no nationally recognized standard exists, the basis for calibration should be documented. When calibrating and/or checking M&TE for use, consideration should be given to computer programs that are part of the M&TE. The use of each item of M&TE should be traceable and associated with the item of M&TE. This is because measurements and tests performed with the M&TE may need to be reevaluated if the item of M&TE is subsequently found to be out of its acceptable calibration range. Systems that rely on recording the identity of the M&TE in work packages are ineffective because it is usually almost impossible to review all work packages to identify each use of a particular item of M&TE.

**Handling, Storage, Shipping, and Preservation of Material, Parts, or Components**

Work processes should be established and implemented to protect items in accordance with specified technical standards and administrative controls to prevent damage, loss, or deterioration. Work processes should specify protective methods to be used for sensitive or perishable items, such as special handling, shipping, and storage controls for precision instrumentation and limited shelf life items, and items requiring special protective environmental controls, such as temperature and humidity controls.

**Nonconformity of Material, Parts, or Components**

According to DOE O 414.1C, items that do not conform to established requirements are not normally considered S/CIs if nonconformity results from one or more of the following conditions (which must be controlled by site procedures as nonconforming items):

- Defects resulting from inadequate design or production quality control;
- Damage during shipping, handling, or storage;
- Improper installation;
- Deterioration during service;
- Degradation during removal;
- Failure resulting from aging or misapplication; or
- Other controllable causes.

**Corrective Action**

The following is taken from DOE O 414.1C,

*Reporting findings.* Within 10 calendar days of issuance, the assessing organization submits the final assessment report, along with a synopsis of assessment report findings, to (1) the appropriate field element managers (FEMs) and Secretarial Officers (SOs), and (2) the Office of ES&H.
Corrective Action Plan (CAP) development, approval, and review.

### Development
The FEM, in consultation with the appropriate SO, must prepare a comprehensive CAP in writing to address assessment findings and field and Headquarters corrective actions for each finding. Guidance for implementing these requirements is outlined in volume 2, appendix G, of DOE G 450.4-1B, *Integrated Safety Management System Guide*.

**NOTE:** DOE O 470.2B, *Independent Oversight and Performance Assurance Program*, includes additional CAP reporting requirements.

When findings and/or corrective actions to be addressed apply to more than one SO, a lead SO must be appointed by mutual agreement or be appointed by the Deputy Secretary to coordinate and approve the CAP.

When findings and/or corrective actions to be addressed involve multiple sites or organizations, to include DOE Headquarters organizations or other elements, the lead SO must designate a lead FEM as overall manager to coordinate and develop the CAP and track and report CAP data in the corrective action tracking system (CATS) database.

Other responsible sites/organizations must forward their portions of the CAP to the designated lead FEM for consolidation and submission. Failure to provide this information will be brought to the attention of the lead SO for action. For each finding, the CAP must address:
- a thorough analysis of the underlying causal factors to determine whether systemic program weaknesses exist;
- steps to address the cause(s) of the finding;
- detailed descriptions of corrective action(s) to resolve each finding and prevent recurrence;
- a general outline for the conduct of the proposed independent corrective action effectiveness review.

For each corrective action, the CAP must address:
- deliverable(s) that will signify completion;
- responsible individuals and organizations;
- dates actions will be initiated;
- dates actions are planned to be completed;
- how actions will be tracked to completion;
- mechanisms for independent verification of closure.

### Approval
The CAP must be prepared on a schedule that will allow for review and approval by the SO or designee within 60 calendar days from the date the transmittal forwarding the formal final assessment/investigation report was issued.

The SO or designee must approve the CAP and all proposed corrective actions from responsible sites/organizations for each finding.

When a finding addresses a deficiency in DOE policy, the applicable DOE policy organization (e.g., Office of Environment, Safety and Health, Office of Science) must develop and implement appropriate corrective actions. Corrective actions must be
included in the CAP addressing all other findings in the assessment report, or a separate CAP must be developed by the policy organization for approval, tracking, and reporting. Separate CAPs developed by a DOE policy organization must be approved by organization directors.

When a proposed CAP cannot be submitted to the SO for approval within the required 60 days, or the SO does not approve the proposed CAP, the DOE CATS User’s Guide outlines the formal process for requesting an extension from the SO.

- **Review.** The SO or designee must forward copies of an approved CAP to the organization that conducted the assessment and to the Office of ES&H.

The organization that conducted the assessment must review the approved CAP and provide comments to the SO and FEM within 30 calendar days from the date the approved CAP was transmitted.

The SO must evaluate comments from the organization that conducted the assessment and provide written response on how the comments will be addressed. If the SO decides the CAP must be revised, the FEM must be notified to revise and resubmit the CAP for SO approval within a specified time frame not to exceed 60 calendar days from the date the SO directed the revision. The revised CAP must be submitted to the organization that conducted the assessment for review and a copy provided to the Office of ES&H.

Disagreements that cannot be resolved between the organization that conducted the assessment and the SO must be elevated through the organizational level of management hierarchy up to the Office of the Secretary, if necessary for resolution.

**Tracking and Reporting Implementation.** The FEM

- is responsible for implementing the approved CAP and ensuring timely and effective completion of all corrective actions;
- must enter, track, and report the status of the CAP and associated corrective actions to closure in the DOE CATS database;
- must enter CAP corrective action data as stated in the approved CAP for each finding in CATS within 10 working days after approval;
- must ensure that all corrective actions are tracked and their status reported to completion and verification.

Completion of each corrective action must be annotated in the CATS descriptive status and completion date fields.

Other sites/organizations that forwarded portions of the CAP and corrective actions to the lead FEM must track and provide the FEM updates of their portions of the CAP and corrective actions to completion and verification within the time frames specified in DOE O 414.1C, Quality Assurance.

The FEM must update the CAP status field and corrective action descriptive status fields on a frequent basis (e.g., monthly) and enter the date at the beginning of each update. Requests for CAP changes in CATS (i.e., planned corrective action completion date) must be approved by the SO who approved the CAP and submitted as outlined in the CATS Users Guide.

Information in CATS will be used to provide periodic (e.g., quarterly) status reports to assist
senior DOE management in monitoring the status of the corrective action management program (CAMP).

Corrective action effectiveness review. Evaluation of findings and implementation of corrective actions is conducted to correct the underlying causes for the finding. In some instances completed corrective actions have failed to effectively resolve or prevent recurrence of the same or similar assessment findings.

Effectiveness reviews will
- determine whether completed corrective actions have or have not effectively resolved and prevented recurrence of the same or similar findings at the performance level;
- identify additional actions necessary to effectively resolve the findings and prevent recurrence;
- collect effectiveness data for subsequent analyses and sharing of lessons learned.

Upon completion of the corrective actions, the FEM must initiate a follow-up review of the completed corrective actions to verify they are closed, ensure all findings were effectively resolved, and ensure the same or similar findings will not recur. A formal review report approved by the FEM must be completed within 6 months after the CAP completion date (the date when all corrective actions for all findings listed in the CAP have been completed).

NOTE: This requirement is effective on the approval date of this Order for all CAPs that have not been approved, CAPs that have been approved but are not complete (all corrective actions in the CAP are not complete and there is not a CAP completion date), and all future CAPs. The FEM will determine the following:
- How the review is conducted
- Who conducts the review
- Which specific completed corrective actions are reviewed for each finding
- When the review is initiated
- How the review report will be formatted

Other sites/organizations that tracked and provided updates of their responsible corrective actions to completion and verification must coordinate effectiveness review activities with the lead FEM for consolidation and submission.

For each finding, the FEM will select for review a sufficient number of completed corrective actions to allow an objective, accurate assessment of effectiveness in resolving the finding and preventing recurrence. Standards for conducting effectiveness reviews include the following:
- A 100 percent review of all corrective actions is not required to determine effectiveness.
- Effectiveness reviews can be initiated at any time during CAP implementation.
- Reviews are initiated based on severity of a finding
- length of time needed to review selected corrective actions
- availability of resources to review corrective actions
- length of time before all corrective actions for the finding are to be completed
Effectiveness reviews are performed by federal and/or contractor personnel who are not associated with the findings or corrective actions.

Mechanisms used to conduct effectiveness reviews are determined by the FEM and may include:
- Document reviews
- Performance analyses
- Work observations/facility tours
- Performance testing
- Interviews
- Trending of performance
- Monitoring performance metrics based on operational data
- Tracking performance utilizing targeted assessments
- Performing tailored scheduled assessments to gather the data

Reporting and follow-up. A formal report documenting the results of the effectiveness review must be completed and approved by the FEM no later than six months after the CAP completion date (the date all corrective actions are completed).

If the FEM determines that additional time is required to successfully complete the effectiveness review, the effectiveness review approval date field in the CAP data section of CATS must be updated to read, “See CAP Status.” Information on the status of the review and the revised planned approval date must be entered into the CAP status field in the CAP data section.

The report includes an executive summary outlining overall scope, results, conclusions, rating, and recommendations. A separate report form for each finding describing which corrective actions were reviewed, review activities and results, conclusions, rating (i.e., effective, partially effective, ineffective), and any recommendation for completion is to be attached to the executive summary.

FEM approval of the report must be recorded in the review approval date field in the cap data section of CATS. An effectiveness description of the effectiveness review results and follow-up actions must be outlined in the effectiveness review results field.

Upon FEM approval, report recommendations must be implemented and followed up on as directed by the FEM. The report and supporting documents must be retained in accordance with the local records management process.

If the FEM revises the completed CAP based on report recommendations, the CAP revision with additional or revised corrective actions, as applicable, must be approved by the SO. Upon approval, CAP revisions must be entered into CATS and tracked to successful completion. Guidance for entering the revisions is outlined in the CATS User’s Guide.

Lessons learned. At any time during the CAMP process, the FEM must develop and implement lessons learned as identified from the assessment findings, corrective actions in response to the findings, and results of corrective action effectiveness reviews, as applicable.
The FEM must evaluate proposed lessons learned to determine whether they are applicable to the wider DOE community and distribute the information to a select list of recipients through the DOE Corporate Lessons Learned Collection.

Corrective Action Management (CAM) Team. The CAM Team, a cross-organizational working group of representatives from Headquarters and field offices, must be maintained to support and coordinate effective line management implementation of the CAMP.

A charter outlining mission, functions, operations, membership, and leadership of the team must be maintained. The CAM Team is sponsored by the Office of ES&H and co-chaired by an SO representative and the Office of ES&H.

Quality Assurance Records
The following is taken from DOE G 414.1-2A.

Documents and records are required to effectively manage, perform, and assess work. Documents and records should include applicable requirements to indicate that work (including safety) has been properly specified and accomplished. Management should identify any documents and records that must be developed and controlled. Management is responsible to provide the resources necessary to accomplish the document and record requirements.

A document control system should be in place to control the preparation, review, approval, issue, control, and revision of documents. Documents are required by organizations, projects, or programs to control policy and administrative and/or technical information. A document may describe work to be done, data to be used at different locations or by different people, or, in changing situations, data to be controlled from time to time for reference purposes. The document control system should be established to supply the documents necessary for personnel to safely and correctly perform their assigned responsibilities. Document control systems ensure that the mechanisms developed to implement the safety management functions of DOE P 450.4, Safety Management System Policy, are properly prepared, controlled, and available for use.

A record contains information that is retained for its expected future value. Records should be sufficient to support technical and regulatory decisions and provide evidence that work was correctly performed. Records may be in a variety of forms (e.g., electronic, written, or printed data; microfilm; photographs; radiographs; or optical disks). Typical records include procedures, plans, and manuals; training and qualification results; acceptance test results; technical/regulatory correspondence; operational records; design basis descriptions, design review results, design revisions, and configuration management data; and quality problem resolutions. Records should be compiled in a records management system. The system should include provisions for specifying, preparing, reviewing, approving, disposing, and maintaining records. Records retention, protection, preservation, change, traceability, accountability, and retrievability should also be specified. The records management system should have schedules for records retention and disposition consistent with the requirements of DOE O 200.1A, Information Management Program. The hardware and software tools used to create and store records should be maintained to ensure that the records can be
Audits
The following is taken from DOE G 414.1-2A.

Managers at every level should periodically assess their organizations and functions to: determine how well they meet customer and performance expectations and mission objectives, identify strengths or improvement opportunities, and correct problems. Assessments should address the effective use of resources to achieve the organization’s goals and objectives. Management assessments should determine whether an integrated management system exists and whether it focuses on meeting both customer and performance requirements and strategic goals.

Senior management should also establish and implement a process to obtain an independent assessment of the organization’s programs, projects, contractors, and suppliers. The purpose of this type of assessment is to evaluate compliance performance of work processes with regard to requirements, expectations of customers, and efforts required to achieve the mission and goals of the organization. The results of independent assessments provide an objective form of feedback to senior management that is useful in confirming acceptable performance and should be used for identifying improvement opportunities. DOE has developed expanded guidance on this subject that should be consulted for planning and performing independent assessments in DOE G 414.1-1B, Management and Independent Assessments Guide for Use with 10 CFR Part 830, Subpart A, and DOE O 414.1C, Quality Assurance; DOE M 450.4-1, Integrated Safety Management System Manual; and DOE O 226.1A, Implementation of Department of Energy Oversight Policy. The independent assessment process includes compliance- and performance-based approaches that focus on results. Compliance-based assessments focus on verification of adherence to established requirements. Performance-based assessments are conducted on activities and processes that relate directly to performance expectations and that emphasize safety and reliability.

DOE line organizations should apply the independent assessments to their work and the work of their contractors. Contractor line organizations should apply the independent assessments to their work and the work of their subcontractors.

c. **Describe the screening process for the identification and inspection of suspect or counterfeit (S/CI) material items.**

The following is taken from DOE G 414.1-3.

A suspect item is one in which visual inspection, testing, or other means indicate that it may not conform to established Government or industry-accepted specifications or national consensus standards; or one whose documentation, appearance performance, material, or other characteristics may have been misrepresented by the supplier or manufacturer. A counterfeit item is a suspect item that has been copied or substituted without legal right or authority to do so or one whose material, performance, or characteristics are misrepresented by the supplier or manufacturer. An item that does not conform to established requirements is retrieved. The National Archives and Records Administration provides a recommended approach for maintenance of records, including electronic records management.
not normally considered an S/CI if the nonconformity results from one or more of the following conditions, which are controlled by site procedures as nonconforming items:

- Defects resulting from inadequate design or production quality control;
- Damage during shipping, handling, or storage;
- Improper installation;
- Deterioration during service;
- Degradation during removal;
- Failure resulting from aging or misapplication; or
- Other controllable causes.

An item identified as S/CI may have one or more of the indications described above and not be fraudulent. If an item exhibits some of the indications listed above it may warrant further investigation and be considered suspect. Contact with the supplier and/or manufacturer may help establish whether the item in question has a quality control problem or is actually fraudulent.

d. Describe the roles and responsibilities of DOE quality assurance personnel and construction personnel for quality control during construction activities.

The following is taken from DOE G 413.3-2.

*QA Guidance for critical decision (CD)-3, Approve Start of Construction*

Either the cognizant Federal project direction (FPD) and the integrated project team (IPT) or the contractor performs the following prior to CD-3 submittal:

- Ensure the QA program is updated prior to the submittal of CD-3
- Ensure acquisition documents include appropriate QA requirements
- Ensure the technical evaluation is supported by experienced QA individuals
- Ensure design interfaces are reviewed and approved
- Ensure the use of qualified vendors
- Ensure in-depth oversight of the QA program(s) of the prime contractor and key subcontractors (if applicable) is conducted
- Ensure SSCs are properly graded
- Ensure adequate systems, processes, implementing procedures are in place and mature, and supported by experienced personnel
- Ensure integrated oversight/assessment/surveillance/inspection plans and schedules are developed, implemented, and maintained
- Ensure proper contractor performance metrics are established
- Ensure IPT and project meetings include a QA representative and a review of QA activities
- Ensure there is appropriate QA organization representation during revisions to the project execution plan
- Ensure there is appropriate QA organization representation during external independent reviews for construction or execution readiness
- Ensure there is a process in place to integrate the results of project oversight programs
- Ensure the distribution of oversight is adjusted based on the level of maturity of the contractor’s oversight programs
- Ensure the quality-related activities are reflected in the integrated project schedule and work breakdown structure
- Ensure documents and records (objective evidence) for in-process and completed quality-related items and activities are maintained and readily retrievable, consistent with applicable codes, regulations, and directives
- Ensure, through independent assessments, that quality is being incorporated into the work processes – not inspected in
- Evaluate/accommodate changes in skills mix and specific disciplines as the project progresses through the construction phase.

**QA Guidance for CD-4, Approve Start of Operations or Project Completion**

Either the cognizant FPD and the IPT or the contractor performs the following prior to CD-4 submittal:
- Ensure continuous improvement; execution, oversight, feedback from oversight, and modification
- Ensure, through observation, oversight, the use of QA representatives, and independent assessments, that quality is being incorporated into the work processes and activities – not inspected in
- Evaluate/accommodate changes in skills mix and specific disciplines as the project progresses through the construction phase
- Routinely evaluate QA organization performance and make staffing adjustments as necessary
- Ensure project lessons learned (positive and negative) are produced
- Ensure complex wide lessons learned are analyzed and project changes are implemented, as necessary
- Ensure as-builts are developed, including maintaining plant configuration
- Ensure the project is implementing an effective issues management system
- Provide an updated QA program plan and lessons learned to operations as a source for updating existing operational QA program plans and other operational-related documentation
- Ensure records validation/authentication and turnover, consistent with applicable codes, regulations, and directives

28. **Construction management personnel shall demonstrate a working level knowledge of the unreviewed safety question (USQ) process of 10 CFR 830.**

a. **Discuss the reasons for performing a USQ determination.**

The following is taken from DOE G 424.1-1A.

10 CFR 830.203, “Unreviewed Safety Question Process,” allows contractors to make physical and procedural changes and to conduct tests and experiments without prior DOE approval if the proposed change can be accommodated within the existing safety basis. The contractor must evaluate any proposed change to ensure that it will not affect the safety basis of the facility either explicitly or implicitly.
b. Describe the situations that require implementation of the USQ process.

The following is taken from DOE G 424.1-1A.

10 CFR 830.203 is implemented using contractor procedures for ensuring that proposed changes to physical characteristics or technical procedures are evaluated relative to the approved safety basis and that those proposed changes determined to involve USQs are brought to the attention of DOE for review and approval before changes are made.

c. Define the situations that represent an Unreviewed Safety Question.

The following is taken from 10 CFR 830.203.

A proposed change or test involves a USQ if
- the probability or consequences of an accident or malfunction of equipment important to safety could be increased;
- the possibility of a different type of accident than previously evaluated in the documented safety analysis (DSA) could be introduced;
- margins of safety could be reduced.

d. Describe your contractors USQ process.

This is a performance-based KSA. The local Qualifying Official will evaluate its completion.

29. Construction management personnel shall demonstrate a working level knowledge of the Documented Safety Analysis (DSA) and the Technical Safety Requirements (TSR) as described in 10 CFR 830, and safety implementation in accordance with DOE Order 420.1A, Facility Safety.

a. Describe the purpose, scope, and application of requirements detailed in the above documents.

10 CFR 830.204, Documented Safety Analysis
Development of a DSA or preliminary documented safety analysis is the process whereby facility hazards are identified, controls to prevent and mitigate potential accidents involving those hazards are proposed, and commitments are made for design, construction, operation, and disposition so as to ensure adequate safety at DOE nuclear facilities.

10 CFR 830.205, Technical Safety Requirements (TSR)
TSRs define the performance requirements of SSCs and identify the safety management programs used by personnel to ensure safety. TSRs are aimed at confirming the ability of the SSCs and personnel to perform their intended safety functions under normal, abnormal, and accident conditions. These requirements are identified through hazard analysis of the activities to be performed and identification of the potential sources of safety issues. Safety analyses to identify and analyze a set of bounding accidents that take into account all potential causes of releases of radioactivity also contribute to development of TSRs.
DOE O 420.1A, Facility Safety

[Note: DOE O 420.1A has been superseded by DOE O 420.1B.]

The purpose of DOE O 420.1B is to establish facility safety requirements for DOE, including the NNSA for the following:

- Nuclear safety design
- Criticality safety
- Fire protection
- Natural phenomena hazards mitigation
- A system engineer program

b. Discuss the purpose of the DSA and TSRs.

Refer to element “a” of this competency for the purpose of DSAs and TSRs.

c. Describe the responsibilities of contractors authorized to operate defense nuclear facilities regarding the DSA and TSRs.

DSAs

The following is taken from DOE G 421.1-2.

10 CFR 830, subpart B, “Safety Basis Requirements,” requires the contractor responsible for a DOE nuclear facility to analyze the facility, the work to be performed, and the associated hazards and to identify the conditions, safe boundaries, and hazard controls necessary to protect workers, the public, and the environment from adverse consequences. These analyses and hazard controls constitute the safety basis upon which the contractor and DOE rely to conclude that the facility can be operated safely. Performing work consistent with the safety basis provides reasonable assurance of adequate protection of workers, the public, and the environment.

10 CFR 830 requires that a contractor responsible for a DOE hazard category 1, 2 or 3 nuclear facility must

- establish and maintain a safety basis for the facility;
- perform work in accordance with the safety basis and, in particular, with the hazard controls that ensure adequate protection of workers, the public, and the environment; and
- pending issuance of a safety evaluation report in which DOE approves a safety basis for an existing DOE nuclear facility, the contractor responsible for the facility must continue to perform work in accordance with the safety basis for the facility in effect on October 10, 2000, or as approved by DOE at a later date, and maintain the existing safety basis consistent with the rule requirements.

In establishing the safety basis for a hazard category 1, 2, or 3 DOE nuclear facility, the contractor responsible for the facility must

- define the scope of the work to be performed;
- identify and analyze the hazards associated with the work;
- categorize the facility consistent with DOE-STD-1027-92, Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear
Safety Analysis Reports, Change Notice No. 1, September 1997, or successor document:

- prepare a DSA for the facility; and
- establish the hazard controls upon which the contractor will rely to ensure adequate protection of workers, the public, and the environment.

**TSRs**

The following is taken from DOE G 423.1-1.

10 CFR 830.205, “Technical Safety Requirements,” requires DOE contractors responsible for category 1, 2, and 3 DOE nuclear facilities to develop TSRs. These TSRs identify the limitations to each DOE owned, contractor operated nuclear facility based on the DSA and any additional safety requirements established for the facility. Although not required by the 10 CFR 830, there also may be a need to establish TSRs for safe operation of radiological facilities.

The TSR rule requires contractors to prepare and submit TSRs for DOE approval. The appendix to subpart B of the nuclear safety management rule specifies the types of safety limits, operating limits, surveillance requirements, and administrative controls that define the safety envelope necessary to protect the health and safety of the public and workers. The TSR derivation chapter in the DSA is the key component that provides the basis for TSRs.

**d. Discuss how hazard and accident analysis are used in design and evaluation of SSCs.**

The following is taken from DOE-STD-3009-94.

**Hazard Analysis**

The hazard analysis provides final facility hazard categorization and considers and incorporates into programmatic requirements measures to protect workers, the public, and the environment from hazardous and accident conditions. TSRs and safety-significant structures, systems, and components, that are major contributors to worker safety and defense in depth, are identified in the hazard analysis.

**Accident Analysis**

The accident analysis designates safety-class SSCs and safety controls as a function of the evaluation guideline.

**e. Describe how safety SSCs are addressed in the DSA and discuss the implications of the following classifications:**

- Safety-class
- Safety-significant
- Defense in depth

The following is taken from DOE G 421.1-2.

In the area of safety system designation, it is instructive to revisit both the concept and the process. The safety class designation process for SSCs proceeds from first the determination
of need for such designation at a given facility, to the actual selection process among the individual safety systems. The determination of “need for safety class designation” at a nuclear explosive facility is a moot point, vis-a-vis the concept of potential offsite consequences. In other words, there is no need for performing an explicit unmitigated release consequence analysis in accordance with appendix A of DOE-STD-3009-94 to determine that nuclear explosive facilities must have safety class SSCs for accident prevention or mitigation. This means that any accident scenario that can cause an explosive dispersal of plutonium, or its source-term equivalent, should be prevented or mitigated by a safety class SSC (if feasible). This is because of the nature of nuclear explosive operations that are conducted in a variety of facilities and locations, including onsite and offsite transportation, and the desire to remove a layer of uncertainty from the analytical process.

All safety-related controls (criticality related or otherwise) are identified and characterized during the course of the hazards and accident analyses performed in support of the DSA. A subset of all controls will get safety class or safety significant designation, and some of these may be related to control of criticality accidents. Controls that are identified and discussed in criticality safety evaluations may or may not end up as safety class or safety significant depending on the basis for these designations derived from the hazards analysis and accident analysis in the DSA.

Safety-Class
The safety class SSC classification was instituted to deal with SSCs that have special importance with regard to protection of the public, modeled after engineered safety features of power reactors that are required to meet siting criteria.

Safety-Significant
The safety significant SSC classification was instituted to provide additional public protection by providing multiple means of dealing with accidents (defense in depth) and to provide protection for onsite personnel who may not be protected by distance factors, as the public is, because of large DOE sites.

Defense-in-Depth
In the context of defense in depth, the intent is threefold. First, associated with the classical defense-in-depth philosophy, SSCs identified as safety significant are intended to build in layers of defense against the release of hazardous materials (not just radioactive materials) so that no one layer, no matter how good, is completely relied upon. Second, in recognition that several DOE sites are quite large and that the site boundary distance from any given facility may also be large, application of the evaluation guideline for safety class SSCs, alone, may not provide an adequate level of protection for persons outside of the facility but within the site boundary, safety significant SSC designation can provide such protection. Finally, because the evaluation guideline for safety class SSCs is not intended to imply an acceptable level of public dose, safety significant SSCs for defense in depth provide for achieving public dose levels from accidents to significantly below 25 rem, especially when unmitigated dose calculations would not trigger a safety class SSC.
f. Discuss the relationship between the construction schedule and the development or modification of the facility DSA.

The following is taken from DOE G 421.1-2.

During design and construction, the governing safety basis document is the preliminary documented safety analysis (PDSA). It is updated as the design matures and is approved prior to procurement and construction activities. Until approval, the PDSA and its updates serve to keep DOE informed as to how DOE nuclear safety design criteria are being addressed in the design. Project design reviews provide the vehicle by which safety-related changes are reviewed, giving DOE the information needed to be able to provide guidance to the contractor. Prior to operations, the PDSA evolves to a final DSA that reflects the facility as actually constructed.

30. Construction management personnel shall demonstrate a working level knowledge of the Occupational Safety and Health Act (OSHA) requirements in the following chapters of the Code of Federal Regulations:
   - 29 CFR 1910, Occupational Safety and Health Standards
   - 29 CFR 1926, Safety and Health Regulations for Construction

a. Discuss how the OSHA applies to and impacts Department construction projects.

The following is taken from DOE G 440.1-2.

DOE O 440.1B requires DOE to review safety and health program elements developed by the host for site maintenance and operation activities to determine suitability and cost effectiveness on site construction projects. The intent of this requirement is twofold. First, in instances where the host and construction contractors mutually expose their employees to common hazards, it is probably both desirable and cost effective to mandate construction contractor adherence to site-wide occupational safety and health policies and procedures. However, there are also instances where mandated compliance by the construction contractor with host occupational safety and health program requirements that go beyond applicable DOE adopted occupational safety and health standards or are poorly suited to construction will have little, if any, positive impact on safety and health but will adversely affect project cost and schedule.

b. Identify the requirements in the Occupational Safety and Health Act that form the basis of authority for construction management personnel in the oversight and management of construction projects.

The following is taken from DOE, Office of Health, Safety, and Security, Federal Employee Occupational Safety and Health (FEOSH) Program Overview.

Congress established Public Law 91-596, “The Occupational Safety and Health Act of 1970” (OSH Act) to ensure so far as possible every working man and woman in the Nation safe and healthful working conditions and to preserve our human resources.” Section 19 of the OSH Act contains broad responsibilities and requirements for Federal agency safety and health programs to ensure safe and healthful working conditions for Federal employees.
Executive Order 12196, *Occupational Safety and Health Programs for Federal Employees*, contains, among other items, additional responsibilities for the heads of Federal agencies and a requirement for the Secretary of Labor to issue basic program elements for Federal agency safety and health programs in conformance with the OSH Act.

The basic program elements mandated by the President in Executive Order 12196 are issued in the Department of Labor’s implementing regulations in 29 CFR 1960, “Basic Program Elements for Federal Employee Occupational Safety and Health Programs and Related Matters.” This OSHA standard establishes and communicates the requirements under which Federal agencies, including the DOE, must develop and implement their FEOSH program.

DOE O 440.1B, Worker *Protection Management for DOE Federal and Contractor Employees*, contains the required components to be utilized by DOE Elements in the development, implementation, and management of site-specific DOE Federal employee worker protection programs consistent with the requirements for FEOSH programs in 29 CFR 1960.

All FEOSH program management components (i.e., organization, training, inspections, self-assessments, hazard abatement, accident investigations, etc.) should be built around the DOE Integrated Safety Management system.

c. Discuss the basic requirements in the listed documents for each of the following areas associated with construction projects:

- Personnel protective equipment (PPE)
- Electrical safety
- Safety hazards associated with welding
- Safety hazards associated with materials handling and storage
- Safety hazards associated with machinery
- Safety hazards associated with portable and hand tools
- Safety hazards associated with concrete and masonry
- Safety hazards associated with scaffolding

**PPE**

The following is taken from 29 CFR 1910.132, “General Requirements.”

Protective equipment, including personal protective equipment for eyes, face, head, and extremities, protective clothing, respiratory devices, and protective shields and barriers, shall be provided, used, and maintained in a sanitary and reliable condition wherever it is necessary by reason of hazards of processes or environment, chemical hazards, radiological hazards, or mechanical irritants encountered in a manner capable of causing injury or impairment in the function of any part of the body through absorption, inhalation or physical contact.

The following is taken from 29 CFR 1926.28, “Personal Protective Equipment.”

The employer is responsible for requiring the wearing of appropriate personal protective equipment in all operations where there is an exposure to hazardous conditions or where 29 CFR 1926 indicates the need for using such equipment to reduce the hazards to the employees.
Regulations governing the use, selection, and maintenance of personal protective and lifesaving equipment are described under subpart E of 29 CFR 1926.

**Electrical Safety**
The following is taken from 29 CFR 1926.403, “General Requirements.”

**Approval**
All electrical conductors and equipment shall be approved.

**Examination, Installation, and Use of Equipment**

**Examination**
The employer shall ensure that electrical equipment is free from recognized hazards that are likely to cause death or serious physical harm to employees. Safety of equipment shall be determined on the basis of the following considerations:

- Suitability for installation and use in conformity with the provisions of 29 CFR 1926. Suitability of equipment for an identified purpose may be evidenced by listing, labeling, or certification for that identified purpose.
- Mechanical strength and durability, including, for parts designed to enclose and protect other equipment, the adequacy of the protection thus provided.
- Electrical insulation.
- Heating effects under conditions of use.
- Arcing effects.
- Classification by type, size, voltage, current capacity, specific use.
- Other factors that contribute to the practical safeguarding of employees using or likely to come in contact with the equipment.

**Installation and Use**
Listed, labeled, or certified equipment shall be installed and used in accordance with instructions included in the listing, labeling, or certification.

**Interrupting Rating**
Equipment intended to break current shall have an interrupting rating at system voltage sufficient for the current that must be interrupted.

**Mounting and Cooling of Equipment**

**Mounting**
Electric equipment shall be firmly secured to the surface on which it is mounted. Wooden plugs driven into holes in masonry, concrete, plaster, or similar materials shall not be used.

**Cooling**
Electrical equipment that depends on the natural circulation of air and convection principles for cooling of exposed surfaces shall be installed so that room air flow over such surfaces is not prevented by walls or by adjacent installed equipment. For equipment designed for floor mounting, clearance between top surfaces and adjacent surfaces shall be provided to dissipate rising warm air. Electrical equipment provided with ventilating openings shall be installed so
that walls or other obstructions do not prevent the free circulation of air through the equipment.

Splices
Conductors shall be spliced or joined with splicing devices designed for the use or by brazing, welding, or soldering with a fusible metal or alloy. Soldered splices shall first be so spliced or joined as to be mechanically and electrically secure without solder and then soldered. All splices and joints and the free ends of conductors shall be covered with an insulation equivalent to that of the conductors or with an insulating device designed for the purpose.

Arcing Parts
Parts of electric equipment which in ordinary operation produce arcs, sparks, flames, or molten metal shall be enclosed or separated and isolated from all combustible material.

Marking
Electrical equipment shall not be used unless the manufacturer’s name, trademark, or other descriptive marking by which the organization responsible for the product may be identified is placed on the equipment and unless other markings are provided giving voltage, current, wattage, or other ratings as necessary. The marking shall be of sufficient durability to withstand the environment involved.

Identification of Disconnecting Means and Circuits
Each disconnecting means required by 29 CFR 1926 for motors and appliances shall be legibly marked to indicate its purpose, unless located and arranged so the purpose is evident. Each service, feeder, and branch circuit, at its disconnecting means or overcurrent device, shall be legibly marked to indicate its purpose, unless located and arranged so the purpose is evident. These markings shall be of sufficient durability to withstand the environment involved.

600 Volts, Nominal, or Less
This paragraph applies to equipment operating at 600 volts, nominal, or less.

Working Space About Electric Equipment
Sufficient access and working space shall be provided and maintained about all electric equipment to permit ready and safe operation and maintenance of such equipment.

Working clearances. The dimension of the working space in the direction of access to live parts operating at 600 volts or less and likely to require examination, adjustment, servicing, or maintenance while alive shall not be less than indicated in table 14. In addition to the dimensions shown in table 14, workspace shall not be less than 30 in. wide in front of the electric equipment. Distances shall be measured from the live parts if they are exposed, or from the enclosure front or opening if the live parts are enclosed. Walls constructed of concrete, brick, or tile are considered to be grounded. Working space is not required in back of assemblies such as dead-front switchboards or motor control centers where there are no renewable or adjustable parts such as fuses or switches on the back and where all connections are accessible from locations other than the back.
Table 14. Working clearances

<table>
<thead>
<tr>
<th>Nominal voltage to ground</th>
<th>Minimum clear distance for conditions¹</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a) Feet²</td>
<td>(b) Feet²</td>
</tr>
<tr>
<td>0-150</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>151-600</td>
<td>3</td>
<td>3 1/2</td>
</tr>
</tbody>
</table>

¹ Conditions (a), (b), and (c) are as follows: (a) Exposed live parts on one side and no live or grounded parts on the other side of the working space, or exposed live parts on both sides effectively guarded by insulating material, insulated wire or insulated busbars operating at not over 300 volts are not considered live parts. (b) Exposed live parts on one side and rounded parts on the other side. (c) Exposed live parts on both sides of the workspace as provide in condition (a) with the operator between.

² Note: For international system of units one foot = 0.3048 meter

Source: 29 CFR 1926.403

Clear spaces. Working space required by 29 CFR 1926 shall not be used for storage. When normally enclosed live parts are exposed for inspection or servicing, the working space, if in a passageway or general open space, shall be guarded.

Access and entrance to working space. At least one entrance shall be provided to give access to the working space about electric equipment.

Front working space. Where there are live parts normally exposed on the front of switchboards or motor control centers, the working space in front of such equipment shall not be less than 3 feet.

Headroom. The minimum headroom of working spaces about service equipment, switchboards, panelboards, or motor control centers shall be 6 feet 3 in..

Guarding of live parts.
Live parts of electric equipment operating at 50 volts or more shall be guarded against accidental contact by cabinets or other forms of enclosures, or by any of the following means:
- By location in a room, vault, or similar enclosure that is accessible only to qualified persons.
- By partitions or screens so arranged that only qualified persons will have access to the space within reach of the live parts. Any openings in such partitions or screens shall be so sized and located that persons are not likely to come into accidental contact with the live parts or to bring conducting objects into contact with them.
- By location on a balcony, gallery, or platform so elevated and arranged as to exclude unqualified persons.
• By elevation of 8 feet or more above the floor or other working surface and so installed as to exclude unqualified persons.

In locations where electric equipment would be exposed to physical damage, enclosures or guards shall be so arranged and of such strength as to prevent such damage.

Entrances to rooms and other guarded locations containing exposed live parts shall be marked with conspicuous warning signs forbidding unqualified persons to enter.

*Over 600 volts, Nominal*

**General**

Conductors and equipment used on circuits exceeding 600 volts, nominal, shall comply with all applicable provisions of 29 CFR 1926 and with the following provisions which supplement or modify those requirements.

**Enclosure for Electrical Installations**

Electrical installations in a vault, room, closet or in an area surrounded by a wall, screen, or fence, access to which is controlled by lock and key or other equivalent means, are considered to be accessible to qualified persons only. A wall, screen, or fence less than 8 feet in height is not considered adequate to prevent access unless it has other features that provide a degree of isolation equivalent to an 8-foot fence.

The entrances to all buildings, rooms or enclosures containing exposed live parts or exposed conductors operating at over 600 volts, nominal, shall be kept locked or shall be under the observation of a qualified person at all times.

Installations accessible to qualified persons only. Electrical installations having exposed live parts shall be accessible to qualified persons only and shall comply with the applicable provisions of 29 CFR 1926.

Installations accessible to unqualified persons. Electrical installations that are open to unqualified persons shall be made with metal-enclosed equipment or shall be enclosed in a vault or in an area, access to which is controlled by a lock. Metal-enclosed switchgear, unit substations, transformers, pull boxes, connection boxes, and other similar associated equipment shall be marked with appropriate caution signs. If equipment is exposed to physical damage from vehicular traffic, guards shall be provided to prevent such damage. Ventilating or similar openings in metal-enclosed equipment shall be designed so that foreign objects inserted through these openings will be deflected from energized parts.

**Workspace About Equipment**

Sufficient space shall be provided and maintained about electric equipment to permit ready and safe operation and maintenance of such equipment. Where energized parts are exposed, the minimum clear workspace shall not be less than 6 feet 6 in. high (measured vertically from the floor or platform), or less than 3 feet wide (measured parallel to the equipment).

The depth shall be as required in table 15. The workspace shall be adequate to permit at least a 90-degree opening of doors or hinged panels.
**Working space.** The minimum clear working space in front of electric equipment such as switchboards, control panels, switches, circuit breakers, motor controllers, relays, and similar equipment shall not be less than specified in table 15 unless otherwise specified in 29 CFR 1926. Distances shall be measured from the live parts if they are exposed, or from the enclosure front or opening if the live parts are enclosed. However, working space is not required in back of equipment such as deadfront switchboards or control assemblies where there are no renewable or adjustable parts (such as fuses or switches) on the back and where all connections are accessible from locations other than the back. Where rear access is required to work on de-energized parts on the back of enclosed equipment, a minimum working space of 30 in. horizontally shall be provided.

<table>
<thead>
<tr>
<th>Nominal voltage to ground</th>
<th>Conditions¹</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a)</td>
<td>(b)</td>
<td>(c)</td>
</tr>
<tr>
<td>Feet²</td>
<td>Feet²</td>
<td>Feet²</td>
<td></td>
</tr>
<tr>
<td>601 to 2,500</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2,501 to 9,000</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>9,000 to 25,000</td>
<td>5</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>25,001 to 75kV</td>
<td>6</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Above 75kV</td>
<td>8</td>
<td>10</td>
<td>12</td>
</tr>
</tbody>
</table>

¹Conditions (a), (b), and (c) are as follows: (a) Exposed live parts on one side and no live or grounded parts on the other side of the working space, or exposed live parts on both sides effectively guarded by insulating materials. Insulated wire or insulated busbars operating at not over 300 volts are not considered live parts. (b) Exposed live parts on one side and grounded parts on the other side. Walls constructed of concrete, brick, or tile are considered to be grounded surfaces. (c) Exposed live parts on both sides of the workspace [not guarded as provided in condition (a)] with the operator between.

²Note: For SI units: one foot=0.3048 m.

**Source:** 29 CFR 1926.403

**Lighting outlets and points of control.** The lighting outlets shall be so arranged that persons changing lamps or making repairs on the lighting system will not be endangered by live parts or other equipment. The points of control shall be so located that persons are not likely to come in contact with any live part or moving part of the equipment while turning on the lights.

**Elevation of unguarded live parts.** Unguarded live parts above working space shall be maintained at elevations not less than specified in table 16.
Table 16. Elevation of unguarded energized parts above working space

<table>
<thead>
<tr>
<th>Nominal voltage between phases</th>
<th>Minimum elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>601-7,500</td>
<td>8 feet 6 in.¹</td>
</tr>
<tr>
<td>7,501-35,000</td>
<td>9 feet</td>
</tr>
<tr>
<td>Over 35kV</td>
<td>9 feet + 0.37 in. per kV above 35kV</td>
</tr>
</tbody>
</table>

¹Note: For SI units: one inch=25.4 mm; one foot=0.3048 m.

Source: 29 CFR 1926.403

Entrance and Access to Workspace
At least one entrance not less than 24 in. wide and 6 feet 6 in. high shall be provided to give access to the working space about electric equipment. On switchboard and control panels exceeding 48 in. in width, there shall be one entrance at each end of such board where practicable. Where bare energized parts at any voltage or insulated energized parts above 600 volts are located adjacent to such entrance, they shall be guarded.

Safety Hazards Associated with Welding
The following is taken from the Occupational Safety and Health Administration, Welding Health Hazards.

Chemical Agents
**Zinc** is used in large quantities in the manufacture of brass, galvanized metals, and various other alloys. Inhalation of zinc oxide fumes can occur when welding or cutting on zinc-coated metals. Exposure to these fumes is known to cause metal fume fever. Symptoms of metal fume fever are very similar to those of common influenza. They include fever (rarely exceeding 102 °F), chills, nausea, dryness of the throat, cough, fatigue, and general weakness and aching of the head and body. The victim may sweat profusely for a few hours, after which the body temperature begins to return to normal. The symptoms of metal fume fever have rarely, if ever, lasted beyond 24 hours. The subject can then appear to be more susceptible to the onset of this condition on Mondays or on weekdays following a holiday than they are on other days.

**Cadmium** is used frequently as a rust-preventive coating on steel and also as an alloying element. Acute exposures to high concentrations or cadmium fumes can produce severe lung irritation, pulmonary edema, and in some cases, death. Long-term exposure to low levels of cadmium in air can result in emphysema (a disease affecting the ability of the lung to absorb oxygen) and can damage the kidneys. Cadmium is classified by OSHA as a potential human carcinogen.

**Beryllium** is sometimes used as a alloying element with copper and other base metals. Acute exposure to high concentrations of beryllium can result in chemical pneumonia. Long-term
exposure can result in shortness of breath, chronic cough, and significant weight loss, accompanied by fatigue and general weakness.

Iron is the principal alloying element in steel manufacture. During the welding process, iron oxide fumes arise from both the base metal and the electrode. The primary acute effect of this exposure is irritation of nasal passages, throat, and lungs. Although long-term exposure to iron oxide fumes may result in iron pigmentation of the lungs, most authorities agree that these iron deposits in the lung are not dangerous.

Mercury compounds are used to coat metals to prevent rust or inhibit foliage growth (marine paints). Under the intense heat of the arc or gas flame, mercury vapors will be produced. Exposure to these vapors may produce stomach pain, diarrhea, kidney damage, or respiratory failure. Long-term exposure may produce tremors, emotional instability, and hearing damage.

Lead. The welding and cutting of lead-bearing alloys or metals whose surfaces have been painted with lead-based paint can generate lead oxide fumes. Inhalation and ingestion of lead oxide fumes and other lead compounds will cause lead poisoning. Symptoms include metallic taste in the mouth, loss of appetite, nausea, abdominal cramps, and insomnia. In time, anemia and general weakness, chiefly in the muscles of the wrists, develop. Lead adversely affects the brain, central nervous system, circulatory system, reproductive system, kidneys, and muscles.

Fluoride compounds are found in the coatings of several types of fluxes used in welding. Exposure to these fluxes may irritate the eyes, nose, and throat. Repeated exposure to high concentrations of fluorides in air over a long period may cause pulmonary edema (fluid in the lungs) and bone damage. Exposure to fluoride dusts and fumes has also produced skin rashes.

Chlorinated hydrocarbons solvents are used in degreasing or other cleaning operations. The vapors of these solvents are a concern in welding and cutting because the heat and ultraviolet radiation from the arc will decompose the vapors and form highly toxic and irritating phosgene gas.

Phosgene is formed by decomposition of chlorinated hydrocarbon solvents by ultraviolet radiation. It reacts with moisture in the lungs to produce hydrogen chloride, which in turn destroys lung tissue. For this reason, any use of chlorinated solvents should be well away from welding operations or any operation in which ultraviolet radiation or intense heat is generated.

Carbon monoxide is a gas usually formed by the incomplete combustion of various fuels. Welding and cutting may produce significant amounts of carbon monoxide. In addition, welding operations that use carbon dioxide as the inert gas shield may produce hazardous concentrations of carbon monoxide in poorly ventilated areas. This is caused by a breakdown of shielding gas. Carbon monoxide is odorless, colorless and tasteless and cannot be readily detected by the senses. Common symptoms of overexposure include pounding of the heart, a dull headache, flashes before the eyes, dizziness, ringing in the ears, and nausea.
Ozone is produced by ultraviolet light from the welding arc. Ozone is produced in greater quantities by gas metal arc welding, gas tungsten arc welding, and plasma arc cutting. Ozone is a highly active form of oxygen and can cause great irritation to all mucous membranes. Symptoms of ozone exposure include headache, chest pain, and dryness of the upper respiratory tract. Excessive exposure can cause fluid in the lungs (pulmonary edema). Both nitrogen dioxide and ozone are thought to have long-term effects on the lungs.

Nitrogen oxides. The ultraviolet light of the arc can produce nitrogen oxides from the nitrogen and oxygen in the air. Nitrogen oxides are produced by gas metal arc welding, gas tungsten arc welding, and plasma arc cutting. Even greater quantities are formed if the shielding gas contains nitrogen. Nitrogen dioxide, one of the oxides formed, has the greatest health effect. This gas is irritating to the eyes, nose and throat but dangerous concentrations can be inhaled without any immediate discomfort. High concentrations can cause shortness of breath, chest pain, and fluid in the lungs (pulmonary edema).

Physical Agents

Ultraviolet radiation is generated by the electric arc in the welding process. Skin exposure to ultraviolet radiation can result in severe burns, in many cases without prior warning. Ultraviolet radiation can also damage the lens of the eye. Many arc welders are aware of the condition known as arc-eye, a sensation of sand in the eyes. This condition is caused by excessive eye exposure to ultraviolet radiation. Exposure to ultraviolet rays may also increase the skin effects of some industrial chemicals.

Infrared radiation (IR) exposure, produced by the electric arc and other flame cutting equipment may heat the skin surface and the tissues immediately below the surface. Except for this effect, which can progress to thermal burns in some situations, infrared radiation is not dangerous to welders. Most welders protect themselves from IR with a welder’s helmet and protective clothing.

Intense visible light. Exposure of the human eye to intense visible light can produce adaptation, pupillary reflex, and shading of the eyes. Such actions are protective mechanisms to prevent excessive light from being focused on the retina. In the arc welding process, eye exposure to intense visible light is prevented for the most part by the welder’s helmet. However, some individuals have sustained retinal damage due to careless viewing of the arc. At no time should the arc be observed without eye protection.

Safety Hazards Associated with Materials Handling and Storage

The following is taken from the Occupational Safety and Health Administration, Material Handling and Storage.

Handling and storing materials involves diverse operations such as hoisting tons of steel with a crane, driving a truck loaded with concrete blocks, manually carrying bags and material, and stacking drums, barrels, kegs, lumber, or loose bricks.

The efficient handling and storing of materials is vital to industry. These operations provide a continuous flow of raw materials, parts, and assemblies through the workplace, and ensure that materials are available when needed. Yet, the improper handling and storing of materials can cause costly injuries.
Workers frequently cite the weight and bulkiness of objects being lifted as major contributing factors to their injuries. In 1990, back injuries resulted in 400,000 workplace accidents. The second factor frequently cited by workers as contributing to their injuries was body movement. Bending, followed by twisting and turning, were the more commonly cited movements that caused back injuries. Back injuries accounted for more than 20 percent of all occupational illnesses, according to data from the National Safety Council.

In addition, workers can be injured by falling objects, improperly stacked materials, or by various types of equipment. When manually moving materials, however, workers should be aware of potential injuries, including the following:

- Strains and sprains from improperly lifting loads, or from carrying loads that are either too large or too heavy.
- Fractures and bruises caused by being struck by materials, or by being caught in pinch points; and
- Cuts and bruises caused by falling materials that have been improperly stored, or by incorrectly cutting ties or other securing devices.

Since numerous injuries can result from improperly handling and storing materials, it is important to be aware of accidents that may occur from unsafe or improperly handled equipment and improper work practices, and to recognize the methods for eliminating, or at least minimizing, the occurrence of those accidents. Consequently, employers and employees can and should examine their workplaces to detect any unsafe or unhealthful conditions, practices, or equipment and take the necessary steps to correct them.

**Safety Hazards Associated with Concrete and Masonry**


**Health Effects**

Cement can cause ill health by skin contact, eye contact, or inhalation. Risk of injury depends on duration and level of exposure and individual sensitivity.

Hazardous materials in wet concrete and mortar include

- Alkaline compounds such as lime (calcium oxide) that are corrosive to human tissue,
- Trace amounts of crystalline silica which is abrasive to the skin and can damage lungs,
- Trace amounts of chromium that can cause allergic reactions.

**Skin Contact**

The hazards of wet cement are due to its caustic, abrasive, and drying properties.

Wet concrete contacting the skin for a short period and then thoroughly washed off causes little irritation. But continuous contact between skin and wet concrete allows alkaline compounds to penetrate and burn the skin.
When wet concrete or mortar is trapped against the skin—for instance, by falling inside a worker’s boots or gloves or by soaking through protective clothing—the result may be first, second, or third degree burns or skin ulcers. These injuries can take several months to heal and may involve hospitalization and skin grafts.

First degree burn - outer skin layer

Second degree burn - middle skin layer

Third degree burn - deep skin layer
Ironically, severe cases often occur when personal protective clothing or equipment is worn. Wet concrete may get trapped inside rubber boots or gloves or gradually soak through coveralls. Concrete finishers kneeling on fresh concrete have had their knees severely burned. Corrosive bleed water from the concrete is absorbed by the worker’s pants and held against the skin for prolonged periods.

Without waterproof knee pads, kneeling on wet concrete can irritate or burn the skin.

Cement dust released during bag dumping or concrete cutting can also irritate the skin. Moisture from sweat or wet clothing reacts with the cement dust to form a caustic solution.

Allergic Skin Reaction
Some workers become allergic to the hexavalent chromium in cement. A small yet significant percentage of all workers using cement will develop an allergy to chromium, with symptoms ranging from a mild rash to severe skin ulcers.

In addition to skin reactions, hexavalent chromium can cause a respiratory allergy called occupational asthma. Symptoms include wheezing and difficulty breathing. Workers may develop both skin and respiratory allergies to hexavalent chromium.

It is possible to work with cement for years without any allergic skin reaction and then to suddenly develop such a reaction. The condition gets worse until exposure to even minute quantities triggers a severe reaction. The allergy usually lasts a lifetime and prevents any future work with wet concrete or powder cement.

Eye Contact
Exposure to airborne dust may cause immediate or delayed irritation of the eyes. Depending on the level of exposure, effects may range from redness to chemical burns and blindness.

Inhalation
Inhaling high levels of dust may occur when workers empty bags of cement. In the short term, such exposure irritates the nose and throat and causes choking and difficult breathing.
Sanding, grinding, or cutting concrete can also release large amounts of dust containing high levels of crystalline silica. Prolonged or repeated exposure can lead to a disabling and often fatal lung disease called silicosis. Some studies also indicate a link between crystalline silica exposure and lung cancer.

Dry cutting generates high levels of dust

*Safety Hazards Associated with Scaffolding*

The following is taken from the Mason Contractors Association of America, Scaffolding Hazards.

Electricity is a major hazard when using scaffolds. Electrical lines are generally elevated to keep individuals a safe distance away. The purpose of the scaffold is obviously to allow one to work at these heights which brings workers close to this hazard.

Overloading scaffolds is another major hazard. The mason industry by nature requires heavy loads on scaffolds. Too often contractors place excessive strain on scaffolds as shown by the following case.

The most common hazard on scaffolding is the potential for falling. The following case demonstrates a violation frequently seen when workers use a scaffold. A crew was working on a scaffold applying stucco to a six-story college dormitory. An employee on the fifth floor stepped on a guardrail to access the next level of the scaffold. The guardrail gave way allowing the employee to fall 48 feet to his death.

To prevent this type of fall OSHA requires employees to use an appropriate access for any scaffold higher then 2 feet. Climbing on any part of the frame is prohibited. Appropriate access can include a ladder built into the scaffold, which meets OSHA ladder specifications, or an attached ladder.
d. Discuss the responsibilities of the construction manager in ensuring compliance with OSHA requirements.

The following is taken from DOE O 440.1B.

The following requirements and responsibilities apply for construction projects above the monetary threshold established by the Davis-Bacon Act at Government-owned or -leased facilities where the contract clause “Safety and Health (Government-Owned or-Leased Facility)” applies:

- Determine the necessity for requiring dedicated construction contractor safety and health personnel on project workplaces.
- Ensure that construction project acquisition documents provide information or reference to existing documentation that describes known hazards to which project workers may be exposed.
- Ensure that a pre-work safety meeting is conducted with the construction contractor to review project safety and health requirements.
- Ensure that the project safety and health plan is approved prior to any on-site project work and that required hazard analyses are completed and approved prior to start of work on affected construction operations.
- Ensure that project safety and health plans and hazard analyses are revised, as necessary, to address identified deficiencies in project safety and health performance or changes in project operations, contractors, or personnel.
- Through personal on-site involvement and/or formal delegation to support staff and/or the construction manager, perform frequent and regular documented on-site reviews of construction contractor safety and health program effectiveness.
- Ensure documentation exists for all formal contract actions taken to enforce construction contractor compliance with project safety and health requirements.

e. Describe the actions to be taken to correct a deficiency with the requirements of the listed documents.

The following is taken from DOE G 414.1-5.

Corrective action programs should meet the basic criteria of the generalized process for feedback and improvement within the DOE ISMS. This generalized process, illustrated in figure 47, includes the following steps.

- Identify and report problem findings
- Evaluate each problem finding and develop appropriate corrective actions and corrective action plans
- Close and implement corrective actions and resolve each problem finding
- Close each problem finding and determine effectiveness of corrective actions
Identify and Report Problem Findings

Identifying and reporting problem findings from a variety of sources to include a specific operational event, internal or external assessment or investigation, observation during daily work performance, and worker safety concern is the first generalized step for the feedback and improvement core safety function. All workers should be encouraged to evaluate performance and safety of workers, products, services, and processes; identify potential and actual problems at the earliest possible time before they become more significant; and immediately report these problems. This first step should be formally defined and fully integrated with the site/organization continuous performance and safety improvement strategy.

Evaluate Each Problem Finding and Develop Appropriate Corrective Actions and Corrective Action Plans

The second generalized step provides the framework for defining a problem by collecting and evaluating relevant information to determine the facts and causal factors, including root causes. The site/organization responsible for the function/activity where the problem finding was identified should have a clear understanding and description of the finding supported by the facts and causal factors in order to develop the most appropriate, timely corrective actions to resolve the finding and prevent recurrence. These corrective actions are then incorporated into the CAP. Other considerations in corrective action planning should include determining the actual and potential significance, complexity, and impact of the problem finding on the safety, reliability and mission performance of the site/organization and the workers. This second generalized step is considered the cornerstone of the feedback and improvement process core safety function and oftentimes the most difficult and least understood.

Source: DOE G 414.1-5

Figure 47. Feedback and improvement
Close and Implement Corrective Actions and Resolve Each Problem Finding

The third generalized step in the feedback and improvement core safety function includes closing and implementing corrective actions to resolve the findings delineated in the CAP. Completion and implementation status is tracked and reported to ensure timely and adequate resolution of each finding. The completion and implementation of the CAP can be a tedious process with potential for ineffectiveness in the corrective action process. Although the findings have been identified and detailed plans to correct the findings have been developed, the often long and weary process of actively completing and implementing all of the corrective actions for each finding in the CAP has the propensity to receive less attention as emphasis is shifted to other more immediate initiatives, crises, and requirements. It is important that closure and implementation of the CAP receive continuous management attention, progress monitored and updated, and status periodically reported.

Close Each Problem Finding and Determine Effectiveness of Corrective Actions

The fourth generalized step in the feedback and improvement core safety function includes completion of all corrective actions for the findings listed in the CAP and an independent follow-up assessment by the responsible site/organization to verify closure and review the This follow-up step is paramount to the success of the feedback and improvement core safety function and corrective action program. The resources expended to identify the finding and implement the corrective actions will be fruitless if the causal factors involved in the finding have not been effectively resolved or the same or similar findings recur. There may also be financial costs based on repeat violations and civil penalties associated with the failure to resolve the finding effectively. Most importantly, the potential adverse impact of an unresolved finding to the mission and safety of workers would remain for unsuspecting managers and workers who implemented the corrective actions and presumed the finding was resolved.

f. Develop an assessment plan for inspection of construction activities and the construction site for compliance with Occupational Safety and Health Act requirements.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

31. Construction management personnel shall demonstrate a working level knowledge of National Fire Protection Association (NFPA) industry standards for construction management and engineering.

a. Discuss the purpose, scope, and application of the NFPA industry standards. Include in this discussion key terms, essential elements, and personnel responsibilities and authorities.

The following is taken from the NFPA Web site.

The mission of the international nonprofit NFPA, established in 1896, is to reduce the worldwide burden of fire and other hazards on the quality of life by providing and advocating consensus codes and standards, research, training, and education.
The world’s leading advocate of fire prevention and an authoritative source on public safety, NFPA develops, publishes, and disseminates more than 300 consensus codes and standards intended to minimize the possibility and effects of fire and other risks.

NFPA membership totals over 75,000 individuals around the world and more than 80 national trade and professional organizations.

NFPA is responsible for 300 codes and standards that are designed to minimize the risk and effects of fire by establishing criteria for building, processing, design, service, and installation in the United States, as well as many other countries. Its more than 200 technical code- and standard- development committees are comprised of over 6,000 volunteer seats. Volunteers vote on proposals and revisions in a process that is accredited by the American National Standards Institute (ANSI).

Some of the most widely used codes are:

- **NFPA 1, Fire Code**
  Provides requirements to establish a reasonable level of fire safety and property protection in new and existing buildings.

- **NFPA 54, National Fuel Gas Code**
  The safety benchmark for fuel gas installations.

- **NFPA 70®, National Electric Code®**
  The world’s most widely used and accepted code for electrical installations.

- **NFPA 101®, Life Safety Code®**
  Establishes minimum requirements for new and existing buildings to protect building occupants from fire, smoke, and toxic fumes.

b. **Identify the National Fire Protection Association industry standards necessary to evaluate the appropriate elements of a project.**

The primary industry standard for fire protection is NFPA Code 5000, *Building Construction and Safety Code*.

c. **Determine contractor compliance with the requirements of the National Fire Protection Association industry standards as they apply to contract design requirements and construction activities during a walkthrough at a defense nuclear facility.**

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

32. **Construction management personnel shall demonstrate a working level knowledge of the Uniform Building Code (UBC) industry standards for construction management and engineering.**

a. **Discuss the purpose, scope, and application of the Uniform Building Code industry standards. Include in this discussion key terms, essential elements, and personnel responsibilities and authorities.**

[Note: The Uniform Building Code has been superseded by the International Building Code 2009.]
The following is taken from the International Code Council (ICC), International Building Code, chapter 1, Administration.

The provisions of the International Building Code apply to the construction, alteration, movement, enlargement, replacement, repair, equipment, use and occupancy, location, maintenance, removal and demolition of every building or structure or any appurtenances connected or attached to such buildings or structures.

The purpose of the code is to establish the minimum requirements to safeguard the public health, safety and general welfare through structural strength, means of egress facilities, stability, sanitation, adequate light and ventilation, energy conservation, and safety to life and property from fire and other hazards attributed to the built environment and to provide safety to fire fighters and emergency responders during emergency operations.

The code creates the building Department of Building Safety. The executive official in charge of the building department is named the building official. In actuality the person who is in charge of the department may hold a different title such as construction official. For the purpose of the code, that person is referred to as the building official.

The building official is authorized and directed to enforce the provisions of the code. The building official has the authority to render interpretations of the code and to adopt policies and procedures to clarify the application of its provisions.

b. Identify the Uniform Building Code industry standards necessary to evaluate the appropriate elements of a project.

[Note: The Uniform Building Code has been superseded by the International Building Code 2009.]

The following is taken from the International Code Council, International Building Code, chapter 1, Administration.

The ICC promulgates a complete set of codes to regulate the built environment. Brief descriptions of those codes follow.

*ICC Electrical Code*

The provisions of the ICC Electrical Code apply to the installation of electrical systems, including alterations, repairs, replacement, equipment, appliances, fixtures, fittings and appurtenances thereto.

*International Fuel Gas Code*

The provisions of the International Fuel Gas Code apply to the installation of gas piping from the point of delivery, gas appliances and related accessories as covered in the code. These requirements apply to gas piping systems extending from the point of delivery to the inlet connections of appliances and the installation and operation of residential and commercial gas appliance and related accessories.
International Mechanical Code
The provisions of the International Mechanical Code apply to the installation, alterations, repairs and replacement of mechanical systems, including equipment, appliances, fixtures, fittings and/or appurtenances, including ventilating, heating, cooling, air-conditioning and refrigeration systems, incinerators, and other energy-related systems.

International Plumbing Code
The provisions of the International Plumbing Code apply to the installation, alteration, repair and replacement of plumbing systems, including equipment, appliances, fixtures, fittings and appurtenances, and where connected to a water or sewage systems and all aspects of a medical gas systems.

International Property Maintenance Code
The provisions of the International Property Maintenance Code apply to existing structures and premises; equipment and facilities; light, ventilation, space heating, sanitation, life and fire safety hazards, responsibilities of owners, operators and occupants; and occupancy of existing premises and structures.

International Fire Code
The provisions of the International Fire Code apply to matters affecting or relating to structures, processes and premises from the hazard of fire and explosion arising from the storage, handling or use of structures, materials, or devices; form conditions hazardous to life, property, or public welfare in the occupancy of structures or premises; and from the construction, extension, repair, alteration or removal of fire suppression and alarm systems or fire hazards in the structure or on the premises from occupancy or operation.

International Energy Conservation Code
The International Energy Conservation Code contains provisions for the efficient use of energy in building construction by regulating the design of building envelopes for thermal resistance and low air leakage and the design and selection of mechanical systems for effective use of energy.

c. Determine contractor compliance with the requirements of the Uniform Building Code industry standards as they apply to contract design requirements and construction activities during a walkthrough at a defense nuclear facility.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.
33. Construction management personnel shall demonstrate a working level knowledge of the Pre-stressed Concrete Institute (PCI) industry standards for construction management and engineering.

a. Discuss the purpose, scope, and application of the PCI industry standards. Include in this discussion key terms, essential elements, and personnel responsibilities and authorities.

The following is taken from the Precast/Prestressed Concrete Institute, *PCI Design Handbook/Sixth Edition*.

The Precast/Prestressed Concrete Institute, a non-profit corporation, was founded in 1954 for the purpose of advancing the design, manufacture, and use of structural precast/prestressed concrete and architectural precast concrete in the United States and Canada. To meet this purpose, PCI continually disseminates information on the latest concepts, techniques and design data to the architectural and engineering professions through regional and national programs and technical publications.

PCI’s 4 core initiatives drive investment in 4 program areas. Three of these involve education and one involves research, following simple investment philosophies to maximize effectiveness and minimize overlap with other industry education and research efforts. Investment in each of the PCI’s four program areas goes to support the programs in each area. The 4 core initiatives are to

- cultivate productive relationships between the industry and the academic community;
- develop and attract high-potential students to productive careers within the industry;
- facilitate inclusion of precast concrete systems and technologies in college and university curricula;
- foster the development of sustainable, protective, and constructive precast concrete.

b. Identify the PCI industry standards necessary to evaluate the appropriate elements of a project.

The following is taken from PCI, Plant Certification.

PCI’s Plant Certification Program ensures that each plant has developed and documented an in-depth, in-house quality system based on time-tested, national industry standards. To become PCI Certified, plants must demonstrate they have appropriate experience and training in manufacturing precast concrete, quality systems and procedures in place and a commitment to quality throughout their organization. Each plant is required to develop a plant-specific quality systems manual. This manual defines in detail how their operations work and is reviewed and approved by PCI. After the quality systems manual is completed, an initial unannounced audit will take place. Upon passing its first audit, a plant is certified.

Once a year, each plant undergoes two thorough, unannounced audits. They are conducted by third-party engineers who audit the plant according to requirements specifically targeted to the products being manufactured at that location. PCI-certified plants are audited in accordance with standards published in three PCI quality-control manuals:

- MNL-116, *Quality Control for Plants and Production of Structural Precast Concrete Products*
• MNL-117, *Quality Control for Plants and Production of Architectural Precast Concrete Products*
• MNL-130, *Quality Control for Plants and Production of Glass Fiber-Reinforced Concrete Products*

Inspectors also randomly inspect products to their project specifications to ensure that products meet their design intent and criteria.

Since the various precast concrete product lines require different levels of expertise and production techniques to produce, PCI Certification provides a system of categories. This system ensures that producers are qualified to produce the products that you are specifying. Precast concrete plants can be certified in as many as four product groups:

Below is a breakdown of the PCI manuals

*Manual for Quality Control for Plants and Production of Architectural Precast Concrete Products*

Architectural precast concrete products, through their finish, shape, color, or texture, contribute to a structure’s architectural expression. These products may be custom designed or feature standard shapes. They may be manufactured with conventional mild-steel reinforcement, or they may be pretensioned or post-tensioned. These products typically have more stringent requirements for dimensional tolerances, finish variations, and color consistency.

*Manual for Quality Control for Plants and Production of Structural Precast Concrete Products*

Bridge components consist of precast concrete or precast, prestressed concrete products and are usually produced with gray cement and local aggregates

*Manual for Quality Control for Plants and Production of Structural Precast Concrete Products*

This manual includes structural and nonstructural precast or precast, prestressed concrete elements for buildings and other structures. These products have no special architectural finish and may be suitable for painting if specified.

c. Discuss application of PCI industry standards to construction activities and inspection during a walkthrough of a concrete structure.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

34. Construction management personnel shall demonstrate a working level knowledge of construction methods and accepted construction practices associated with reinforced concrete design as described in the following American Concrete Institute (ACI) documents:
• ACI-301, *Specifications for Structural Concrete for Buildings*
• ACI-315, *Detailing of Concrete Reinforcement*
• ACI-318, *Building Code Requirements for Structural Concrete and Commentary*
Sanitary Engineering Structures

The following is taken from Gravity Sanitary Sewer Design and Construction by Paul Bizier.

Sanitary sewers are normally installed in a relatively narrow trench excavated in undisturbed soil and then covered with backfill to the proposed ground level. In this type of installation, the backfill material will tend to settle downward relative to the undisturbed soil in which the trench is excavated. This relative settlement of backfill generates upward friction forces, causing an arching action of the backfill that relieves the load on the pipe, such that the load is equal to the weight of the prism of backfill within the trench minus the upward friction forces. For narrow trenches the backfill load is less than the weight of the prism of backfill over the pipe. As the trench width is increased for any given pipe size, backfill material, and trench depth, a limiting width is reached beyond which the trench width no longer affects the backfill load. The trench width at which this condition occurs is defined as the transition width. Once the transition width is realized, the backfill load is a maximum and remains constant regardless of any further increase in the trench width.

For the direct design procedure described below, a detailed earth load analysis is not conducted but, rather, the backfill load is related to the weight of the prism of backfill over the pipe multiplied by a vertical arching factor, varying from 1.35 to 1.45.

The backfill or fill load on buried pipe depends on the installation, and standard installations have been defined for rigid pipe and flexible pipe. The earth load on flexible pipe is determined as equal to the weight of the prism of earth over the pipe and is given by the equation:

\[ W_e = wHD_0 \]

where

\( W_e \) = the vertical earth load
w = unit weight of soil
H = design height of earth above top of pipe
D₀ = outside diameter of pipe

The earth load on rigid pipe is determined as equal to the weight of the prism of earth over the pipe increased by a vertical arching factor (VAF) from 1.35 to 1.45, depending on the standard installation type, and is given by the equation:

\[ W_e = \text{VAF} \times [wD_0] \times [H + (0.107D_0)] \]

The loads given above may be used with the various design methods outlined by the pipe manufacturing association to calculate required pipe strengths. Many times these calculations are integrated into a computer program designed for a particular piping material. These methods, which are specific to various piping organizations, are outlined in the following paragraphs,

Although these direct design methods are typically preferred, there may be times when the older Marston-Spangler load analysis may be preferred. Maston developed methods for determining the vertical load on buried conduits caused by soil forces in all of the most commonly encountered construction conditions. These methods are historically based on theory and experiment and have generally achieved acceptance as being useful and reliable, although perhaps overly conservative.

In general, the theory states that the load on a buried pipe is equal to the weight of the prism of soil directly over it, called the interior prism, plus or minus the frictional shearing forces transferred to that prism by the adjacent prisms of soil—the magnitude and direction of the frictional forces being a function of the relative settlement between the interior and adjacent soil prisms. The theory makes the following assumptions:

- The calculated load is the load that will develop when ultimate settlement has taken place.
- The magnitude of the lateral pressures that induce the shearing forces between the interior and adjacent soil prisms is computed according to Rankin’s theory.

The general form of Marston’s equation is:

\[ W = CwB^2 \]

in which W is the vertical load per unit length acting on the sewer pipe because of gravity soil loads, w is the unit weight of soil; B is the trench width or sewer pipe width, depending on installation conditions; and C is a dimensionless coefficient that marries the effect of the following variables:

- The ratio of the height of fill to width of trench or sewer pipe.
- The shearing forces between interior and adjacent soil prisms
- The direction and amount of relative settlement between interior and adjacent soil prisms for embankment conditions.

Concrete Forms

The following is taken from Toolbox Services, Insulating Concrete Forms.
Concrete forms have taken a new shape-and purpose. Insulating concrete forms (ICFs) are rigid plastic foam forms that hold concrete in place during curing and remain in place afterwards to serve as thermal insulation for concrete walls. The foam sections are lightweight and result in energy-efficient, durable construction.

ICFs consist of insulating foam, commonly expanded polystyrene or extruded polystyrene. The three basic form types are hollow foam blocks, foam planks held together with plastic ties, and 4 x 8 panels with integral foam or plastic ties. ICFs can be used to form various structural configurations, such as a standard wall, post and beam, or grid. They provide backing for interior and exterior finishes.

Insulation values of ICF walls vary depending on the material and its thickness. Typical insulation values range from R-17 to R-26, compared to between R-13 and R-19 for most wood-framed walls. The strength of ICF structures relative to lumber depends on configuration, thickness, and reinforcement. However, ICF walls are designed as reinforced concrete, having high wind and seismic resistance.

There are many ICF wall types. Products are differentiated based on the type of form and the shape of the concrete sections. Products are further differentiated by how forms attach to each other, how finishes are attached to the wall, insulating values, foam types and other features. Introductory information on the most basic product types follows. The book, *Insulating Concrete Forms for Residential Design and Construction*, available from the Portland Cement Association, includes an in-depth discussion of design principles, details, types of ICFs, field assembly, and performance and cost data.

**Concrete Reinforcement**
The following is taken from the Portland Cement Association, Reinforced Concrete.

Concrete is reinforced to give it extra strength; without reinforcement, many concrete buildings wouldn’t be possible. Reinforced concrete can encompass many types of structures and components, including slabs, walls, beams, columns, mats, frames and more. There are multiple ways of reinforcing concrete; the two main methods are conventional reinforcement (nonprestressed) and prestressing.

Reinforced concrete is two materials merged together; plain concrete, which is characterized by having high compressive strength but low tensile strength, and steel bars embedded in concrete to provide the needed strength in tension.

In prestressed members, compressive stresses are introduced into the concrete to reduce tensile stresses resulting from applied loads including the self weight of the member (dead load). Prestressing steel, such as strands, bars or wires, is used to impart compressive stresses to the concrete. Pre-tensioning is a method of prestressing in which the tendons are tensioned before concrete is placed and the prestressing force is primarily transferred to the concrete through bond. Post-tensioning is a method of prestressing in which the tendons are tensioned after the concrete has hardened and the prestressing force is primarily transferred to the concrete through the end anchorages.
Much of the focus on reinforcing concrete is placed on floor systems. Designing and implementing the most efficient floor system is key to creating optimal structures. Small changes in the design of a floor system can have significant impact on material costs, construction schedule, ultimate strength, operating costs, occupancy levels and end use of a building.

*Cast-in-Place Concrete and Pre-Cast Concrete*

**Cast-in-Place Concrete**
The following is taken from the Portland Cement Association, Removable Forms (Cast-in-Place).

This traditional concrete forming technique uses temporary forms, typically made of aluminum. Rigid foam insulation is placed inside the forms or between the forms and held in place with a system of non-conductive ties. Concrete is then poured on either side of or between the foam. Steel rebar is also generally used to add strength to the wall. Once the concrete has cured, the forms can be removed and re-used many times with a minimum of maintenance.

The obvious advantage of this system is speed. All exterior and interior walls can be poured at the same time, with door and window openings cast right along with everything else. Some systems even have floor and ceiling forms. Many different interior and exterior finishes are available to texture the concrete, or the walls can be furred out and finished.

**Pre-Cast Concrete**
The following is taken from the Portland Cement Association, Precast/Prestressed Concrete.

Precast concrete systems combine structural and architectural components to create long-lasting buildings and structures. From high-rise office buildings to landmark bridges, parking structures to correctional facilities, stadiums to schools—even in high seismic zones—precast concrete can achieve safe, beautiful, and durable results.

Because components are precast at manufacturing facilities, quality control measures ensure that every piece is made to specifications. The components can be cast and transported to the job site while designs are still being finalized, helping to speed construction schedules. Evolutions in self-consolidating concrete also promise to offer new options and challenges for designers using precast.

As with all concrete wall systems, precast offers high durability and strength as well as thermal mass, which contributes to increased energy efficiency. Precast systems use locally derived materials, and can incorporate recycled supplementary cementitious materials like fly ash and slag cement, one of the key reasons why they are often used in sustainable or “green” buildings.

One of the biggest benefits of precast systems is in their design: tight controls mean more efficient mix designs, resulting in smaller structural members and longer spans. Construction waste is reduced because the exact amount of necessary components is delivered to the site; any spare components can be recycled, and their materials used again in another structure.
Precast systems can adopt almost any aesthetic, incorporating a variety of colors and textures, or emulating natural stone. By crafting systems that not only look great, but also act as structural walls and support floor loads, designers can reduce material redundancy—and project costs.

The idea of “total precast” has become a buzzword in recent years, and the practice is common in many metro areas, especially in residential applications. By combining many precast elements to produce a complete structure, concrete’s benefits are maximized.

*Cementitious Decks for Buildings*

The following is taken from the Portland Cement Association, Glossary.

Cementitious material (cementing material) is any material having cementing properties or contributing to the formation of hydrated calcium silicate compounds. When proportioning concrete, the following are considered cementitious materials: portland cement, blended hydraulic cement, fly ash, ground granulated blast-furnace slag, silica fume, calcined clay, metakaolin, calcined shale, and rice husk ash.

The following is taken from the Portland Cement Association, Building Green with Grey Concrete.

Interest in using supplementary cementitious materials to enhance concrete’s performance continues to grow. Cementitious materials can increase the sustainable attributes of a green building material like concrete in many ways. Optimized concrete mixes with cementitious materials like slag cement, fly ash, silica fume and others can provide enhanced benefits, creating structures of the likes we have never seen before.”

Jan Prusinski, executive director of the Slag Cement Association, says the hottest thing going in SCMs is ternary mixes. “Ternary mixes that incorporate portland cement, slag cement, and fly ash are the next wave in utilization of supplementary cementitious materials,” says Prusinski. “They are an excellent way to reduce the total cement in a mix while improving durability.”

*Mass Concrete*

The following is taken from the Portland Cement Association, Mass Concrete.

Mass concrete brings with it many challenges, among them the generation of high heat and problems that can stem from it. While creating these projects can be difficult, careful design of mass concrete can minimize or eliminate issues, and new research points to approaches that will allow us to create bigger projects than ever before.

ACI Committee 116 defines mass concrete as “any large volume of cast-in-place concrete with dimensions large enough to require that measures be taken to cope with the generation of heat and attendant volume change to minimize cracking.” This categorization can include structural components with moderate- to high-cement-content concrete, massive structural elements of mat foundations, and to dams and other large structures that use concrete with a low cement content.
In any mass concrete application, temperatures rise through heat of hydration. As the interior concrete rises in temperature, the outer concrete may be cooling and contracting; if the temperature varies too much within the structure, the material can crack. A variety of factors influence temperature changes, including the size of the component, the amount of reinforcement, the ambient temperature, the initial temperature of the concrete at time of placement and curing program.

Design Options
Engineers use a variety of approaches to tackle the potential for thermal cracking and successfully create mass concrete. These methods include: refining concrete mix proportions, protecting exposed surfaces and formwork from environmental extremes, using aggregate with desirable thermal properties, pre-cooling the concrete constituent materials, using internal pipes to cool the concrete itself, and placing the concrete in several lifts or pours.

Some designs include supplementary cementitious materials in the mix, including slag cement or fly ash. The Slag Cement Association offers some guidance on specifying slag cement for mass concrete here. The American Coal Ash Association offers information here on the benefits and specification of fly ash.

Post-Tension Concrete
The following is taken from the Portland Cement Association, Post-Tensioned Concrete.

Designers use post-tensioning as a way to reinforce concrete by prestressing it. In prestressed members, compressive stresses are introduced into the concrete to reduce tensile stresses resulting from applied loads including the self weight of the member (dead load). Prestressing steel, such as strands, bars or wires, is used to impart compressive stresses to the concrete. Pre-tensioning is a method of prestressing in which the tendons are tensioned before concrete is placed and the prestressing force is primarily transferred to the concrete through bond. Post-tensioning is a method of prestressing in which the tendons are tensioned after the concrete has hardened and the prestressing force is primarily transferred to the concrete through the end anchorages.

Post-Tensioning Explained
Unlike precast, which can only be done at a precast manufacturing facility, post-tensioning is performed on the jobsite in cast-in-place applications. The concrete component is cast with steel reinforcing strands installed in a way that protects them from bonding with the concrete. This practice gives designers the flexibility to further optimize material use by creating thinner concrete members.

The materials used to post-tension concrete members are ultra-high-strength steel strands and bars. Horizontal applications (like beams, slabs, bridges, and foundations) typically employ strands. Walls, columns, and other vertical applications usually utilize bars. Steel strands used for post-tensioning typically have a tensile strength of 270,000 psi, are about a half-inch in diameter, and are stressed to a force of 33,000 pounds.
Benefits
While concrete is strong in compression, it is weak in tension. Steel is strong under forces of tension, so combining the two elements results in the creation of very strong concrete components. Post-tensioning can help create innovative concrete components that are thinner, longer, and stronger than ever before.

Many of today’s high-performance concrete structures, including many landmark bridges and buildings, employ some type of prestressing. Parking garages, high-rise residential towers, and many other kinds of structures also employ post-tensioning techniques.

Tilt-Up Concrete
The following is taken from the Portland Cement Association, Tilt-Up Concrete.

Tilt-up concrete construction is one of the fastest-growing building technologies in North America, with at least 10,000 structures—enclosing more than 650 million square feet of space—being built every year. While tilt-up has been in existence for more than a century, the 1940s saw a surge of interest in the method, and today tilt-up builds more than 15 percent of industrial buildings in the U.S., according to the Tilt-Up Concrete Association.

Building Process
When building with tilt-up, the site is prepared, walls are cast on-site on the floor slab, and then tilted up and secured in place. Engineering plays a key role in the creation of tilt-up buildings: wall panels must be able to withstand lifting loads, and floor slabs must be able to withstand crane and/or bracing loads during construction. Recent evolutions in component and mix design mean that structures can incorporate thinner, taller panels than ever before. And tilt-up panels can be finished in myriad ways, offering aesthetic flexibility.

One of the most evident benefits of tilt-up concrete construction is speed. Wall panels are often placed while the rest of the building systems are designed, and trades can begin work quickly, speeding time to occupancy. Tilt-up structures also offer all the energy efficiency, strength, and durability long associated with concrete.

Sustainability
Tilt-up is widely recognized as an environmentally friendly construction method. Because walls are cast on-site, transportation costs are minimized. Typically, the thermal mass of tilt-up eliminates the need for insulation. Of the approximately 25 percent of panels that are insulated, most use non-conductive ties to take best advantage of thermal mass properties—creating a solid, insulated energy-efficient wall. The large panels require less energy and labor for erection and finishing. And tilt-up buildings can be designed to accommodate change, with panels that are easy to move, remove and reuse, or even recycle if necessary.

b. Discuss the construction climatic considerations for hot and cold weather concreting, including the code requirements in ACI-305R and ACI-306R.

The following is taken from the Portland Cement Association, Weather Conditions.
Hot-Weather Concreting

The ACI categorizes hot weather as a period when, for more than three consecutive days, the following conditions exist:

- The average daily air temperature is greater than 25 \(^\circ\)C (77 \(^\circ\)F). The average daily temperature is the mean of the highest and the lowest temperatures occurring during the period from midnight to midnight.
- The air temperature for more than one-half of any 24-hour period is not less than 30 \(^\circ\)C (86 \(^\circ\)F).

Preparation for hot-weather paving should take place long before paving begins. Whenever the construction team anticipates building a project in the summer, they should verify the concrete mixture for these conditions. Verification testing is conducted in the laboratory during the mix design phase. The testing laboratory mixes trial batches and casts specimens at temperatures representative of the site conditions to flag whether compatibility problems may arise.

During hot weather, problems that may occur include the following:
- Rapid slump loss
- Reduced air contents
- Premature stiffening
- Plastic shrinkage cracking
- Thermal cracking

During hot weather, the construction team should take steps to reduce the evaporation rate from the concrete. The likelihood of plastic shrinkage cracking increases when the evaporation rate increases. Plastic shrinkage cracking results from the loss of moisture from the concrete before initial set. The evaporation rate is a function of the following:

- Air temperature.
- Concrete temperature.
- Relative humidity.
- Wind speed.

If the evaporation rate exceeds 1.0 kg/m\(^2\)/hr (0.2 lb/ft\(^2\)/hr), it is advisable to provide a more effective curing application, such as fog spraying, or to apply an approved evaporation reducer.

One or more of the following precautions can minimize the occurrence of plastic shrinkage cracking. They should be considered while planning for hot-weather concrete construction or while dealing with the problem after construction has started. The precautions are listed in the order in which they should be done during construction:

- Moisten dry, absorptive aggregates.
- Keep the concrete temperature low by cooling aggregates and mixing water.
- Dampen the subgrade and fog forms before placing the concrete.
- Erect temporary windbreaks to reduce wind velocity over the concrete surface.
- Erect temporary sunshades to reduce concrete surface temperatures.
If conditions of temperature, relative humidity, and wind are too severe to prevent plastic shrinkage cracking, or if corrective measures are not effective, paving operations should be stopped until weather conditions improve.

The following are general recommendations/options/considerations for hot-weather concreting:

- Do not exceed the maximum allowable water/cementitious materials ratio or the manufacturer’s maximum recommended dosage of any admixture.
- Consider retarding admixtures if their performance has been verified during trial batches.
- Substitute ground, granulated blast-furnace slag or class F fly ash for part of the portland cement. These materials hydrate more slowly and generate lower heats of hydration than cement, reducing tendencies toward slump loss, premature stiffening, and thermal cracking. Certain class C fly ashes, with high calcium and aluminum contents, may cause premature stiffening.
- Low air contents can be corrected by increasing the dosage of air-entraining admixture. Better or longer mixing may allow maintenance of a constant air-void spacing factor without a greater air content. Using additional water reducer may also be helpful.
- Risk of early-age thermal cracking is reduced by ensuring that the temperature of the plastic concrete is as low as practical.
  - Sprinkling with water may cool aggregates; be sure to correct for the aggregate moisture.
  - Aggregates need to be batched in a saturated surface-dry condition to avoid absorbing mixture water.
  - Chilling the mixing water or adding chipped ice in substitution for some of the water lowers the mix temperature. Be sure that all of the ice melts during mixing.
- Consider painting the mixing and transporting equipment white or another light color to minimize the heat absorbed from the sun.
- In extreme conditions, consider scheduling concrete placements for during the evening or night.
- Moisten the base before the concrete is placed to keep the temperature down and to keep it from absorbing water from the concrete.
- Place and finish the concrete as rapidly as possible to apply the curing compound at the earliest possible time. The use of a white curing compound will reflect the sun’s heat. If there is any delay in applying the curing compound, use a fog spray or evaporation retardant to keep the surface from drying out.
- Refer to ACI 305, *Hot Weather Concreting*, for additional information.

Cold Weather Concreting
Cold weather is defined by ACI as a period when, for more than three consecutive days, the following conditions exist:
- The average daily air temperature is less than 4 °C (40 °F). The average daily temperature is the mean of the highest and lowest temperatures occurring during the period from midnight to midnight.
- The air temperature is not greater than 10 °C (50 °F) for more than one-half of any 24-hour period.

Cold-weather paving requires special considerations. The contractor and material supplier should address these considerations well before temperature forecasts predict temperatures to drop close to or below freezing. The primary concern is to keep the temperature of the concrete above freezing so that the hydration reaction continues and to control cracking through joint placement.

Trial batches are needed to verify that the proposed mixtures will achieve the desired strength at the potential temperatures. Mixtures with accelerating admixtures must be treated carefully to ensure that they accelerate the setting and/or early strength gain of concrete but do not lead to workability or constructability challenges.

The following are recommendations/options/considerations for cold-weather concreting:

- Consider using a higher portland cement content in concrete mixture designs for placement at cooler temperatures.
- Reduce or eliminate ground, granulated blast furnace slag, fly ash, and natural pozzolans from the mixture unless they are required for durability.
- The necessary air-entraining admixture dosage will likely be lower for cold-weather concrete than for concrete designed for normal temperatures.
- An accelerating admixture conforming to ASTM C 494, *Standard Specification for Chemical Admixtures for Concrete*, Type C or E may be used, provided its performance has been previously verified by trial batches.
- Do not use admixtures containing added chlorides. Also, do not use calcium chloride.
- Aggregates must be free of ice, snow, and frozen lumps before being placed in the mixer.
- Because the concrete will take longer to set, there is more risk for plastic shrinkage cracking, especially if the concrete is much warmer than the ambient air or the wind speed is significant.
- Consider heating the mix water (if practical for the size of the pour). The temperature of the mixed concrete should not be less than 10 °C (50 °F).
  - The mixture water and/or aggregates may be heated to 66 °C (150 °F).
  - The material must be heated evenly.
- Insulating blankets also are necessary for curing concrete pavement in cool weather. The blankets reduce heat loss and lessen the influence of both air temperature and solar radiation on the pavement temperature. The blankets are not a substitute for curing compound, which is still needed to contain moisture for complete hydration.
- The concrete temperature should be maintained at 10 °C (50 °F) or above for at least 72 hours after placement and at a temperature above freezing for the remainder of the curing time (when the concrete attains a compressive strength of 20 MPa [3,000 lb/in²]). Corners and edges are the most vulnerable to freezing.
- Concrete should not be placed when the temperatures of the air at the site or the surfaces on which the concrete is to be placed are less than 4 °C (40 °F).
Concrete placed in cold weather gains strength slowly. Concrete containing supplementary cementitious materials gains strength very slowly.
  - Sawing of joints and opening to traffic may be delayed.
  - Verify the in-place strength by a maturity method, temperature-matched curing, nondestructive testing, or tests of cores from the pavement before opening the pavement to traffic.

- Allow the slabs to cool before completely removing insulating blankets to avoid a thermal shock to the pavement that might induce contraction cracking. Insulating blankets may be temporarily rolled aside to saw contraction joints.
- Refer to ACI 306, *Cold Weather Concreting*, for additional information.

c. Identify and discuss the minimum building code requirements for reinforced concrete in ACI-318.

The following is taken from the Portland Cement Association, Bookstore, ACI 318-08.

This most recent edition of the ACI building code includes revisions to the 2005 edition. It provides minimum requirements for the design and construction of reinforced concrete structural elements. Written in such format that it may be adopted by reference in a general building code, the 22 chapters and 4 appendices include the latest revisions on a variety of topics. This publication is the most sought-after and most used structural design code. The fourth edition of the International Building Code will adopt ACI 318-08 by reference.

This new edition of the ACI Building Code covers the materials, design, and construction of structural concrete used in buildings and where applicable in nonbuilding structures. The Code also covers the strength evaluation of existing concrete structures. Among the subjects covered are: drawings and specifications; inspection; materials; durability requirements; concrete quality, mixing, and placing; formwork; embedded pipes; construction joints; reinforcement details; analysis and design; strength and serviceability; flexural and axial loads; shear and torsion; development and splices of reinforcement; slab systems; walls; footings; precast concrete; composite flexural members; prestressed concrete; shells and folded plate members; strength evaluation of existing structures; provisions for seismic design; structural plain concrete; strut-and-tie modeling in appendix A; alternative design provisions in appendix B; alternative load and strength reduction factors in appendix C; and anchoring to concrete in appendix D. The quality and testing of materials used in construction are covered by reference to the appropriate ASTM standard specifications. Welding of reinforcement is covered by reference to the appropriate American Welding society (AWS) standard. The commentary includes background details or suggestions for carrying out the requirements or intent of the code. Some of the considerations of the committee in developing the code portion are discussed within the commentary, with emphasis given to the explanation of new or revised provisions. Much of the research data referenced in preparing the code is cited for the user desiring to study individual questions in greater detail. Other documents that provide suggestions for carrying out the requirements of the code are also cited.
d. **Identify and discuss the requirements for concrete construction in ACI-349.**

The following is taken from Techstreet, ACI 349-06, *Code Requirements for Nuclear Safety-Related Concrete Structures and Commentary*.

This standard covers the proper design and construction of concrete structures that form part of a nuclear power plant and that have nuclear safety-related functions, but does not cover concrete reactor vessels and concrete containment structures. The structures covered by the standard include concrete structures inside and outside the containment system. This standard may be referenced and applied subject to agreement between the owner and the regulatory authority. The format of this standard is based on ACI 318-05, *Building Code Requirements for Structural Concrete* and incorporates recent revisions of that standard. The commentary, which is presented after the standard, discusses some of the considerations of ACI Committee 349 in developing ACI 349-06, *Code Requirements for Nuclear Safety-Related Concrete Structures*. This information is provided in the commentary because the standard is written as a legal document and therefore cannot present background details or suggestions for carrying out its requirements.

**e. Discuss the longitudinal and shear reinforcement requirements for beam design.**

**Longitudinal Reinforcement**

The following is taken from the *Indiana Design Manual*, section 63-6.05(02).

In regions of high shear stress, such as near the support, the longitudinal reinforcement must also be able to carry the additional stress due to shear: i.e., the horizontal component $T$ of the diagonal compression field. Therefore, the amount and development of the longitudinal reinforcement must be greater than or equal to the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD), equation 5.8.3.5-1, as follows:

$$ T = \frac{M_u}{d_v \Phi} + \frac{N_u \Phi}{2} + \left( \frac{V_u - V_s - V_p}{2} \right) \cot \theta $$

This equation should be satisfied, especially near non-continuous supports where a substantial portion of the prestressing strands are either debonded or draped. Draped or debonded strands are not effective in contributing to this longitudinal reinforcement requirement because either they are above the midheight of the member (h/2), or they are not bonded to the concrete.

AASHTO Load and Resistance Factor Design LRFD, article 5.8.3.5 requires that the longitudinal reinforcement on the flexural tension side of the member (below h/2) shall resist a tensile force of $(V_u - 0.5V_s - V_p)\cot \theta$ at the inside edge of the bearing area at the simple end supports. The values of $V_u$, $V_s$, $V_p$, and $\theta$, calculated for the critical section $0.5d_v\cot \theta$, or $d_v$ from the face of the support, may be used. In calculating the tensile resistance of the longitudinal reinforcement, a linear variation of resistance over the transfer length may be assumed.
Shear Reinforcement

The following is taken from Composites Technology, Composites for Construction: FRP Rebar — Shear Reinforcement and Detailing.

In a reinforced concrete section that develops a critical diagonal shear crack — one that initiates from a flexural crack at the bottom of the beam and propagates toward the top — the shear resistance comes from several sources: 1) the shear strength of the top portion of the beam, 2) frictional resistance between the two sides of the crack, known as aggregate interlock, 3) the vertical component of shear force carried in the main tensile reinforcement, or dowel action, which tends to prevent vertical crack growth, 4) the vertical force component provided by any additional reinforcing bars along the length of the beam, or shear reinforcement, and 5) any additional thrust provided by the compression arch, known as arching action, which develops in the beam roughly parallel to the shear cracks.

Unfortunately, no analytical methods yet exist to quantitatively determine these factors — current practice is to lump everything, except for the shear reinforcement contribution, in a general category of shear capacity, or \( V_c \). Typically, the value of \( V_c \) has been obtained empirically by testing beams that have steel main reinforcement but do not have shear reinforcement.

When a fiberglass reinforced panel (FRP)-reinforced section and a steel-reinforced section are designed for the same moment-carrying capacity, the shear capacity of the FRP-reinforced section is much lower than the latter for a variety of reasons, but research and testing have confirmed that the main reason is the lower longitudinal modulus of the glass FRP bars.

The nominal shear capacity, \( V_n \), of an FRP-reinforced beam is given as:

\[
V_n = V_c + V_f
\]

where \( V_c \) is the concrete’s contribution to shear resistance and \( V_f \) is the contribution from FRP shear reinforcement, typically in the form of stirrups (the “f” subscript denotes the use of FRP rather than steel). The stirrups are typically bent into a “U” or rectangular shape and installed perpendicular to the longitudinal reinforcing bars.

The method for calculating \( V_c \) has evolved over time; the current equation is:

\[
V_c = 5 \times \text{the square root of } f_c b_w c
\]

where \( b_w \) is the width of the beam web and \( c \) is the depth of the neutral axis in the cracked elastic section as defined for the serviceability limit state flexural behavior. Note that the equation above is the traditional equation for the concrete shear contribution, \( V_c \), multiplied by 2.5\( k \) (\( k \) being the ratio of the depth of the neutral axis to the effective depth of the section under service loads). Because FRP bars have less axial stiffness than steel, both the value of \( k \) and the contribution to the shear capacity will be less than in the case of steel.

The shear capacity of FRP stirrups, \( V_f \), is calculated using equations similar to those given for steel stirrups. Note that the design strength of an FRP stirrup can’t be used in place of the yield stress of a steel stirrup, because FRP doesn’t yield like steel. The stress in an FRP
stirrup is limited by its tensile strain or by its strength at its bent portion — for best performance, a minimum inside radius-to-diameter ratio of 3 is required for bent FRP stirrups. This is because of stresses induced in the FRP bars when they’re bent, which can lead to premature linear-elastic failures. FRP bars can’t be bent in the field, unlike steel, and have to be produced with a bend by the manufacturer — typically only 90° bends are available. This requires close coordination with the manufacturer during the design phase to pre-order stirrups to specific dimensions.

The design process for FRP shear reinforcement involves determining the shear demand, \( V_u \), using the same loading as that used for the flexural design. The concrete’s shear capacity, \( V_c \), is calculated using the equation shown above. If \( V_u \leq 0.5\mu V_c \), minimum FRP shear reinforcement must be provided, and if \( V_u \leq \mu V_c \) additional FRP shear reinforcement, \( A_{Fv} \), must be provided. Use a resistance factor of \( \mu = 0.75 \) to determine the factored shear strength of the member; if the shear demand is not met, revisit the overall beam design — greater beam thickness and/or more flexural reinforcement may be needed. Again, this is significantly different from a steel-reinforced design, where shear usually does not control member thickness.

f. Describe the inspection methods used for concrete during a walkthrough of a concrete structure. Relate these inspection methods to the structure and its construction.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

35. Construction management personnel shall demonstrate a working level knowledge of welding, weld testing and inspection, and the criteria in the following American Welding Society (AWS) codes:
   - AWS D1.1, Structural Welding Code — Steel
   - AWS D1.2, Structural Welding Code — Aluminum
   - AWS D1.3, Structural Welding Code — Sheet Steel
   - AWS D5.2, Standard for Welded Steel, Elevated Tanks, Standpipes, and Reservoirs for Water Storage

a. Describe the welding techniques, materials, and equipment used for different metals and applications.

The following is taken from Welding Explained, Arc, Spot, Gas and Aluminum Welding.

**Arc Welding**

Arc welding processes use a welding power supply to create an electric arc between an electrode and the base material to melt metals at the welding point. They can use either direct (DC) or alternating (AC) current, and consumable or non-consumable electrodes. The welding region is sometimes protected by some type of inert or semi-inert gas, known as a shielding gas, and filler material is sometimes used as well.

**Power Supplies**

To supply the electrical energy necessary for arc welding processes, a number of different power supplies can be used. The most common classification is constant current power.
supplies and constant voltage power supplies. In arc welding, the voltage is directly related to the length of the arc, and the current is related to the amount of heat input. Constant current power supplies are most often used for manual welding processes such as gas tungsten arc welding and shielded metal arc welding, because they maintain a relatively constant current even as the voltage varies. This is important because in manual welding, it can be difficult to hold the electrode perfectly steady, and as a result, the arc length and thus voltage tend to fluctuate. Constant voltage power supplies hold the voltage constant and vary the current, and as a result, are most often used for automated welding processes such as gas metal arc welding, flux cored arc welding, and submerged arc welding. In these processes, arc length is kept constant, since any fluctuation in the distance between the wire and the base material is quickly rectified by a large change in current. For example, if the wire and the base material get too close, the current will rapidly increase, which in turn causes the heat to increase and the tip of the wire to melt, returning it to its original separation distance.

The type of current used in arc welding also plays an important role in welding. Consumable electrode processes such as shielded metal arc welding and gas metal arc welding generally use direct current, but the electrode can be charged either positively or negatively. In welding, the positively charged anode will have a greater heat concentration, and as a result, changing the polarity of the electrode has an impact on weld properties. If the electrode is positively charged, it will melt more quickly, increasing weld penetration and welding speed. Alternatively, a negatively charged electrode results in more shallow welds. Non-consumable electrode processes, such as gas tungsten arc welding, can use either type of direct current, as well as alternating current. However, with direct current, because the electrode only creates the arc and does not provide filler material, a positively charged electrode causes shallow welds, while a negatively charged electrode makes deeper welds. Alternating current rapidly moves between these two, resulting in medium-penetration welds. One disadvantage of AC, the fact that the arc must be re-ignited after every zero crossing, has been addressed with the invention of special power units that produce a square wave pattern instead of the normal sine wave, making rapid zero crossings possible and minimizing the effects of the problem.

Methods
One of the most common types of arc welding is shielded metal arc welding (SMAW), which is also known as manual metal arc welding or stick welding. Electric current is used to strike an arc between the base material and consumable electrode rod, which is made of steel and is covered with a flux that protects the weld area from oxidation and contamination by producing CO2 gas during the welding process. The electrode core itself acts as filler material, making a separate filler unnecessary. The process is very versatile, requiring little operator training and inexpensive equipment. However, weld times are rather slow, since the consumable electrodes must be frequently replaced and because slag, the residue from the flux, must be chipped away after welding. Furthermore, the process is generally limited to welding ferrous materials, though specialty electrodes have made possible the welding of cast iron, nickel, aluminum, copper, and other metals. The versatility of the method makes it popular in a number of applications, including repair work and construction.

Gas Metal Arc Welding
Gas metal arc welding (GMAW), also known as metal inert gas (MIG) welding, is a semi-automatic or automatic welding process that uses a continuous wire feed as an electrode and
an inert or semi-inert gas mixture to protect the weld from contamination. Since the electrode is continuous, welding speeds are greater for GMAW than for SMAW. However, because of the additional equipment, the process is less portable and versatile, but still useful for industrial applications. The process can be applied to a wide variety of metals, both ferrous and non-ferrous. A related process, flux-cored arc welding, uses similar equipment but uses wire consisting of a steel electrode surrounding a powder fill material. This cored wire is more expensive than the standard solid wire and can generate fumes and/or slag, but it permits higher welding speed and greater metal penetration.

Gas Tungsten Arc Welding
Gas tungsten arc welding (GTAW), or tungsten inert gas welding, is a manual welding process that uses a non-consumable electrode made of tungsten, an inert or semi-inert gas mixture, and a separate filler material. Especially useful for welding thin materials, this method is characterized by a stable arc and high quality welds, but it requires significant operator skill and can only be accomplished at relatively low speeds. It can be used on nearly all weldable metals, though it is most often applied to stainless steel and light metals. It is often used when quality welds are extremely important, such as in bicycle, aircraft and naval applications. A related process, plasma arc welding, also uses a tungsten electrode but uses plasma gas to make the arc. The arc is more concentrated than the GTAW arc, making transverse control more critical and thus generally restricting the technique to a mechanized process. Because of its stable current, the method can be used on a wider range of material thicknesses than can the GTAW process, and furthermore, it is much faster. It can be applied to all of the same materials as GTAW except magnesium, and automated welding of stainless steel is one important application of the process. A variation of the process is plasma cutting, an efficient steel cutting process.

Submerged arc welding is a high-productivity welding method in which the arc is struck beneath a covering layer of flux. This increases arc quality, since contaminants in the atmosphere are blocked by the flux. The slag that forms on the weld generally comes off by itself, and combined with the use of a continuous wire feed, the weld deposition rate is high. Working conditions are much improved over other arc welding processes, since the flux hides the arc and no smoke is produced. The process is commonly used in industry, especially for large products. Other arc welding processes include atomic hydrogen welding, carbon arc welding, electroslag welding, electrogas welding, and stud arc welding.

Gas Welding
The most common gas welding process is oxyfuel welding, also known as oxyacetylene welding. It is one of the oldest and most versatile welding processes, but in recent years it has become less popular in industrial applications. It is still widely used for welding pipes and tubes, as well as repair work. The equipment is relatively inexpensive and simple, generally employing the combustion of acetylene in oxygen to produce a welding flame temperature of more than 3000 ºC. The flame, since it is less concentrated than an electric arc, causes slower weld cooling, which can lead to greater residual stresses and weld distortion, though it eases the welding of high alloy steels. A similar process, generally called oxyfuel cutting, is used to cut metals. Other gas welding methods, such as air acetylene welding, oxygen hydrogen welding, and pressure gas welding are quite similar, generally differing only in the type of gases used. A water torch is sometimes used for precision welding of items such as jewelry.
Gas welding is also used in plastic welding, though the heated substance is air, and the temperatures are much lower.

**Resistance Welding**

Resistance welding involves the generation of heat by passing current through the resistance caused by the contact between two or more metal surfaces. Small pools of molten metal are formed at the weld area as high amounts of current are passed through the metal. In general, resistance welding methods are efficient and cause little pollution, but their applications are somewhat limited and the equipment cost can be high.

Spot welding is a popular resistance welding method used to join overlapping metal sheets of up to 3 mm thick. Two electrodes are simultaneously used to clamp the metal sheets together and to pass current through the sheets. The advantages of the method include efficient energy use, limited work piece deformation, high production rates, easy automation, and no required filler materials. Weld strength is significantly lower than with other welding methods, making the process suitable for only certain applications. It is used extensively in the automotive industry. Ordinary cars can have several thousand spot welds. A specialized process, called shot welding, can be used to spot weld stainless steel.

Like spot welding, seam welding relies on two electrodes to apply pressure and current to join metal sheets. However, instead of pointed electrodes, wheel-shaped electrodes roll along and often feed the work piece, making it possible to make long continuous welds. In the past, this process was used in the manufacture of beverage cans, but now its uses are more limited. Other resistance welding methods include flash welding, projection welding, and upset welding.

**Energy Beam Welding**

Energy beam welding methods, namely laser beam welding and electron beam welding, are relatively new processes that have become quite popular in high production applications. The two processes are quite similar, differing most notably in their source of power. Laser beam welding employs a highly focused laser beam, while electron beam welding is done in a vacuum and uses an electron beam. Both have a very high energy density, making deep weld penetration possible and minimizing the size of the weld area. Both processes are extremely fast, and are easily automated, making them highly productive. The primary disadvantages are their very high equipment costs (though these are decreasing) and a susceptibility to thermal cracking. Developments in this area include laser-hybrid welding, which uses principles from both laser beam welding and arc welding for even better weld properties.

**Solid-State Welding**

Like the first welding process, forge welding, some modern welding methods do not involve the melting of the materials being joined. One of the most popular, ultrasonic welding, is used to connect thin sheets or wires made of metal or thermoplastic by vibrating them at high frequency and under high pressure. The equipment and methods involved are similar to that of resistance welding, but instead of electric current, vibration provides energy input. Welding metals with this process does not involve melting the materials; instead, the weld is formed by introducing mechanical vibrations horizontally under pressure. When welding plastics, the materials should have similar melting temperatures, and the vibrations are
introduced vertically. Ultrasonic welding is commonly used for making electrical connections out of aluminum or copper, and it is also a very common polymer welding process.

Another common process, explosion welding, involves the joining of materials by pushing them together under extremely high pressure. The energy from the impact plasticizes the materials, forming a weld, even though only a limited amount of heat is generated. The process is commonly used for welding dissimilar materials, such as the welding of aluminum with steel in ship hulls or compound plates. Other solid-state welding processes include co-extrusion welding, cold welding, diffusion welding, friction welding, high frequency welding, hot pressure welding, induction welding, and roll welding.

b. Describe the welding techniques, materials, and equipment used for nonmetals.

The following is taken from Industrial Laser Solutions for Industrial Manufacturing, Welding Plastics with Near IR Lasers.

Welding involves joining two parts by locally melting and fusing material at their common interface. As with metals, thermoplastics can be thermally softened or melted, however, there are a number of important differences between welding metals and thermoplastics. Metals absorb most common laser wavelengths but are excellent conductors of heat, requiring very high local temperatures before they will melt and weld. Conversely, many plastics are transparent at these same laser wavelengths and are notoriously poor conductors of heat. Moreover, thermoplastics soften or melt at relatively low temperatures. In addition, plastics are best welded through reaching a highly softened state rather than a true liquid melt.

These differences have an impact on the way laser welding is performed in plastics. The majority of plastics welding applications involve transmitting laser light through one of the parts to be joined. The second part then absorbs the light, producing intense local heating and softening only at the interface between the parts. Both butt welds and lap welds can be created in this way.

In order to develop a through transmission welding application, it is necessary to understand the transmission/absorption properties of the plastic(s) to be joined. Because cost is often a driving issue, most plastics welding is performed in the near infrared where there are economical lasers with the required power level—a few watts to tens of watts. The near-infrared absorption properties of the materials could be measured with a spectrophotometer, but it is usually better to just use a laser and power meter. Because absorption is not always linear as a function of power, it is important to measure the absorption at the intended power level. Also, most job shops and plants simply won't have a spectrophotometer on site.

Ideally, one material will be completely transparent at the laser wavelength and the other will exhibit very high absorption. In practice, most clear plastics exhibit less than 10 percent absorption through one inch of material. As a rule of thumb, absorption levels up to 20 percent per inch thickness can usually be tolerated. This amount of absorption can produce modest bulk heating but will not significantly affect the overall process.
Once the light has been transmitted to the welding interface, how do we achieve high local absorption, given that the two parts must be of similar composition in order to get a strong weld? By far the most common method is to dope the second part with carbon black filler, which yields very high absorption, without significantly affecting overall strength. More recently, several research groups have been developing special high-absorption films to allow welding of two nominally transparent parts. One example of this is Clearweld, which was jointly developed by Gentex Corp. and the TWI Advanced Materials and Laser Processes Group. In practice, a thin layer of one of these new materials is applied at the interface of the two parts to be welded. The film’s high absorption results in rapid heating and produces an optically clear join with no particles or visible discoloration.

c. Discuss the requirements for welder qualification and the methods for ensuring that qualifications are current.

The following is taken from The Fabricator, ASME and AWS Welding Codes—Similarities and Differences.

The most commonly used codes for qualifying welders are the ASME, section IX and AWS D1.1. Committees and subcommittees comprising volunteer workers interested in furthering the quality and efficiency of the welding industry work together to develop these codes.

We all have heard that ASME codes are more stringent than AWS codes and vice versa. In some areas both are the same. In others they are very different.

The most obvious difference between ASME section IX and AWS D1.1 is that D1.1 addresses fabrication, erection, inspection, and welder and welding procedure qualification. ASME is specifically for welder and welding procedure qualification. A code of construction, such as ASME section VIII, division I, must be used in conjunction with section IX for fabrication.

Some work contracts require that a specific code be used for qualifying the welders, but in many cases either code is sufficient. If the job consists totally of structural welding and the contract specifies the AWS structural code, then that is the code that must be used for all aspects of the job.

If the job entails pressure vessels or piping, the ASME boiler and pressure vessel code must be used.

If the job is related to ductwork associated with a boiler, the contract usually allows qualification with either code. Choosing a specific code when one is not specified in the contract often involves a fine line.

Qualification Basics

The basic contents of a procedure qualification are the same in both programs.

The welding procedure specification (WPS) is a document that is intended to provide direction for the welder. It also depicts the joint design and welding materials, parameters, and technique and code requirements.
The procedure qualification record (PQR) is a record of test results for the welds made in accordance with the WPS. Destructive testing (tensile pulls, bends, etc.) is required for PQRs in all codes. AWS D1.1 also requires nondestructive testing for procedure qualification. ASME section IX does not.

The welder qualification test record (WQTR) comprises the results of a test to prove that a welder is qualified to weld to a certain WPS. It includes qualification of the range of base materials, weld materials, positions, and so forth. These tests consist of guided bends, breaking of fillet welds, and macroetching. In some cases, the test coupons may be radiographed in lieu of destructive testing.

AWS D1.1 Specifics

The AWS D1.1 code qualification is specifically for carbon and low-alloy metals. The minimum thickness addressed is 1/8 in. The maximum yield strength addressed is 100 kilopound per square inch (KSI).

This code, generally used for buildings and support structures, is useful for fabricating and erecting any welded structure.

Materials for Prequalification by AWS D1.1

The prequalification section 3 of AWS D1.1 lists materials for prequalifying the WPS. These materials are listed in groups that are assigned Roman numerals. Although the groups reflect a somewhat ascending alignment as to the yield strength, there are instances of overlapping within three of the four groups.

Group I lists the lowest-yield-strength materials from 30 KSI to 46 KSI. Group II lists materials at 36 KSI to 80 KSI. Group III, 46 KSI to 90 KSI. Group IV, 70 KSI materials only. Each material list shows matching electrode, and filler metal, to be used to establish prequalified procedures.

If a fabricator wants to use a material that is not listed in the table, a procedure must be qualified by testing and with a written PQR.

ASME materials are listed by P and S numbers. There are very few restrictions as to size and strength of material. This is a reason for qualifying welders and procedures to the ASME section IX when possible.

Welding codes are intended to improve skills, processes, materials, and equipment. They are important in achieving maximum quality and efficiency.

d. Describe the techniques and requirements for destructive testing of welds.

The following is taken from Welding-Advisors, Welding Testing, The All Important Proof.

Mechanical welding-testing is regarded as the most reliable and least expensive to determine strength and other properties. Welding-testing specimens to destruction is one of the most important means to assess the quality of welds.
Among mechanical welding-testing, classic tensile tests are performed using instruments called universal mechanical testing systems, on prepared test specimens precisely machined through weld material to the dimensions and shape required by standards. Sometimes specifications require getting strength results in the weld equal at least to those of the base metal. Other times they permit that a weld exhibit a given percentage of the base metal strength.

Bend tests are popular and informative tests. Usually they can be performed with simple equipment, like a jack or a press, readily available in many shops. But Specification requirements must be followed accurately for the test to be valid. The result of the test should be as demanded.

Sometimes a certain angle of bend should be reached without fracture. Either warping of the test piece without fracture or a break outside the weld or whatever other feature should be according to specification requirements. In any case the welding-testing result must be documented in a test report, possibly with a photo, and the test piece itself must be identified and kept for later inspection.

Guided bend tests are a special type, being performed on specially prepared test pieces, using a jig manufactured to constrain the specimen to follow a given contour.

Metallographic tests require a minimum of metallurgical experience, and some specific equipment, like a disk sectioning machine, a specimen mounting press, grinding, polishing turntables, some acid etching capabilities and an optical metallurgical microscope with magnification capacity of up to x500 at least.

Welding-testing to find the weld position or to view the weld bead shape or obvious discontinuities in a prepared section is not difficult to interpret, but if a need arises to discern between metallographic phases in different areas of the weld, for determining the adequacy of a certain welding procedure, or for investigating the reasons of unacceptable results, one must use the resources of a professional metallurgist whose preparation is tuned to these more demanding tasks.

Hardness testing on metallographic sections as above gives indications on the microstructure developed in and around the weld: too hard a material may be prone to cracking, and special procedures may be required to avoid such dangerous conditions.

e. Discuss the following methods of weld inspection:
   - Visual
   - Radiographing
   - Dye penetrant
   - Ultrasonic

Visual
The following is taken from *Ensuring Weld Quality in Structural Applications* by Duane K. Miller.

AWS D.1-1, *Structural Welding Code*, states that all welds shall be visually inspected. In the chapter on inspection, the following directions are given to the inspector:
- The inspector shall make certain that only materials conforming to the requirements of AWS D.1-1 are used.
- The inspector shall verify that all WPSs have been approved by the engineer.
- The inspector shall inspect all welding equipment to be used in the work to make certain that it conforms to requirements.
- The inspector shall permit welding to be performed only by welders, welding operators, and tack welders who are qualified in accordance with the requirements.
- The inspector shall make certain that only welding procedures are employed that meet the provisions of AWS D.1-1.
- The inspector shall make certain that electrodes are used only in the positions and with the type of welding current polarity for which they are classified.
- The inspector shall, at suitable intervals, observe joint preparation, assembly practice, the welding techniques, and performance of each welder, welding operator, and tack welder to make certain the applicable requirements of AWS D.1-1 are met.

These code requirements make it obvious that visual inspection must take place before the work is completed. This may deviate from the approach used by many inspectors, but it is the only approach that can actually prevent the formation of welding defects. For example, when the base materials being used are examined, the inspector can prevent the use of the wrong type of material in a specific application. Careful examination of welding procedures will reveal the suitability of a specific procedure for a particular application. The welder’s credentials will help determine the suitability of that individual for the specific application.

The quality of the completed weld can also be visually determined in many situations. A good-looking weld is generally a good weld. A poor-looking weld may or may not be a poor weld. However, the presence of visually discernible criteria that deviate from good appearance is generally an indication that one or more variables are not being properly addressed.

**Radiographing**

The following is taken from Welding-Advisors, Welding Inspections for Soundness and Efficiency.

Radiographic welding-inspection is performed by pointing a radiation source (an x-ray tube or a radioactive isotope) to the portion of the weldment to be inspected and by exposing for a certain time a radiographic film to the radiation on the underside (or the other side away from the source). An exposed and developed film contains information on the internal features of the weld, much as a medical radiograph is used to check the human body.

In practice a radiographer should first develop by trial and error a welding-inspection technique which takes into account the particular requirements of the job at hand. All the relevant parameters are then recorded on a technique sheet, which should be approved by a knowledgeable authority, who agrees that the technique employed is suitable to expose the discontinuities looked for.

Due to the harmful nature of ionizing radiation (like x-rays or gamma rays) it is most important that the manipulation of ionizing sources be entrusted to trained and knowledgeable inspectors that will not endanger themselves or passers by.
In modern practice there is an increasing tendency to substitute the sensitive element (film) with electronic sensors capable of collecting and of displaying x-ray images on computer screens. The next step on which researches are working is to develop acceptable methods of digital image processing, automatic analyzing for feature extraction of indications, and defect evaluation through tools of pattern recognition.

Interpretation

The radiographic welding-inspection interpretation of the subtle cues appearing in the radiograph, requires understanding the basics of the process, learning the variables and their influence, knowing how to generate a meaningful film exposure and what are the possible expressions on the film of internal features present in the weldment.

In general, the film registers local differences of absorption of radiation by the material, as a function of density and of thickness. So, very thin discontinuities parallel to the surface may go undetected. The normal radiograph is a flat reproduction of the sums of all the features present along the thickness of the welded structure, without indication of the position along the line of radiation: special (tomographic) techniques must be put in place if it is important to know where in the depth the defect is.

Acceptance

Acceptance criteria for welding-inspection are established by the designer with reference to standard images, called reference radiographs, identified in accepted specifications by letters and numbers according to base material classes and to thicknesses and issued by ASTM and by other organizations.

The appearance of a radiograph has to be compared visually by the inspector with the limiting reference radiograph established by the designer in the instructions for welding-inspection. If it appears equal to or better than the reference radiograph then it is accepted, otherwise it is rejected. In this case somebody with knowledge and experience has to decide if the weldment can be repaired and how. In the end a new radiograph has to be taken.

Dye Penetrant

The following is taken from Welding-Advisors, Welding Inspections for Soundness and Efficiency.

Penetrant welding-inspection is based on the fact that specially formulated liquids have the property of penetrating in tiny cracks or discontinuities open to the surface. When the part is further washed of all excessive liquid on its surface and when a type of absorbing material (called developer) is spread on it, the remaining liquid, including a visible dye, absorbed in the cracks seeps outside and spreads on the surface of the developer making itself visible to inspection.

This type of inspection is used for all non magnetic materials like aluminum, magnesium, titanium, copper etc. and is most apt to detect the finest cracks. The penetrant liquid may contain instead a suspension of fluorescent particles which are visible under ultra-violet light
(black light) for improved sensitivity: this method is then called fluorescent penetrant inspection.

**Ultrasonic**
The following is taken from Welding-Advisors, Welding Inspections for Soundness and Efficiency.

Ultrasonic welding-inspection is based on the fact that acoustic waves of a frequency not heard by the human ear can propagate in materials, and be reflected in various ways by internal interfaces and by distant surfaces. The acoustic waves are generated by piezoelectric transducers which transform electrical vibrations into mechanical vibrations and vice-versa.

By examining the traces of the signals of those reflections, in modern instruments on a computer screen, and by making reference to standard reflectors (normally flat bottom holes carefully machined on specimens of the same material) of given shape and size, the experienced inspector can conclude that if an echo is present where it should not be and if its trace is larger than that of comparison, then there is an indication of discontinuity that must be evaluated.

Depending on the outcome of the evaluation, which may make use of additional techniques, the result of the inspection, either to accept or to reject, is decided. It should be emphasized that ultrasonic testing is capable of detecting thin interfaces normal to the line of propagation of the wave (that X-Rays cannot detect) so that both testing methods complement each other.

f. During a facility or construction site walkthrough, evaluate accessible weld joints. Describe welding methods and inspection techniques that apply to each weld.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

36. Construction management personnel shall demonstrate a working level knowledge of construction methods and accepted construction practices associated with structural steel as described in the following documents:
   - American Institute of Steel Construction AISC-M021, Manual of Steel Construction

   [Note: AISC-M021 has been replaced by AISC-325-05, Steel Construction Manual. AISC-N690-94 has been replaced by AISC-N690-06.]

   a. Discuss the structural design requirements and standard construction methods associated with the following:
      - Light-gauge steel
      - Pre-engineered metal buildings
      - Steel water tanks
      - Transmission towers
Light-Gauge Steel

The following is taken from Building Envelope Research, Light Gauge Steel Framing.

Light gauge steel framing is often used in commercial construction. It consists of studs and channels. The channels are used at the top and bottom of a wall, like the plates in wood construction. The C-shaped studs fit into the channels and are held in place by self tapping screws. They can also be crimped or welded together.

There are two basic types of light gauge steel framing: load bearing and non-load bearing. Load bearing studs are stronger and heavier. Depending on the thickness of the steel (20 gauge to 14 gauge) they can be used in multi-story construction. Non-load bearing studs (also called drywall studs) are not as sturdy (25 gauge to 20 gauge) and are only designed to support interior partitions covered with drywall or plaster lath.

Load bearing joists are also available, in sizes comparable to 2X6s to 2X14s. They can also be used for rafters and window headers. Manufacturers have standard details worked out for all connections depending on the loading requirements.

The non-load bearing studs are available in sizes as small as a wood 2X2. All studs and joists are galvanized, making them rustproof. They also have holes punched in them that electrical wiring or plumbing can be run through. A major advantage of steel over wood is quality control. There are no knots, and there is no warping. A steel framed house can sometimes qualify for reduced insurance rates because it is non-combustible.

Any type of finish material can be used with steel framing. It is simply attached with self tapping screws. Trim screws are available that resemble finish nails with a small Phillips head.

Pre-Engineered Metal Buildings

The following is taken from Pre-Engineered Metal Buildings: Advantages and Disadvantages by Jon A. Schmidt and Ronald L. Younker.

Pre-engineered metal building (PEMB) structures and their individual elements are often customized to the specific stress distributions produced by the design loads, reducing material costs. Because they consist almost entirely of standardized components, PEMBs can be fabricated and erected quickly, resulting in lower labor costs and shorter schedules. PEMBs are commonly furnished complete with roofing and siding, so that a single source is responsible for providing the entire building envelope. These factors have combined to make PEMBs increasingly attractive for a wide range of building types.

However, PEMBs do have their drawbacks. Perhaps the most significant from a design standpoint is the fact that PEMB manufacturers generally do not perform any foundation design. The engineering consultant still must complete this task and provide for the
foundations in the contract documents. Unfortunately, if the entire project is issued for bid in one package, it is necessary for the structural engineer to do the following:

- Assume a structural system type (braced and/or rigid frames) and configuration.
- Calculate approximate dead, collateral, live, snow, wind, seismic, and other loads.
- Estimate the building base reactions.
- Design the anchor bolts and foundations accordingly for bidding purposes.

To prevent excessive changes later, the engineer will prepare the contract documents, especially the PEMB specification itself, to ensure that the building actually provided will be consistent with the foundation design. This may limit the PEMB manufacturer’s ability to economize the superstructure design. For example, the engineer might assume that the building is braced and has columns with pinned bases to minimize foundation costs. The PEMB manufacturer will have to design and furnish the building accordingly, even if rigid frames with fixed bases might result in a less expensive structure.

Only well after the construction contract has been awarded will the selected PEMB supplier submit the final reactions and anchor bolt requirements, which the engineer must then review and compare with the design assumptions. Even if the building configuration matches that assumed, more often than not the engineer still must perform at least some redesign, and the owner must then issue a change order.

Sometimes, to avoid this, the engineer will deliberately oversize the foundations from the beginning to account for the uncertainties, which adds to the construction cost. An alternative is to issue a separate PEMB package for bid and award as early as possible in the design process, so that the engineer can obtain reactions before preparing the foundation drawings. The danger here is that the information included in the PEMB package, which may be preliminary at best, will be incomplete, resulting in coordination problems and, again, change orders down the line.

Other issues to consider when evaluating whether to use a PEMB for a particular project include the following:

- Limitations on building geometry. PEMBs are best suited for regular, rectangular construction. Although they certainly can be adapted to other building configurations, such complexities diminish the advantages PEMBs have to offer. Also, even relatively minor changes in the owner’s requirements for the building during design and/or construction — for example, relocating cranes or roof-mounted equipment, or adding a mezzanine — may require a redesign of all or part of the PEMB.
- Applicability of manufacturer’s standards. Every PEMB manufacturer has its own set of standards for such items as wall panel, roof, and coating systems, and there is usually a cost premium associated with any deviation from them. However, they are not compatible with the requirements of every project. For example, an owner may opt for an exterior paint system that is more corrosion-resistant, or perhaps just a different color, than the one typically provided by the PEMB supplier.
- Excessive deflections. PEMBs tend to exhibit relatively large movements under design loads, which can create problems for sensitive finishes or equipment. For example, if an owner prefers masonry or precast concrete exterior walls to the metal siding traditionally offered by PEMB manufacturers, the specified lateral deflection
tolerances under wind and seismic loads must be much tighter than usual, which again may negate the traditional benefits of using a PEMB.

- Lack of flexibility for future modifications. PEMBs typically consist of a series of rigid frames, which may have lean-to bays on one or both sides. Unless specific provisions are made in the original design, PEMBs are generally difficult to expand except by providing additional rigid frames at one end or the other. Also, since members are sized very carefully for the original design loads, there is not a great deal of reserve strength, and even if there is some, it is difficult or impossible to determine how much. Reinforcement may be necessary if the building’s function or layout changes significantly in the years ahead, but may not be practical since the structure typically must somehow be unloaded as much as possible before the changes can be made. In any case, an owner cannot undertake any significant modification of a PEMB without considerable participation by its original designer/manufacturer.

The following is taken from 29 CFR 1926.758.

Each structural column shall be anchored by a minimum of four anchor rods (anchor bolts).

Rigid frames shall have 50 percent of their bolts or the number of bolts specified by the manufacturer (whichever is greater) installed and tightened on both sides of the web adjacent to each flange before the hoisting equipment is released.

Construction loads shall not be placed on any structural steel framework unless such framework is safely bolted, welded or otherwise adequately secured.

In girt and eave strut-to-frame connections, when girts or eave struts share common connection holes, at least one bolt with its wrench-tight nut shall remain connected to the first member unless a manufacturer-supplied, field-attached seat or similar connection device is present to secure the first member so that the girt or eave strut is always secured against displacement.

Both ends of all steel joists or cold-formed joists shall be fully bolted and/or welded to the support structure before
- Releasing the hoisting cables;
- Allowing an employee on the joists; or
- Allowing any construction loads on the joists.

Purlins and girts shall not be used as an anchorage point for a fall arrest system unless written approval is obtained from a qualified person.

Purlins may only be used as a walking/working surface when installing safety systems, after all permanent bridging has been installed and fall protection is provided.

Construction loads may be placed only within a zone that is within 8 feet of the center-line of the primary support member.
Steel Water Tanks

The following is taken from Today’s Composite Elevated Storage Tanks by Stephen Meier.

A composite elevated water tank is comprised of a welded steel tank for watertight containment, a single pedestal concrete support structure, a foundation and accessories. The steel tank provides a proven, watertight container derived from the AWWA D 100-05, Welded Carbon Steel Tanks for Water Storage which has demonstrated superior performance through decades of use by the water industry. The reinforced concrete support column provides a cost effective, structurally robust pedestal with minimal maintenance.

The basic configurations of the composite elevated storage tanks built in the US and Canada over the last 25 years are shown in figure 48.

Source: Today’s Composite Elevated Storage Tanks

Figure 48. Common composite tank

The most common composite tank is the domed concrete floor with a carbon steel liner (style A). The advantages and disadvantages of each style are shown in table A.
<table>
<thead>
<tr>
<th>Style</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-Dome</td>
<td>• Balance of forces at tank-to-pedestal intersection</td>
<td>• Special formwork for dome</td>
</tr>
<tr>
<td></td>
<td>• Scalable to large capacity tanks</td>
<td>• Intersection with steel tank may be more complex for inexperienced builder</td>
</tr>
<tr>
<td></td>
<td>• Reduced dead storage</td>
<td>• Liner fitting/grouting dome shape</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Underside of liner inaccessible for coating similar to ground storage tank</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Additions or modification to tank bottom are difficult.</td>
</tr>
<tr>
<td>B-Suspended bottom</td>
<td>• Bottom is accessible for coating and addition or modification</td>
<td>• Tolerances at top of pedestal are critical for skirt support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Skirt to cone intersection design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• More dead storage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Condensation on bottom may require a condensate ceiling for interior uses</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Additional maintenance to paint tank bottom</td>
</tr>
<tr>
<td>C-Slab</td>
<td>• Reduced dead storage</td>
<td>• Limited to smaller capacity tanks</td>
</tr>
<tr>
<td></td>
<td>• Liner is not formed</td>
<td>• Bending tension stresses cause cracking in lower face of slab</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Underside of lining inaccessible for coating similar to a ground storage tank</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Additions or modifications to bottom are difficult</td>
</tr>
</tbody>
</table>

*Source: Today’s Composite Elevated Storage Tanks*
Construction
The typical construction sequence for the modern composite tank involves the following steps:

Step 1: Foundation

The foundation is usually a spread footing for average soil bearing conditions since the tank footprint is relatively large although deep foundations may be required in some locations. It is important that the foundation and wall starter rebar be located within tolerance so the wall construction can start with the correct geometry.

Step 2: Pedestal Wall Construction

From the footing, the wall forms are erected and the process of building the wall begins. Form systems are usually proprietary to the tank constructor. The forms typically have strips fastened to the formwork that create rustications in the concrete that hide construction joints and give a pleasing panel-like appearance. Regardless of the formwork details, care should be taken to ensure wall tolerances on thickness and plumbness are met. Additional reinforcement near openings, block outs for the wall openings and embedment installation should be monitored. The concrete mix, placement and vibration should be implemented in such a way to achieve good consolidation and minimal surface defects (fins, bugholes, etc) and shading.

Step 3: Tank Erection – In Place

One popular method of construction is to construct the steel tank in-place similar to that used in welded steel elevated tanks. After the pedestal and dome are erected, the subassemblies of the tank sections are lifted and fit into position. Welding, radiographic and tolerance examinations, and coating work are also done in final position.

Jacking

For this erection method, supports are erected around base of the tank and the conical sections and vertical shell are fit and welded. Lifting supports are installed on the tank. Radiographic and the coating work may also be completed while the tank is in low position.

Lifting frames and hydraulic cable jacks are supported on the top of the pedestal/dome and used to hoist the tank into final position. When the tank reaches the final position, the tank is pinned in place with proprietary locking systems until the final concrete placement can be made to permanently lock the tank and tower together.

Step 4: Completing tank

After tank is secured to the pedestal the lifting equipment is removed and the tank roof and any internals are installed. The floor liner is installed and, if required, the space between the liner and dome is grouted. The remainder of accessories, roof handrails and communication antennas (if required) are installed. Coatings are applied to roof and remaining tank components.
Step 5: Interior of Pedestal

If specified, the interior of the pedestal can be finished for a variety of uses – storage, office space, training areas and other imaginative uses. If the tank is used for communication antennas, the interior may be sub-divided to provide space for the communication carriers. The interior space also provides a convenient space for controls and valves for the tank. One word of caution, storage of explosive or flammable material inside the pedestal is not recommended.

Typically a 1.5 million gallon tank can be completed in approximately 1 year from the issuance of the notice to proceed.

Transmission Towers

The following is taken from Transmission Towers by Edwin Le Roy Gemmill.

So long as electrical wires were kept only a short distance above the ground, wood poles made an ideal support for them under ordinary conditions. But, when higher supports had to be considered, transmission line engineers began looking about for other supporting structures which would lend themselves more readily to all the varying conditions of service.

The steel structure was immediately suggested as the proper support to take the place of the wood poles. But these supports when built of steel were more expensive than the wood poles had been, and to keep the total cost of the line equipment down to a minimum, and to make such an installation compare favorably with a similar line using the wood poles, it became necessary to space the steel supports farther apart, so as to use fewer of them to cover the same length of line.

The steel support, however, had come to stay, and the whole problem resolved itself into a matter of making a careful investigation and study of each installation. From these several project the different types of structures that are in use today for transmission line work evolved. They are roughly divided into three general types, namely poles, flexible frames and rigid towers.

Poles

All supports that are relatively small at the base or ground line are generally classified as poles. At the ground line and near the top they are made in several different shapes. They may be round, square, rectangular, or triangular. As a rule, their general outline is continued below the ground line to the extreme bottom of the anchorage. They are usually intended merely to take care of the vertical loads combined with horizontal loads across or at right angles to the direction of the line. They may have greater strength transverse to the line than in the direction of the line, but they are often made of the same strength in each direction. Poles are very rarely designed to take care of any load in the direction of the line when combined with the specified load across the line. They must be spaced closer together than the heavier structures but can be spaced much farther apart than wood poles. A very common spacing for steel poles is about 300 feet apart.
Flexible Frames
Flexible frames are heavier structures than the poles, and are intended to take care of longer spans. Like the poles, their chief function is to take care of transverse loads with a small margin of safety so that under unusually conditions of service they could also provide a little resistance in the direction of the line. The flexible frames may transfer all loads coming on them in the direction of the line to a point where they will be resisted, by a frame of similar construction and strength, but which is made secure against the action of such loads by being anchored in this direction with guy lines.

These flexible frames are almost always rectangular in plan. Generally, the parallel faces in both directions will get smaller as the top is approached, but often the two faces parallel to the direction of the line will be of the same width from the bottom to the top. But the two faces transverse to the line almost always taper from the ground line up, and get smaller toward the top. The two faces parallel to the line are generally extended below the ground line to form the anchorages.

Rigid Towers
Rigid towers are the largest and heaviest structures made for transmission line supports, and as would be implied by the designation given them, they are intended to have strength to carry loads coming upon them, either in the direction of the line or at right angles to this direction. They are usually designed to take a combination of loads in both directions. These towers are built in triangular, rectangular, and square types, depending on the particular conditions under which the structure is to be used. When a plan of the tower at the ground line is square in outline, each side of the square will be very much larger than in the case of either poles or flexible frames. The width of one side of a rigid tower, measured at the ground line will vary somewhere between about one-seventh and one-third of the total height of the structure. This dimension is usually determined by the construction which will give the most economical design, especially when there are a large number of the towers required. But it often happens that the outline of one or more of the structures will be determined by local conditions which are entirely foreign to the matter of economy of design. Then, too, the conditions of loading may be such as to make a special outline the most economical design.

Steel Joists
The following is taken from the 29 CFR 1926.757.

General Construction
Where steel joists are used and columns are not framed in at least two directions with solid web structural steel members, a steel joist shall be field-bolted at the column to provide lateral stability to the column during erection.

For the installation of this joist

- a vertical stabilizer plate shall be provided on each column for steel joists. The plate shall be a minimum of 6 inch by 6 inch and shall extend at least 3 in. below the bottom chord of the joist with a 13/16 inch hole to provide an attachment point for guying or plumbing cables.
- the bottom chords of steel joists at columns shall be stabilized to prevent rotation during erection.
• hoisting cables shall not be released until the seat at each end of the steel joist is field-bolted, and each end of the bottom chord is restrained by the column stabilizer plate.

Where constructibility does not allow a steel joist to be installed at the column
• an alternate means of stabilizing joists shall be installed on both sides near the column and shall:
  o provide stability equivalent to paragraph (a)(1) of 29 CFR 1926.757, “Open Web Steel Joists;”
  o be designed by a qualified person;
  o be shop installed; and
  o be included in the erection drawings.

• hoisting cables shall not be released until the seat at each end of the steel joist is field-bolted and the joist is stabilized.

Where steel joists at or near columns span 60 feet or less, the joist shall be designed with sufficient strength to allow one employee to release the hoisting cable without the need for erection bridging.

Where steel joists at or near columns span more than 60 feet, the joists shall be set in tandem with all bridging installed unless an alternative method of erection, which provides equivalent stability to the steel joist, is designed by a qualified person and is included in the site-specific erection plan.

A steel joist or steel joist girder shall not be placed on any support structure unless such structure is stabilized.

When steel joist(s) are landed on a structure, they shall be secured to prevent unintentional displacement prior to installation.

No modification that affects the strength of a steel joist or steel joist girder shall be made without the approval of the project structural engineer of record.

Field-bolted joists. (i) Except for steel joists that have been pre-assembled into panels, connections of individual steel joists to steel structures in bays of 40 feet or more shall be fabricated to allow for field bolting during erection. These connections shall be field bolted unless constructibility does not allow.

Steel joists and steel joist girders shall not be used as anchorage points for a fall arrest system unless written approval to do so is obtained from a qualified person.

A bridging terminus point shall be established before bridging is installed.

Attachment of Steel Joists and Steel Joist Girders
Each end of ‘‘K’’ series steel joists shall be attached to the support structure with a minimum of two 1/8-inch fillet welds 1 inch long or with two 1/2-inch bolts, or the equivalent.
Each end of ‘‘LH’’ and ‘‘DLH’’ series steel joists and steel joist girders shall be attached to the support structure with a minimum of two 1/4-inch fillet welds 2 in. long, or with two 3/4-inch bolts, or the equivalent.

Except as provided in paragraph (b)(4) of 29 CFR 1926.757, each steel joist shall be attached to the support structure, at least at one end on both sides of the seat, immediately upon placement in the final erection position and before additional joists are placed.

Panels that have been pre-assembled from steel joists with bridging shall be attached to the structure at each corner before the hoisting cables are released.

Employees shall not be allowed on steel joists where the span of the steel joist is equal to or greater than the span shown in tables A and B except in accordance with 29 CFR 1926.757(d).

When permanent bridging terminus points cannot be used during erection, additional temporary bridging terminus points are required to provide stability.

Erection of Steel Joists
Both sides of the seat of one end of each steel joist that requires bridging under tables A and B of 29 CFR 757 shall be attached to the support structure before hoisting cables are released.

For joists over 60 feet, both ends of the joist shall be attached as specified in paragraph (b) of 29 CFR 1926.757 and the provisions of paragraph (d) of 29 CFR 1926.757 before the hoisting cables are released.

On steel joists that do not require erection bridging under tables A and B of 29 CFR 1926.757, only one employee shall be allowed on the joist until all bridging is installed and anchored.

Steel Decking
The following is taken from 29 CFR 1926.754.

Hoisting, Landing and Placing of Metal Decking Bundles
Bundle packaging and strapping shall not be used for hoisting unless specifically designed for that purpose.

If loose items such as dunnage, flashing, or other materials are placed on the top of metal decking bundles to be hoisted, such items shall be secured to the bundles.

Bundles of metal decking on joists shall be landed according to with 29 CFR 1926.757(e)(4).

Metal decking bundles shall be landed on framing members so that enough support is provided to allow the bundles to be unbanded without dislodging the bundles from the supports.
At the end of the shift or when environmental or jobsite conditions require, metal decking shall be secured against displacement.

Roof and Floor Holes and Openings
Metal decking at roof and floor holes and openings shall be installed as follows:

- Framed metal deck openings shall have structural members turned down to allow continuous deck installation except where not allowed by structural design constraints or constructibility.
- Roof and floor holes and openings shall be decked over. Where large size, configuration or other structural design does not allow openings to be decked over (such as elevator shafts, stair wells, etc.) employees shall be protected in accordance with 29 CFR 1926.760(a)(1), “Fall Protection.”
- Metal decking holes and openings shall not be cut until immediately prior to being permanently filled with the equipment or structure needed or intended to fulfill its specific use and which meets the strength requirements of paragraph (e)(3) of 29 CFR 1926.754, “Structural Steel Assembly,” or shall be immediately covered.

Covering Roof and Floor Openings
Covers for roof and floor openings shall be capable of supporting, without failure, twice the weight of the employees, equipment and materials that may be imposed on the cover at any one time.

All covers shall be secured when installed to prevent accidental displacement by the wind, equipment or employees.

All covers shall be painted with high-visibility paint or shall be marked with the word HOLE or COVER to provide warning of the hazard.

Smoke dome or skylight fixtures that have been installed, are not considered covers for the purpose of this section unless they meet the strength requirements of paragraph (e)(3)(i) of 29 CFR 1926.754.

Decking Gaps Around Columns
Wire mesh, exterior plywood, or equivalent, shall be installed around columns where planks or metal decking do not fit tightly. The materials used must be of sufficient strength to provide fall protection for personnel and prevent objects from falling through.

Installation of Metal Decking
Metal decking shall be laid tightly and immediately secured upon placement to prevent accidental movement or displacement.

During initial placement, metal decking panels shall be placed to ensure full support by structural members.
Derrick Floors
A derrick floor shall be fully decked and/or planked and the steel member connections completed to support the intended floor loading.

Temporary loads placed on a derrick floor shall be distributed over the underlying support members so as to prevent local overloading of the deck material.

*Structural Steel Connections and Fastening*

The following is taken from 29 CFR 1926.754.

Shear connectors such as headed steel studs, steel bars or steel lugs, reinforcing bars, deformed anchors or threaded studs shall not be attached to the top flanges of beams, joists or beam attachments so that they project vertically from or horizontally across the top flange of the member until after the metal decking, or other walking/working surface, has been installed.

When shear connectors are used in construction of composite floors, roofs and bridge decks, employees shall lay out and install the shear connectors after the metal decking has been installed, using the metal decking as a working platform. Shear connectors shall not be installed from within a controlled decking zone, as specified in 29 CFR 1926.760, “Fall Protection.”

**b. Define the following:**

- Minimum edge distance
- Unbraced length
- Beam bearing plate
- Web crippling

*Minimum Edge Distance*

The following is taken from Structural Steel Detailer, Minimum Edge Distance.

The distance from the center of a standard hole to an edge of a connected part shall be not less than the applicable value from table 18.

<table>
<thead>
<tr>
<th>Nominal bolt diameter (in,)</th>
<th>At sheared edges</th>
<th>At rolled edges of plates, shapes or bars bas cut or saw-cut edges&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>7/8</td>
<td>3/4</td>
</tr>
<tr>
<td>5/8</td>
<td>1 1/8</td>
<td>7/8</td>
</tr>
<tr>
<td>3/4</td>
<td>1 1/4</td>
<td>1</td>
</tr>
<tr>
<td>7/8</td>
<td>1 1/2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1 1/8</td>
</tr>
<tr>
<td>1</td>
<td>1 3/4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1 1/4</td>
</tr>
<tr>
<td>1 1/8</td>
<td>2</td>
<td>1 1/2</td>
</tr>
<tr>
<td>1 1/4</td>
<td>2 1/4</td>
<td>1 5/8</td>
</tr>
<tr>
<td>Over 1 1/4</td>
<td>1 3/4x diameter</td>
<td>1 1/4x diameter</td>
</tr>
</tbody>
</table>

<sup>a</sup> For oversized or slotted holes, see table 19.

<sup>b</sup> All edge distances in this column may be reduced 1/8-in. when the hole is at a point where stress does not exceed 25 percent of the maximum design strength in the element.

<sup>c</sup> These may be 1 ¼ in. at the ends of beam connection angles.
Anchor Bolt Holes

Hole sizes for steel-to-steel structural connections are not the same as hole sizes for steel-to-concrete anchorage applications. In the case of steel-to-steel connections, the parts are made in a shop under good quality control, so standard holes (bolt diameter plus 1/16"), oversized holes (bolt diameter plus 3/16"), and short and long-slotted holes can be used quite successfully. However, the field placement of anchorage devices has long been subject to more permissive tolerances (and often, inaccuracies that exceed those tolerances anyway and may require consideration by the structural Engineer of Record).

AISC published Steel Design Guide Series 1, Column Base Plates back in the early 1990s. At that time, it was recognized that the quality of foundation work was getting worse and worse. To allow the erector (and designer) greater latitude when possible, the permissible hole sizes in base plates were increased. These same larger hole sizes were included in the 2nd ed. LRFD manual. The values there are maximums, not a required size. Smaller holes can be used if desired. Plate washers are generally required with these holes because ASTM F436 washers can collapse into the larger-sized holes, even under erection loads.

The larger hole sizes are primarily intended for the majority of base plates that transfer only axial compression from the column into the foundation. The anchor rods don't usually do much after erection in that case.

To allow for misplaced bolts, holes in base plates are oversized. The AISC Steel Construction Manual recommends the following oversized hole diameters for each bolt diameter:

Table 19. Anchor bolt hole dimensions

<table>
<thead>
<tr>
<th>Bolt diameter</th>
<th>Hole size</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4</td>
<td>1 5/16</td>
</tr>
<tr>
<td>7/8</td>
<td>1 9/16</td>
</tr>
<tr>
<td>1</td>
<td>1 13/16</td>
</tr>
<tr>
<td>1 1/4</td>
<td>2 1/16</td>
</tr>
<tr>
<td>1 1/2</td>
<td>2 5/16</td>
</tr>
<tr>
<td>1 3/4</td>
<td>2 3/4</td>
</tr>
<tr>
<td>2</td>
<td>3 1/4</td>
</tr>
<tr>
<td>2 1/2</td>
<td>3 3/4</td>
</tr>
</tbody>
</table>

Source: Structural Steel Detailer

AISC, Steel Design Guide Series 1, Column Base Plates, suggests that using oversize holes meeting these criteria may still not accommodate field variations in anchor bolt placement and suggests adding 1/4 in. to the hole diameter listed. The guide recommends using a heavy plate washer over the holes. The AISC Structural Steel Educational Council cites the following example: If bolts are misplaced up to 1/2 inch, the oversized base plate holes normally allow the base plate and column to be placed near or on the column line. If the bolts are misplaced by more than 1/2 inch, then corrective work is required.
Based on AISC oversize holes, the AISC Structural Steel Educational Council recommendations, and concrete contractor anchor-bolt placement techniques, ASCC (American Society of Concrete Contractors) concrete contractors recommend the following tolerance for each bolt location:

- 3/4-in. and 7/8-in. diameter bolts: ±1/4 in.
- 1-in., 1-1/4-in., and 1-1/2-in. diameter bolts: ±3/8 in.
- 1-3/4-in., 2-in., and 2-1/2-in. diameter bolts: ±1/2 in.

**Unbraced Length**

The following is taken from Lateral Bracing of Seismic Beams by Ralph M. Richard.

The maximum unbraced beam length required to prevent global lateral torsional buckling for beams in special moment resisting frames (SMRF) using Seismic Structural Design Associate’s slotted web (SW) connections is given in the 13th edition of the AISC Specifications, appendix 1. The plastic design maximum unbraced length equation is

\[ L_{pd} = [0.12 + 0.076(M_2/M_1)](E/F_y)r_y \]

where
- \( M_2 \) = smaller moment at the end of unbraced length
- \( M_1 \) = larger moment at the end of unbraced length
- \( r_y \) = radius of gyration about the beam minor axis

and \((M_2/M_1)\) is positive for moments which cause reverse curvature and negative for moments which cause single curvature.

In SMRFs under seismic loading with SW connections the plastic hinges and plastic moments in the beam occur at the face of the column with an inflection point at midspan as shown in figure 49 where the maximum unbraced length is shown equal to the span of the beam.

*Source: Lateral Bracing of Seismic Beams*

**Figure 49. Moment Diagram for a Seismically Loaded Beam**

For example, for a W36x150 beam with \( r_y = 2.47'' \), \( F_y = 50 \) KSI, and \( E = 29,000 \) KSI the maximum unbraced clear span would be 280” or 23’- 4”.

If the beam is laterally braced at midspan, one half the beam can be modeled as a cantilever beam laterally braced at the tip. In this case with \( M_2 = 0 \) and the equation becomes
\[ L_{pd} = [0.12] \left( \frac{E}{F_y} \right) r_y \]

where the maximum unbraced length is equal to one half the span of the beam.

For example, if a W36x150 beam with \( r_y = 2.47” \), \( F_y = 50 \text{ KSI} \), and \( E = 29,000 \text{ KSI} \) is braced at midspan, \( L_{pd} \) is 14'-4” so that this beam can have a clear span of 28'-8” with only a single brace at midspan.

**Beam Bearing Plate**

The following is taken from Beam-Bearing Plates and Column Base Plates by AISC Steel Construction Manual.

When a steel column is supported by a footing, it is necessary for the column load to be spread over a sufficient area of the footing. We do this by a steel base plate. The base plate can be welded or by some type of welded or bolted lug angles.

OSHA requires that you use no less than four anchor bolts for each column base plate. The lengths and widths of column base plates are usually selected in even in., like 8” X 10”. The thickness is in 1/8” increments up to 1.25 in. and 1/4” inch increments thereafter.

**Web Crippling**

The following is taken from AISC, *Specification for Structural Steel Buildings*.

Usually stiffeners are needed, as ab and dc in figure 50, in line with the flanges of a beam rigidly connected to the flange of a second member so located that their webs lie in the same plane to prevent crippling of the web of the latter opposite the compression flange of the former. A stiffener may also be required opposite the tension flange to protect the weld joining the two flanges; otherwise the stress in the weld might be too great in the region of the beam web, because of the lack of bending stiffness in the flange to which the beam is connected.

*Source: AISC, Specification for Structural Steel Buildings*
Figure 50. Stiffener requirements to prevent web crippling

c. Given data and the appropriate equations, calculate the following for a steel member:
   - Average shear stress
   - Parabolic shear stress
   - Bending stress
   - Axial stress
   - Torsional shear stress

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

d. List the causes of buckling of load bearing columns and beams.

The following is taken from Economic Expert, Buckling in Columns.

The ratio of the length of a column to the least radius of gyration of its cross section is called the slenderness ratio. This ratio affords a means of classifying columns. All the following are approximate values used for convenience. A short steel column is one whose slenderness ratio does not exceed 50; an intermediate length steel column has a slenderness ratio ranging from 50 to 200, while long steel columns may be assumed as one having a slenderness ratio greater than 200. A short concrete column is one having a ratio of unsupported length to least dimension of the cross section not greater than 10. If the ratio is greater than 10 it is a long column. Timber columns may be classed as short columns if the ratio of the length to least dimension of the cross section is equal to or less than 10. The dividing line between intermediate and long timber columns cannot be readily evaluated. One way of defining the lower limit of long timber columns would be to set it as the smallest value of the ratio of length to least cross sectional area that would just exceed a certain constant K of the material. Since K depends on the modulus of elasticity and the allowable compressive stress parallel to the grain it can be seen that this arbitrary limit would vary with the species of the timber. The value of K is given in most structural handbooks.

If the load on a column is applied through the center of gravity of its cross section it is called an axial load. A load at any other point in the cross section is known as an eccentric load. A short column under the action of an axial load will fail by direct compression but a long column loaded in the same manner will fail by buckling (bending), the buckling effect being so large that the effect of the direct load may be neglected. The intermediate length column will fail by a combination of direct stress and bending.

In the middle of the 18th century a mathematician named Leonhard Euler derived a formula which gives the maximum axial load that a long, slender ideal column can carry without buckling. An ideal column is one which is perfectly straight, homogenous, and free from initial stress. The maximum load, sometimes called the critical load, causes the column to be in a state of unstable equilibrium, that is, any increase in the loads or the introduction of the slightest lateral force will cause the column to fail by buckling. The Euler formula for columns is:

\[
F = \frac{(K\pi^2EI)}{l^2}
\]
where

\[ F = \text{maximum or critical force (vertical load on column)} \]
\[ E = \text{modulus of elasticity} \]
\[ I = \text{moment of inertia} \]
\[ l = \text{unsupported length of column (lowercase letter 'L')} \]
\[ K = \text{a constant whose value depends upon the conditions of end support of the column, For both ends free to turn } K = 1; \text{ for both ends fixed } K = 4; \text{ for one end free to turn and the other end fixed } K = 2 \text{ approximately, and for one end fixed and the other end free to move laterally } K = 1/4. \]

e. Describe the following types of connections:
   - Friction
   - Bearing
   - Tension
   - Rigid
   - Non-rigid
   - Semi-rigid

Friction
The following is taken from Pneumatic Installation Guidelines: Friction Type Bolted Connections.

Bolted connections that are to transmit torque are best designed as friction connections. In a friction connection the torque is transmitted through the friction between the mating surfaces developed by the clamp load applied by the fasteners. A friction connection is preferred for connections where torque reversals and fluctuations are present, and for connections where slip is not permitted. Friction connections are not difficult to design if the designer has a good understanding of the relationship between normal force, coefficient of friction, and friction force; and the torque / tension relationship of threaded fasteners.

Bearing
The following is taken from Freepatents Online, Bearing Connections.

A bearing connection in a building structure is for distributing downward gravity bearing loads through fasteners driven through sheet metal connectors and into a load carrying wood structural member such as a floor joist, a roof rafter or a wood truss member, through a pair of sheet metal connectors and into a wood plate member via fasteners driven through the connectors and into the plate member. Seismic, hurricane or other upward forces are also resisted by the same connectors and fasteners. Relative movement between the load carrying structural member and the plate member is also resisted in a generally horizontal direction transverse as well as parallel to the plate member.

Tension
The following is taken from the University of Tennessee, Mechanical Fasteners.

A tension connection is a threaded fastener connection with clearance gaps that are used to assemble the connection. The connection can be loaded in either tension/compression or
shear. Because of the clearance gaps, dowel pins are often used for accurately positioning of mating parts. A bolt is used to clamp two parts together. Turning the nut on the threads will stretch the bolt to create a clamping force. The clamping force will impart a compressive force on the mating parts. The clamping force is called preload or initial tension.

**Rigid**
The following is taken from Lite Steel Technologies, Rigid Connections.

Rigid connections are those connections that are required to transmit bending moment as the primary design action. The behavior of the connection is such that the design bending moment is resisted with very little joint rotation. A perfect rigid joint would have no joint rotation at the design bending moment, cut this is never achieved in practice.

Beam-to-column connections in unbraced rectangular frames, and ridge and knee connections in portal frame structures are typical applications of rigid connections.

**Non-Rigid**
The following is taken from *Numerical Structural Analysis: Methods, Models and Pitfalls* by Anatoly V. Perelmutter, Vladimir I. Slivker.

Generally, we refer to a non-rigid connection between an element and a node in cases in which those are connected in such a manner that some of the constraints between the node and the element have been removed or when a removed rigid constraint is replaced by a linearly responsive elastic link with its stiffness coefficient $c$.

**Semi-Rigid**
The following is taken from *Connections in Steel Structures 3* by Reidar Bjorhovde, André Colson, Riccardo Zandonini.

Semi-rigid connection is a type of moment connection for which the initial angle between the connected members, at the intersection of their axes, changes with the connection moment. The join is an infinite small point. Based on this concept, the first mechanical model used to represent a semi-rigid connection consisted of a rotational spring placed between the end of the beam axis and the column axis.

**f. Evaluate scaffolding and temporary work platform arrangements for structural integrity and stability.**

The following is taken from *Elevated Work Platforms and Scaffolding: Job Site Safety Manual* by Matthew J. Burkart, Michael McCann, Daniel M. Paine.

There are many visual clues indicating the condition of scaffold planking. As wood ages and reacts to usage, it will begin to show checks, splits, and notches. These can vary in degree depending on loads imposed, weather conditions, and the length of service.

Splits (cracks going clear through the wood) more than a few in. in length should not remain in service. These splits may render the plank unable to maintain the necessary load-bearing capacity.
The following information is taken from OSHA, 29 CFR 1926.451.

“A scaffold plank is considered a component of the scaffolding. As such it must be capable of supporting four times the maximum intended load without failure. The fact that a plank might have a split in one end does not automatically mean that it must be removed from service provided it does not otherwise create a hazard to the employee.”

The competent person must examine all planks and determine that they are safe for use. Checks (cracks on the surface only and not clear through the wood) should be watched as checks may develop into splits over time. Notches (small checks at the ends of the plank) should also be watched as over time these notches can lengthen and deepen until they become splits.

Scaffold planks that have accumulated layers of paint, plaster, etc., should not be permitted to remain in service it is impossible to determine the condition of the wood. Dangerous splits may be hidden beneath the paint, plaster, etc.

If a scaffold plank has been used as a mudsill, it should not be returned to service on a platform. Moisture that the plank has absorbed from standing water, as well as point loading from the scaffold legs, may have weakened the plank, making it unable to bear the weight that will be placed on it.

Evaluating the Span of a Scaffold Plank
The span is the distance the plank runs between supports. The longer the span, the more bend or deflection, it will have. Therefore, the longer the span the less its load-bearing capacity will be.

If fabricated planks and platforms are being used, maximum spans are to be as recommended by the manufacturer. To assure that scaffold planking remains within its safe load-bearing capacity, it shall not be allowed to deflect more than 1/60 of its span between supports.

g. Walkthrough a structure with exposed structural steel and discuss the applicable construction methods and practices associated with the structural steel.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

37. Construction management personnel shall demonstrate a working level knowledge of electrical equipment installation methods and National Electrical Code (NEC) requirements.

a. Discuss the classification of electric cable.

The following information is taken from National Electrical Manufacturer’s Association, User’s Guide to Product Specifications for Electrical Building Wire and Cable.

This guide is published by the building wire and cable section of the National Electrical Manufacturers Association to assist users of commonly used electrical building wire and
cable on the proper identification of U.S. standard applicable to wire and cable types recognized by the National Electrical Code. In addition to meeting the requirements of the National Electrical Code, the applicable standards\(^{(1)(3)}\) are listed in table 20.

<table>
<thead>
<tr>
<th>Wire and Cable Types</th>
<th>Applicable Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>TW, THW, THW-2, THWN, THWN-2, THHN, THHW</td>
<td>Underwriters Laboratories Inc.(^{(2)}) Standard UL 83</td>
</tr>
<tr>
<td>TBS, TFE, FEP, FEPB, PFA, PFAH, Z, ZW</td>
<td>Underwriters Laboratories Inc. Standard UL 83A</td>
</tr>
<tr>
<td>RHW, RHW-2, RHH, XHHW, XHHW-2, SA, SIS, XHH</td>
<td>Underwriters Laboratories Inc. Standard UL 44</td>
</tr>
<tr>
<td>MTW</td>
<td>Underwriters Laboratories Inc. Standard UL 1063</td>
</tr>
<tr>
<td>NM-B</td>
<td>Underwriters Laboratories Inc. Standard UL 719</td>
</tr>
<tr>
<td>UF, UF-B</td>
<td>Underwriters Laboratories Inc. Standard UL 493</td>
</tr>
<tr>
<td>SE-U, SE-R, USE, USE-2</td>
<td>Underwriters Laboratories Inc. Standard UL 854</td>
</tr>
<tr>
<td>ACHH, ACTH, ACTHH</td>
<td>Underwriters Laboratories Inc. Standard UL 4</td>
</tr>
<tr>
<td>MC</td>
<td>Underwriters Laboratories Inc. Standard UL 1569</td>
</tr>
<tr>
<td>TC</td>
<td>Underwriters Laboratories Inc. Standard UL 1277</td>
</tr>
</tbody>
</table>

Notes:

(1) The ASTM published standards for materials used in the manufacture of building wire and cable. The wire and cable manufacturer should be consulted for the applicable ASTM specification numbers. ASTM standard can be obtained by contacting ASTM or by visiting [www.astm.org](http://www.astm.org).

(2) Additional guidance may be found in the Underwriters Laboratories Construction and Materials Directory under the various classifications so wire and cable types at [www.ul.com/wire/categories/html](http://www.ul.com/wire/categories/html).

(3) The Government Services Administration has authorized the use of Federal specification A-A-59544 by all government agencies in the specification of electrical wire and cable. Federal specification A-A-59544 includes the Underwriters Laboratories building wire and cable types covered by the above except for types TC and MTW.

b. **Determine the requirements in NEC for the installation of electrical equipment under a given set of conditions.**

This is a performance-based competency based on a site-specific set of conditions. The Qualifying Official will evaluate the completion of this competency. Helpful information
Regarding the installation of electrical equipment is available in the National Electrical Code, section 110.

c. Describe the construction methods, equipment, and components used to install electrical distribution systems.

The following is taken from DOE Order 6430.1A.

General
All systems shall comply with NFPA 70, National Electrical Code. Electrical systems shall be designed so that all components operate within their capacities for initial and projected loads. Preferred standard voltages in conformance with ANSI C84.1, Electric Power Systems and Equipment, shall be used, with a single-voltage level characteristic in any classification, to minimize stocks of spare equipment and to standardize operating and maintenance practices and procedures.

Electrical materials and equipment shall be Underwriters Laboratories (UL)- or Factory Mutual (FM)-tested, with a label attached, for the purpose intended whenever such products are available. Where there are no UL- or FM-listed products of the type, testing and certification by another nationally recognized testing agency may be acceptable. Installation methods shall be in accordance with the manufacturer’s instructions, with NFPA 70, and with other applicable requirements.

On-site acceptance testing shall be required for each major electrical system. Tests shall be specified to demonstrate that each function and important parameter is implemented. Specific criteria shall be included to determine pass/fail acceptance. Tests shall be performed in the presence of a government representative. Copies of all test results shall be submitted for approval.

Raceways
Raceways that penetrate fire-rated assemblies shall be noncombustible. The complete installation shall be suitably sealed to maintain the established fire ratings as defined in UL Building Materials Directory and UL 1479.

Raceways shall be 1/2-inch minimum in diameter. Raceways embedded in concrete or masonry shall be 3/4-inch minimum and shall be adequate in number and capacity for the initial and projected facility requirements.

Conductors
Conductors for interior electrical systems shall be copper, except that aluminum conductors size No. 4 AWG and larger may be used. Conductors for power and lighting branch circuits shall be not smaller than No. 12 AWG. No. 10 and No. 12 AWG conductors for power and lighting branch circuits shall be solid. No. 8 AWG conductors and larger shall be stranded.

Conductors for class 1 remote-control and signal circuits shall be enclosed in cable and shall comply with NFPA 70. Conductors for class 2 low-energy remote-control and signal circuits shall be not smaller than No. 18 AWG. Power and lighting conductors shall be 600-volt, Type THW, XHHW, or THWN. Conductors required to be rated 90 degrees C in accordance
with NFPA 70 shall be Type RHH, THW, or THHN. Conductors in high-temperature areas shall be NEC Type FEP or TFE as required. Direct-burial conductors shall be type UF, UL 493. Bonding and grounding conductors shall be ASTM B1 solid, bare copper for sizes No. 8 AWG and smaller, and shall be ASTM B8 Class B stranded copper for wire sizes No. 6 AWG and larger.

Each set of contract documents shall indicate the basis for the size of the conductors shown on those plans when the option for aluminum conductors has been chosen.

Receptacles

Receptacles shall comply with general grade specifications as defined in FS W-C-596. Receptacle circuits shall be provided with ground-fault circuit-interrupters as directed by NFPA 70.

Receptacle circuits that serve receptacles installed outdoors (except receptacles that are in secure circuits and are not readily accessible) and within 6 feet of sinks and building entrances shall be provided with ground-fault circuit-interrupters.

d. During a facility walkthrough describe the NEC requirements for the facility and construction activities to install the electrical equipment.

This is a performance-based KSA. The Qualifying Official will evaluate its completion.

38. Construction management personnel shall demonstrate a working level knowledge of project management principles and the methods used to ensure that contractor resources are applied to meet quality, safety, technical, cost, and schedule commitments.

a. Explain the purpose of project management, and describe the life cycle of a typical project.

The Purpose of Project Management

The following is taken from DOE P 413.1.

Federal program and project managers are accountable for the planning, programming, budgeting, and acquisition of capital assets. The principal DOE goal is to deliver capital assets on schedule, within budget, and fully capable of meeting mission performance and environmental, safety, and health standards. DOE Federal program and project managers are responsible for ensuring that capital asset projects are managed with integrity and in compliance with applicable laws. Major DOE objectives include obtaining quality products, ensuring timeliness of performance, controlling cost, and mitigating adverse events. To achieve these goals, Federal program and project managers should assemble an integrated team, which includes other DOE functional areas such as budget, financial, legal, safety, and contracting, to assist them with the planning, programming, budgeting, and acquisition of capital assets.

DOE Federal managers will

- justify budgets needed for acquisition of capital assets,
ensure line management involvement in and accountability for project performance,
establish and maintain strong project management organizations and systems,
use appropriate project management tools and train personnel, and
develop and implement programs for institutionalizing project management
capabilities.

*Life Cycle of a Typical Project*

The following is taken from DOE O 413.3A.

**Project Phases**

**Initiation Phase**

During this phase, preconceptual planning activities focus on the Program’s strategic goals
and objectives. User needs are analyzed for consistency with the department’s strategic plan,
Congressional direction, administration initiatives, and political and legal issues. One
outcome of the analysis could be a determination that a user need exists that cannot be met
through other than material means. This outcome leads to the development and approval of a
mission need statement. The information developed during this phase also provides the basis
for the project engineering and design budget request when preliminary design activities are
planned.

**Definition Phase**

Upon approval of mission need, the project enters the definition phase where alternative
concepts, based on user requirements, risks, costs, and other constraints, are analyzed to
arrive at a recommended alternative. This is accomplished using systems engineering and
other techniques and tools such as alternatives analysis and value management/value
engineering. This ensures the recommended alternative provides the essential functions and
capability at optimum life cycle cost, consistent with required performance, scope, schedule,
cost, security, and environment, safety and health considerations. During this phase, the
required value management assessment is completed, and more detailed planning is
accomplished which further defines required capabilities. The products produced by this
planning provide the detail necessary to develop a range of estimates for the project cost and
schedule.

**Execution Phase**

Following the definition phase, preliminary design activities mark the beginning of the
execution phase. Systems engineering continues to balance requirements, cost, schedule, and
other factors to optimize the design, cost, and capabilities that satisfy the mission need.
Engineering and design continue until the project has a sufficiently mature design that can be
implemented successfully within a firm performance baseline.

During this phase, the initial design concepts and the preliminary design are developed into
detailed and final designs and plans. These plans are used to procure or manufacture
components, fabricate subsystems, or construct, remediate, decommission or demolish
facilities. Major activities in this phase include:

- Establishing performance measurement baselines and implementing change control
  procedures;
- Satisfying environmental and safety requirements;
- Obtaining approved National Environmental Policy Act documentation, if required, prior to the start of detail or final design;
- Continuing to refine and optimize cost estimates, schedules, and designs;
- Approving the final design for procurement and implementation; and
- Identifying and addressing security concerns.

Execution comprises the longest and most costly phase of a project. Value management and value engineering are implemented throughout the project execution phase to ensure the most effective solutions are implemented.

If the delivery method is design-build versus design-bid-build and a single contract is awarded for both design and construction, it may be necessary to tailor the project’s execution process to allow the project team to propose cost-effective innovative approaches that reduce project duration and cost.

Transition/Closeout Phase

When the project nears completion and has progressed into formal transition and commissioning, which generally includes final testing, inspection, and documentation, the project is prepared for operation, long-term care, or closeout. The nature of the transition and its timing depends on the type of project and the requirements that were identified subsequent to the mission need.

b. Describe the primary roles and responsibilities of construction management and engineering personnel.

The following is taken from DOE Order 4700.1.

The project manager has direct primary responsibility and accountability for the management of the construction effort. He or she normally will be designated as the contract administrator or contracting officer’s technical representative for the construction effort by the contracting office. Among the usual functions of the project manager are the following:
- Assures that cost, schedule, and scope requirements are met
- Acts as the principal contact and serves as the liaison for the exchange of information between the contractor and DOE
- Assures that instructions to the contractor are within the terms of the contract
- Assures compliance by the contractor with the technical, safety, and administrative requirements of the contract
- Participates in formulating and approving plans and schedules
- Arranges for contacts between the construction contractor, other participants, and appropriate staff, as required
- Assures continuity in performance and information exchange among the project team participants
- Initiates to the contracting officer procurement request packages for contract modifications
A construction manager provides professional services to, and functions in support of, the project manager. He or she becomes part of the project team consisting of the project manager, the architect-engineer, the construction manager, and operating and construction contractors. It is seldom beneficial for the construction manager to be from the same firm as (or from a subsidiary of) the architect-engineer or construction contractor because of the possibility of organizational conflict of interest. In cases where the construction manager is contemplated as being from the same firm as (or from a subsidiary of) any of the other project participants, specific approval shall be obtained from the responsible outlay program manager and the Department’s senior procurement official. Tasks that the construction manager can perform encompass the full spectrum of management activities of a project. The decision to use a construction manager on a project is not as difficult as determining the tasks he or she must undertake and the method of payment for these services. Considerable thought must be given to the tasks assigned to the construction manager in order to effect the best management of the project at the minimum cost. Factors that help determine construction manager tasks are the size and complexity of the job, the capabilities of project management staff, and the contemplated scope of the architect-engineer and the construction contracts.

The project or construction engineer is the individual responsible for construction projects for which a construction manager is not assigned. He or she performs within well defined responsibilities established by the Head of the Field Element. Specific responsibilities vary depending upon the field office management method. He or she may be assigned as the contracting officer’s technical representative.

The architect-engineer usually furnishes Titles I and II engineering services, with optional Title III services, consults with the contract administrator on questions concerning services, and coordinates the work with the operating and construction contractors and public utilities, as required by contract. The architect-engineer may also develop conceptual designs, assist in the preparation of design criteria, and perform special studies.

c. Describe typical documents and data sources used in project management.

The following is taken from DOE O 413.3A.

The following documents are included in project management:

- **Acquisition Strategy.** An acquisition strategy is a high-level description of a business and technical management approach designed to achieve project objectives within specified resource constraints. The acquisition strategy conveys the IPT’s’s approach for the successful acquisition of the project, its intended outcomes, and rationale for that approach. This document is a CD-1 requirement and is the framework for planning, organizing, staffing, controlling, and leading a project.

- **Conceptual Design Report.** As a minimum, the conceptual design report should develop the following: the scope required to satisfy the program mission requirements, the project feasibility and attainment of specified performance levels, reliable cost and schedule range estimates, project criteria and design parameters, and identification of requirements and features.

- **Earned Value Management System.** An earned value management system is the integrated set of policies, processes, procedures, systems, and practices that meet the intent of the guidelines identified in ANSI/Electronics Industry Alliance (EIA)-748-
A, **Earned Value Management Systems.** This system is generally documented by a system description and procedures that translate the earned value management policy into specific organizational approaches of how the 32 guidelines in ANSI/EIA -748-A-1998 will be executed.

- **Environment, Safety and Health Documentation.** At CD-2, a preliminary safety design report is developed from the conceptual safety design report to reflect more refined analyses based on the evolving design and safety integration activities during preliminary design. The preliminary safety design report should include the results of process hazards analyses and confirm or adjust, as appropriate, the items included in the conceptual safety design report. At CD-3, a preliminary documented safety analysis report is prepared and updates the safety information in the preliminary safety design report and identifies and justifies changes from the design approach described in the preliminary safety design report. At CD-4, a documented safety analysis report is developed based on information from the preliminary documented safety analysis report and the safety evaluation report.

- **Performance Baseline.** The performance baseline, as established in the project execution plan, defines the cost, schedule, performance, and scope commitment to which the Department must execute a project.

- **Project Execution Plan.** The project execution plan is the core document for management of a project. The Federal project director is responsible for the preparation of this document. It establishes the policies and procedures to be followed to manage and control project planning, initiation, definition, execution, and transition/closeout, and uses the outcomes and outputs from all project planning processes, integrating them into a formally approved document.

- **Quality Assurance.** The project’s application of quality assurance is documented in either the organizational or project-specific quality assurance program that addresses 10 basic criteria: program, personnel training and qualification, quality improvement, documents and records, work processes, design, procurement, inspection and acceptance, management access, and independent assessment.

- **Risk Management.** Risk Management is an essential element of every project. The DOE risk management approach must be analytical, forward looking, structured, informative, and continuous. Risk assessments are started as early in the project life cycle as possible and should identify critical technical, performance, schedule, and cost risks. Once risks are identified, sound risk mitigation strategies and actions are developed and documented.

d. **Identify, explain, and discuss the relationship of the major elements of a project.**

The following is taken from DOE O 413.3A.

In addition to the elements discussed in element c of this competency the following elements are included in project management:

- **IPT’s.** The IPT’s, organized and led by the Federal project director, is an essential element in DOE’s acquisition process and is used during all phases of a project’s life cycle. This team consists of professionals representing diverse disciplines with the specific knowledge, skills, and abilities to support the Federal project director in successfully executing a project.
- **Integrated Safety Management System.** The integrated safety management system is designed to ensure that safety is appropriately addressed throughout the life cycle of a project. Identification of potential hazards must begin early in project planning and continue throughout the life cycle of the project. DOE policy requires safety management systems be used to systematically integrate safety into management and work processes at all levels.

- **Key Performance Parameters.** A key performance parameter is a vital characteristic of the project or facility mission. It is a characteristic, function, requirement, or design basis that if changed would have a major impact on the system or facility performance, schedule, cost, and/or risk; or, the ability of an interfacing project to meet its mission requirements.

- **Safeguards and Security.** Safeguards and security refers to an integrated system of activities, systems, programs, facilities, and policies for the protection of classified information and/or classified matter, unclassified control information, nuclear materials, nuclear weapons, nuclear weapon components, and/or the Department’s and its contractors’ facilities, property, and equipment.

**e. Explain the purpose and use of a project execution plan**

The following is taken from DOE G 413.3-15.

The project execution plan is the governing document that establishes the means to execute, monitor, and control, projects which are subject to DOE O 413.3A. The project execution plan serves as the main communication vehicle to ensure that everyone is aware and knowledgeable of project objectives and how they will be accomplished. The plan is the primary agreement between Headquarters and the federal project director and a preliminary plan should be developed and approved at CD-1.

**f. Discuss the five elements of the Department of Energy program for operational configuration management as described in DOE-STD-1073-2003, Configuration Management:**

- Design requirements
- Document control
- Program management
- Change control
- Assessments

The following descriptions are taken from DOE-STD-1073-2003.

*Design Requirements*

The objective of the design requirements element of configuration management is to document the design requirements. The design requirements define the constraints and objectives placed on the physical and functional configuration. The design requirements to be controlled under configuration management will envelope the safety basis and, typically, the authorization basis. Consequently, proper application of the configuration management process should facilitate the contractor’s efforts to maintain the safety basis and the authorization basis. Contractors must establish procedures and controls to assess new facilities and activities and modifications to facilities and activities to identify and document design requirements.
**Document Control**

Document control ensures that only the most recently approved versions of documents are used in the process of operating, maintaining, and modifying the nuclear facility. Document control helps ensure that

- important facility documents are properly stored;
- revisions to documents are controlled, tracked, and completed in a timely manner;
- revised documents are formally distributed to designated users;
- information concerning pending revisions is made available.

As controlled documents are updated to reflect changes to the requirements and/or physical installation, the contractor must ensure that

- each updated document is uniquely identified, and includes a revision number and date;
- each outdated document is replaced by the latest revision.

**Program Management**

Program management is not described in DOE-STD-1073-2003.

**Change Control**

Contractors must establish and use a formal change control process as part of the configuration management process. The objective of change control is to maintain consistency among design requirements, the physical configuration, and the related facility documentation, even as changes are made. The change control process is used to ensure that changes are properly reviewed and coordinated across the various organizations and personnel responsible for activities and programs at the nuclear facility.

Through the change control process, contractors must ensure that

- changes are identified and assessed through the change control process;
- changes receive appropriate technical and management review to evaluate the consequences of the change;
- changes are approved or disapproved;
- waivers and deviations are properly evaluated and approved or denied, and the technical basis for the approval or the denial is documented;
- approved changes are adequately and fully implemented, or the effects of the partial implementation are evaluated and accepted;
- implemented changes are properly assessed to ensure the results of the changes agree with the expectations;
- documents are revised consistent with the changes, and the revised documents are provided to the users.

**Assessments**

The quality assurance criteria of 10 CFR 830, Subpart A, require DOE contractors for nuclear facilities (including activities and operations) to assess management processes and measure the adequacy of work performance. Furthermore, the assessment criteria require that the persons performing the assessments

- have sufficient authority and freedom from line management
- are qualified to perform the assessments
The maintenance criteria of DOE O 433.1B, *Maintenance Management Program for DOE Nuclear Facilities*, also require periodic assessments to verify the condition of systems and equipment.

DOE-STD-1073-2003, *Configuration Management*, discusses five different types of assessments that can be performed to determine the effectiveness of different aspects of the configuration management process (see section 7.1). Periodic assessments help ensure that work processes continue to function properly, or that problems are identified, root causes are determined, and problems are corrected. DOE-STD-1073-2003 provides guidance on performing assessments directly related to configuration management. While contractors may perform these assessments of the configuration management process separate from other assessments, it may be more efficient to combine these assessments with other periodic assessments of the activity. All or part of the assessment of the adequacy of configuration management for an activity may be integrated into broader management and performance assessments, such as quality assurance, maintenance, or integrated safety management assessments. If the contractor decides to fold the assessment of configuration management into a broader assessment, the criteria in DOE-STD-1073-2003 must be considered when developing the assessment criteria for the broader assessment.

The five specific types of assessments discussed in DOE-STD-1073-2003 are:

- construction assessments, which are performed to ensure configuration is managed throughout the construction process for new construction or major modifications;
- physical configuration assessments, which are conducted to evaluate the consistency between the physical configuration and the facility documentation;
- design assessments, which are done to ensure that design documents have been updated to reflect changes and accurately reflect the physical configuration of the nuclear facility;
- post-construction, post-modification, or post-installation inspections and tests, which are performed either after construction, modification, or installation to verify operation is as expected;
- periodic performance assessments, which are conducted to verify that systems and components continue to meet design and performance requirements in their current configurations.

**g. Explain the use of safety plans in the management of projects.**

The following is taken from DOE-STD-5503-94.

In the 1986 amendments to CERCLA, Congress tasked the administrators of the EPA and Occupational Safety and Health Administration, the secretary of the Department of Transportation, and the director of the National Institute for Occupational Safety and Health to modify the NCP to provide for protection of health and safety of employees involved in response actions. To satisfy this directive, standards requiring the development of a site-specific health and safety plan were established by OSHA in 29 CFR 1910.120, and incorporated into the NCP. Additionally, the NCP requires compliance with standards and regulations of OSHA, including such standards as 29 CFR 1926, and 29 CFR 1910, where applicable.
h. Discuss the relationship between work breakdown structure (WBS) and cost and schedule.

The following is taken from DOE G 430.1-1, chapter 5.

A WBS shows the relationship of all elements of a project. This provides a sound basis for cost and schedule control.

During that period of a project’s life from its inception to a completed project, a number of diverse financial activities must take place. These activities include cost estimating, budgeting, accounting, reporting, controlling and auditing. A WBS establishes a common frame of reference for relating job tasks to each other and relating project costs at the summary level of detail.

Since the WBS divides the package into work packages, it can also be used to interrelate the schedule and costs. The work packages or their activities can be used as the schedule’s activities. This enables resource loading of a schedule, resource budgeting against time, and the development of a variety of cost budgets plotted against time.

i. Describe the purpose and use of work packages and/or planning packages.

The following is taken from DOE G 430.1-2.

The detailed procedures and work packages provide the details of the work to be accomplished, the frequency (if applicable), and the process for doing such work safely and efficiently. To be effective, the procedures or work packages need to include the following items:

- A description of specific work scope to be performed;
- Identification of the type of hazard analysis required for the activity and verification that the analysis was performed;
- A method to ensure that hazards associated with each of the planned activities are documented and shared with workers together with the steps to eliminate, minimize or reduce the risk of those hazards to an acceptable level;
- Work and radiological permits necessary to conduct such work;
- The necessary training requirements to perform each task;
- A listing of specialized equipment and each item's intended use;
- The personal protective equipment needed to limit exposure to the identified hazards;
- The emergency response procedures applicable to the task and the area of work;
- A description of the management structure, including communication and reporting channels; and
- The expected results upon completion of the task.

The procedures and work packages also provide the structure of activities needed to sufficiently inform all involved parties of the work to be accomplished and its potential impact on other activities planned to be conducted in the same area. This documentation ensures that impacts, including safety and health, have been verified and that controls are established prior to proceeding with the work.
Finally, the planned work activities are evaluated against the potential impact to the safety authorization of the facility. A safety review is conducted to ensure that work activities are authorized to be performed within the facility safety envelope. The formality and rigor of this type of process may vary due to the existing hazards or the hazard classification of the facility.

j. **Describe the purpose of schedules, and discuss the use of milestones and activities.**

The following is taken from DOE G 430.1-1, chapter 12.

The schedule is one of the building blocks for project development. A schedule helps determine the duration of the project, the critical activities, and when funds are required.

The basic elements comprising the schedule consist of the activities in the project, the duration of each activity, and the sequence in which those activities occur.

*Activities*

The activities from a work breakdown structure become the building blocks for a schedule. An activity is any specific element of work. It is important that activities not be confused with schedule events. Events are indicators of the beginning or completion of an activity. An event milestone is usually one specific point in time, whereas an activity occurs over a period of time.

*Durations*

The activity duration is simply the time required to complete the work involved in a specific activity.

*Sequence*

The sequence of activities refers to the order in which the activities are scheduled to be performed.

*Critical Path*

The longest series or path of interdependent activities of a project is connected end to end. The critical path of a project may change from time to time as activities are completed ahead or behind schedule.

k. **Describe the critical path method of scheduling.**

The following is taken from DOE G 413.3-5.

The critical path is the longest path through a network schedule that consequently defines the shortest possible duration for completing a project. This path and its duration are determined by performing forward and backward passes through the network diagram based on the defined activity sequence and estimated activity durations.
I. Explain the concept of a project management baseline and describe the baseline used in project management.

The following is taken from DOE G 413.3-5.

Traditionally, in DOE a project, “baseline” comprised three components—technical, cost, and schedule—each of which is intimately related to the others. The requirement to establish key performance parameters has become a prominent feature of DOE project management.

m. Discuss the following elements of construction project contract labor:
   - Availability of labor skills
   - Interaction of labor crafts
   - Standby requirements and their impact on the schedule
   - Craft jurisdiction
   - Union vs. non-union
   - Skills and labor rates

Availability of Labor Skills

The following is taken from the Construction User’s Roundtable, UP-403, Construction Labor: Managing the Construction Workforce.

The project labor strategy includes the following components:

Labor Posture

Project labor posture identifies the source of personnel for the project workforce. Three options are possible:
   - Union – The workforce is assembled by contractors that have contracts with the organized building trades.
   - Non-union – The workforce is assembled by contractors from the open-shop sector.
   - Merit – The workforce is assembled by contractors from both the organized building trades and the open-shop sector.

Labor posture is often selected based on a local labor survey, which includes a thorough review of:
   - Local business conditions – What the status of the local economy is and what the projected construction workload is for the area.
   - Construction skills assessment – What craft skills are required for this project.
   - Construction craft availability – What local construction labor pools exist within the organized and open-shop sectors.
   - Local craft training programs – What craft training programs are available to supplement any shortage of skilled craft.

Other issues that might influence selection of labor posture include:
   - In-house labor agreements – The agency may have internal agreements with other, non-construction segments of organized labor. This might influence their ability or willingness to contract for construction labor from outside the organized sector.
   - Experience on past projects – The agency may have past experience, either positive or negative, that might influence the decision.
The project team should evaluate each labor posture option as part of the decision-making process. One approach that provides some objectivity is the use of a weighted decision matrix. Each selection factor can be weighted based on the project objectives. For example, if workforce availability is a critical factor, then it would receive a higher weighting.

Interaction of Labor Crafts
The following is taken from the Foundation for Electrical Construction, Labor - Management Interaction and Customer Satisfaction.

The basic level for labor and management interaction is at the individual contractor level where the contractor interacts with the craft workers employed by his or her firm. At the individual contractor level, labor and management interaction would include consideration of such issues as work processes, customer requirements, jobsite procedures, etc. This is the level at which construction work is performed and there is direct contact between the contractor and contractor’s personnel and the customer. Thus, it is at this level that the performance and actions of labor have a direct impact on the customer’s satisfaction. Labor and management at this level, have the opportunity to identify the needs and concerns of their customers to engage in the behaviors that address concerns and satisfy needs. There is a direct relationship at this level between the contractor and his/her personnel and the customer.

In addition to interaction with his/her own employees, the individual contractor may interact with the local union. Interaction at this level would address specific issues of concern to the contractor and how they can be addressed within the collective bargaining agreement.

The primary level of interaction between labor and management in the construction industry has been the level between the local union representing craft workers and the contractor’s association representing the contractors employing those craft workers. Collective bargaining is typically conducted at this level. Any issue of concern to the workers, union and contractors is subject to discussion at this level. Labor management cooperative committees have been formed at this level to overcome the historical adversarial relationship between labor and management. These committees have attempted to identify issues of mutual importance and concern and work to address those issues for the benefit of both parties.

Standby Requirements and Their Impact on the Schedule
The following is taken from U.S. Department of Transportation, Federal Highway Administration, Guide For Construction Contract Time Determination Procedures.

The following items should be considered when determining contract time:

- Effects of maintenance of traffic requirements on scheduling and the sequence of operations;
- Curing time and waiting periods between successive operations or between operations;
- Seasonal limitations for certain items when determining the number of days the contractor will be able to work as well as production rates;
- Conflicting operations of adjacent projects;
- Time for reviewing false-work plans, shop drawings, post-tensioning plans, etc.;
- Time for fabrication of structural steel and other specialty items;
Coordination with utilities;
Time to obtain necessary permits;
The effect of permitting conditions and/or restrictions;
Restrictions for nighttime and weekend operations;
Time of the year of the letting as well as duration of the project;
Additional time for obtaining specialty items or materials with long-lead requirements;

These items represent idle hours and need to be planned for and included in the project scheduling process.

**Craft Jurisdiction**
The following is taken from the Construction User’s Roundtable, Exclusive Jurisdiction in Construction.

Exclusive jurisdiction in the building trades—the concept that each element of craft work is within the exclusive jurisdiction of a particular union—has been a source of conflict and inefficiency in construction for generations.

Specific skills for certain construction tasks are often unique to a given trade, but a substantial portion of the work performed by each craft lies within the skills and capabilities of other crafts.

Unnecessarily precise jurisdictional lines frequently limit both the owner’s choice of contractors and the contractor’s ability to assign work efficiently. They also inhibit innovative techniques and development of new technology. Experienced observers contend that all this adds needless costs to union construction.

The building trades unions have insisted from their early years that they alone must determine what work should be done by each craft. Over the years these definitions have grown more and more detailed as construction techniques, equipment and materials have grown more complicated and as conflicts have arisen between the unions.

Questions over work assignments have been resolved by the acceptance of trade practice, by agreements between the unions themselves, and by union-controlled dispute-settlement machinery that produced decisions of record.

In recent years employers have been brought into the voluntary dispute-settlement mechanism, but the unions have continued to dominate its procedures through reliance on old agreements as criteria for settling disputes and through the power of their position in the industry.

**Union versus Non-Union**
The following is taken from Union Versus Nonunion Construction in the U.S. by Raymond E. Levitt.

A major study of the construction industry was conducted by the Massachusetts Institute of Technology, Department of Civil Engineering, to compare and contrast wages and labor
management practices in union and nonunion construction. Union firms were found to be larger and primarily engaged in commercial, industrial, or heavy construction; nonunion firms are smaller and primarily engaged in light construction. Nonunion wages are, on average, considerably lower than union wages; however, the distribution of nonunion wages for any trade is large, with the top 10 percent exceeding the union journeyman’s rate for that trade. Occupational structure was found to be a key determinant of relative efficiency; union journeymen are too narrowly specialized for small-scale light construction and too broadly skilled for very large-scale industrial projects. Consequently, nonunion firms dominate light construction and are rapidly gaining ground, using new training approaches on the super projects. Nonunion firms are attempting to penetrate the middle-size range by developing common benefit plans and job-referral programs to compete with union firms.

Skills and Labor Rates
The following is taken from DOE G 430.1-1, chapter 15.

Several good publications provide an estimate of the labor hours required for a task that an estimator should use unless adequate experience has given the estimator a more accurate base for determining labor hours required. One important item that must be remembered when using general estimating publications is that these publications are based on a national average construction project for private industry.

The situation at various DOE sites may not be the same as an average construction site. Some examples of possible differences are: (1) security areas, (2) remote locations, (3) nuclear radiation areas, (4) degrees of inspection, (5) documentation, etc. For reasons like these, local productivity studies should be conducted to monitor the productivity at the specific site versus the labor hours given in the general estimating publications. If an estimate is derived using the publications, the site productivity factor must be incorporated into the estimated labor-hours. This should be done prior to multiplication of the labor-hours by the labor rate.

When estimating labor costs, the worker’s base rate plus all payroll indirect costs, such as Federal Insurance Contributions Act and payroll insurance, are multiplied by the estimated labor hours to generate the labor cost. Typically, this sum is handled as a direct labor cost. For ease of estimating, an average crew rate can be used and rounded to the nearest even dollar hourly rate.

n. Describe how performance and productivity rates are established.

The following is taken from U.S. Department of Transportation, Federal Highway Administration, Guide For Construction Contract Time Determination Procedures.

A production rate is the quantity produced or constructed over a specified time period. Estimating realistic production rates is important when determining appropriate contract completion time. Production rates may vary considerably depending on project size, geographic location, and rural or urban setting, even for the same item of work. Production rate ranges should be established in the agency’s written procedures based on project type (grading, structures, etc.), size, and location for controlling items of work.
In establishing production rates to be used for determining contract time, an accurate database should be established by using normal historical rates of efficient contractors. One method of establishing production rates is to divide the total quantity of an item on previously completed projects by the number of days/hours the contractor used to complete the item. Production rates based upon eight-hour crew days or per piece of equipment are recommended. Production rates developed by reviewing total quantities and total time are not recommended as they may result in misleading rates which tend to be low since they may include startup, cleanup, interruptions, etc.

The most accurate data will be obtained from site visits or review of project records (i.e., field diaries and other construction documents) where the contractor’s progress is clearly documented based on work effort, including work crew make up, during a particular time frame. A data file based on three to five years of historical data (time, weather, production rates, etc.) should be maintained.

o. Discuss the use of a resource loaded, time based, CPM schedule for the day-to-day control of a project and its importance in meeting cost and schedule baseline.

The following is taken from Exponent, Critical Path Method Schedule Preparation and Review.

For some time now, the construction industry has embraced the practice and use of critical path method (CPM) scheduling as a project management tool to plan, coordinate and schedule the execution of construction-related projects. Through the identification of discrete work activities required to complete the project and the relationship of those activities to one another, CPM scheduling allows for the determination of what activities are critical to completing the project, those that must be performed on their early start and finish dates to avoid any delay to the project’s completion. Therefore, non-critical activities have the ability to be delayed in their start and/or finish by some defined amount of time, commonly referred to as “float,” without the risk of delaying the project.

On or about the commencement of a project, a baseline CPM schedule is developed, typically by the general contractor or construction manager, to provide an understanding of how the contractor intends to orchestrate its subcontractors and timely execute the project. Once this baseline schedule is published, the contractor’s progress can be periodically monitored and evaluated to determine what activities are critical to completing the project by updating the baseline schedule. This updating process requires the observation of work completed to date and an understanding of how the contractor intends to proceed with the balance of the work remaining as of the observation date, or data date.
39. Construction management personnel shall demonstrate the ability to apply construction management principles in the execution of construction methods, constructability reviews, planning, and performance measurement for a construction project at a working level.

   a. Determine whether a construction project execution plan can be implemented safely and cost-effectively and still meet the project specifications.

   b. Determine the availability of the resources, equipment, and qualified subcontractors necessary to implement a construction project execution plan.

   c. Evaluate a contractor decision to make or buy.

   d. Evaluate construction project execution plans and schedules for feasibility.

   e. Manage contingency funding.

   f. Prepare a project status report and determine deviations from the estimates.

All of the KSAs of this competency are performance-based. The Qualifying Official will evaluate their completion.

40. Construction management personnel shall demonstrate the ability to apply principles of risk management in preparing a risk assessment for a construction project at a familiarity level.

   a. Assess construction project risks that identify critical systems, subsystems, and other factors that require focused work and resolution.

   b. Evaluate the assessed level of risk for a construction project.

KSAs a and b of this competency are performance-based. The Qualifying Official will evaluate their completion.

   c. Describe the basis for a risk assessment.

The following is taken from DOE G 413.3-7.

Risk assessment includes the overall processes of risk identification and analysis. The risk assessment process provides the IPT’s with the definition of risk for the project by identifying, analyzing, and quantifying potential program and project risks in terms of probability and consequences. Risk analysis is a technical and systematic process that is designed to examine risks, identify assumptions regarding those risks, identify potential causes for those risks, and determine any relationships to other identified risks, as well as stating the overall risk factor in terms of the probability and consequence, if the risk should occur.
d. Identify the critical construction project elements that contribute to the risk.

e. Identify the consequences of the risk.

f. Identify the stage of the construction project in which the risk exists.

KSAs e, f, and g of this competency are performance-based and relate to the risk identified in KSAs a and b. The Qualifying Official will evaluate their completion.

41. Construction management personnel shall demonstrate the ability to perform project management duties in providing construction management and engineering support to a project at a working level.

a. Ensure that cost, schedule, and scope requirements are met.

b. Act as principal contact and liaison for the exchange of information between the contractor and the Department.

c. Ensure that instructions to the contractor are within the terms of the contract.

d. Ensure compliance by the contractor with the technical, safety, and administrative requirements of the contract.

e. Participate in the formulation and approval of plans and schedules.

f. Arrange for contacts between the construction contractor, other participants, and appropriate staff as required.

All of the KSAs in this competency are performance-based. The Qualifying Official will evaluate their completion.

42. Construction management personnel shall demonstrate a working level knowledge of assessment techniques, reporting, and follow-up actions used to evaluate contractor performance.

a. Describe the role of construction management personnel in overseeing Government-Owned Contractor-Operated (GOCO) facilities.

The following is taken from the DOE Brookhaven Group Operational Awareness Program.

The role of construction management personnel is to ensure that safety requirements necessary for a practical safeguarding of applicable DOE facilities and personnel are being adequately implemented. Practical safe work procedures include training of skilled and unskilled personnel who work in construction. Safety measures shall protect personnel against both normal operations and emergency situations. In addition, only qualified persons who are capable of working safely in construction and are familiar with the proper use of special precautionary techniques, personal protective equipment, TSRs, and operating procedures may perform work. Construction management personnel perform DOE line management oversight of their assigned facilities to ensure that
- the contractor is operating facilities safely and efficiently (i.e., within the boundaries of those controls invoked in the facility authorization basis);
- the contractor’s management system is effectively controlling conduct of operation as related to nuclear safety;
- effective lines of communication between DOE and its operating contractors are maintained during periods of normal operation, and following reportable events, in accordance with DOE Orders and requirements.

b. Describe the assessment requirements and limitations of construction management and engineering personnel associated with the interfacing with contractor employees.

As assessment requirements and limitations associated with the interface of contractor employees vary from site to site, the local Qualifying Official will evaluate the completion of this competency.

c. Describe how planning, observing, interviewing, and document research are used during an assessment.

The following is taken from DOE G 414.1-1B.

Effective assessments use a combination of tools and techniques to maximize the productivity of the assessment team and resources. Such assessment techniques include document reviews, interviews, and observations. In using these techniques, the assessor should not forget that the objective is to verify accomplishment of an organization’s mission. To save time, the assessor should gather only data and information relevant to overall program performance and the achievement of program objectives.

It is generally not acceptable to identify suspicions about the adequacy or inadequacy of a program, system, or process. Investigations should be sufficiently thorough and information gathered with sufficient diligence that accurate, detailed conclusions and issues can be provided to assist the organizations that will receive the final report.

In using any of these techniques, assessors should maintain good records of the assessment results. These may include personal notes or other information to support the assessment and may be included in the checklist information. These records are useful in writing the report and any associated findings and recommendations, and will become invaluable if questions arise during the report review process. All classified notes should be disposed of properly in accordance with established and agreed-upon procedures. A discussion of each of the techniques follows.

**Document Review**

Document reviews provide the objective evidence to substantiate compliance with applicable requirements. A drawback is that the accuracy of the records cannot be ascertained by review alone. This technique should be combined with interviews, observation, inspection, and/or performance testing to complete the performance picture. Records and documents should be selected carefully to ensure that they adequately characterize the program, system, or process being assessed.
Interviews

Interviews provide the means of verifying the results of observation, document review, inspection, and performance testing; allow the responsible person to explain and clarify those results; help to eliminate misunderstandings about program implementation; and provide a venue where apparent conflicts or recent changes can be discussed and organization and program expectations can be described.

Observation

Observation, the viewing of actual work activities is often considered the most effective technique for determining whether performance is in accordance with requirements. Assessor should understand the effect their presence has on the person being observed and convey an attitude that is helpful, constructive, positive, and unbiased. The primary goal during observation is to obtain the most complete picture possible of the performance, which should then be put into perspective relative to the overall program, system, or process.

d. Explain the essential elements of a performance-based assessment, including investigation, fact-finding, and reporting. Include a discussion of the essential elements and processes of the following assessment activities:
   - Exit interview
   - Closure process
   - Tracking to closure
   - Follow-up
   - Contractor corrective action implementation

The Exit Meeting

The following is taken from DOE G 414.1-1B.

This meeting is used primarily by the assessment team to present the assessment summary. Reasonable time should be allowed to discuss any concerns, but this meeting should not be used to argue the assessment findings or methodology. There should be no surprises during the exit meeting since the assessment team should have taken every effort possible during the assessment to ensure that the assessed organization was aware of the team’s findings and concerns. Prior to the exit meeting the assessment team should consider combining related findings into a small number of well-supported findings to help focus management’s opportunities for improvement.

Closure Process

The following is taken from DOE-STD-3006-2000.

To verify closure, support may be requested from the assessment team leader or members but remains a line management responsibility. DOE line management verify adequacy of corrective action plans for all findings from the assessment.

Monitoring and verification of satisfactory closure of prestart findings from the assessment is a line management responsibility. The assessment team leader and team members may be requested to assist in the verification or adequate resolution of findings.
Tracking to Closure

The following is taken from DOE G 414.1-5.

An integral part of a successful corrective action program is the capability to maintain a systematic approach for tracking and reporting the status of the corrective actions to successful closure and implementation. This may be accomplished manually or electronically.

Maintaining and updating this information provides consistent data for tracking and analyzing program status and trends. The process used to track and report corrective action progress should be readily accessible and provide sufficient data to appraise, analyze, and report the status of corrective actions affecting the safety, mission performance, and security of the site/organization.

Characteristics of an effective corrective action tracking and reporting system for consideration include:

- The number of data elements to enter, track, trend, and report information should be standardized and relevant for the reader to fully comprehend what, how, when, and by whom the problem finding will be effectively resolved so it will not recur. An excessive number of data elements to track and report may become too cumbersome and complicated, and may over-burden the ability of the system to provide qualitative and consistent information.
- The process for populating data elements should be clearly promulgated and enforced.
- The system should employ information technology that implements user-friendly, controlled access to the system and flexible reporting.
- A dedicated, highly reliable, automated database system may be the most cost-effective approach for tracking the CAP implementation, and it may significantly enhance the data collection, storage management, and processing of data and information in a timely manner. For the DOE CAMP, the CATS is used.
- A basic and simple process requiring minimal training and easy access to enter and retrieve data by both the computer technical expert and novice entry level member up through senior management will allow for increased participation and involvement by all personnel involved in identifying the findings and implementing corrective actions.
- The system should contain an automated workflow or a relationship capability for linking findings to corrective actions.
- The system should contain a pre-designed reporting capability for generating summary statistics and reporting timely, consistent, and accurate corrective action information.
- The information to be entered into the system should be consistent with simple, well defined data elements and attributes for the data to be entered. Unorganized and inconsistent data collection significantly reduces the usefulness of the data. Guidance for the type of information to enter into the system should be thorough, clearly defined, and easily understood with a minimum of training and instruction.
- Access security to the data should be an integral component of the system. Access should be limited to only those with a need to know. That may include members
involved in the identification of finding and implementing the associated corrective actions. The corrective action information may delineate vulnerabilities of a site or organization and should not be available to the general population. Editor access to the system for updating data should be restricted to those registered personnel authorized by their management to access and enter only data involving the specified sites or organizations for which they have received authority. For the CATS, registration is required for both readers and editors.

- The system should possess the capability to pinpoint problem areas and track trends. It should maintain historical data that supports ongoing problem resolution, trend analysis, and recurrence control activities.
- The system should allow flexible reporting, Corrective Action Program (CAP) changes and status, and real-time visibility of open and closed findings and corrective actions.
- The system should be able to integrate and link with other applicable databases.
- The system should be capable of conducting a flexible interactive search and retrieval of information for tracking and trending corrective action program status.
- The system should be continuously monitored, feedback requested from users, and changes made to ensure the system is meeting the needs of the users and the objectives of the corrective action program.
- Strong management support and participation in the operation and funding of the tracking and reporting system is critical to the effectiveness of the system.

**Follow-up**

The following is taken from DOE G 414.1-1B.

A follow-up assessment with special focus may be performed and should be completed in accordance with applicable corrective action documents. Particularly, this follow-up assessment should evaluate the effectiveness of corrective actions. A reasonable subset of corrective actions should be reviewed for effectiveness.

**Contractor Corrective Action Implementation**

The following is taken from DOE G 414.1-1A. ( Archived)

Managers responsible for the activities assessed are also responsible for the development of effective corrective actions for the problem areas or deficiencies discovered during the assessment. At a minimum, the corrective actions should include the following:

- Measures to correct each deficiency,
- Identification of all root causes for significant deficiencies,
- Determination of the existence of similar deficiencies,
- Corrective actions to preclude recurrence of like or similar deficiencies,
- Assignment of corrective action responsibility, and
- Completion dates for each corrective action.

For independent assessments, the proposed corrective actions should be reviewed for concurrence by the assessment team leader, with input from the assessment team. The senior line management to whom the assessed organization is accountable should approve the
corrective actions. This will help ensure that the planned actions will be effective in resolving the problem areas and deficiencies reported by the assessment team.

e. Describe the actions to be taken if the contractor challenges the assessment findings and explain how such challenges can be avoided.

The following is taken from DOE G 450.4-1B.

Differences in professional opinion could occur at several points during the process of resolving safety issues:
- Disagreement between line organizations regarding the completeness, priority, cost effectiveness or funding of the proposed CAP;
- Office of Oversight disagreement with the adequacy of the line’s CAP;
- Office of Oversight or line disagreement with the adequacy of CAP efforts at some time after implementation has begun;
- Technical disagreement or funding inadequacies that arise during CAP implementation; and
- Disputes identified during the CAP completion/closure verification process.

When a dispute is initially identified during this process, attempts are normally made to resolve it at the lowest organizational level possible using a traditional process of discussion, mutual agreement, or compromise. It is assumed that within 30 days of stated objections, most areas of dispute can be resolved without the involvement of the Secretary. Both oral and written communications are considered effective tools for focusing issues, stating facts and rationale, and communicating information consistently to all interested parties. If informal discussions successfully resolve the dispute, the resolution should be documented in a mutually agreeable way.

If an identified dispute cannot be resolved by informal discussions, it is elevated for resolution through a process that incorporates the following attributes, as appropriate.
- The dispute is appropriately documented to support its consideration by higher authority, with each party having equal opportunity for input on such documentation.
- The appropriate higher authorities are solicited to negotiate or arbitrate the dispute.
- Disputes are elevated to the minimum extent necessary to reach resolution, following the chain-of-command of the organizations involved.
- Dispute resolution is pursued as a priority, tracked in CATS, and completed by the higher authority within 30 days. Additional information, actions, or mutual decision to elevate the dispute to the next organizational level, should also be completed within the 30-day target period.
- Discussions between organizations are coordinated in advance to ensure full participation of all parties.
- Resolution is documented in a mutually agreeable way or elevated to the Office of the Secretary.

If an issue is not resolved through the process described above, it is elevated to the Office of the Secretary for resolution through a process that incorporates the following attributes.
The dispute is appropriately documented, each party has equal input on such documentation, and the heads of the affected organizations concur with the documentation.

The heads of the affected organizations work together to identify and brief the appropriate individual. An initial briefing may be provided at the senior policy/program advisor level, or the parties may prefer to discuss the matter directly with the Secretary or designee.

Resolution by the Secretary or designee is documented in accordance with established methods. The heads of the affected organizations provide any additional documentation required to support this effort.

43. Construction management personnel shall demonstrate the ability to assess contractor and/or federal construction management and engineering activities and make all necessary reports at a working level.

a. Given different sets of performance data, compare and contrast the data to highlight acceptable and unacceptable work performance.

This is performance-based KSA. The Qualifying Official will evaluate its completion.

b. Describe the methods by which noncompliance is determined and communicated to contractor and DOE management.

The following is taken from DOE G 414.1-2.

During the assessment of contractor activities, there are certain criteria useful in determining the acceptance or noncompliance of an item or activity. The following criteria summarized from 10 CFR 830.120, provide the basis for contractor assessments:

- **Programs.** Organizations shall develop a written plan that describes the organizational structure, functional responsibilities, levels of authority, and interfaces for those managing, performing, and assessing adequacy of work.

- **Personnel training and qualifications.** Personnel shall be trained and qualified to ensure they are capable of performing their assigned work. Training should emphasize correct performance of work, provide understanding of quality requirements, and stimulate professional development.

- **Quality improvement.** The organization shall establish and implement processes to detect and prevent quality problems and to ensure quality improvement. Items and processes that do not meet established requirements shall be identified, controlled, and corrected. Correction shall include identifying the cause of the problems and preventing reoccurrence. Item reliability, process implementation, and other quality-related information shall be reviewed and data analyzed to identify items and processes needing improvement.

- **Documents and records.** Documents shall be prepared, reviewed, approved, issued, used, and revised to prescribed processes, specified requirements, or established designs. Records should be maintained and provisions provided for retention, protection, preservation, traceability, accountability, and retrievability.

- **Work processes.** Work should be performed to technical standards and administrative controls. Work shall be performed under controlled conditions using approved instructions, procedures, or other appropriate means.
Design. The design process should use sound engineering/scientific principles and appropriate standards. Design work, including changes, shall be incorporated into applicable requirements and design bases.

Procurement. The procurement of items or services must meet established requirements and be performed as specified. Prospective suppliers shall be evaluated and selected on the basis of specific criteria.

Inspection and testing. Items must be inspected and tested to be deemed acceptable or not acceptable based on established acceptance and performance criteria.

Documented assessment results should be presented to the organization that was assessed and provided to the appropriate levels of management for review. Strengths and weaknesses affecting the process should be identified so that management can take meaningful action.

Management should evaluate the assessment results to identify improvement actions and determine whether similar problems may exist elsewhere in the organization. Lessons learned from assessment results should be communicated to other organizations with similar activities or concerns.

Management should track improvement actions until a resolution has been implemented and verified as completed.

c. Conduct an assessment of a contractor's construction management and engineering activities and develop and submit the resulting assessment report.

d. Perform an independent assessment of contractor operations.

e. Conduct an interview representative of one that would be conducted during an occurrence investigation.

f. Develop an assessment report using the findings from an assessment.

g. Discuss the results of construction management assessments in a formal meeting between DOE management and senior contractor management.

KSAs c through g are performance-based KSAs. The Qualifying Official will evaluate their completion.

44. Construction management personnel shall demonstrate a working level knowledge of problem analysis principles and the techniques necessary to identify problems, determine potential causes of problems, and identify corrective action(s).

a. Compare and contrast immediate, short-term, and long-term actions taken as a result of problem identification or an occurrence.

The following is taken from DOE G 225.1A-1.

[Note: Corrective actions are no longer classified as short term and long term.]
The final report is submitted by the appointing official to senior managers of organizations identified in the judgments of need in the report, with a request for the organizations to prepare corrective action plans. These plans contain actions for addressing judgments of need identified in the report and include milestones for completing the actions.

Corrective actions fall into four categories:

- Immediate corrective actions that are taken by the organization managing the site where the accident occurred to prevent a second or related accident.
- Corrective actions required to satisfy judgments of need identified by the board in the final report. These corrective actions are developed by the heads of field elements and/or contractors responsible for the activities resulting in the accident and are designed to prevent recurrence and correct system problems.
- Corrective actions determined by the appointing official to be appropriate for DOE-wide application. The appointing official recommends these corrective actions when the report is distributed.
- DOE Headquarters corrective actions that result from discussions with senior management. These actions usually address DOE policy.

b. Given event and/or occurrence data, apply problem analysis techniques and identify the problems and how they could have been avoided.

This is performance-based KSA. The Qualifying Official will evaluate its completion.

c. Describe various data gathering techniques and the use of trending/history when analyzing problems.

The following is taken from the DOE Performance-Based Management Handbook, vol. 5.

Data should be collected from all possible sources. The analysis plan should indicate what data has been collected on these various aspects or where to pull that data.

- Baseline data
- Performance measurements (self-assessments, on-site reviews, etc.)
- Relevant in-depth evaluation studies (expert review, Government Accountability Office studies, etc.)
- Status of assumptions about external influencing factors
- Other parts of the organization, programs, and facilities

Goals and stretch targets can be numerical or they can be stated in terms of achievement of a significant, improving trend. One way of determining and showing a trend is a statistical process control chart. Another is to use expert opinion about qualitative definitions of success in a peer review. If a control chart is used, the chart becomes the criterion for determination of success. In both cases, numerical targets are not used. With the control chart, the goal or stretch target is stated as to “achieve statistically significant improvement” in certain measures over certain time frames. Goals that are stated in terms of achievement of statistically significant improvements are easy to monitor using a control chart. This methodology eliminates the problem of “we achieved a 49 percent improvement, but the target was 50 percent, so we failed.” Also, it prevents a random, lucky fluctuation in
performance from being declared as a success. As part of asking “Is there a trend?” an analyst would ask:

- Is the performance measure improving, degrading, or remaining stable?
- Is the data predictable and is variability in the data predictable and small, or is the process very unpredictable and/or is there large variation in the data?

The goal of trend analysis is to detect trends indicating that a performance measure or indicator is improving, declining, or remaining stable. In the context of this procedure, a trend is a statistically significant change in time-series data. Trend analysis can provide important information that a simple table or bar chart of the raw data cannot provide. Simply reviewing the raw data may cause a person to overreact to random fluctuations (variation) in the process data and wrongly assume that progress is being made towards or away from the goal. If numerical targets are used, the trend analysis gives more information than how far the current data point is from the target. Trend analysis answers these questions:

- Is the target achievable by the current process?
- Is the current process data stable in a range where the target can be achieved?
- Is progress being made to close the gap between actual and the target, or is the gap opening?

d. Interpret a fault tree analysis.

e. Participate in a contractor or Department of Energy problem analysis and critique the results.

KSAs d and e are performance-based KSAs. The Qualifying Official will evaluate their completion.

45. Construction management personnel shall demonstrate the ability to interact with federal, state, local, and public stakeholder representatives at a working level.

a. Discuss the roles and responsibilities of site and/or community advisory boards on construction management issues.

The following is taken from the Community Advisory Board (CAB) for Nevada Test Site Programs.

The CAB is comprised of volunteer members who represent stakeholders by reviewing and commenting on environmental restoration (i.e., groundwater contamination, historic nuclear test area clean-up, etc.) and waste management (i.e., radioactive waste transportation and disposal) activities at DOE sites. The CAB members bring a variety of perspectives to the Board on issues of significant concern to the region. Members also offer scientific and technical expertise to the Board, while also including rural interests, environmental concerns, and local government viewpoints.
b. Discuss DOE’s position on construction management and engineering issues that impact federal, state, local, and public stakeholder segments.

The following is taken from DOE P 141.2.

Public participation is open, ongoing, two-way communication, both formal and informal, between DOE and its stakeholders concerning DOE’s missions and activities. Effective public participation is at the core of good community relations, which is essential for DOE facilities to achieve their missions. Regular, interactive communication enables all parties to learn about and better understand the views and positions of each other.

The Department recognizes the many benefits to be derived from public participation and good community relations, for both stakeholders and DOE. Public participation provides a means for DOE to gather a diverse collection of opinions, perspectives, and values from the broadest spectrum of the public, enabling the Department to make more informed decisions. Public participation benefits stakeholders by creating an opportunity to provide input on decisions that affect their communities and our nation.

c. Discuss the Freedom of Information Act and its impact on DOE construction management programs. Discuss security precautions to be taken in relevant programs in terms of the Freedom of Information Act (FOIA).

The following is taken from the DOE Environmental Policy and Assistance Information Brief HS-22-IB-2008-13.

FOIA carries a presumption of disclosure; the burden is on the government—not the public—to substantiate why information may not be released. Thus, a written request under FOIA requires DOE, as a federal agency, to release its records or explain why they cannot be released. FOIA lists, in section 552(b), nine specific exemptions that allow agencies to withhold either certain information contained in records or entire records from public disclosure. One of the FOIA exemptions allows an agency to withhold records “specifically exempted from disclosure by statute.” This exemption includes two qualifications: the statute must require that the matters be withheld from the public in such a manner as to leave no discretion on the issue or establish particular criteria for withholding or refer to particular types of matters to be withheld. This exemption includes cultural resource information that is exempt from disclosure under the cultural resource statutes discussed below. According to its 2007 annual report on the administration of FOIA, DOE has used this exemption to withhold cultural resource information.

Cultural Resource Statutes
The National Historic Preservation Act (NHPA) and the Archaeological Resources Protection Act (ARPA) specifically restrict disclosure of certain types of sensitive information regarding cultural resources. These statutory provisions may result in information developed under these acts being withheld from public disclosure under the FOIA exemption discussed above.

NHPA is the principal federal law dealing with historic preservation. As defined in section 301(5) of the Act, “historic property” or “historic resource” means “any prehistoric or
Section 304 of the NHPA protects some information about historic resources from public disclosure. Specifically, it requires federal agencies, such as DOE, to “withhold from disclosure to the public, information about the location, character, or ownership of a historic resource if the agency and the Secretary of the Interior agree that disclosure may (1) cause a significant invasion of privacy, (2) risk harm to the historic resource, or (3) impede the use of a traditional religious site by practitioners.” For purposes of this section of NHPA the Secretary of the Interior acts through the director of the National Park Service (NPS). DOE, therefore, consults with the NPS to make a determination to withhold information from the public.

Once a determination to withhold information from the public has been made, the NPS, in consultation with DOE, will determine who (if anyone) may have access to the information for NHPA purposes. If the information was developed in order to comply with NHPA section 106 or section 110(f), the NPS must consult with the Advisory Council on Historic Preservation in making the determinations regarding withholding the information from the public and restricting access to the site.

ARPA provides a comprehensive framework to protect and regulate archaeological resources on Federal and Indian lands. It also provides for issuance of permits for excavation and removal of resources and provides confidentiality of resource locations. ARPA defines archeological resource as any material remains of past human life or activities which are of archaeological interest, including, but not limited to: pottery, basketry, bottles, weapons, weapon projectiles, tools, structures or portions of structures, pit houses, rock paintings, rock carvings, intaglios, graves, human skeletal materials, or any portion or piece of any of the foregoing items. Items must be at least 100-years old to be considered as archeological resources. A more detailed definition of archeological resource is provided in the uniform regulations implementing ARPA, 43 CFR 7, Protection of Archaeological Resources, subsection 7.3.

Section 9 of ARPA specifically prohibits the release of information concerning the nature and location of archaeological resources for which the excavation or removal requires a permit or other permission under this Act unless the DOE land manager determines that releasing the information furthers the purposes of ARPA and will not create a risk of harm to the resources.

Section 9(b) of ARPA does, however, provide for sharing such information with state governors upon written request, if they guarantee to protect its confidentiality in order to guard the resources from commercial exploitation. Because ARPA only applies on public or Indian lands, it does not protect information from archaeological sites on private or non-federal public lands.
d. Communicate effectively with the public and other stakeholders.

e. Given construction management related program data, identify those portions of the data required to be communicated to organizations external to the DOE construction management personnel. Discuss any potential impacts on DOE programs.

f. Communicate with Headquarters Program Office representatives, DOE legal representatives, contractors, state, and local officials.

KSAs d through f are performance-based KSAs. The Qualifying Official will evaluate their completion.

46. Construction management personnel shall demonstrate the ability to define and ensure effective implementation of required quality assurance activities for a construction project at a working level.

a. Describe the quality assurance program for a construction project.

The following is taken from DOE G 413.3-2.

The following sections summarize important QA-related considerations for the FPD at each CD as identified in DOE O 413.3A.

*QA Guidance for CD-0, Approval of Mission Need*
DOE O 413.3A, table 2, CD-0 Requirement—No project-specific QA program is needed. (At CD-0, a FPD has not been selected; however, the following QA activities should be considered.)
- Quality of mission need products should be controlled by the site or program office QA program. See additional DOE guides for developing mission need products.

*QA Guidance for CD-1, Approval of Alternative Selection and Cost Range*
DOE O 413.3A, table 2, CD-1 Requirement - Determine that the QA program is acceptable and continues to apply. The QA program must fully address all applicable QA criteria as defined in 10 CFR 830 Subpart A (QA Rule) and the DOE QA Order.

With regard to QA program development, there are instances where the FPD develops the QA program. However, it is more typical for the FPD to oversee the contractor’s development of the QA program prior to CD-1 submittal. In either event, the following should be performed:
- Develop a project-specific QA program that includes portions of the existing site QA program, as appropriate, with emphasis on:
  - Building quality into design prior to starting work (in preparation for CD-2)
  - Defining roles and responsibilities, including interfaces, of project, contractor, and subcontractor personnel, in detail
  - Ensuring that records management and document control processes are consistent with applicable codes, regulations, and directives
Design activities, including: constructability, vendor capability, component and system attainability, testability/acceptability, maintainability, and sustainability

Designing QA/Quality Control (QC) processes and procedures (and management systems) to control the design and changes

- Software control, especially safety software
- S/CI control
- Personnel training and qualification

- Ensure independence of the QA organization (QA organization is independent from the line organization and has the ability to raise issues independent of cost and schedule)
- Determine how and where to address QA in the project executive plan (PEP)
- Investigate the project acquisition strategy and quality levels (grading process) and ensure consistency between the acquisition strategy and QA Program
- Confirm there are adequate numbers of trained and qualified QA organization staff

**QA Guidance for CD-2, Approval of Performance Baseline**

DOE O 413.3A, table 2, CD-2 Requirement - Determine that the QA program is acceptable and continues to apply. The QA program must fully address all applicable QA criteria as defined in 10 CFR 830 Subpart A (QA Rule) and the DOE QA Order.

Either the cognizant FPD and their IPT’s or the contractor performs the following to refine the QA program prior to CD-2 submittal:

- Further refine the existing comprehensive project-specific assessment program that includes the levels of Federal and contractor activities
- Ensure that work processes covered by the QA Program are established and documented in procedures
- Review and revise the QA program based on improved knowledge of the project
- Ensure the Federal and contractor organizations have the correct balance of quality related expertise (i.e., individuals with requisite training and qualifications)
- Ensure there is appropriate QA organization representation during the development of and subsequent revisions to the PEP
- Ensure there is appropriate QA organization representation during safety reviews

Either the cognizant FPD or contractor should understand:

- Flowdown of requirements and expected implementation (including oversight activities)
- SSCs and associated quality levels
- National standard design and construction tolerance relationships
- Design philosophy (identification and flowdown of requirements into the design/performance specifications) to ensure it is coordinated with the acquisition strategy and QA strategy

For projects with a significant construction component, the FPD should understand and consider the following during CD-2 preparation:

- Ensure the IPT’s and the contractor have a common understanding of the QA requirements established in the latest versions of applicable DOE Orders, 10 CFR 830
Subpart A, and the contract and have qualified personnel in place to manage, perform, and assess work activities

- Ensure the IPT’s and the contractor have a common understanding of the acquisition strategy/plan and how the QA requirements are going to be identified, allocated, and implemented
- Ensure the IPT’s, the contractor, and the contractor procurement manager have a common understanding of the technical and programmatic risks associated with implementing the stated QA requirements within the acquisition strategy/plan and initiate the necessary mitigating activities to ensure the industry/market that will be solicited or performing the work clearly understands the expectations/requirements
- Ensure proper organizational QA processes and implementing procedures are developed, and assigned personnel are properly trained and qualified
- Ensure QA resources are defined, communicated to management, and incorporated into project budget requests

**QA Guidance for CD-3, Approve Start of Construction**

DOE O 413.3A, Table 2, CD-3 Requirement - Update the Quality Assurance program for construction, field design changes, and procurement activities.

Either the cognizant FPD and their IPT’s or the contractor performs the following prior to CD-3 submittal:

- Ensure the QA program is updated prior to the submittal of CD-3
- Ensure acquisition documents (e.g., construction Request for Proposal, etc.) include appropriate QA requirements
- Ensure the technical evaluation is supported by experienced QA individuals
- Ensure design interfaces are reviewed and approved
- Ensure the use of qualified vendors
- Ensure in-depth oversight of the QA program(s) of the prime contractor and key subcontractors (if applicable) is conducted
- Ensure SSCs are properly graded
- Ensure adequate systems, processes, implementing procedures are in place and mature, and supported by experienced personnel
- Ensure integrated oversight/assessment/surveillance/inspection plans and schedules are developed, implemented, and maintained
- Ensure proper contractor performance metrics are established
- Ensure IPT and project meetings include a QA representative and a review of QA activities
- Ensure there is appropriate QA organization representation during revisions to the PEP
- Ensure there is appropriate QA organization representation during external independent reviews for construction or execution readiness
- Ensure there is a process in place to integrate the results of project oversight programs
- Ensure the distribution of oversight is adjusted based on the level of maturity of the contractor’s oversight programs
- Ensure the quality-related activities (e.g., hold points, assessments, oversight, etc.) are reflected in the integrated project schedule and WBS
Ensure documents and records (objective evidence) for in-process and completed quality related items and activities are maintained and readily retrievable, consistent with applicable codes, regulations, and directives

Ensure, through independent assessments, that quality is being incorporated into the work processes (e.g., design, construction, etc.) – not inspected in (i.e., not relying on oversight to find and fix issues)

Evaluate/accommodate changes in skills mix and specific disciplines (e.g., electrical, civil, mechanical) as the project progresses through the construction phase.

QA Guidance for CD-4, Approve Start of Operations or Project Completion

DOE O 413.3A, table 2, CD-4 Requirement: Issue an updated QA Plan to address testing, identified deficiencies, startup, transition, and operation activities.

Either the cognizant FPD and their IPT or the contractor performs the following prior to CD-4 submittal:

- Ensure continuous improvement; execution, oversight, feedback from oversight, and modification
- Ensure, through observation, oversight, the use of QA representatives, and independent assessments, that quality is being incorporated into the work processes and activities (e.g., design, construction, etc.) – not inspected in
- Evaluate/accommodate changes in skills mix and specific disciplines (e.g., electrical, civil, mechanical) as the project progresses through the construction phase
- Routinely evaluate QA organization performance and make staffing adjustments as necessary
- Ensure project lessons learned (positive and negative) are produced
- Ensure complex wide lessons learned are analyzed and project changes are implemented, as necessary
- Ensure as-builts are developed, including maintaining plant configuration
- Ensure the project is implementing an effective issues management system
- Provide an updated QA program plan and lessons learned to operations as a source for updating existing operational QA program plans and other operational-related documentation
- Ensure records validation/authentication and turnover, consistent with applicable codes, regulations, and directives
b. Participate in material and test evaluations to validate that material specification requirements have been met.

c. Participate in source supply certification of mills, quarries, labs, batch plants, and weld shops.

d. Gather trending data and trace actions to correct recurring deficiency problems.

e. Evaluate the contractor’s quality assurance plan.

f. Monitor quality assurance activities in the field and measure them against the quality assurance plan.

g. Participate in quality assurance plan surveillance.

KSAs b through g are performance-based KSAs. The Qualifying Official will evaluate their completion.
Selected Bibliography and Suggested Reading

**Code of Federal Regulations**

29 CFR 1926.45, “
29 CFR 1926.49, “
48 CFR 15.403-4, Requiring Cost or Pricing Data.” October 1, 2008.
48 CFR 32.904, Determining Payment Due Dates.” October 1, 2008.


All About Circuits, Battery Ratings.

American Ductile Iron Pipe, Flanged Pipe Description, Details and Accessories.

American Concrete Institute


American Institute of Steel Construction

*Beam-Bearing Plates and Column Base Plates*. February 1, 2006.

American Meteorological Society. AMS Glossary.

American National Standards Institute


American Society of Civil Engineers

American Society for Mechanical Engineers


American Society for Testing and Materials
American Water Works Association

American Welding Society

Asphalt Roofing Manufacturer’s Association

Automated Environmental Systems. Packaged Pumping Stations.
Building Envelope Research, Light Gauge Steel Framing.
Carnegie Mellon University, Urban Watersheds.
City of Batavia. Wastewater Terminology.

Community Advisory Board (CAB) for Nevada Test Site Programs.
Consumer Fraud Lawyer, Types of Warranties. 2009.

**Construction User’s Roundtable**
- Exclusive Jurisdiction in Construction. October 1990.

Creative Homemaker, Projects Online: Forming a Compression Joint.


Dataweek. Battery Selection and Life Expectancy.


Diesel Generator Engine.


Electric Motors Reference Center. DC Motors.


Encarta. Solid Waste Disposal


Freepatents Online, Bearing Connections.

**General Polymers**


GeoEngineer. Permeability and Seepage.

George Washington University, School of Engineering and Applied Sciences, Current Carrying Capacity of Copper Conductors

**GlobalSpec**

- Compressed Air Dryers.
- Pipe Hangers and Pipe Supports.


H₂ Safety Best Practices, Glossary.

Hvachome. What is HVAC?


Houseblueprint.net, chapter 10, Construction Tools Guide.

Hyperphysics, AC Motor.

*Indiana Design Manual*, section 63-6.05(02), Design Procedure. 2009.


**Integrated Publishing**

- *Construction*, “Differential Leveling.”
- *Engineering*, “Care and Adjustment of Surveying Equipment.”
- *Engineering*, “Linear Error of Closure.”
- *Engineering*, “Pipe Insulation.”
- *Engineering*, “Turning Points Pins and Plates.”
- *Engineering*, “Use of Drawings and Specifications.”


Lite Steel Technologies, Rigid Connections.


Miller, Duane K. *Ensuring Weld Quality in Structural Applications*.

MoDOT Engineering Policy Guide.


**National Fire Protection Association**


**National Geodetic Survey**

- *GPS Survey Equipment*.


**National Roofing Contractors Association**


North Carolina Department of Environment and Natural Resources, Division of Pollution Prevention and Environmental Assistance, *Dust Control.*

Northern Tool and Equipment Generator Buyer’s Guide.

**Occupational Safety and Health Administration**

Ohio State University. *Wastewater Treatment Principles and Regulations.*

PDH Center. *Field Compaction Methods for Soils.*

Penn State University, Department of Geography. “Chapter 5: Land Surveying and GPS.” January 26, 2009.


Pneumatic Installation Guidelines: Friction Type Bolted Connections.

**Portland Cement Association**
- *Building Green with Grey Concrete.* 2009.
- *Post-Tensioned Concrete.* 2009.
- *Precast/Prestressed Concrete.* 2009.
- *Removable Forms (Cast-in-Place).* 2009.


**Precast/Prestressed Concrete Institute**
- *MNL-116, Quality Control for Plants and Production of Structural Precast Concrete Products*
- *MNL-117, Quality Control for Plants and Production of Architectural Precast Concrete Products*
MNL-130, *Quality Control for Plants and Production of Glass Fiber-Reinforced Concrete Products*
Plant Certification.

Pumps-in-Stock.com, Submersible Pumps.

Richard, Ralph M. *Lateral Bracing of Seismic Beams*.


Shultz, George, P. *Transformers and Motors*. 1997.


**State of Texas, Department of Transportation**


The Fabricator, ASME and AWS Welding Codes—Similarities and Differences. August 26, 2008.

Toolbox Services, Insulating Concrete Forms.


Transtronics. Sealed Lead Acid Battery Applications.

**Underwriter’s Laboratory**.


Uniform Plumbing Code.
U.S. Code
Title 40, subtitle II, part A, chapter 33, section 3307, Congressional Approval of Proposed Projects, January 8, 2008.

U.S. Congress


U.S. Department of Energy (Orders, Guides, Manuals, and Policies)
DOE Guide 413.3-1, Managing Design and Construction Using Systems Engineering for Use with DOE O 413.3A. September 23, 2008.


**U.S. Department of Energy (Handbooks and Standards)**


U.S. Department of Energy (Other References)


**U.S. Geological Society**
- Natural Aggregates—Foundation of America’s Future.

University of Tennessee, Mechanical Fasteners.

University of Washington. Specifications.


Washington State, Department of Transportation, Geotechnical Services Division, Foundation Design. 2003.

Water Encyclopedia. Wastewater Treatment and Management.

Water Treatment Plant, Water Clarifier/Clarification.

Water/Wastewater Distance Learning, Trickling Filters.

**Welding-Advisors**
- Welding Testing, The All Important Proof.
- Welding Inspections for Soundness and Efficiency.
- Welding Explained, Arc, Spot, Gas and Aluminum Welding.
