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<td>A facility representative must demonstrate a working level knowledge of engineering prints and drawings.</td>
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<td>31</td>
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<td>VAC</td>
<td>voltage alternating current</td>
</tr>
<tr>
<td>VDC</td>
<td>voltage direct current</td>
</tr>
<tr>
<td>VFD</td>
<td>variable frequency drive</td>
</tr>
<tr>
<td>VSI</td>
<td>variable source inverter</td>
</tr>
<tr>
<td>W/cm²</td>
<td>watts per square centimeter</td>
</tr>
<tr>
<td>wg</td>
<td>water gage</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 Facility Representative 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
This reference guide addresses the competency statements in the October 2010 edition of DOE-STD-1151-2010, Facility Representative Functional Area Qualification Standard. The qualification standard contains 42 competency statements.

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 October 2010. 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 (TQP).

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. In those cases where a reference is not included, the information was provided by members of the team that developed the FAQS. The authors of the FAQS are listed in the Acknowledgements section of the standard.
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.
1. A facility representative must demonstrate a familiarity level knowledge of principles of steam system theory.

   a. Discuss the application of the following concepts to steam systems:
      - Enthalpy
      - Saturation
      - Superheat
      - Steam quality
      - Moisture content
      - Condensation
      - Sensible heat
      - Carryover
      - Thermal expansion
      - Thermal contraction

The following definitions are taken from DOE-HDBK-1012/1-92.

**Enthalpy**

   Enthalpy is a property of a substance, like pressure, temperature, and volume, but it cannot be measured directly. Normally, the enthalpy of a substance is given with respect to some reference value. For example, the specific enthalpy of water or steam is given using the reference that the specific enthalpy of water is zero at .01 Celsius (°C) and normal atmospheric pressure. The fact that the absolute value of specific enthalpy is unknown is not a problem, however, because it is the change in specific enthalpy (Δh) and not the absolute value that is important in practical problems. Steam tables include values of enthalpy as part of the information tabulated.

**Saturation**

   Saturation defines a condition in which a mixture of vapor and liquid can exist together at a given temperature and pressure. The temperature at which vaporization (boiling) starts to occur for a given pressure is called the saturation temperature or boiling point. The pressure at which vaporization (boiling) starts to occur for a given temperature is called the saturation pressure. For water at 212 Fahrenheit (°F) the saturation pressure is 14.7 absolute pressure (psia), and for water at 14.7 psia the saturation temperature is 212°F. For a pure substance, there is a definite relationship between saturation pressure and saturation temperature. The higher the pressure, the higher the saturation temperature will be. The graphical representation of this relationship between temperature and pressure at saturated conditions is called the vapor pressure curve.

**Superheat**

   If a substance exists entirely as vapor at saturation temperature, it is called saturated vapor. Sometimes the term dry saturated vapor is used to emphasize that the quality is 100 percent. When the vapor is at a temperature greater than the saturation temperature, it is said to exist as superheated vapor. The pressure and temperature of superheated vapor are independent properties, since the temperature may increase while the pressure remains constant. Actually, the substances we call gases are highly superheated vapors.
Steam Quality

Most practical applications using the saturated steam tables involve steam-water mixtures. The key property of such mixtures is steam quality, defined as the mass of steam present per unit mass of steam-water mixture, or steam moisture content, defined as the mass of water present per unit mass of steam-water mixture. When a substance exists as part liquid and part vapor at saturation conditions, its quality is defined as the ratio of the mass of the vapor to the total mass of both vapor and liquid. Thus, if the mass of the vapor is 0.2 pound-mass (lbm) and the mass of the liquid is 0.8 lbm, the quality is 0.2 or 20 percent. Quality is an intensive property. Quality has meaning when the substance is in a saturated state only, at saturation pressure and temperature.

Moisture Content

The moisture content of a substance is the opposite of its quality. Moisture is defined as the ratio of the mass of the liquid to the total mass of both liquid and vapor. The moisture of the mixture in the previous paragraph would be 0.8 or 80 percent.

Condensation

If heat is removed at a constant pressure from a saturated vapor, condensation will occur and the vapor will change phase to liquid.

Sensible Heat

When a substance is heated its temperature increases, and when it is cooled its temperature decreases. The heat added to or removed from a substance to produce a change in its temperature is called sensible heat.

 Carryover

The following is taken from Kansas State University, Principles of Feed Manufacturing: Efficient Boiler Operation.

Carryover occurs when water in the boiler is incorporated with the steam and leaves the boiler. Carryover results in loss of steam quality and potential steam equipment damage from deposits. To avoid or reduce the incidence of scale, corrosion, and carryover, boiler feed water is treated to control suspended solids, total dissolved solids, dissolved gases, and water pH.

Thermal Expansion

As temperature increases, metal will expand. This expansion has to be accommodated in the design and support of the metal (e.g., expansion joints). Additionally, an increase in temperature will add stress and increase a metal’s ductility.

Thermal Contraction

As temperature decreases, metal will contract. This contraction has to be accommodated in the design and support of the metal. Additionally, a decrease in temperature will cause a decrease in ductility and a change from ductile to more brittle behavior. Stress may or may not be relieved.
b. Discuss steam tables and the Mollier diagram and demonstrate their use.

The following is taken from DOE-HDBK-1012/1-92.

Steam tables consist of two sets of tables of the energy transfer properties of water and steam: saturated steam tables and superheated steam tables. Portions of the tables are shown in table 1. Both sets of tables are tabulations of pressure (P), temperature (T), specific volume (ν), specific enthalpy (h), and specific entropy(s). The following notation is used in steam tables. Some tables use ν for v (specific volume) because there is little possibility of confusing it with velocity.

- T = temperature (°F)
- P = pressure
- ν = specific volume (ft³/lbm)
- νᵣ = specific volume of saturated liquid (ft³/lbm)
- νᵣ = specific volume of saturated vapor (ft³/lbm)
- νfg = specific volume change of vaporization (ft³/lbm)
- h = specific enthalpy (British thermal unit [Btu]/lbm)
- hᵣ = specific enthalpy of saturated liquid (Btu/lbm)
- hᵣ = specific enthalpy of saturated vapor (Btu/lbm)
- hfg = specific enthalpy change of vaporization (Btu/lbm)
- s = specific entropy (Btu/lbm- Rankine Scale [°R])
- sf = specific entropy of saturated liquid (Btu/lbm- °R)
- sg = specific entropy of saturated vapor (Btu/lbm-°R)
- sfg = specific entropy change of vaporization (Btu/lbm-°R)
- SH = number of degrees of superheat (°F)
Table 1. Steam tables

### Saturated Steam: Pressure Table

<table>
<thead>
<tr>
<th>Abs. Press. Lb/Sq.in</th>
<th>Temp. Fahr.</th>
<th>Sat. Liquid $v_f$</th>
<th>Evap. $v_{fg}$</th>
<th>Sat. Vapor $v_g$</th>
<th>Sat. Liquid $h_f$</th>
<th>Evap. $h_{fg}$</th>
<th>Sat. Vapor $h_g$</th>
<th>Sat. Liquid $s_f$</th>
<th>Evap. $s_{fg}$</th>
<th>Sat. Vapor $s_g$</th>
<th>Abs. Press. Lb/Sq.in</th>
</tr>
</thead>
<tbody>
<tr>
<td>200.0</td>
<td>381.80</td>
<td>0.01839</td>
<td>2.2689</td>
<td>2.2873</td>
<td>355.5</td>
<td>842.8</td>
<td>1199.3</td>
<td>0.5438</td>
<td>1.0016</td>
<td>1.5454</td>
<td>200.0</td>
</tr>
<tr>
<td>210.0</td>
<td>385.91</td>
<td>0.01844</td>
<td>2.176373</td>
<td>2.18217</td>
<td>359.9</td>
<td>839.1</td>
<td>1199.0</td>
<td>0.5490</td>
<td>0.9923</td>
<td>1.5413</td>
<td>210.0</td>
</tr>
</tbody>
</table>

### Saturated Steam: Temperature Table

<table>
<thead>
<tr>
<th>Abs. Press. Lb/Sq.in</th>
<th>Sat. Water</th>
<th>Sat. Steam</th>
<th>Temperature—Degrees Fahrenheit</th>
</tr>
</thead>
<tbody>
<tr>
<td>466.87</td>
<td>460.8</td>
<td>0.01961</td>
<td>0.97463</td>
</tr>
<tr>
<td>485.56</td>
<td>464.8</td>
<td>0.01969</td>
<td>0.93588</td>
</tr>
</tbody>
</table>

### Superheated Steam

<table>
<thead>
<tr>
<th>Abs. Press. Lb/Sq.in</th>
<th>450</th>
<th>500</th>
<th>550</th>
<th>600</th>
<th>650</th>
<th>700</th>
<th>800</th>
<th>900</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 sh</td>
<td>5.40</td>
<td>55.40</td>
<td>105.40</td>
<td>155.40</td>
<td>205.40</td>
<td>255.40</td>
<td>355.40</td>
<td>455.50</td>
<td>555.50</td>
</tr>
<tr>
<td>v</td>
<td>0.01934</td>
<td>1.1610</td>
<td>1.1738</td>
<td>1.2841</td>
<td>1.3836</td>
<td>1.4763</td>
<td>1.5646</td>
<td>1.6499</td>
<td>1.8151</td>
</tr>
<tr>
<td>h</td>
<td>424.17</td>
<td>1204.6</td>
<td>1208.8</td>
<td>1245.1</td>
<td>1277.5</td>
<td>1307.4</td>
<td>1335.9</td>
<td>1363.4</td>
<td>1417.0</td>
</tr>
<tr>
<td>s</td>
<td>0.6217</td>
<td>1.4847</td>
<td>1.4894</td>
<td>1.5282</td>
<td>1.5611</td>
<td>1.5901</td>
<td>1.6163</td>
<td>1.6406</td>
<td>1.6850</td>
</tr>
</tbody>
</table>

**Source:** DOE-HDBK-1012/1-92

The saturated steam tables give the energy transfer properties of saturated water and saturated steam for temperatures from 32°F to 705.47°F (the critical temperature), and for the corresponding pressure from 0.08849 pounds per square inch (psi) to 3208.2 psi. Normally, the saturated steam tables are divided into two parts: temperature tables, which list the properties according to saturation temperature; and pressure tables, which list them according to saturation pressure. Table 1 shows a portion of a typical saturated steam temperature table and a portion of a typical saturated steam pressure table. The values of enthalpy and entropy given in these tables are measured relative to the properties of saturated liquid at 32°F. Hence, the enthalpy of saturated liquid and the entropy of saturated liquid have values of approximately zero at 32°F.

Most practical applications using the saturated steam tables involve steam-water mixtures. The key property of such mixtures is steam quality (x), defined as the mass of steam present per unit mass of steam-water mixture, or steam moisture content (y), defined as the mass of water present per unit mass of steam-water mixture. The following relationships exist between the quality of a liquid-vapor mixture and the specific volumes, enthalpies, or entropies of both phases and of the mixture itself. These relationships are used with the saturated steam tables.

- \( v = x v_g + (1 - x) v_f \)
- \( x = (v - v_f) / v_{fg} \)
- \( h = x h_g + (1 - x) h_f \)
- \( x = (h - h_f) / h_{fg} \)
- \( s = x s_g + (1 - x) s_f \)
- \( x = (s - s_f) / s_{fg} \)

The Mollier diagram, shown in figure 1 is a chart on which enthalpy (h) versus entropy (s) is plotted. It is sometimes known as the h-s diagram and has an entirely different shape from...
the T-s diagrams. The chart contains a series of constant temperature lines, a series of constant pressure lines, a series of constant moisture or quality lines, and a series of constant superheat lines. The Mollier diagram is used only when quality is greater than 50 percent and for superheated steam.

*Source:* DOE-HDBK-1012/1-92

**Figure 1.** Mollier diagram
To solve problems in thermodynamics, information concerning the “state” of the substance studied must be obtained. Usually, two properties (e.g., \(v, p, T, h, s\)) of the substance must be known in order to determine the other needed properties. These other properties are usually obtained using either the Mollier diagram or the saturated and superheated steam tables.

The following two examples illustrate the use of the Mollier diagram and the steam tables.

**Example 1: Use of the Mollier chart**

Superheated steam at 700 psia and 680 °F is expanded at constant entropy to 140 psia. What is the change in enthalpy?

**Solution:**

Use the Mollier chart. Locate point 1 at the intersection of the 700 psia and the 680 °F line. Read \(h = 1333\) Btu/lbm.

Follow the entropy line downward vertically to the 140 psia line and read \(h = 1178\) Btu/lbm.

\[ h = 1178 - 1333 = -155 \text{ Btu/lbm} \]

**Example 2: Use of steam tables**

What are the specific volume, enthalpy, and entropy of steam having a quality of 90 percent at 200 psia?

**Solution:**

From the steam tables at 200 psia:

\[
\begin{align*}
\nu_f &= 0.01839 & \nu_{fg} &= 2.2689 & h_f &= 355.5 \\
h_{fg} &= 842.8 & s_f &= 0.5438 & s_{fg} &= 1.0016 \\
\end{align*}
\]

\[
\begin{align*}
\nu &= \nu_f + x(\nu_{fg}) \\
\nu &= 0.01839 + (0.9)(2.2689) = 2.0604 \text{ lbm/ft}^3 \\
h &= h_f + x(h_{fg}) \\
h &= 355.5 + (0.90)(842.8) = 1114.02 \text{ Btu/lbm} \\
s &= s_f + x(s_{fg}) \\
s &= 0.5438 + (0.9)(0.1.0016) = 1.44524 \text{ Btu/lbm-°R} \\
\end{align*}
\]

2. **A facility representative must demonstrate a working level knowledge of steam system operation, including startup, normal and off-normal operation, and shutdown.**

   a. **Describe the following steam system evolutions and associated precautions:**

      - Pressurization and warm-up of a cold steam system
      - Initiation of steam flow in a stagnant, but pressurized steam system
      - Isolation of a portion of a steam system
      - Pressurization and warm-up of an isolated portion of a steam system
      - Isolation and de-pressurization of an in-service steam system

   **Pressurization and Warm-Up of a Cold Steam System**

   Flow changes in piping systems should be done slowly as part of good operator practice. To prevent water and steam hammer during pressurization/warm-up of a cold steam system, operators should ensure liquid systems are properly vented and gaseous or steam systems are properly drained during startup. When possible, initiate pump starts against a closed discharge valve, and open the discharge valve slowly to initiate system flow. If possible,
startup smaller capacity pumps before larger capacity pumps. Use warm-up valves around main stream stop valves whenever possible. If possible, close pump discharge valves before stopping pumps. Periodically verify proper function of moisture traps and air traps during operation.

**Initiation of Steam Flow in a Stagnant, but Pressurized Steam System**

To initiate steam flow in a stagnant, but pressurized steam system, ensure all checklists and alignments are complete, including the vent and drain valves upstream and downstream from the closed steam isolation valve. Open the isolation valve (or isolation valve bypass valve) slowly to reduce the differential pressure (DP) across the isolation valve to within limits (e.g., 50 psid) prior to fully opening the isolation valve in order to avoid damaging the valve or causing steam hammer. Monitor downstream temperature and pressure, close or check closed the isolation bypass valve, close or check closed all drain valves, and check all systems for proper operation.

**Isolation of a Portion of a Steam System**

To isolate a portion of a steam system, check that no technical safety requirements (TSRs) will be violated as a result of the isolation, and then secure equipment related to the portion of the steam system to be isolated. Shut the steam isolation valve and line up the drain valves and steam traps on the isolated portion of the steam system to drain any condensate resulting from cool down of the system. If the system is to be de-pressurized, see below. Line up the isolated system and components per procedures and/or checklists.

**Pressurization and Warm-Up of an Isolated Portion of a Steam System**

The pressurization and warm-up of an isolated portion of a steam system is similar to the initiation of flow into a pressurized system (above) with the following exceptions. Pressurization and warm-up will be accomplished by opening the isolation valve warm-up or bypass valve (or cracking open the isolation valve if it does not have a warm-up or bypass valve). Pressurization and heat-up rate will be controlled to within limits (e.g., less than 100 F per hour), and vent, drain, and steam trap operations will be closely monitored for proper operation to prevent steam or condensate-induced water hammer.

**Isolation and De-Pressurization of an In-Service Steam System**

To isolate and depressurize an in-service steam system, isolate the steam system as discussed above. Depressurize the system using steam-driven components connected to the system (e.g., pumps) and/or vent valves. Observe any related pressure and/or temperature cool-down limits (e.g., less than 100°F per hour). Line up the depressurized system and components per procedures and/or checklists.

b. Discuss the function/application of the following steam system components and describe how the components contribute to steam system operation:
   - Isolation valves
   - Isolation valve bypass valves
   - Vent valves
   - Drain valves
   - Safety/relief valves
   - Flow control valves
   - Steam trap bypass valves
- Expansion joints
- Pressure control valves
- Moisture separators
- Pipe hangers/supports
- Mist eliminators
- Evaporators
- Condensers
- Boilers
- Reboilers
- Steam traps (mechanical, impulse, thermostatic)

**Isolation Valves**

Pump isolation valves are sometimes interlocked with the pump. In some applications, these interlocks act to prevent the pump from being started with the valves shut. The pump/valve interlocks can also be used to automatically turn off the pump if one of its isolation valves shuts, or to open a discharge valve at some time interval after the pump starts.

**Isolation Valve Bypass Valves**

The following is taken from Nuclear Regulatory Commission, NRC AP1000.

Isolation valve bypass valves isolate the secondary side of each of the steam generators to prevent the uncontrolled blow down of more than one steam generator and isolate non-safety-related portions of the system.

Isolation valve bypass valves are small valves used to bypass isolation valves in order to warm up piping downstream from the isolation valve, and/or to equalize pressure across the isolation valve prior to opening the isolation valve.

**Vent Valves**

According to Surface Production Operations by Ken Arnold, vent valves are required for purging a system.

Vent valves are small valves installed in system high points that are used to relieve or prevent the build up of pressure inside pipes or other components (e.g., the shell side of a condenser).

**Drain Valves**

According to Surface Production Operations by Ken Arnold, drain valves are required to drain liquids out of a system for maintenance.

**Safety/Relief Valves**

The following is taken from DOE-HDBK-1018/2-93.

Safety/relief valves prevent equipment damage by relieving accidental over-pressurization of fluid systems. If a system contains both a relief and a safety valve, the relief valve will open before the safety valve. Relief valves are typically used for incompressible fluids (e.g., water or oil), while safety valves are typically used for compressible fluids (e.g., steam or other gases). Most relief and safety valves open against the force of a compression spring. The pressure set point is adjusted by turning the adjusting nuts on top of the yoke to increase or decrease the spring compression.
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, only opening as necessary to relieve the over-pressure condition. A safety valve rapidly opens fully as soon as the pressure setting is reached, and stays 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 “blow down.”)

**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 flow control 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

**Steam Trap Bypass Valves**
The following is taken from DOE-HDBK-1018/2-93.

In general, a steam trap consists of a valve and a device or arrangement that causes the valve to open and close as necessary to drain the condensate from piping without allowing the escape of steam. Steam traps are installed at low points in the system or machinery to be drained. Some types of steam traps that are used in DOE facilities are described in DOE-HDBK-1018/2-93

**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
**Pressure Control Valves**
The following is taken from Integrated Publishing, *Engine Mechanics, Pressure Control Valves*.

The safe and efficient operation of fluid power systems, system components, and related equipment requires a means of controlling pressure. There are many types of automatic pressure control valves. Some of them merely provide an escape for pressure that exceeds a set pressure; some only reduce the pressure to a lower pressure system or subsystem; and some keep the pressure in a system within a required range.

**Moisture Separators**
Moisture separators utilize centrifugal force to collect moisture and solids at the bottom of the moisture separator. They are installed at the discharge of an after cooler to remove liquid moisture and solids from compressed air, and at the exhaust of a high-pressure turbine stage to remove condensation from the steam, thereby increasing steam quality back to nearly 100 percent. This steam may be sent to a reheater or directly expanded through a low-pressure turbine stage to the condenser.

**Pipe Hangers/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.

**Mist Eliminators**
Mist eliminators are highly effective for removing liquid entrainment from gas streams providing high efficiency and low pressure drops in scrubbers, cooling towers, gas absorbers, and ventilation systems.

**Evaporators**
The following is taken from the Environmental Protection Agency, EPA, *Capsule Report: Evaporation Process*.

Evaporation may be accomplished operating at a vacuum or at atmospheric pressure. Atmospheric evaporators are used when components in the wastewater are thermally stable. Vacuum conditions reduce boiling temperatures and prevent decompositions. Decompositions can readily occur in zinc and cadmium cyanide solutions.
Condensers
The following is taken from DOE-HDBK-1018/1-93.

The steam condenser, shown in figure 2, is a major component of the steam cycle in power generation facilities. It is a closed space into which the steam exits the turbine and is forced to give up its latent heat of vaporization. It is a necessary component of the steam cycle for two reasons. One, it converts the used steam back into water for return to the steam generator or boiler as feed water. This lowers the operational cost of the plant by allowing the clean and treated condensate to be reused, and it is far easier to pump a liquid than steam. Two, it increases the cycle’s efficiency by allowing the cycle to operate with the largest possible delta-T and delta-P between the source (boiler) and the heat sink (condenser).

Source: DOE-HDBK-1018/1-93

Figure 2. Single-pass condenser

Because condensation is taking place, the term latent heat of condensation is used instead of latent heat of vaporization. The steam’s latent heat of condensation is passed to the water flowing through the tubes of the condenser. After the steam condenses, the saturated liquid continues to transfer heat to the cooling water as it falls to the bottom of the condenser, or hot well. This is called sub-cooling, and a certain amount is desirable. A few degrees sub-cooling prevents condensate pump cavitation. The difference between the saturation temperature for the existing condenser vacuum and the temperature of the condensate is termed condensate depression. This is expressed as a number of degrees condensate depression or degrees sub-cooled. Excessive condensate depression decreases the operating efficiency of the plant because the sub-cooled condensate must be reheated in the boiler, which in turn requires more heat from the reactor, fossil fuel, or other heat source.
There are different condenser designs, but the most common, at least in the large power
 generation facilities, is the straight-through, single-pass condenser illustrated in figure 2. This
 condenser design provides cooling water flow through straight tubes from the inlet water box
 on one end, to the outlet water box on the other end. The cooling water flows once through
 the condenser and is termed a single pass. The separation between the water box areas and
 the steam condensing area is accomplished by a tube sheet to which the cooling water tubes
 are attached. The cooling water tubes are supported within the condenser by the tube support
 sheets. Condensers normally have a series of baffles that redirect the steam to minimize
direct impingement on the cooling water tubes. The bottom area of the condenser is the hot
 well, as shown in figure 2. This is where the condensate collects and the condensate pump
takes its suction. If non-condensable gases are allowed to build up in the condenser, vacuum
 will decrease and the saturation temperature at which the steam will condense increases.

Non-condensable gases also blanket the tubes of the condenser, thus reducing the heat
 transfer surface area of the condenser. This surface area can also be reduced if the condensate
 level is allowed to rise over the lower tubes of the condenser. A reduction in the heat transfer
 surface has the same effect as a reduction in cooling water flow. If the condenser is operating
 near its design capacity, a reduction in the effective surface area results in difficulty
 maintaining condenser vacuum.

The temperature and flow rate of the cooling water through the condenser controls the
 temperature of the condensate. This in turn controls the saturation pressure (vacuum) of the
 condenser.

To prevent the condensate level from rising to the lower tubes of the condenser, a hot well
 level control system may be employed. Varying the flow of the condensate pumps is one
 method used to accomplish hot well level control. A level sensing network controls the
 condensate pump speed or pump discharge flow control valve position. Another method
 employs an overflow system that spills water from the hot well when a high level is reached.

Boilers
The following is taken from DOE-HDBK-1018/2-93.

The primary function of a boiler is to produce steam at a given pressure and temperature. To
 accomplish this, the boiler serves as a furnace where air is mixed with fuel in a controlled
 combustion process to release large quantities of heat. The pressure-tight construction of a
 boiler provides a means to absorb the heat from the combustion and transfer this heat to raise
 water to a temperature such that the steam produced is of sufficient temperature and quality
 (moisture content) for steam loads.

Two distinct heat sources used for boilers are electric probes and burned fuel (e.g., oil, coal,
 etc.). This reference guide will use fuel boilers to illustrate the typical design of boilers. Refer
to figure 3 during the following discussion.

The boiler has an enclosed space where the fuel combustion takes place, usually referred to
 as the furnace or combustion chamber. Air is supplied to combine with the fuel, resulting in
 combustion. The heat of combustion is absorbed by the water in the risers or circulating
 tubes. The density difference between hot and cold water is the driving force to circulate the
water back to the steam drum. Eventually the water will absorb sufficient heat to produce steam. Steam leaves the steam drum via a baffle, which causes any water droplets being carried by the steam to drop out and drain back to the steam drum. If superheated steam is required, the steam may then travel through a super heater. The hot combustion gases from the furnace will heat the steam through the super heater’s thin tube walls. The steam then goes to the steam supply system and the various steam loads.

Source: DOE-HDBK-1018/2-93

Figure 3. Typical fuel boiler
Some boilers have economizers to improve cycle efficiency by preheating inlet feed water to the boiler. The economizer uses heat from the boiler exhaust gases to raise the temperature of the inlet feed water.

Fuel Boiler Components
Figure 3 illustrates a typical fuel boiler. Some of the components are explained in the following paragraphs.

Steam Drum
The steam drum separates the steam from the heated water. The water droplets fall to the bottom of the tank to be cycled again, and the steam leaves the drum and enters the steam system. Feed water enters at the bottom of the drum to start the heating cycle.

Downcomers
Downcomers are the pipes in which the water from the steam drum travels in order to reach the bottom of the boiler where the water can enter the distribution headers.

Distribution Headers
The distribution headers are large pipe headers that carry the water from the downcomers to the risers.

Risers
The piping or tubes that form the combustion chamber enclosure are called risers. Water and steam run through these to be heated. The term risers refers to the fact that the water flow direction is from the bottom to the top of the boiler. From the risers, the water and steam enter the steam drum and the cycle starts again.

Combustion chamber
Located at the bottom of a boiler, the combustion chamber is where the air and fuel mix and burn. It is lined with the risers.

Reboilers
The following is taken from The Distillation Group, Inc., *Reboiler Exchangers and System Type Selection*.

Reboilers generate vapor to drive fractional distillation separation. In classical fractional distillation services all the vapor to drive the separation comes from the reboiler. (Alternate systems may use externally generated vapor, feed preheat, or inter-reboiler systems.) Proper reboiler operation is vital to effective distillation.

The most critical element of reboiler design is the selection of the proper type of reboiler for a service. Most reboilers are shell-and-tube exchangers. Specific services may use other specialized designs including stab-ins, plate-fins, spiral-plate and others.

Steam Traps (Mechanical, Impulse, Thermostatic)
The following is taken from DOE-HDBK-1018/2-93.
A steam trap consists of a valve and a device or arrangement that causes the valve to open and close as necessary to drain the condensate from the lines without allowing the escape of steam. Steam traps are installed at low points in the system or machinery to be drained.

Mechanical steam traps operate on the principle that water (in steam) is heavier and thus can be measured by a float (e.g., ball or bucket float). As the water level rises, a drain is opened and the condensate is released from the trap.

Thermostatic steam traps (e.g., bellows type) are more compact and have fewer moving parts than most mechanical steam traps.

Impulse steam traps pass steam and condensate through a strainer before entering the trap. A circular baffle keeps the entering steam and condensate from impinging on the cylinder or on the disk. The impulse type of steam trap is dependent on the principle that hot water under pressure tends to flash into steam when the pressure is reduced.

c. Describe condensation-induced water hammer and its potential impact on steam systems.

The following is taken from *Steam Condensation Induced Waterhammer* by Wayne Kirsner.

A condensation-induced water hammer is a rapid condensation event. It could also be aptly termed a rapid steam bubble collapse. It occurs when a steam pocket becomes totally entrapped in sub-cooled condensate. As the steam gives up its heat to the surrounding condensate and pipe walls, steam changes from a vapor to a liquid state. As a liquid, the volume formerly occupied by the steam shrinks by a factor of from several hundred to over a thousand, depending on the saturated steam pressure. Likewise, the pressure in the void drops to the saturated vapor pressure of the surrounding condensate (e.g., the saturated vapor pressure of condensate at ambient temperature is less than 1 psia). This leaves a low-pressure void in the space formerly occupied by the steam that the surrounding condensate, under steam pressure itself, will rush in to fill. The resulting collision of condensate generates an over-pressurization that reverberates throughout the condensate-filled portion of the pipe.

The specific factors that influence the severity of a condensation-induced water hammer are: 1) the steam pressure, 2) the degree of condensate subcooling, 3) the presence of non-condensables left over in the void, and 4) the size of the void. If the steam pressure is high, the condensate is sub-cooled, non-condensables are absent, and the void is large enough for a slug to pick up some velocity; the overpressure resulting from an event can easily exceed 1000 pounds per square inch (psi). This is enough pressure to fracture a cast iron valve, blow out a steam gasket, or burst an accordion type expansion joint. And, in fact, failure of each of these components in separate condensation-induced water hammer accidents has resulted in operator fatalities.

d. Describe the expected operator response to, and where possible, how to prevent the following steam system abnormal conditions. Include a discussion of associated hazards:

- Water hammer during pressurization/warm-up of a cold steam system
- Water hammer during initiation of flow in an in-service steam system
- Seat leakage of an isolation valve
Steam leakage to atmosphere
Steam header rupture

Water Hammer during Pressurization/Warm-Up of a Cold Steam System

The following is taken from DOE-HDBK-1012/3-92.

Flow changes in piping systems should be done slowly as part of good operator practice. To prevent water and steam hammer during pressurization/warm-up of a cold steam system, operators should ensure liquid systems are properly vented and gaseous or steam systems are properly drained during start-up. When possible, initiate pump starts against a closed discharge valve, and open the discharge valve slowly to initiate system flow. If possible, start-up smaller capacity pumps before larger capacity pumps. Use warm-up valves around main stream stop valves whenever possible. If possible, close pump discharge valves before stopping pumps. Periodically verify proper function of moisture traps and air traps during operation.

Water Hammer during Initiation of Flow in an In-Service Steam System

To prevent steam-induced water hammer during initiation of flow in an in-service steam system, open isolation valves (or isolation valve bypass valves) slowly.

Seat Leakage of an Isolation Valve

The following is taken from Flowserve Corp., FCD ADAMS8011-00.

A problem encountered with isolation valves is leakage across the seats. These valves are used to isolate high-energy fluid, making even small leaks serious. When one considers the proximity of workmen to these barriers, the importance of having leak-tight valves becomes apparent. Because of the frequency of leakage encountered with “commercial” valves in the past, it has become necessary to double-valve both the inlet and outlet heater lines. Even then, a drain tap between the two valves is used to check the integrity of the first seal prior to allowing workmen to enter the area.

The leakage that’s associated with isolation valves is the result of the large temperature change and severe pipe loads subjected on these valves. The isolation valve’s sealing ability is dependent on the angular relationship between the wedge and seat faces. Even an angular difference of a few seconds can cause leakage. Using a flexible wedge can minimize the effect of some thermal transients. However, when the temperature change is great, the dimensional mismatch can exceed the deflection capabilities of even the most flexible designs.

Steam Leakage to Atmosphere

Steam leaks can harm personnel and damage equipment. Operators should check for steam leaks during rounds, and notify operations and maintenance personnel of any leaks found. Adjusting the valve packing stops minor valve leaks. All other types of steam leaks usually require isolation before repair.

Steam Header Rupture

A steam header rupture can harm personnel, damage equipment, and generate significant stresses due to rapid cool-down and depressurization. Operators should immediately ensure
that automatic protective equipment has isolated the affected line, or identify and isolate the line manually.

3. **A facility representative must demonstrate a familiarity level knowledge of basic pneumatic and hydraulic systems theory.**

   a. **Define the following terms:**
      - Force
      - Pressure
      - Pneumatic
      - Hydraulic

   The following definitions are taken from DOE-HDBK-1018/2-93.

   **Force and Pressure**
   The foundation of modern hydraulic powered systems was established when a scientist named Blaise Pascal discovered that pressure in a fluid acts equally in all directions. This concept is known as Pascal’s law. The application of Pascal’s law requires the understanding of the relationship between force and pressure.

   Force may be defined as a push or pull exerted against the total area of a surface. It is expressed in pounds. Pressure is the amount of force on a unit area of the surface. That is, pressure is the force acting upon one square inch of a surface. The relationship between pressure and force is expressed mathematically.

   \[ F = PA \]

   where:
   
   - \( F \) = force in lbf
   - \( P \) = pressure in lbf/in.\(^2\) (psi)
   - \( A \) = area in in.\(^2\)

   **Pneumatic**
   The term pneumatic refers to air. Compressed air has numerous uses throughout a facility including the operation of equipment and portable tools. Pneumatic actuators are used to position control valves. They are normally used to control processes requiring quick and accurate response because they do not require a large amount of motive force.

   **Hydraulic**
   The operation of a typical hydraulic system is illustrated in figure 4. Oil from a tank or reservoir flows through a pipe into a pump. Often a filter is provided on the pump suction to remove impurities from the oil. The pump, usually a gear-type, positive displacement pump, can be driven by an electric motor, air motor, gas or steam turbine, or an internal combustion engine.

   The pump increases the pressure of the oil. The actual pressure developed depends on the design of the system. Most hydraulic systems have some method of preventing overpressure. As seen in figure 4, one method of pressure control involves returning hydraulic oil to the oil
reservoir. The pressure control box shown on figure 4 is usually a relief valve that provides a means of returning oil to the reservoir upon over-pressurization.

**Figure 4.** Basic hydraulic system

The high pressure oil flows through a control valve (directional control). The control valve changes the direction of oil flow, depending upon the desired direction of the load. In figure 4 the load can be moved to the left or to the right by changing the side of the piston to which the oil pressure is applied. The oil that enters the cylinder applies pressure over the area of the piston, developing a force on the piston rod. The force on the piston rod enables the movement of a load or device. The oil from the other side of the piston returns to a reservoir or tank.

4. A facility representative must demonstrate a working level knowledge of pneumatic and hydraulic systems operations.

   a. Describe the following pneumatic and hydraulic system evolutions and associated precautions and hazards:
      - Start-up and shutdown
      - Normal operation
      - System rupture or leakage

   The following descriptions are taken from DOE-HDBK-1018/2-93.
**Start-Up and Shutdown**

Closed valves should be slowly cracked open to allow pressure 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.

**Normal Operation**

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.

The hazards and precautions for air compressors are applicable to hydraulic systems as well, because most of the hazards are associated with high-pressure conditions. Any use of a pressurized medium can be dangerous. Hydraulic systems carry all the hazards of pressurized systems and special hazards that are related directly to the composition of the fluid used. When using oil as a fluid in a high-pressure hydraulic system, the possibility of fire or an explosion exists. A severe fire hazard is generated when a break in the high-pressure piping occurs and the oil is vaporized into the atmosphere. Extra precautions against fire should be practiced in these areas.

If oil is pressurized by compressed air, an explosive hazard exists if the high-pressure air comes into contact with the oil, because it may create a diesel effect and subsequent explosion. A carefully followed preventive maintenance (PM) plan is the best precaution against explosion.

**System Rupture or Leakage**

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.
5. A facility representative must demonstrate a familiarity level knowledge of heat exchanger construction and theory.

a. Discuss the following types of heat exchanger construction:
   - Shell and tube
   - Plate

The following is taken from DOE-HDBK-1018/1-92.

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.

*Shell and Tube*

The most basic and the most common type of heat exchanger construction is the tube and shell, as shown in figure 5. 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 5 also act as baffles to direct the flow of fluid within the shell back and forth across the tubes.

*Source: DOE-HDBK-1018/1-93*
Plate
A plate type heat exchanger, as illustrated in figure 6, consists of plates instead of tubes to separate the hot and cold fluids. 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.

Source: DOE-HDBK-1018/1-93
b. Discuss hot and cold fluid flow in parallel flow, counter flow, and cross flow heat exchangers.

The following is taken from DOE-HDBK-1018/1-93.

Because heat exchangers come in so many shapes, sizes, makes, and models, they are categorized according to common characteristics. One common characteristic that can be used to categorize them is the direction of flow the two fluids have relative to each other. The three categories are parallel flow, counter flow, and cross flow.

Parallel flow, as illustrated in figure 7, exists when the tube side fluid and the shell side fluid flow in the same direction. In this case, the two fluids enter the heat exchanger from the same end with a large temperature difference. As the fluids transfer heat, hotter to cooler, the temperatures of the two fluids approach each other. Note that the hottest cold-fluid temperature is always less than the coldest hot-fluid temperature.

\[\text{Source: DOE-HDBK-1018/1-93}\]

**Figure 7.** Parallel flow heat exchanger

Counter flow, as illustrated in figure 8, exists when the two fluids flow in opposite directions. Each of the fluids enters the heat exchanger at opposite ends. Because the cooler fluid exits the counter flow heat exchanger at the end where the hot fluid enters the heat exchanger, the cooler fluid will approach the inlet temperature of the hot fluid. Counter flow heat exchangers are the most efficient of the three types. In contrast to the parallel flow heat exchanger, the counter flow heat exchanger can have the hottest cold-fluid temperature greater than the coldest hot-fluid temperature.
Cross flow, as illustrated in figure 9, exists when one fluid flows perpendicular to the second fluid; that is, one fluid flows through tubes and the second fluid passes around the tubes at a 90° angle. Cross flow heat exchangers are usually found in applications where one of the fluids changes state. An example is a steam system’s condenser, in which the steam exiting the turbine enters the condenser shell side, and the cool water flowing in the tubes absorbs the heat from the steam, condensing it into water. Large volumes of vapor may be condensed using this type of heat exchanger flow.

Source: DOE-HDBK-1018/1-93

Figure 8. Counter flow heat exchanger

Source: DOE-HDBK-1018/1-93

Figure 9. Cross flow heat exchanger
c. Discuss the following heat exchanger applications:
   - Air conditioner evaporator
   - Air conditioner condenser
   - Preheater
   - Radiator
   - Cooling tower

The following is taken from DOE-HDBK-1018/1-93.

*Air Conditioner Evaporator*

All air conditioning systems contain at least two heat exchangers, usually called the evaporator and the condenser. In either case the refrigerant flows into the heat exchanger and transfers heat, either gaining or releasing it to the cooling medium. Commonly, the cooling medium is air or water. In the case of the condenser, the hot, high-pressure refrigerant gas must be condensed to a sub-cooled liquid.

The condenser accomplishes this by cooling the gas, transferring its heat to either air or water. The cooled gas then condenses into a liquid. In the evaporator, the sub-cooled refrigerant flows into the heat exchanger, but the heat flow is reversed, with the relatively cool refrigerant absorbing heat from the hotter air flowing on the outside of the tubes. This cools the air and boils the refrigerant.

*Air Conditioner Condenser*

All air conditioning systems contain at least two heat exchangers, usually called the evaporator and the condenser. In either case, evaporator or condenser, the refrigerant flows into the heat exchanger and transfers heat, either gaining or releasing it to the cooling medium. Commonly, the cooling medium is air or water.

In the case of the condenser, the hot, high-pressure refrigerant gas must be condensed to a sub-cooled liquid. The condenser accomplishes this by cooling the gas and transferring its heat to either air or water. The cooled gas then condenses into a liquid. In the evaporator, the sub-cooled refrigerant flows into the heat exchanger, but the heat flow is reversed, with the relatively cool refrigerant absorbing heat from the hotter air flowing on the outside of the tubes. This cools the air and boils the refrigerant.

*Preheater*

In large steam systems, or in any process requiring high temperatures, the input fluid is usually preheated in stages, instead of trying to heat it in one step from ambient to the final temperature. Preheating in stages increases the plant’s efficiency and minimizes thermal shock stress to components, as compared to injecting ambient temperature liquid into a boiler or other device that operates at high temperatures. In the case of a steam system, a portion of the process steam is tapped off and used as a heat source to reheat the feed water in preheater stages. Figure 10 is an example of the construction and internals of a U-tube feed water heat exchanger found in a large power generation facility in a preheater stage. As the steam enters the heat exchanger and flows over and around the tubes, it transfers its thermal energy and is condensed. Note that the steam enters from the top into the shell side of the heat exchanger, where it not only transfers sensible heat but also gives up its latent heat of vaporization. The condensed steam then exits as a liquid at the bottom of the heat exchanger.
The feed water enters the heat exchanger on the bottom right end and flows into the tubes. Note that most of these tubes will be below the fluid level on the shell side.

This means the feed water is exposed to the condensed steam first and then travels through the tubes and back around to the top right end of the heat exchanger. After making the 180° bend, the partially heated feed water is then subjected to the hotter steam entering the shell side.

Source: DOE-HDBK-1018/1-93

Figure 10. U-tube feed water heat exchanger

The feed water is further heated by the hot steam and then exits the heat exchanger. In this type of heat exchanger, the shell side fluid level is very important in determining the efficiency of the heat exchanger, as the shell side fluid level determines the number of tubes exposed to the hot steam.

Radiator

Commonly, heat exchangers are thought of as liquid-to-liquid devices only. But a heat exchanger is any device that transfers heat from one fluid to another. Some of a facility’s equipment depends on air-to-liquid heat exchangers. The most familiar example of an air-to-liquid heat exchanger is a car radiator. The coolant flowing in the engine picks up heat from the engine block and carries it to the radiator. From the radiator, the hot coolant flows into the tube side of the radiator (heat exchanger). The relatively cool air flowing over the outside of the tubes picks up the heat, reducing the temperature of the coolant. Because air is such a poor conductor of heat, the heat transfer area between the metal of the radiator and the air must be maximized. This is done by using fins on the outside of the tubes. The fins improve
the efficiency of a heat exchanger and are commonly found on most liquid-to-air heat exchangers and in some high efficiency liquid-to-liquid heat exchangers.

The following is taken from DOE-HDBK-1012/2-92.

Cooling Tower
The typical function of a cooling tower is to cool the water of a steam power plant by air that is brought into direct contact with the water. The water is mixed with vapor that diffuses from the condensate into the air. The formation of the vapor requires a considerable removal of internal energy from the water; the internal energy becomes latent heat of the vapor. Heat and mass exchange are coupled in this process, which is a steady-state process like the heat exchange in the ordinary heat exchanger.

Wooden cooling towers are sometimes employed in nuclear facilities and in factories of various industries. They generally consist of large chambers loosely filled with trays or similar wooden elements of construction. The water to be cooled is pumped to the top of the tower where it is distributed by spray or wooden troughs. It then falls through the tower, splashing down from deck to deck. A part of it evaporates into the air that passes through the tower. The enthalpy needed for the evaporation is taken from the water and transferred to the air, which is heated while the water cools. The air flow is either horizontal due to wind currents (cross flow) or vertically upward in counter-flow to the falling water. The counter-flow is caused by the chimney effect of the warm humid air in the tower or by fans at the bottom (forced draft) or at the top (induced flow) of the tower. Mechanical draft towers are more economical to construct and smaller in size than natural-convection towers of the same cooling capacity.

6. A facility representative must demonstrate a working level knowledge of heat exchanger systems operations.

a. Describe the following heat exchanger system evolutions and associated precautions and hazards:
   - Startup and shutdown
   - Normal operation
   - System rupture or leakage

Startup and Shutdown
The following is taken from Sentry Equipment Corporation, Brazed Plate Heat Exchanger.

Operating personnel should be familiar with all nameplate data, drawings, specification sheets, and any special instructions prior to startup or operation. The heat exchanger design pressures and temperatures should not be exceeded during startup or operation.

Prior to operation and if possible to do so safely, the heat exchanger system should be vented of air (non-condensables) to ensure the performance of the exchanger meets specification. Venting should only be done if operator and environmental safety requirements can be met. After completely filled, close all vents.

If specific instructions or operating procedures are not provided, the fluid stream closest to ambient temperature should be gradually introduced into the heat exchanger first, followed
by the second. Avoid thermally shocking the unit by slowly increasing flow, instead of providing full flow immediately.

Shutdown should be accomplished in the reverse order of the start-up procedure. Complete drainage of fluids is essential when freezing or accelerated corrosion is possible during the shutdown time period.

**Normal Operation**

Periodically verify actual flow rates against design flow rates to avoid subjecting exchanger to excessive velocities.

Excessive vibration or audible noise from a heat exchanger is abnormal. If this occurs, the cause should be investigated immediately. Verify that operating parameters (e.g., flows, pressures, temperatures) do not exceed design. If any operating parameter exceeds design, take corrective action immediately to bring any exceeded parameter back within design. Additional corrective actions may require removal of the exchanger from service and inspection.

Water hammer can cause vibration or audible noise in a heat exchanger. Causes of water hammer can be complex and involve quick closing valves and inadequate condensate removal, among other sources. A thorough investigation may be required to determine the source of the water hammer and the appropriate steps to eliminate it.

**System Rupture or Leakage**

The following is taken from Emerson Process Management, ADS 43-020/rev.C.

Energy costs continue to impact the bottom line at many industrial plants. Wherever possible, heat exchangers are used to capture waste heat for reuse in other areas. The capital cost of a heat exchanger is compensated by reduced fuel costs over the lifetime of the heat exchanger.

Corrosion and eventual leakage in heat exchangers can have several undesirable effects. A concentrated process stream may leak into cooling water that is discharged into a lake or river, causing pollution.

Process water, used to condense steam to feed a large boiler, may leak into the condensate and severely damage the boiler. In non-critical applications, corrosion is a problem because a corroded heat exchanger is less efficient and energy is wasted.

Engineers use a heat balance to calculate the efficiency of a heat exchanger, but a small leak actually appears to improve heat transfer (although the process is then much less efficient).

Leaks can be detected easily with pH and conductivity measurement. Flow will occur from the high pressure side to the low pressure side, so monitoring the low pressure side is recommended. Conductivity is an excellent indicator of contamination for boiler feed water because the condensate has very low conductivity and even a small leak of process water will sharply increase the reading. More conductive liquids can be monitored by pH measurement if the other side of the heat exchanger contains an acid or base of a different strength. In
cases where process conditions can change, measurements before and after the heat exchanger can be used to isolate possible leaks.

7. A facility representative must demonstrate a familiarity level knowledge of pump components and characteristics.

a. Describe the principles of operation for centrifugal pumps, including series and parallel pump operation.

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 11 is a simplified diagram of a typical centrifugal pump that shows the relative locations of the pump suction, impeller, volute, and discharge.

Source: DOE-HDBK-1018/1-93

Figure 11. Centrifugal pump
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 be classified based on the manner in which fluid flows through the pump. The manner in which fluid flows through the pump is determined by the design of the pump casing and the impeller. The three types of flow through a centrifugal pump are radial flow, axial flow, and mixed flow. In a radial flow pump, the liquid enters at the center of the impeller and is directed out along the impeller blades in a direction at right angles to the pump shaft. In an axial flow pump, the impeller pushes the liquid in a direction parallel to the pump shaft. Axial flow pumps are sometimes called propeller pumps because they operate essentially in the same manner as the propeller of a boat. Mixed flow pumps borrow characteristics from both radial flow and axial flow pumps. As liquid flows through the impeller of a mixed flow pump, the impeller blades push the liquid out and away from the pump shaft and to the pump suction at an angle greater than 90°.

For a given centrifugal pump operating at a constant speed, the flow rate through the pump is dependent on the DP or head developed by the pump. The lower the pump head, the higher the flow rate.

The following is taken from DOE-HDBK-1012/3-92.

In order to increase the volumetric flow rate in a system or to compensate for large flow resistances, centrifugal pumps are often used in parallel or in series. Figure 12 depicts two identical centrifugal pumps operating at the same speed in parallel.

Source: DOE-HDBK-1012/3-92

Figure 12. Pump characteristic curve for two identical centrifugal pumps used in parallel
Since the inlet and the outlet of each pump shown in figure 12 are at identical points in the system, each pump must produce the same pump head. The total flow rate in the system, however, is the sum of the individual flow rates for each pump.

When the system characteristic curve is considered with the curve for pumps in parallel, the operating point at the intersection of the two curves represents a higher volumetric flow rate than for a single pump and a greater system head loss. As shown in figure 13, a greater system head loss occurs with the increased fluid velocity resulting from the increased volumetric flow rate. Because of the greater system head, the volumetric flow rate is actually less than twice the flow rate achieved by using a single pump.

![Operating point for two parallel centrifugal pumps](Image)

*Source: DOE-HDBK-1012/3-92*

**Figure 13. Operating point for two parallel centrifugal pumps**

Centrifugal pumps are used in series to overcome a larger system head loss than one pump can compensate for individually. As illustrated in figure 14, two identical centrifugal pumps operating at the same speed with the same volumetric flow rate contribute the same pump head.

Since the inlet to the second pump is the outlet of the first pump, the head produced by both pumps is the sum of the individual heads. The volumetric flow rate from the inlet of the first pump to the outlet of the second remains the same.
Figure 14. Pump characteristic curve for two identical centrifugal pumps used in series

As shown in figure 15, using two pumps in series does not actually double the resistance to flow in the system. The two pumps provide adequate pump head for the new system and also maintain a slightly higher volumetric flow rate.

Source: DOE-HDBK-1012/3-92
b. Define the following terms and explain their relationship:
- Shutoff head
- Net positive suction head
- Cavitation
- Pump run-out

The following is taken from DOE-HDBK-1018/1-93.

**Shutoff Head**
Shutoff head is the maximum head that can be developed by a centrifugal pump operating at a set speed.

**Net Positive Suction Head**
To avoid cavitation in centrifugal pumps, the pressure of the fluid at all points within the pump must remain above saturation pressure. The quantity used to determine if the pressure of the liquid being pumped is adequate to avoid cavitation is the net positive suction head (NPSH). The net positive suction head available (NPSHₐ) is the difference between the pressure at the suction of the pump and the saturation pressure for the liquid being pumped. The net positive suction head required (NPSHₐ) is the minimum net positive suction head...
necessary to avoid cavitation. The condition that must exist to avoid cavitation is that the NPSHA must be greater than or equal to the NPSHR. It is possible to ensure that cavitation is avoided during pump operation by monitoring the NPSH of the pump. The NPSH for a pump is the difference between the suction pressure and the saturation pressure of the fluid being pumped. The NPSH is used to measure how close a fluid is to saturated conditions. The following equation can be used to calculate the NPSHA for a pump. The units of NPSH are feet of water.

\[
NPSH = P_{\text{suction}} - P_{\text{saturation}}
\]

where:
- \(P_{\text{suction}}\) = suction pressure of the pump
- \(P_{\text{saturation}}\) = saturation pressure for the fluid

By maintaining the available NPSH at a level greater than the NPSH required by the pump manufacturer, cavitation can be avoided.

**Cavitation**

The flow area at the eye of the pump impeller is usually smaller than either the flow area of the pump suction piping or the flow area through the impeller vanes. When the liquid being pumped enters the eye of a centrifugal pump, the decrease in flow area results in an increase in flow velocity accompanied by a decrease in pressure. The greater the pump flow rate, the greater the pressure drop between the pump suction and the eye of the impeller. If the pressure drop is large enough, or if the temperature is high enough, the pressure drop may be sufficient to cause the liquid to flash to vapor when the local pressure falls below the saturation pressure for the fluid being pumped. Any vapor bubbles formed by the pressure drop at the eye of the impeller are swept along the impeller vanes by the flow of the fluid. When the bubbles enter a region where local pressure is greater than saturation pressure farther out the impeller vane, the vapor bubbles abruptly collapse. This process of the formation and subsequent collapse of vapor bubbles in a pump is called cavitation.

Cavitation in a centrifugal pump has a significant effect on pump performance. Cavitation degrades the performance of a pump, resulting in a fluctuating flow rate and discharge pressure. Cavitation can also be destructive to a pump’s internal components. When a pump cavitates, vapor bubbles form in the low-pressure region directly behind the rotating impeller vanes. These vapor bubbles then move toward the oncoming impeller vane, where they collapse and cause a physical shock to the leading edge of the impeller vane. This physical shock creates small pits on the leading edge of the impeller vane. Each individual pit is microscopic in size, but the cumulative effect of millions of these pits formed over a period of hours or days can literally destroy a pump impeller.

Noise is one of the indications that a centrifugal pump is cavitating. A cavitating pump can sound like a can of marbles being shaken. Other indications that can be observed from a remote operating station are fluctuating discharge pressure, flow rate, and pump motor current.

If a centrifugal pump is cavitating, several changes in the system design or operation may be necessary to increase the NPSHA above the NPSHR and stop the cavitation. One method for
increasing the NPSHA is to increase the pressure at the suction of the pump. For example, if a pump is taking suction from an enclosed tank, either raising the level of the liquid in the tank or increasing the pressure in the space above the liquid increases suction pressure. It is also possible to increase the NPSHA by decreasing the temperature of the liquid being pumped. Decreasing the temperature of the liquid decreases the saturation pressure, causing the NPSHA to increase. Large steam condensers usually sub-cool the condensate to less than the saturation temperature, called condensate depression, to prevent cavitation in the condensate pumps. If the head losses in the pump suction piping can be reduced, the NPSHA will be increased. Various methods for reducing head losses include increasing the pipe diameter, reducing the number of elbows, valves, and fittings in the pipe, and decreasing the length of the pipe.

It may also be possible to stop cavitation by reducing the NPSHR for the pump. The NPSHR is not a constant for a given pump under all conditions, but depends on certain factors. Typically, the NPSHR of a pump increases significantly as flow rate through the pump increases. Therefore, reducing the flow rate through a pump by throttling a discharge valve decreases NPSHR. NPSHR is also dependent upon pump speed. The faster the impeller of a pump rotates, the greater the NPSHR will be. Therefore, if the speed of a variable speed centrifugal pump is reduced, the NPSHR of the pump decreases. However, since a pump’s flow rate is most often dictated by the needs of the system on which it is connected, only limited adjustments can be made without starting additional parallel pumps, if available.

The NPSHR to prevent cavitation is determined through testing by the pump manufacturer, and depends upon factors including the type of impeller inlet, impeller design, pump flow rate, impeller rotational speed, and the type of liquid being pumped. The manufacturer typically supplies curves of NPSHR as a function of pump flow rate for a particular liquid (usually water) in the vendor manual for the pump.

**Pump Run-out**

Pump run-out is the maximum flow that can be developed by a centrifugal pump without damaging the pump.

c. Describe the principles of operations for positive displacement pumps, and discuss the importance of not operating against a closed valve on the discharge side of the 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.

All positive displacement pumps operate on the same basic principle. This principle can be most easily demonstrated by considering a reciprocating positive displacement pump consisting of a single reciprocating piston in a cylinder with a single suction port and a single discharge port. Check valves in the suction and discharge ports allow flow in only one direction. During the suction stroke, the piston moves to the left, causing the check valve in the suction line between the reservoir and the pump cylinder to open and admit water from the reservoir. During the discharge stroke, the piston moves to the right, seating the check valve in the suction line and opening the check valve in the discharge line. The volume of liquid moved by the pump in one cycle (one suction stroke and one discharge stroke) is equal to the change in the liquid volume of the cylinder as the piston moves from its farthest left position to its farthest right position.

The following is taken from DOE Energy Efficiency and Renewable Energy, Operations and Maintenance, Types of Pumps.

A positive displacement pump, unlike a centrifugal pump, will produce the same flow at a given revolutions per minute (RPM) no matter what the discharge pressure is. A positive displacement pump cannot be operated against a closed valve on the discharge side of the pump, (i.e., it does not have a shut-off head like a centrifugal pump does). If a positive displacement pump is allowed to operate against a closed discharge valve, it will continue to produce flow which will increase the pressure in the discharge line until either the line bursts or the pump is severely damaged or both.

8. A facility representative must demonstrate a familiarity level knowledge of valve construction, operation, and application.

a. Describe the operation of the following valve classifications to include purpose, construction and application:
   - Ball
   - Check
   - Diaphragm
   - Gate
   - Globe
   - Relief
   - Safety

The following descriptions are taken from DOE-HDBK-1018/2-93.

**Ball Valve**

A ball valve is a rotational motion valve that uses a ball-shaped disk to stop or start fluid flow. The ball, shown in figure 16, performs the same function as the disk in the globe valve. When the valve handle is turned to open the valve, the ball rotates to a point where the hole through the ball is in line with the valve body inlet and outlet. When the valve is shut, the ball is rotated so that the hole is perpendicular to the flow openings of the valve body and the flow is stopped.
Most ball valve actuators are of the quick-acting type, which require a 90° turn of the valve handle to operate the valve. Other ball valve actuators are planetary gear-operated. This type of gearing allows the use of a relatively small hand wheel and operating force to operate a fairly large valve.

Some ball valves have been developed with a spherical surface coated plug that is off to one side in the open position and rotates into the flow passage until it blocks the flow path completely. Seating is accomplished by the eccentric movement of the plug. The valve requires no lubrication and can be used for throttling service.

A ball valve is generally the least expensive of any valve configuration and has low maintenance costs. In addition to quick, quarter turn on-off operation, ball valves are compact, require no lubrication, and give tight sealing with low torque.

Conventional ball valves have relatively poor throttling characteristics. In a throttling position, the partially exposed seat rapidly erodes because of the impingement of high velocity flow.

Source: DOE-HDBK-1018/2-93

Figure 16. Typical ball valve
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.

Diaphragm

A diaphragm valve is a linear motion valve that is used to start, regulate, and stop fluid flow. The name is derived from its flexible disk, which mates with a seat located in the open area at the top of the valve body to form a seal. A diaphragm valve is illustrated in figure 17.

Source: DOE-HDBK-1018/2-93

Figure 17. Straight through diaphragm valve

Diaphragm valves are, in effect, simple pinch clamp valves. A resilient, flexible diaphragm is connected to a compressor by a stud molded into the diaphragm. The compressor is moved up and down by the valve stem. Hence, the diaphragm lifts when the compressor is raised. As the compressor is lowered, the diaphragm is pressed against the contoured bottom in the straight through valve illustrated in figure 17 or the body weir in the weir-type valve.

Diaphragm valves can also be used for throttling service. The weir-type is the better throttling valve but has a limited range. Its throttling characteristics are essentially those of a quick opening valve because of the large shutoff area along the seat.

A weir-type diaphragm valve is available to control small flows. It uses a two-piece compressor component. Instead of the entire diaphragm lifting off the weir when the valve is opened, the first increments of stem travel raise an inner compressor component that causes only the central part of the diaphragm to lift. This creates a relatively small opening through the center of the valve. After the inner compressor is completely open, the outer compressor component is raised along with the inner compressor and the remainder of the throttling is similar to the throttling that takes place in a conventional valve. Diaphragm valves are particularly suited for the handling of corrosive fluids, fibrous slurries, radioactive fluids, or other fluids that must remain free from contamination.
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. Figure 18 illustrates a gate valve.

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°, 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

Source: DOE-HDBK-1018/2-93

Figure 18. Gate valve
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:

- 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. A Z-body globe valve is illustrated in figure 19.

As shown in figure 19 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 both stopping and starting fluid flow and for regulating flow. When compared to a gate valve, a globe valve generally yields much less

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Source: DOE-HDBK-1018/2-93

**Figure 19.** Z-body globe valve
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, heavier weight than other valves of the same flow rating, and the cantilevered mounting of the disk to the stem.

*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, illustrated in figure 20, gradually opens as the inlet pressure increases above the set-point.
Source: DOE-HDBK-1018/2-93

Figure 20. Relief valve

A relief valve opens only as necessary to relieve the over-pressure condition. A safety valve, illustrated in figure 21, 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 blow down (blow down is expressed as a percentage of the actuating pressure set-point).

Relief valves are typically used for incompressible fluids such as water or oil. Safety valves are typically used for compressible fluids such as steam or other gases. Safety valves can often be distinguished by the presence of an external lever at the top of the valve body, which is used as an operational check.

As indicated in figure 21, system pressure provides a force that is attempting to push the disk of the safety valve off its seat. Spring pressure on the stem is forcing the disk onto the seat. At the pressure determined by spring compression, system pressure overcomes spring pressure and the relief valve opens. As system pressure is relieved, the valve closes when spring pressure again overcomes system pressure. Most relief and safety valves open against the force of a compression spring. The pressure set point is adjusted by turning the adjusting nuts on top of the yoke to increase or decrease the spring compression.

Figure 21. Safety valve

Source: DOE-HDBK-1018/2-93
b. Given the specific valve below, match the valve to the applicable classification.

- Butterfly
- Lift check
- Needle
- Pinch
- Plug
- Pressure reducing
- Stop check
- Swing check

The following is taken from DOE-HDBK-1018/2-93.

Butterfly Valve

A butterfly valve, illustrated in figure 22, is a rotary motion valve that is used to stop, regulate, and start fluid flow.

![Figure 22. Typical butterfly valve](image)

Source: DOE-HDBK-1018/2-93

Butterfly valves are easily and quickly operated because a 90° rotation of the handle moves the disk from a fully closed to 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.

*Lift Check Valve*
A lift check valve, illustrated in figure 23, is commonly used in piping systems in which globe valves are being used as a flow control valve. They have similar seating arrangements as globe valves.

Source: DOE-HDBK-1018/2-93

**Figure 23. Lift check valve**

Lift check valves are suitable for installation in horizontal or vertical lines with upward flow. They are recommended for use with steam, air, gas, water, and on vapor lines with high flow velocities. These valves are available in three body patterns: horizontal, angle, and vertical.

*Needle Valve*
A needle valve, as shown in figure 24, is used to make relatively fine adjustments in the amount of fluid flow. The distinguishing characteristic of a needle valve is the long, tapered, needlelike point on the end of the valve stem. This needle acts as a disk. The longer part of the needle is smaller than the orifice in the valve seat and passes through the orifice before the needle seats. This arrangement permits a very gradual increase or decrease in the size of the opening. Needle valves are often used as component parts of other, more complicated valves. For example, they are used in some types of reducing valves.
Most constant-pressure pump governors have needle valves to minimize the effects of fluctuations in pump discharge pressure. Needle valves are also used in some components of automatic combustion control systems where very precise flow regulation is necessary.

*Pinch Valve*

The relatively inexpensive pinch valve, illustrated in figure 25, is the simplest in any valve design. It is simply an industrial version of the pinch cock used in the laboratory to control the flow of fluids through rubber tubing. Pinch valves are suitable for on-off and throttling services. However, the effective throttling range is usually between 10 and 95 percent of the rated flow capacity.

Pinch valves are ideally suited for the handling of slurries, liquids with large amounts of suspended solids, and systems that convey solids pneumatically. Because the operating mechanism is completely isolated from the fluid, these valves also find application where corrosion or metal contamination of the fluid might be a problem.

The pinch control valve consists of a sleeve molded of rubber or other synthetic material and a pinching mechanism. All of the operating portions are completely external to the valve. The molded sleeve is referred to as the valve body. Pinch valve bodies are manufactured of natural and synthetic rubbers and plastics which have good abrasion resistance properties.
These properties permit little damage to the valve sleeve, thereby providing virtually unimpeded flow. Sleeves are available with either extended hubs and clamps designed to slip over a pipe end, or with a flanged end having standard dimensions.

Source: DOE-HDBK-1018/2-93

Figure 25. Pinch valve

Plug Valve

A plug valve is a rotational motion valve used to stop or start fluid flow. The name is derived from the shape of the disk, which resembles a plug. A plug valve is shown in figure 26. The simplest form of a plug valve is the petcock. The body of a plug valve is machined to receive the tapered or cylindrical plug. The disk is a solid plug with a bored passage at a right angle to the longitudinal axis of the plug.

In the open position, the passage in the plug lines up with the inlet and outlet ports of the valve body. When the plug is turned 90° from the open position, the solid part of the plug blocks the ports and stops fluid flow.

Plug valves are available in either a lubricated or a non-lubricated design and with a variety of styles of port openings through the plug as well as a number of plug designs.
Reducing valves automatically reduce supply pressure to a preselected pressure as long as the supply pressure is at least as high as the selected pressure. As illustrated in figure 27, the principal parts of the reducing valve are the main valve; an upward-seating valve that has a piston on top of its valve stem, an upward-seating auxiliary (or controlling) valve, a controlling diaphragm, and an adjusting spring and screw.

Reducing valve operation is controlled by high pressure at the valve inlet and the adjusting screw on top of the valve assembly. The pressure entering the main valve assists the main valve spring in keeping the reducing valve closed by pushing upward on the main valve disk. However, some of the high pressure is bled to an auxiliary valve on top of the main valve. The auxiliary valve controls the admission of high pressure to the piston on top of the main valve. The piston has a larger surface area than the main valve disk, resulting in a net downward force to open the main valve. The auxiliary valve is controlled by a controlling diaphragm located directly over the auxiliary valve.

Source: DOE-HDBK-1018/2-93

Figure 26. Plug valve

Pressure Reducing Valve
A stop check valve, illustrated in figure 28, is a combination of a lift check valve and a globe valve. It has a stem which, when closed, prevents the disk from coming off the seat and provides a tight seal (similar to a globe valve).

When the stem is operated to the open position, the valve operates as a lift check. The stem is not connected to the disk and functions to close the valve tightly or to limit the travel of the valve disk in the open direction.
Swing Check Valve
A swing check valve is illustrated in figure 29. The valve allows full, unobstructed flow and automatically closes as pressure decreases. These valves are fully closed when the flow reaches zero and prevent back flow. Turbulence and pressure drop within the valve are very low. A swing check valve is normally recommended for use in systems employing gate valves because of the low pressure drop across the valve.

Swing check valves are available in either Y-pattern or straight body design. A straight check valve is also available. In either style, the disk and hinge are suspended from the body by means of a hinge pin. Seating is either metal-to-metal or metal seat to composition disk. Composition disks are usually recommended for services where dirt or other particles may be present in the fluid, where noise is objectionable, or where positive shutoff is required.

Source: DOE-HDBK-1018/2-93

Figure 28. Stop check valve
c. Given a drawing of a gate, globe, or check valve, identify the following parts, as applicable:
   - Actuator
   - Ball
   - Body
   - Bonnet
   - Disk
   - Packing
   - Packing gland
   - Packing nuts
   - Plug
   - Stem
   - Seat

This is a performance-based KSA. The Qualifying Official will evaluate its completion. Figures 16 through 29 may be of some help.

d. Describe the principle of operation, construction, and application for the following types of valve actuators:
   - Manual
   - Electric motor
   - Pneumatic
   - Hydraulic
   - Solenoid

The following is taken from DOE-HDBK-1018/2-93.

*Manual*

Manual actuators are the most common type of valve actuators. Manual actuators include hand wheels directly attached to the valve stem, and hand wheels attached through gears to
provide a mechanical advantage. Manual actuators are capable of placing the valve in any position, but do not permit automatic operation.

**Electric Motor**

Electric motor actuators consist of reversible electric motors connected to the valve stem through a gear train that reduces rotational speed and increases torque. Electric motors permit manual, semi-automatic, and automatic operation of the valve. The motor is usually a reversible, high-speed type connected through a gear train to reduce the motor speed and thereby increase the torque at the stem. Direction of motor rotation determines direction of disk motion. The electrical actuation can be semi-automatic, as when the motor is started by a control system. A hand wheel, which can be engaged to the gear train, provides for manual operation of the valve. Limit switches are normally provided to stop the motor automatically at full open and full closed valve positions. Limit switches are operated either physically by position of the valve, or torsionally by torque of the motor.

**Pneumatic**

Pneumatic actuators use air pressure on either one or both sides of a diaphragm to provide the force to position the valve. Pneumatic actuators are used in throttle valves for open-close positioning where fast action is required. When air pressure closes the valve and spring action opens the valve, the actuator is termed direct-acting. When air pressure opens the valve and spring action closes the valve, the actuator is termed reverse-acting.

**Hydraulic**

Hydraulic actuators use a pressurized liquid on one or both sides of a piston to provide the force required to position the valve. Hydraulic actuators provide for semi-automatic or automatic positioning of the valve, similar to the pneumatic actuators. These actuators use a piston to convert a signal pressure into valve stem motion. Hydraulic fluid is fed to either side of the piston while the other side is drained or bled. Water or oil is used as the hydraulic fluid. Solenoid valves are typically used for automatic control of the hydraulic fluid to direct either opening or closing of the valve. Manual valves can also be used for controlling the hydraulic fluid, thus providing semi-automatic operation.

**Solenoid**

Solenoid actuators have a magnetic slug attached to the valve stem. The force to position the valve comes from the magnetic attraction between the slug on the valve stem and the coil of the electromagnet in the valve actuator.

e. **State the purpose and location of body marking (bridge wall markings, flow arrows, etc.)**

Valve markings provide information to ensure correct use, provide quality control (QC) information, and assist in proper installation.

Valve markings are performed in accordance with various standards such as American Petroleum Institute, API-602, American Society of Mechanical Engineers, ASME-B16.34 and Manufacturer’s Standardization Society (MSS) SP-25. MSS SP-25, *Standard Marking*
The body of a valve may be marked with the manufacturer’s trademark, valve class, valve size, material specifications, pressure rating, and/or flow direction. This or some of the information may be included in a name plate affixed to the valve body.

The hand wheel may be marked with letters, symbols, or an arrowhead to indicate the direction to turn the hand wheel in order to open or close the valve.

f. Given a process or system, explain what type of valve is best suited for the application, what type of valve should not be used for the application, and why the valve(s) should or should not be used.

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

g. Discuss the various methods that can be used to determine and verify valve position. Include in your discussion operation and location of position indicators.

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.

Another type is a magnetic switch or transformer that senses movement of the magnetic core, which is 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. Non-rising 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.
h. Describe the proper method to lockout valves using the valve actuators below:
   - Manual
   - Electric motor
   - Pneumatic
   - Hydraulic
   - Solenoid

The following descriptions are taken from DOE-HDBK-1018/2-93.

Manual
Manual actuators are capable of placing the valve in any position but do not permit automatic operation. The most common type mechanical actuator is the hand wheel. This type includes hand wheels fixed to the stem, hammer hand wheels, and hand wheels connected to the stem through gears.

Hand wheels fixed to the stem provide only the mechanical advantage of the wheel. When these valves are exposed to high operating temperatures, valve binding makes operation difficult.

The hammer hand wheel moves freely through a portion of its turn and then hits against a lug on a secondary wheel. The secondary wheel is attached to the valve stem. With this arrangement, the valve can be pounded shut for tight closure or pounded open if it is stuck shut.

Electric Motor
Electric motors permit manual, semi-automatic, and automatic operation of the valve. Motors are used mostly for open-close functions, although they are adaptable to positioning the valve to any point opening as illustrated in figure 30. The motor is usually a reversible, high speed type connected through a gear train to reduce the motor speed and thereby increase the torque at the stem. Direction of motor rotation determines direction of disk motion. The electrical actuation can be semi-automatic, as when the motor is started by a control system. A hand wheel, which can be engaged to the gear train, provides for manual operating of the valve. Limit switches are normally provided to stop the motor automatically at full open and full closed valve positions. Limit switches are operated either physically by position of the valve or torsionally by torque of the motor.
Pneumatic
Pneumatic actuators as illustrated in figure 31 provide for automatic or semiautomatic valve operation. These actuators translate an air signal into valve stem motion by air pressure acting on a diaphragm or piston connected to the stem.

Pneumatic actuators are used in throttle valves for open-close positioning where fast action is required. When air pressure closes the valve and spring action opens the valve, the actuator is termed direct-acting.

When air pressure opens the valve and spring action closes the valve, the actuator is termed reverse-acting. Duplex actuators have air supplied to both sides of the diaphragm. The DP across the diaphragm positions the valve stem. Automatic operation is provided when the air signals are automatically controlled by circuitry. Semi-automatic operation is provided by manual switches in the circuitry to the air control valves.

Source: DOE-HDBK-1018/2-93

Figure 30. Electric motor actuator
Hydraulic

Hydraulic actuators provide for semi-automatic or automatic positioning of the valve, similar to the pneumatic actuators. These actuators use a piston to convert a signal pressure into valve stem motion. Hydraulic fluid is fed to either side of the piston while the other side is drained or bled. Water or oil is used as the hydraulic fluid. Solenoid valves are typically used for automatic control of the hydraulic fluid to direct either opening or closing of the valve. Manual valves can also be used for controlling the hydraulic fluid; thus providing semi-automatic operation.

Solenoid

Solenoid actuated valves provide for automatic open-close valve positioning. Most solenoid actuated valves also have a manual override that permits manual positioning of the valve for as long as the override is manually positioned. Solenoids position the valve by attracting a
magnetic slug attached to the valve stem. In single solenoid valves, spring pressure acts against the motion of the slug when power is applied to the solenoid. These valves can be arranged such that power to the solenoid either opens or closes the valve. When power to the solenoid is removed, the spring returns the valve to the opposite position. Two solenoids can be used to provide for both opening and closing by applying power to the appropriate solenoid.

Single solenoid valves are termed fail open or fail closed depending on the position of the valve with the solenoid de-energized. Fail open solenoid valves are opened by spring pressure and closed by energizing the solenoid. Fail closed solenoid valves are closed by spring pressure and opened by energizing the solenoid. Double solenoid valves typically fail as is. That is, the valve position does not change when both solenoids are de-energized.

One application of solenoid valves is in air systems such as those used to supply air to pneumatic valve actuators. The solenoid valves are used to control the air supply to the pneumatic actuator and thus the position of the pneumatic actuated valve.

9. A facility representative must demonstrate a familiarity level knowledge of compressed air systems.

a. Describe the basic operation of the following types of air compressors:
   - Reciprocating
   - Centrifugal
   - Rotary

The following is taken from DOE-HDBK-1018/2-93.

Reciprocating

The reciprocating air compressor, illustrated in figure 32, is the most common design employed today.

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 33. 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 33B and 33C). This difference in pressure causes the inlet valve to open into the cylinder until the piston reaches the bottom of its stroke (figure 33C).

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 33E). From this point, to the end of the stroke (figures 33E and 33A), the air compressed within the cylinder is discharged at practically constant pressure.

Centrifugal
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 gauge pressure (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.

Source: DOE-HDBK-1018/2-93

Figure 33. Single-acting air compressor cylinder
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 34.

![Simplified centrifugal pump diagram](image)

*Source: DOE-HDBK-1018/2-93*

**Figure 34.** 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 34. The pressure of the air is increased as it is pushed along this path. Note in figure 34 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 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.

**Rotary**

The rotary compressor is adaptable to direct drive by induction motors or multi-cylinder 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 35 has longitudinal vanes, sliding radially in a slotted rotor mounted eccentrically in a cylinder. 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 36, 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.

Source: DOE-HDBK-1018/2-93

Figure 35. Rotary slide vane air compressor

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 37, features a forward-inclined, open impeller, in an oblong cavity filled with liquid.

Source: DOE-HDBK-1018/2-93

Figure 36. Rotary lobe air compressor
As the impeller rotates, the centrifugal force causes the seal liquid to collect at the outer edge of the oblong cavity. 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 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 gases and is commonly used in commercial nuclear plants as a means of establishing initial condenser vacuum.

b. Discuss the uses of pressurized air systems.

The following is taken from DOE-HDBK-1018/2-93.

The rotary compressor is frequently used in specialized applications for the compression of extremely corrosive and exothermic gases and is commonly used in commercial nuclear plants as a means of establishing initial condenser vacuum.

The centrifugal 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.

c. Discuss the following major components of air compressors:

- Low pressure stages
- Intercooler
- High pressure stages
- After cooler
- Moisture separators
- Receivers
- Dryers

The following descriptions are taken from DOE-HDBK-1018/2-93 unless stated otherwise.
Low Pressure and High Pressure Stages

Single-stage and two-stage reciprocating compressors are commercially available. Single-stage compressors are generally used for pressures in the range of 70 psig to 100 psig. Two-stage compressors are generally used for higher pressures in the range of 100 psig to 250 psig.

Intercooler

If the 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 after coolers. The result is drier, cooler, compressed air. The structure of a particular cooler depends on the pressure and volume of the air it cools. Air coolers are used because drier compressed air helps prevent corrosion and cooler compressed air allows more air to be compressed for a set volume.

After Cooler

Coolers used on the discharge of a compressor are called after coolers. 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.

Moisture Separators

The following is taken from Integrated Publishing, Aviation, Moisture Separators.

The moisture separator in a system is always located downstream of the compressor. Its purpose is to remove any moisture caused by the compressor. A complete moisture separator consists of a reservoir, a pressure switch, a dump valve, and a check valve, and it may also include a regulator and a relief valve. The dump valve is energized and de-energized by the pressure switch. When de-energized, it completely purges the separator reservoir and lines up to the compressor. The check valve protects the system against pressure loss during the dumping cycle and prevents reverse flow through the separator.

Receivers

According to the U.S. Army Corps of Engineers, Commissioning of Mechanical Systems for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance Facilities, not all compressed air systems incorporate a receiver. The needs of process equipment and the type and size of the compressors determine the need for a receiver. The receiver provides a cushion for compressed air pulses when a reciprocating compressor is used, a storage volume of air to handle peaks of high usage, and a storage volume of air to allow operation of systems during periods of power loss. Receivers usually provide 1 gallon of capacity for each cubic foot of flow. A liquid trap discharges accumulated condensate and oil to an oil/water separator.

Dryers

The following is taken from Maintenance World, Drying Your Compressed Air System Will Save Real Money.
Dryers remove water vapor from the air, which lowers its dew point—the temperature to which air can be cooled before water vapor begins to condense. In broadest terms, there are four basic types of industrial compressed air dryers: deliquescent, regenerative desiccant, refrigeration, and membrane.

Deliquescent dryers contain a chemical desiccant which absorbs moisture contained in the air, whether the moisture has already condensed or is still a vapor. The desiccant is consumed in the water-removal process and must be replenished periodically. The solution that must be drained from these dryers contains both liquid water and the deliquescent chemical, so disposal may be a problem. Local environmental regulations should be checked before disposal of this solution.

Regenerative desiccant dryers remove water from air by adsorbing it on the surface of a microscopically porous desiccant, usually silica gel, activated alumina, or molecular sieve. The desiccant does not react chemically with the water, so it need not be replenished. However, it must be dried, or regenerated, periodically.

Refrigeration dryers condense moisture from compressed air by cooling the air in heat exchangers chilled by refrigerants. These dryers produce dew points in a range from 35° to 50 °F at system operating pressure.

Membrane-type dryers are gas-separation devices. They consist of miniature membrane tubes made of plastic materials compounded to allow water vapor to pass through when there is a vapor pressure differential. They work as your lungs do, venting water vapor each time you exhale.

Typically this membrane material is formed into bundles of thousands of individual fibers from one end of the dryer to the other. Water vapor escapes through the walls of the fiber to a sweep chamber from where it is continually vented to atmosphere as a gas. A fraction of the dried air is routed through the sweep chamber to continuously purge and exhaust moisture vapor.

10. **A facility representative must demonstrate a working level knowledge of air compressor interlocks and safety.**

   **a. State hazards associated with pressurized air systems.**

   The following is taken from DOE-HDBK-1018/2-93.

   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.

b. State the reason for using cooling systems in air compressors.

The following is taken from DOE-HDBK-1018/2-93.

Cooling systems are required in compressed air systems to remove any heat added by the compression. The advantages to cooling the compressed air are that cool air takes less space and holds less moisture. This reduces corrosion and allows more air to be compressed into a given volume.

c. Describe the safety aspects and typical interlocks associated with air compressors, including:
   - Low oil pressure
   - High compressor discharge pressure
   - High compressor discharge temperature
   - High cooling water outlet temperature
   - Oil in breathing air

The following rotary compressor example is taken from Boss Industries, PTO Air Compressor, Operators, Installation and Parts Manual.

During the compression cycle, oil is injected into the compressor and serves these purposes:
   - Lubricates the rotating parts and bearings
   - Serves as a cooling agent for the compressed air
   - Seals the running clearances

Oil from the compressor oil sump, at compressor discharge pressure, is directed through the oil filter, cooling system, and to the side of the compressor stator, where it is injected into the compressor. At the same time oil is directed internally to the bearings and shaft seal of the compressor. The oil-laden air is then discharged back into the sump.

Oil Sump

Compressed, oil-laden air enters the sump from the compressor. As the oil-laden air enters the sump, most of the oil is separated from the air as it passes through a series of baffles and de-fusion plates. The oil accumulates at the bottom of the sump for re-circulation. However, some small droplets of oil remain suspended in the air and are passed on to the coalescer.
Safety Valve
The pop safety valve is set at 170 psi and is located at the top of the air/oil sump. This valve acts as a backup to protect the system from excessive pressure that might result from a malfunction.

Air/Oil Coalescer
The coalescer is self-contained within a spin-on housing and is independent of the sump. When air is demanded at the service line, it passes through the coalescer, which efficiently provides the final stage of oil separation.

Oil Return Line
The oil that is removed by the coalescer accumulates at the bottom of the can and is returned through an oil return line leading to the compressor. The oil return line also contains a check valve which is located at the compressor.

Minimum Pressure Orifice
The minimum pressure orifice is located at the outlet of the coalescer head and serves to maintain a minimum discharge pressure of 60 psig in operation, which is required to ensure adequate compressor lubrication pressure.

Oil Filter
The compressor oil filter is the full-flow replaceable element type and has a safety by-pass built into it.

Compressor Cooling System
The compressor cooling system consists of an oil cooler, electric fan motor, and fan. The fan/cooler package is self-contained in an aerodynamically designed housing allowing for several optional mounting locations. An automated thermostatic control system maintains a continuous temperature check of the lubricant. It then sends an electrical signal to the fan/cooler package forcing ambient air over the cooler fins ensuring a proper operating temperature.

Electrical and Safety Circuit System
The unit is supplied with a 12 volt (V) DC fan switch, electric fan motor, temperature switch gauge, hour meter, pressure switch gauge, and a shutdown switch. The switch gauges activate a shutdown switch in cases of high discharge temperature or high sump pressure.

Instrumentation
The unit is equipped with a discharge air pressure switch gauge, a discharge air/oil temperature switch gauge, and a 12 volt DC electric hour meter with pressure switch. All components are mounted on a compact instrument panel that can be located where desired.

Compressor Discharge Pressure Switch Gauge
This switch gauge indicates the discharge air/oil pressure. Operate the compressor within discharge pressure limits as indicated in the specifications section. The switch gauge ensures
high pressure safety shutdown before the safety relief valve on the sump is discharged, preventing hot pressurized oil spray on the vehicle and/or compressor components.

Hour Meter
The hour meter records the total number of operating hours. It serves as a guide towards following the recommended inspection and maintenance schedule. The hour meter will only run when there is pressure in the system.

Compressor Discharge Air/Oil Temperature Switch Gauge
This switch gauge indicates compressor air discharge temperature. The switch gauge ensures safety shutdown in case of excessive operating temperatures, preventing compressor damage.

Automatic Blow Down Valves
There may be two blow down valves in the compressor system. One blowdown valve is located at the downstream side of the coalescer head and will automatically bleed the sump to zero pressure when the compressor is disengaged. On vehicles without electronic controlled engines, the other blow down valve (controller blow down valve) is located at the load controller and vents the air in the cylinder when the compressor is disengaged to quickly return the truck’s engine to idle. On compressor units equipped with an electronic speed control the load controller blowdown valve is not required.

Control System
The prime components of the compressor control system include the compressor inlet valve and a load controller. The control system is designed to match air supply to air demand and to prevent excessive discharge pressure when compressor is at idle. Control of air delivery is accomplished by both the inlet valve regulation and load controller modulation as directed by the discharge pressure regulator.

Discharge Pressure Regulator Valve
This valve, located on the load controller (or the coalescer head depending on optional equipment), is used to select the desired discharge pressure within the operating pressure range. Turning the regulator screw clockwise increases the working pressure, a counterclockwise movement of the screw reduces the working pressure.

Inlet Valve
The compressor inlet valve is a piston-operated disc valve that has a dual function of regulating the inlet opening to control capacity and serving as a check valve at shutdown.

On compressor packages with a programmable electronic engine speed control system the compressor will automatically go to high idle when the split shaft is engaged. Depending on the programming variables available on your specific engine the truck may fluctuate between a high-speed setting and a low-speed setting depending upon air demand. Timers are incorporated into this system to eliminate the rapid acceleration and deceleration of the engine during use.
11. A facility representative must demonstrate a working level knowledge of heating, ventilation, and air conditioning system operations.

   a. Describe the following heating, ventilation, and air-conditioning system evolutions and associated precautions and hazards:
      ▪ Start-up and shutdown
      ▪ Normal operation
      ▪ HEPA filter maintenance and testing
      ▪ Ventilation system balancing

   **Startup**
   The following is taken from the HVAC Training Institute, *HVAC Startup, Test & Balance, Commissioning*.

   Each piece of HVAC equipment has a startup checklist; failure to properly startup equipment may void the manufactures warranty.

   The startup process may simply be verification that a fan is spinning in the proper direction and greasing motor bearings up to checking refrigerant charge in chillers and verifying correct amp draw from pumps.

   **Shutdown**
   Shutdown should be accomplished in the reverse order of the startup procedure. Complete drainage of fluids is essential when freezing or accelerated corrosion is possible during the shutdown time period.

   **Normal Operation**
   Controls are used to automate HVAC functions because the processes tend to be “On-Off” rather than variable. Cooling or heating air is supplied at design rates (e.g., 100 percent) until the desired temperature is reached. The function of the controls (e.g., thermostats or expansion valves) is usually to sense demand and either actuate or de-actuate.

   **HEPA Filter Maintenance and Testing**
   The following example of testing nuclear grade filters used in a confinement system is taken from DOE-HDBK-1169-2003.

   High efficiency particulate air (HEPA) filters for nuclear service now undergo four tests: 1) a design qualification test performed by a qualified laboratory, 2) QC testing at the manufacturer, 3) a DOE-required acceptance test, and 4) a system leak test at the facility where the filter will be used. Manufacturers submit prototype filters for design qualification testing. This testing examines areas such as media penetration and resistance to airflow, rough handling, pressure, heated air, and spot flame. The filter medium receives the most rigorous and extensive control and evaluation. At present, the U.S. Army’s Edgewood Arsenal in Maryland is the only facility available to perform this qualification testing. This testing is required to be repeated every five years.

   DOE-STD-3022-98, *DOE HEPA Filter Test Program*, requires further acceptance testing of HEPA filters that will be used in DOE nuclear facilities. This testing must be performed at a
DOE filter test facility (FTF). Manufacturers are required to submit their HEPA filters to the DOE FTF.

After being installed at a DOE nuclear facility, an in-place leak test is done to ensure the performance of the confinement ventilation system. Unlike bench tests for new filters that are designed to determine filter quality via a penetration test utilizing an aerosol containing a substantial fraction of particles in the range of the minimum filterable size, in-place tests are designed to reveal the presence of defects in the filter unit that result from such things as rough handling during transportation, paper and gasket damage during installation, inadequate pressure against intact gaskets, and penetrations through the housing to which the filter units are attached. Aerosol penetration during an in-place test in excess of established limits is assumed to indicate defective installation and/or filter damage. Procedures are conducted to locate and correct the defects. Such procedures include increasing gasket compression; examining gaskets for breaks and tears; replacing broken filters (repairs are not permitted for nuclear service in the United States); and welding closed any unauthorized penetrations, cracks, and open seams in the filter house and mounting frames (patching with caulking compounds is not permitted for nuclear service in the United States). Following each repair, the system must be retested until it meets the established criteria for leak tightness.

Ventilation System Balancing
The following is taken from the HVAC Training Institute, HVAC Startup, Test & Balance, Commissioning.

When HVAC equipment is started up, the system must be “balanced” so that the correct air and water flows are present during normal system operation.

From the airside, the balancing technician will slow equipment fans up or down and may even need to change belts or pulleys to achieve the desire flow out of the equipment. The air coming out the ceiling diffusers is usually controlled by a damper off the rectangular duct above the ceiling. Having a volume damper in the face of the grille itself is not recommended because, although it is easier to adjust the airflow at the ceiling, volume dampers in the face of the diffusers are notorious for whistling and rattling over time.

The water side of an HVAC system must also be balanced whether from a chiller, cooling tower, or boiler. The water flow is typically adjusted at a pump and may be as simple as speeding up or slowing the pump or a complicated as replacing the internal components to the pump itself.

b. Describe the purpose of the HVAC system in the following applications:
   - Hoods
   - Gloveboxes
   - Hot cells
   - Confinement systems

Hoods
The following is taken from DOE-HDBK-1169-2003.
The wide, often unpredictable variety of chemical operations conducted in laboratory fume hoods makes selection and installation of HEPA filters difficult and uncertain. Corrosive fumes may damage the filter and its mounting, and moisture and heat from hood operations may accelerate that damage. Operations that produce steam or moisture should be restricted to minimize condensation in the filter or the carryover of water and/or chemical droplets to the filter. The system should be designed so that any droplets will be vaporized prior to reaching the HEPA filter.

Some facilities install fume hood filters in the attic, usually directly above the hood served. Where this design is employed, the attic space should be designed as a confinement zone for easy cleanup in the event of a spill, and should not be used for extraneous purposes such as storage and experimental work when radioactive materials are handled in the hood.

Hood installations in which perchloric acid and certain other chemicals are handled should be provided with wash-down facilities to permit periodic decontamination of the hood and ductwork (perchloric acid hoods should not be used for handling other materials because of the explosion hazard). Offgas scrubbers are often provided in hoods. Both wash-down facilities and scrubbers generate substantial quantities of water droplets. Provision of demisters that meet the requirements should be considered to protect the filters and their mountings. Moisture collected in the demister should be conducted to a hood drain rather than permitted to fall into the workspace of the hood. Demisters should have adequate handling space and be easily accessible for cleaning, inspection, and replacement. Where incandescent particles or flaming trash can be released to the hood exhaust stream, a spark arrester may be needed to protect the HEPA filter. This arrester can be either a commercial flame arrester, a metal-mesh graded-density demister, or at minimum, a piece of 40-mesh metal cloth. In any event, it is recommended that the arrester be located at least 1 foot ahead of the HEPA filter and must be easily accessible for cleaning, inspection, and replacement.

Heat sources such as heating mantles, furnaces, and Bunsen burners are common equipment in laboratory fume hoods and should be planned for in the initial hood and exhaust system design. Designers should control heat-producing operations by limiting the size of heat sources, insulating furnaces, etc., or using air cooling methods.

**Gloveboxes**

The following is taken from DOE-STD-1128-2008.

Gloveboxes should be designed to operate at a negative pressure (0.75 ± 0.25 inch [in.] water gage (wg) with respect to the room in which they are operated. Differential pressure gauges should be installed on each glovebox or integrally connected series of gloveboxes. During abnormal conditions, control devices to prevent excessive pressure or vacuum should be either positive-acting or automatic or both. The ventilation system should be designed to provide and maintain the negative pressure during normal operations and the flow through a breach. There should be exhaust capacity on demand that will promptly cause an inflow of air greater than 125 linear feet per minute through a breach of at least a single glovebox penetration of the largest size possible. Filters, scrubbers, demisters, and other air-cleaning devices should be provided to reduce the quantities of toxic or noxious gases and airborne particulates that enter the ventilation system prior to its entry into the exhaust system.
Each glovebox or integrally connected series of gloveboxes should be equipped with an audible alarm that alerts personnel when a system pressure or vacuum loss is occurring. The alarm should be set at -0.5 in. wg relative to the room in which the glovebox is located. The number of penetrations for glovebox services should be minimized. The fittings should provide a positive seal to prevent the migration of radioactive material. For the same reason, penetrations for rotating shafts should not be permitted except where rotating shafts have seals. Seals for rotating shafts are very reliable and are preferred to motors inside the glovebox. Vacuum systems connected to a glovebox should be designed to prevent an evacuation and possible implosion of the glovebox.

Any gas-supply system connected directly to a glovebox should be designed to prevent pressurization, flow in excess of the exhaust capacity, and backflow.

Flammable or combustible gases should not be used in gloveboxes but if required, should be supplied from the smallest practical size of cylinders. Flammable gas piped to a plutonium processing building should not enter the building at a pressure exceeding 6 in. water. Vacuum pump exhaust should be filtered and exhausted to the glovebox or other acceptable exhaust system.

If process water is provided to a glovebox and the water must be valved on when the box is unattended, a system should be installed to automatically close a block valve in the water-supply line if a buildup of water is detected on the box floor or in the box sump.

Process piping to and from gloveboxes should be equipped with backflow prevention devices and should be of welded stainless steel construction. Vacuum breaker-type devices are generally more reliable than other types.

Glovebox components, including windows, gloves, and sealants, should be of materials that resist deterioration by chemicals and radiation.

Glove ports should be designed to allow for the replacement of gloves while maintaining control of radioactive material. The ports should be located to facilitate both operating and maintenance work. The need for two-handed operation, depth of reach, mechanical strength, and positioning with respect to other ports should be considered in the design. Covers or plugs should be provided for each port. The covers or plugs should provide shielding equivalent to the glovebox walls. Automatic glove-changing systems should be considered.

**Hot Cells**

According to the Nondestructive Testing Resource Center, a hot cell is a heavily shielded and environmentally controlled enclosure in which radioactive materials can be handled remotely with manipulators and viewed through shielding windows to limit danger to operating personnel. Ventilation requirements are similar to those required for a secondary confinement zone, which is described in the following paragraphs, under “Confinement Systems.”

**Confinement Systems**

The following is taken from DOE-STD-1128-2008.
The confinement system is a series of physical barriers that, together with a ventilation system, minimizes the potential for release of radioactive material into work areas and the environment under normal and abnormal conditions. The primary design objective for the confinement system should be to minimize exposure of the public and plant personnel to airborne contamination. Plutonium should be separated from the ambient environment by at least two barriers and from an operator by at least one barrier.

Primary confinement refers to the barrier that is or can be directly exposed to plutonium, e.g., sealed process equipment (pipes, tanks, hoppers), gloveboxes, confinement boxes, open-faced hoods, conveyors, caissons, and cells and their ventilation systems. The primary confinement barrier prevents the dispersion of plutonium through either sealed construction or atmospheric pressure differential or a combination of both. For example, process equipment that is not sealed but contains plutonium material in process should be enclosed in gloveboxes or other confinement barriers. Fuel-rod cladding, bags, and other sealed containers can be considered primary confinement. The chemical reactivity and the heat generation effect of the plutonium compound should be considered when selecting primary confinement material.

The primary confinement barrier protects operators from contamination under normal operating conditions. This type of barrier is likely to be breached under accident conditions (e.g., glove rupture, damaged seals, improper bag-out operations, or leaks of flanged joints).

The primary confinement (with the exceptions of fuel rods, sealed sources, or sealed cans) should be maintained at a negative air pressure with respect to the secondary confinement in which it is located, and it should be exhausted through a ventilation system that uses HEPA filters. The barrier and its accessory equipment should be designed to prevent accidental flooding. All primary confinement piping joints should be tested for leak tightness. Penetrations in the primary confinement barrier, such as conduit, ports, ducts, pipes, and windows, should be protected against the release of radioactive material.

Where necessary, recycle ventilation systems may be used in process enclosures, hot cells, and canyons. Inert gas systems should be designed as recycle systems, unless it is impracticable to do so. Recycled inert gas systems should be maintained completely within the primary barrier system. Extreme caution should be exercised in the use of recycle systems for contaminated or potentially contaminated air. A recirculation system should not direct air to an area where the actual or potential contamination is less than the area from which the air originated. The decision to use a recirculation system in a contaminated area should be based on a documented safety evaluation that compares the risks versus the benefits. Filtration should be provided to limit the concentrations of radioactive material in recirculated air to as-low-as-reasonably-achievable levels. The design should allow for in-place testing of HEPA filters or filter banks.

Continuous sampling and monitoring of recirculated air for airborne radioactive material should be provided downstream of fans and filters. Monitoring should be provided for the DP across the filter stages and for airborne radioactive material behind the first HEPA filter or filter stage. The means for automatic or manual diversion of airflow to a once-through system or stage should be provided. The monitoring system alarm should result in the
automatic diversion of airflow to a once-through system or a parallel set of filters if an automatic system is used.

The secondary confinement barrier encloses the room or compartment in which the primary confinement barrier is located, and provides contamination protection for plant personnel who are outside of the secondary confinement area. HEPA filtration should be required for air supplied to and exhausted from a secondary confinement barrier. Secondary confinement rooms, compartments, or cells should be separated from each other by fire doors or stops. Both the barrier walls and the fire doors should be constructed of materials that are capable of withstanding a design basis accident. The secondary confinement should be designed for pressures that are consistent with the criteria for the ventilation system. The secondary confinement area should be at a positive air pressure with respect to the primary confinement areas and at negative pressure with respect to the outside environment and adjacent building areas that are not primary or secondary barriers.

The building is the structure that encloses the primary and secondary confinement barriers, as well as the offices, change rooms, and other support areas that are not expected to become contaminated. It is the final barrier between the potential contamination and the outside environment. The building structure or any portion thereof may serve as the secondary confinement barrier if the requirements for both structure and confinement are met. The portion of the structure that houses activities involving radioactive material in a dispersible form should be able to withstand design basis accidents, site-related natural phenomena, and missiles without a breach of integrity that would result in releases of radioactive material from the structure in excess of DOE guidelines.

c. Discuss the reason for and significance of the following system parameters:
   - Positive vs. negative system pressure
   - Differential pressure across filters
   - Differential pressure across components

Positive vs. Negative System Pressure

The following is taken from EPA, *Basic Concepts in Environmental Sciences*.

When fans used in industrial systems create gas static pressures above the prevailing atmospheric pressure, the condition is termed positive pressure. When the fans create a gas static pressure below the prevailing atmospheric pressure, negative pressure exists. Both positive and negative pressures are considered relative terms because the static pressure is being described in a form that is compared to the atmospheric pressure.

The static pressure exerted by ambient air is termed either atmospheric or barometric pressure. The atmospheric pressure is an absolute pressure because it is directly related to the number of molecules and their kinetic energy. A barometer measures atmospheric pressure by comparing the pressure of the air against a chamber that approximates a vacuum.

Negative pressure for a system is desirable when that system contains hazardous materials as the negative pressure helps minimize the spread of contaminants in case of an accident. Some facilities require certain systems to be maintained at a negative pressure and make it a safety significant requirement.
A positive pressure system helps prevent or minimize the entry of contamination or contaminants into equipment or a facility from the outside.

Differential Pressure across Filters
The following is taken from DOE-HDBK-1169-2003.

Differential pressure gauges should be installed to monitor dirt loading on the HEPA and pre-filter. Individual gauges for both stages of filtration are desirable. Since the flow rate through a portable system can change significantly depending on ductwork routing and damper adjustments, the user must be aware that observed changes on the DP gauge may not be due to dirt only, but may instead reflect a change in the air velocity through the filter element. For this reason, it is necessary to ensure that, when assessing dirt loading on the filters over time, DP readings are taken under the same flow conditions. Alarms that indicate high filter DP, as well of loss of airflow (which can be indicated by a very low filter DP), are also good features.

The same general caution about the effect of air velocity on filter DP would apply to these alarms as well. As DP across a filter increases, it indicates an increase in the amount of material contained (trapped) in the filters. In radioactive systems, this may lead to increased radiation levels above what is prescribed in the documented safety analysis (DSA).

Differential Pressure across Components
According to the National Institute for Occupational Safety and Health, *A Comparative Evaluation of the Differential-Pressure-Based Respirable Dust Dosimeter with the Personal Gravimetric Respirable Dust Sampler in Underground Coal Mines*, as DP across a component increases, it indicates an increase in the amount of material that settles on the component. For radioactive systems, this may lead to increased radiation levels above what is prescribed in the DSA.

12. A facility representative must demonstrate a familiarity level knowledge of basic electrical fundamentals in the areas of terminology and theory.

   a. Discuss the following terms:
      - Electrostatic force
      - Electrostatic field
      - Conductor
      - Insulator
      - Resistor

The following definitions are taken from DOE-HDBK-1011/1-92.

*Electrostatic Force*
One of the mysteries of the atom is that the electron and the nucleus attract each other. This attraction is called electrostatic force, the force that holds the electron in orbit. Without this electrostatic force, the electron, which is traveling at high speed, could not stay in its orbit.

*Electrostatic Field*
A special force acts between charged objects. Forces of this type are the result of an electrostatic field that exists around each charged particle or object. Charged objects repel or
attract each other because of the way these fields act together. This force is present with every charged object. When two objects of opposite charge are brought near one another, the electrostatic field is concentrated in the area between them. When two objects of like charge are brought near one another, the lines of force repel each other. The strength of the attraction or of the repulsion force depends upon two factors: (1) the amount of charge on each object, and (2) the distance between the objects. The greater the charge on the objects, the greater the electrostatic field will be. The greater the distance between the objects, the weaker the electrostatic field between them, and vice versa. This leads us to the law of electrostatic attraction, commonly referred to as Coulomb’s law of electrostatic charges, which states that the force of electrostatic attraction, or repulsion, is directly proportional to the product of the two charges and inversely proportional to the square of the distance between them.

Conductor
Conductors are materials with electrons that are loosely bound to their atoms, or materials that permit free motion of a large number of electrons. Atoms with only one valence electron, such as copper, silver, and gold, are examples of good conductors. Most metals are good conductors.

Insulator
Insulators, or nonconductors, are materials with electrons that are tightly bound to their atoms and require large amounts of energy to free them from the influence of the nucleus. The atoms of good insulators have their valence shells filled with eight electrons, which means they are more than half filled. Any energy applied to such an atom will be distributed among a relatively large number of electrons. Examples of insulators are rubber, plastics, glass, and dry wood.

Resistor
Resistors are made of materials that conduct electricity, but offer opposition to current flow. These types of materials are also called semiconductors because they are neither good conductors nor good insulators. Semiconductors have more than one or two electrons in their valence shells, but less than seven or eight. Examples of semiconductors are carbon, silicon, germanium, tin, and lead. Each has four valence electrons.

b. Describe the following parameters and their relationship:
- Voltage
- Current
- Resistance
- Ohm’s Law
- Power
- Inductance
- Capacitance

The following descriptions are taken from DOE-HDBK-1011/1-92.

Voltage
Voltage is described as the pressure or force that causes electrons to move in a conductor. In electrical formulas and equations, you will see voltage symbolized by a capital (E), while on laboratory equipment or schematic diagrams the voltage is often represented by a capital (V).
Current
Electron current, or amperage, is described as the movement of free electrons through a conductor. In electrical formulas, current is symbolized by a capital (I), while in the laboratory or on schematic diagrams, it is common to use a capital (A) to indicate amps or amperage.

Resistance
Resistance is defined as the opposition to current flow. The amount of opposition to current flow produced by a material depends on the amount of available free electrons it contains and the types of obstacles the electrons encounter as they attempt to move through the material.

Resistance is measured in ohms and is represented by the symbol (R) in equations; the shorthand notation is the Greek letter capital omega (Ω). One ohm is defined as that amount of resistance that will limit the current in a conductor to one ampere when the potential difference (voltage) applied to the conductor is one V. If a voltage is applied to a conductor, current flows. The amount of current flow depends upon the resistance of the conductor. The lower the resistance, the higher the current flow for a given amount of voltage; the higher the resistance, the lower the current flow for a given amount of voltage.

Ohm’s Law
Ohm’s law defines the relationship between voltage, current, and resistance in an electrical circuit. Ohm’s law can be stated in three ways:

Applied voltage equals circuit current times the circuit resistance. This is represented by the equation:

\[ E = I \times R \]

Current is equal to the applied voltage divided by the circuit resistance. This is represented by the equation:

\[ I = \frac{E}{R} \]

Resistance of a circuit is equal to the applied voltage divided by the circuit current:

\[ R \text{ (or } \Omega) = \frac{E}{I} \]

where:
I = current (A)
E = voltage (V)
R = resistance (Ω)

If any two of the component values are known, the third can be calculated.

Power
Electricity is generally used to do some sort of work, such as turning a motor or generating heat. Specifically, power is the rate at which work is done, or the rate at which heat is generated. The unit commonly used to specify electric power is the watt. In equations, power
is symbolized by the capital letter (P), and watts, the units of measure for power, are symbolized by the capital letter (W). Power is also described as the current (I) in a circuit times the voltage (E) across the circuit.

**Inductance**
Inductance is defined as the ability of a coil to store energy, induce a voltage in itself, and oppose changes in current flowing through it. The symbol used to indicate inductance in electrical formulas and equations is a capital (L). The unit of measurement is a Henry (H), and one Henry is defined as the amount of inductance that permits one V to be induced when the current through the coil changes at a rate of one ampere per second. The mathematical representation of the rate of change in current through a coil per unit of time is as follows:

\[ \frac{\Delta I}{\Delta t} \]

**Capacitance**
Capacitance, measured in farads, is equal to the amount of charge that can be stored in a device or capacitor divided by the voltage applied across the device or capacitor plates when the charge was stored. Capacitance is defined as the ability to store an electric charge.

13. **A facility representative must demonstrate a familiarity level knowledge of basic electrical fundamentals in the area of direct current (DC).**

a. **Discuss the basic principle by which the following components produce DC:**
   - Battery
   - DC Generator
   - Thermocouple

The following is taken from DOE-HDBK-1011/1-92.

**Battery**
A battery consists of two or more chemical cells connected in series. The combination of materials within a battery is used for the purpose of converting chemical energy into electrical energy. The chemical cell is composed of two electrodes made of different types of metal or metallic compounds which are immersed in an electrolyte solution. The chemical actions which result are complicated, and they vary with the type of material used in cell construction. Some knowledge of the basic action of a simple cell will be helpful in understanding the operation of a chemical cell in general.

In the cell, electrolyte ionizes to produce positive and negative ions (part A in figure 38). Simultaneously, chemical action causes the atoms within one of the electrodes to ionize.
Due to this action, electrons are deposited on the electrode, and positive ions from the electrode pass into the electrolyte solution (part B). This causes a negative charge on the electrode and leaves a positive charge in the area near the electrode (part C).

The positive ions, which were produced by ionization of the electrolyte, are repelled to the other electrode. At this electrode, these ions will combine with the electrons. Because this action causes removal of electrons from the electrode, it becomes positively charged.

**DC Generator**
A simple DC generator consists of an armature coil with a single turn of wire. The armature coil cuts across the magnetic field to produce a voltage output. As long as a complete path is present, current will flow through the circuit in the direction shown by the arrows in figure 39. In this coil position, commutator segment 1 contacts with brush 1, while commutator segment 2 is in contact with brush 2.

Rotating the armature one-half turn in the clockwise direction causes the contacts between the commutator segments to be reversed. Now segment 1 is contacted by brush 2, and segment 2 is in contact with brush 1.
Due to this commutator action, that side of the armature coil which is in contact with either of the brushes is always cutting the magnetic field in the same direction. Brushes 1 and 2 have a constant polarity, and pulsating DC is delivered to the load circuit.

**Thermocouple**
A thermocouple (TC) is a device used to convert heat energy into a voltage output. The thermocouple consists of two different types of metal joined at a junction.

As the junction is heated, the electrons in one of the metals gain enough energy to become free electrons. The free electrons will then migrate across the junction and into the other metal. This displacement of electrons produces a voltage across the terminals of the TC. The combinations used in the makeup of a TC include: iron and constantan; copper and constantan; antimony and bismuth; and chromel and alumel. Thermocouples are normally used to measure temperature. The voltage produced causes a current to flow through a meter, which is calibrated to indicate temperature.

**b. Discuss the purpose of a rectifier.**

The following is taken from DOE-HDBK-1011/1-92.

The purpose of a rectifier circuit is to convert alternating current (AC) power to direct current (DC). Most electrical power generating stations produce AC. The major reason for generating AC is that it can be transferred over long distances with fewer losses than DC; however, many of the devices which are used today operate only, or more efficiently, with DC. For example, transistors, electron tubes, and certain electronic control devices require
DC for operation. If we are to operate these devices from ordinary AC outlet receptacles, they must be equipped with rectifier units to convert AC to DC. In order to accomplish this conversion, we use diodes in rectifier circuits. The most common type of solid state diode rectifier is made of silicon. The diode acts as a gate, which allows current to pass in one direction and blocks current in the other direction. The polarity of the applied voltage determines if the diode will conduct. The two polarities are known as forward bias and reverse bias.

c. **Discuss the following terms:**
   - Resistivity
   - Electric circuit
   - Series circuit
   - Parallel circuit

The following definitions are taken from DOE-HDBK-1011/1-92.

**Resistivity**

Resistivity is defined as the measure of the resistance a material imposes on current flow. The resistance of a given length of conductor depends upon the resistivity of that material, the length of the conductor, and the cross-sectional area of the conductor, as shown in the following equation.

\[
R = \frac{\rho L}{A}
\]

where:
- \( R \) = resistance of conductor, \( \Omega \)
- \( \rho \) = specific resistance or resistivity, centimeter (cm)-\( \Omega \)/foot (ft)
- \( L \) = length of conductor, ft
- \( A \) = cross-sectional area of conductor, cm

The resistivity \( \rho \) allows different materials to be compared for resistance, according to their nature, without regard to length or area. The higher the value of \( \rho \), the higher the resistance will be.

**Electric Circuit**

Each electrical circuit has at least four basic parts: 1) a source of electromotive force, 2) conductors, 3) a load or loads, and 4) some means of control.

**Series Circuit**

A series circuit is a circuit where there is only one path for current flow. In a series circuit, the current will be the same throughout the circuit. This means that the current flow through \( R_1 \) is the same as the current flow through \( R_2 \) and \( R_3 \) as shown in figure 40.
Parallel circuits are those circuits that have two or more components connected across the same voltage source. Resistors $R_1$, $R_2$, and $R_3$ in figure 41 are in parallel with each other and the source. Each parallel path is a branch with its own individual current. When the current leaves the source $V$, part $I_1$ of $I_T$ will flow through $R_1$; part $I_2$ will flow through $R_2$; and part $I_3$ will flow through $R_3$. Current through each branch can be different; however, voltage throughout the circuit will be equal.

$$V = V_1 = V_2 = V_3$$
d. Discuss the following terms:
   - Battery
   - Electrode
   - Electrolyte
   - Specific gravity
   - Ampere-hour

The following is taken from DOE-HDBK-1011/2-92.

*Battery*
A battery is a group of two or more connected voltaic cells.

*Electrode*
An electrode is a metallic compound, or metal, which has an abundance of electrons (negative electrode) or an abundance of positive charges (positive electrode).

*Electrolyte*
An electrolyte is a solution which is capable of conducting an electric current. The electrolyte of a cell may be a liquid or a paste. If the electrolyte is a paste, the cell is referred to as a dry cell; if the electrolyte is a solution, it is called a wet cell.

*Specific Gravity*
Specific gravity is defined as the ratio comparing the weight of any liquid to the weight of an equal volume of water. The specific gravity of pure water is 1.000. Lead-acid batteries use an electrolyte which contains sulfuric acid. Pure sulfuric acid has a specific gravity of 1.835, since it weighs 1.835 times as much as pure water per unit volume.
Ampere-Hour
An ampere-hour is defined as a current of one ampere flowing for one hour. Ampere-hours are normally used to indicate the amount of energy a storage battery can deliver.

e. Describe in basic terms what happens when a lead-acid battery is charged and discharged.

The following is taken from DOE-HDBK-1011/2-92.

In a lead-acid battery, two types of lead are acted upon electro-chemically by an electrolytic solution of diluted sulfuric acid. The positive plate consists of lead peroxide, and the negative plate is sponge lead, shown in figure 42.

\[
PbO_2 + Pb + 2H_2SO_4 \xrightarrow{charge} 2PbSO_4 + 2H_2O
\]

Source: DOE-HDBK-1011/2-92

Figure 42. Chemical action during discharge

When a lead-acid battery is discharged, the electrolyte divides into hydrogen \((H_2)\) and sulfate\((SO_4)\). The \(H_2\) will combine with some of the oxygen that is formed on the positive plate to produce water \((H_2O)\), and thereby reduce the amount of acid in the electrolyte. The \(SO_4\) combines with the lead \((Pb)\) of both plates, forming lead sulphate \((PbSO_4)\), as shown below.
As a lead-acid battery is charged in the reverse direction, the action described in the discharge is reversed. The lead sulphate (\(\text{PbSO}_4\)) is driven out and back into the electrolyte (\(\text{H}_2\text{SO}_4\)). The return of acid to the electrolyte will reduce the \(\text{SO}_4\) in the plates and increase the specific gravity. This will continue to happen until all of the acid is driven from the plates and back into the electrolyte. As a lead-acid battery charge nears completion, hydrogen (\(\text{H}_2\)) gas is liberated at the negative plate, and \(\text{O}_2\) gas is liberated at the positive plate. This action occurs since the charging current is usually greater than the current necessary to reduce the remaining amount of (\(\text{PbSO}_4\)) on the plates. The excess current ionizes the water (\(\text{H}_2\text{O}\)) in the electrolyte.

The decrease in specific gravity on discharge is proportional to the ampere-hours discharged. While charging a lead-acid battery, the rise in specific gravity is not uniform, or proportional, to the amount of ampere-hours charged.

**f. Describe the relationship between voltage and current-carrying capacity for series-connected versus parallel-connected batteries.**

The following is taken from DOE-HDBK-1011/2-92.

**Series Cells**

When several cells are connected in series, the total voltage output of the battery is equal to the sum of the individual cell voltages. Therefore, four 1.5-volt cells connected in series provide a total of 6 volts. When cells are connected in series, the positive terminal of one cell is connected to the negative terminal of the next cell. The current flow through a battery connected in series is the same as for one cell.

**Parallel Cells**

Cells connected in parallel give the battery a greater current capacity. When cells are connected in parallel, all the positive terminals are connected together, and all the negative terminals are connected together. The total voltage output of a battery connected in parallel is the same as that of a single cell. Cells connected in parallel have the same effect as increasing the size of the electrodes and electrolyte in a single cell. The advantage of connecting cells in parallel is that it will increase the current-carrying capability of the battery.

**g. Describe the hazards associated with lead-acid storage batteries.**

The following is taken from DOE-HDBK-1011/2-92.

Short circuits cause a great reduction in battery capacity. To prevent short circuits in a battery, overcharging and over discharging should be avoided at all costs.

The adverse effect of gassing is that if gassing occurs and the gases are allowed to collect, an explosive mixture of hydrogen and oxygen can be readily produced. To reduce the amount of gassing, charging voltages above 2.30 volts per cell should be minimized.

Whenever the battery is charged, the current flowing through the battery will cause heat to be generated by the electrolysis of water and by \(I_2R_1\) power generation. 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. Adequate ventilation helps mitigates the adverse effects of battery charging.

14. **A facility representative must demonstrate a familiarity level knowledge of basic electrical fundamentals in the area of alternating current (AC).**

a. **Discuss the basic theory of operation of an AC generator.**

The following is taken from DOE-HDBK-1011/3-92.

The elementary AC generator (figure 43) 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 in the other.

**Source:** DOE-HDBK-1011/3-92

**Figure 43. Simple AC generator**

At the instant the loop is in the vertical position (0°), the coil sides are moving parallel to the field and do not cut magnetic lines of force. In this instant, there is no voltage induced in the loop. As the coil rotates in a counter-clockwise direction, the coil sides will cut the magnetic lines of force in opposite directions. The direction of the induced voltages depends on the direction of movement of the coil. The induced voltages add in series, making slip ring X 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 (90°). 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 (180°). In the other half revolution, an equal voltage is produced except that the polarity is reversed (270°, 360°). The current flow through R is now from X to Y. The periodic reversal of polarity results in the generation of a voltage, as shown in figure 44. The rotation of the coil through 360° results in an AC sine wave output.

Source: DOE-HDBK-1011/3-92

**Figure 44.** Developing a sine wave voltage

A simple generator consists of a conductor loop turning in a magnetic field, cutting across the magnetic lines of force. The sine wave output is the result of one side of the generator loop cutting lines of force. In the first half turn of rotation, this produces a positive current, and in the second half of rotation, this produces a negative current. This completes one cycle of AC generation.

A simple AC generator consists of

- a strong magnetic field
- conductors that rotate through that magnetic field
a means by which a continuous connection is provided to the conductors as they are rotating.

The strong magnetic field is produced by a current flow through the field coil of the rotor. The field coil in the rotor receives excitation through the use of slip rings and brushes. Two brushes are spring-held in contact with the slip rings to provide the continuous connection between the field coil and the external excitation circuit. The armature is contained within the windings of the stator and is connected to the output. Each time the rotor makes one complete revolution, one complete cycle of AC is developed. A generator has many turns of wire wound into the slots of the rotor.

The magnitude of AC voltage generated by an AC generator is dependent on the field strength and speed of the rotor. Most generators are operated at a constant speed; therefore, the generated voltage depends on field excitation, or strength.

b. Discuss the reasons that three-phase power systems are used in industry.

The following is taken from DOE-HDBK-1011/3-92.

Three-phase power systems are used in industry because three-phase circuits weigh less than single-phase circuits of the same power rating; they have a wide range of voltages, and can be used for single-phase loads; three-phase equipment is smaller in size, weighs less, and is more efficient than single-phase equipment.

c. Discuss the basic theory of operation of an AC motor.

The following is taken from DOE-HDBK-1011/4-92.

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.

d. Discuss the basic theory of operation of a transformer.

The following is taken from DOE-HDBK-1011/4-92.

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).

When alternating voltage is applied to the primary winding, an AC will flow that will magnetize the magnetic core, first in one direction and then in the other direction. This alternating flux flowing around the entire length of the magnetic circuit induces a voltage in both the primary and secondary windings. Since both windings are linked by the same flux, the voltage induced per turn of the primary and secondary windings must be of the same
value and same direction. This voltage opposes the voltage applied to the primary winding and is called counter-electromotive force.

15. A facility representative must demonstrate a working level knowledge of basic electrical fundamentals in the area of electrical distribution systems.

a. Explain the following terms as they apply to electrical distribution systems:
   - Single-line diagram
   - Neutral grounding
   - Protective relays
   - Uninterruptible power supply
   - Automatic transfer switch
   - Diesel generator

The following definitions are taken from Pantex Plant vendor manuals and drawings.

Single-Line Diagram
When dealing with a large power distribution system, a special type of schematic diagram called an electrical single line is used to show all or part of the system. This type of diagram depicts the major power sources, breakers, loads, and protective devices, thereby providing a useful overall view of the flow of power in a large electrical power distribution system.

On power distribution single lines, even if it is a three-phase system, each load is commonly represented by only a simple circle with a description of the load and its power rating (running power consumption). Unless otherwise stated, the common units are kilowatts (kW). A single, or one-line, diagram of a distribution system is a simple and easy-to-read diagram showing power supplies, loads, and major components in the distribution system.

Neutral Grounding
Neutral grounding in electrical distribution systems helps prevent accidents to personnel and damage to property caused by: fire, lightning; a breakdown between primary and secondary windings of transformers; or accidental contact of high-voltage wires and low-voltage wires. If some point on the circuit is grounded (in this case neutral ground), lightning striking the wires will be conducted into the ground, and breakdown between the primary and secondary windings of a transformer will cause the primary transformer fuses to blow. Another advantage of neutral grounding is that it reduces the amount of insulation required for high-voltage transmission lines.

Protective Relays
Protective relays are designed to cause the prompt removal of any part of a power system that might cause damage or interfere with the effective and continuous operation of the rest of the system. Protective relays are aided in this task by circuit breakers that are capable of disconnecting faulty components or subsystems.

Protective relays can be used for types of protection other than short circuit or over current. The relays can be designed to protect generating equipment and electrical circuits from any undesirable condition, such as under voltage, under frequency, or interlocking system lineups.
There are only two operating principles for protective relays: 1) electromagnetic attraction, and 2) electromagnetic induction. Electromagnetic attraction relays operate by a plunger being drawn up into a solenoid or an armature that is attracted to the poles of an electromagnet. This type of relay can be actuated by either DC or AC systems. Electromagnetic induction relays operate on the induction motor principle whereby torque is developed by induction in a rotor. This type of relay can be used only in AC circuits.

Uninterruptible Power Supply

An uninterruptible power supply (UPS) provides emergency power to selected loads by supplying power from a separate source in the event that utility (primary) power is lost. While not limited to safeguarding any particular type of equipment, a UPS system is designed to protect critical safety loads from anomalies commonly encountered from power utilities by providing uninterrupted, transient-free power to designated critical safety systems, regardless of source voltage or frequency variations.

Most UPSs are continuously on-line and ready to instantaneously pick up critical loads upon a loss of normal power, as opposed to an off-line system where the load is powered directly by the input power and the backup power circuitry is only invoked when the utility power fails. The on-line system has the additional advantage of protecting equipment that is very sensitive to power line fluctuations or noise (interference). Utility AC power usually contains undesirable electrical signals which distort or interfere with the desired signal (a typical cause is the 50 or 60 Hz AC hum from power circuits or interference from electrical storms) and passing the AC input through the UPS rectifier/inverter circuitry cleans up the signal. This helps prevent false alarms or equipment activation due to noise or power fluctuations.

A UPS, along with its associated battery bank and emergency power panel, constitutes an emergency power system. Typical building units are rated anywhere from 5—50 kilovolt ampere and provide emergency power for at least 30 minutes.

The UPS may have a standby (auxiliary or backup) diesel-generator capable of providing input power after a short startup time (usually ten seconds or less). As an emergency power source, the UPS differs from the standby generator because the generator does not provide instant protection from primary power interruptions. The UPS battery bank provides uninterrupted power until either the standby diesel-generator starts and provides power, utility power is restored, or critical equipment is safely shut down.

UPS Operation

A typical UPS consists of input and output filters, a rectifier, an inverter, a step-up transformer, bypass circuits, isolation breakers, and a battery rack.

Typical UPS

If the building has a redundant UPS it is usually fed via a secondary power feed.

Redundant UPS

Normal Operation

Substations deliver high-voltage primary power to an automatic transfer switch (ATS). The ATS passes the power from one of the two primary feeds to a step-down transformer, which
then feeds 480/277 voltage alternating current (VAC) to the building’s main distribution panel. Power then passes through a motor control center to a local ATS, which in turn feeds a panel breaker for the UPS.

The UPS rectifier converts primary 480 VAC input power to 240 voltage direct current (VDC). The filtered DC power passes to the inverter and simultaneously float-charges the UPS batteries. The inverter converts the DC power back into highly regulated and filtered 208/120 VAC. The inverter output is then stepped up to 480/277 VAC by a small transformer and sent to the critical loads via an emergency power panel.

During normal operations the UPS provides a charge to the battery bank to compensate for battery self-discharge; this condition is referred to as a battery “float charge.” The battery and the load are permanently connected in parallel across the DC charging source and held at a constant voltage below the battery’s upper voltage limit. NOTE: The difference between a float charge and a trickle charge is that the float has circuitry to prevent overcharging. It senses when the battery voltage is at the maximum level and temporarily shuts off the charge (floats voltage at zero or a very minimal charge until it senses that the battery output voltage has fallen, when it resumes charging). It may be kept connected indefinitely.

Emergency Operation
If primary power is lost the critical loads continue to be supplied by the UPS, with power coming solely from the batteries. These batteries are capable of supplying the loads for a minimum of 30—90 minutes.

If available, a standby diesel-generator also starts upon the loss of utility power. When it’s ready to accept loads the building’s ATS switches to the diesel-generator power feed. The UPS will then sense the proper voltage at its AC input and cease drawing power from the batteries. The rectifier resumes supplying filtered DC power to the inverter and simultaneously starts re-charging the batteries; this is an automatic function and causes no interruption to the critical loads. NOTE: To be considered operational, the batteries must re-charge until the average voltage to the battery bank from the UPS is within the battery manufacturer’s recommended float voltage range and the current to the batteries is satisfactory.

NOTE: A site’s electrical distribution system has many redundant systems and power schemes to ensure that normal utility power continues to feed the site loads in the event of external power outages or electrical distribution equipment faults. Most sites have two redundant, cross-connected power distribution loops, each fed from a separate external power source; main ATSs will automatically switch from one loop to another in the event of faults in the site distribution system. Most sites also have an independent emergency distribution loop that can be powered by large backup diesel-generators; these can power selected critical site loads in case site power is lost.

Bypass Mode
If the UPS experiences an overload, a load fault or other internal failures, the internal static bypass switch automatically operates and bypasses the rectifier and inverter, effectively passing input AC (untreated) power straight through to the UPS loads. Return from bypass to normal mode is automatic except for internal failures, which require manual reset.
to the bypass mode can also be initiated manually by operating a switch on the UPS control panel.

Maintenance Mode
If a UPS needs to be taken out of service for maintenance, the loads may be manually transferred using the maintenance bypass switch. Again, what happens depends on whether or not there is another UPS.

First, the UPS is bypassed by manual operation of the internal static bypass switch. Once the UPS is in the bypass mode, the maintenance bypass switch is closed; the maintenance bypass switch is a make-before-break switch so there will be no interruption of power to critical loads. The UPS main supply breaker, secondary input breaker, and battery breaker can be opened to completely isolate the UPS from all sources of power.

Downgrade Mode
If the UPS battery needs to be taken out of service for maintenance, it may be disconnected from the UPS charger by means of a circuit breaker. The UPS will continue to function and meet all performance criteria, except for the reserve time capability.

Automatic Transfer Switch
Normally, an Automatic Transfer Switch (ATS) continuously monitors incoming voltage so that it can detect a loss of normal (utility) power and quickly switch to an alternate power source, such as a diesel-generator. If the ATS senses a loss of utility power it sends a start signal to the diesel-generator. Once the generator is running at proper speed and voltage, the ATS safely opens the utility power line connection and simultaneously connects the diesel-generator power line from the generator. Within seconds, the generator system begins supplying electricity to selected critical loads.

When the diesel-generator is running it is protected by automatic circuitry. Problems such as high engine temperature, low oil pressure and over-speed will cause an automatic shutdown. Additionally, the circuitry may send operating parameters to a remote station and provide alarms for abnormal conditions (e.g., low fuel level in the supply tank).

The ATS continues to monitor the utility line conditions. When it senses that utility line voltage has returned to normal, it transfers the electrical loads back to the utility power line and resumes monitoring incoming voltage. The diesel-generator will continue to run for an engine cool-down period of several minutes and then shut down.

Diesel-Generators
At most DOE sites diesel engines are combined with electrical generators to produce electric energy; these diesel-generators are used as emergency (standby, backup or auxiliary) power supplies.

The electrical generator converts the mechanical energy produced by the diesel engine into electrical energy (usually AC voltage). Industrial three-phase generators range in power from 30 kilowatt (kW) to 6 megawatt (MW).
Diesel generators may be housed in a building, self-contained in a protective shell, or mounted outside on a pad. They normally have a fuel tank located close by to provide fuel for a designated minimum period (e.g., four hours operation at full power). Depending on their use and size, they may be either air- or water-cooled (water-cooled is the norm). The use of electronically controlled engines allows diesel engines to adjust their timing to start according to the environmental conditions of heat and cold, regulate the engine speed in terms of RPM and maintain fuel economy.

Diesel generators are dependable, portable and powerful. They are cheaper to operate and run for longer periods of time when compared to the gasoline generator. They also have lower maintenance costs due to there being no spark plugs and carburetors.

_Diesel Power_

Diesel power is power generated by a diesel-driven generator. Diesel-driven generators are the most economical and practical source of standby power.

**b. Describe the protection provided by fuses and circuit breakers.**

The following is taken from DOE-HDBK-1011/4-92.

A fuse is a device that protects a circuit from an over current condition only. It has a fusible link directly heated and destroyed by the current passing through it. A fuse contains a current-carrying element sized so that the heat generated by the flow of normal current through it does not cause it to melt the element; however, when an over current or short-circuit current flows through the fuse, the fusible link will melt and open the circuit.

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.

A circuit breaker is also used to provide a means for connecting and disconnecting circuits of relatively high capacities without causing damage to them. The three most commonly-used automatic trip features for a circuit breaker are over current, under frequency, and under voltage.

**c. Describe the purpose and functions of a motor controller.**

The following is taken from DOE-HDBK-1011/4-92.

Motor controllers range from a simple toggle switch to a complex system using solenoids, relays, and timers. The basic functions of a motor controller are to control and protect the operation of a motor. This includes starting and stopping the motor, and protecting the motor from over current, under voltage, and overheating conditions that would cause damage to the motor. There are two basic categories of motor controllers: the manual controller and the magnetic controller.
d. Describe the purpose and functions of a variable frequency drive controller.

The following is taken from DOE/GO-102001-1165.

Variable-frequency drives (VFDs), a type of variable-speed drive, are controllers that vary the speed of induction motors. VFDs save substantial energy when applied to variable-torque loads, thus reducing electricity bills for most facilities. These energy savings are possible with variable-torque loads, such as fans and pumps, because torque varies as the square of speed, and horsepower (HP) varies as the cube of speed. For example, if fan speed is reduced by 20 percent, motor HP (and energy consumption) is reduced by 50 percent.

VFDs generate variable voltage and frequency output in the proper volts/hertz ratio for an induction motor from the fixed utility-supplied power. VFDs can be retrofitted into existing motor systems and can operate both standard and high-efficiency motors ranging in size from 1/3 hp to several thousand hp. Unlike mechanical or hydraulic motor controllers, they can be located remotely and do not require mechanical coupling between the motor and the load. This simplifies the installation and alignment of motor systems.

Three major VFD designs are commonly used: pulse-width modulation (PWM), current source inverter (CSI), and variable source inverter (VSI). A fourth type, the flux vector PWM drive, is gaining popularity but is considered too expensive and sophisticated for most applications. Knowing the characteristics of the load is critical in evaluating the advantages and disadvantages of each technology.

- **Pulse-width modulation** is the dominant VFD design in the ½ hp to 500 hp range because of its reliability, affordability, and availability. PWM outputs emulate sinusoidal power waves by varying the width of voltage pulses in each half cycle. Advantages of PWMs are low harmonic motor heating, excellent input displacement power factor, high efficiencies at 92–96 percent, and ability to control multiple motor systems with a single drive.
- **Current source inverter** designs are quite reliable because of their inherent current-limiting characteristics and simple circuitry. CSIs have regenerative power capabilities, meaning that CSI drives can reverse the power flow back from the motor through the drive. However, CSIs “reflect” large amounts of power harmonics back to the source, have poor input power factors, and produce jerky motor operations (cogging) at very low speeds. CSIs are typically used for large (over 300 hp) induction and synchronous motors.
- **Voltage source inverter** designs are similar to CSI designs, but VSIs generate variable-frequency outputs to motors by regulating voltage rather than current. Harmonics, power factor, and cogging at low frequencies can be problems.

16. A facility representative must demonstrate a working level knowledge of electrical systems and components in the area of safety.

a. Discuss the hazards associated with operations and maintenance of electrical systems and components.

The following is taken from DOE-HDBK-1092-2004.
There are numerous injury mechanisms from exposure of a worker to electrical energy. This section briefly presents the various types of injury.

*Electrical Shock*

Electricity is one of the most commonly encountered hazards in any facility. Under normal conditions, safety features (engineering controls) built into electrical equipment protect workers from shock. Shock is the flow of electrical current through any portion of the worker’s body from an external source. Accidents can occur in which contact with electricity results in serious injury or death.

Most electrical systems establish a voltage reference point by connecting a portion of the system to an earth ground. Because these systems use conductors that have electrical potential (voltage) with respect to ground, a shock hazard exists for workers who are in contact with the earth and exposed to the conductors. If a person comes in contact with an energized (ungrounded) conductor while also in contact with a grounded object, an alternate path to ground is formed in which current passes through his or her body.

*Electrical Burn*

Burns suffered in electrical accidents are of three basic types: electrical burns, arc burns, and thermal contact burns. The cause of each type of burn is different, and prevention requires different controls.

**Electrical Burns**

In electrical burns, tissue damage (whether skin-level or internal) occurs because the body is unable to dissipate the heat from the current flow. Typically, electrical burns are slow to heal. Such electrical burns result from shock currents, and thus adhering to shock current thresholds will prevent electrical burns.

**Arc Flash Burns**

Arc flash burns are caused by electric arcs and are similar to heat burns from high temperature sources. Temperatures generated by electric arcs can melt nearby material, vaporize metal in close vicinity, and burn flesh and ignite clothing at distances of several meters, depending on the energy deposited into the arc. The arc can be a stable low-voltage arc, such as in an arc welder, or a short-circuit arc at higher voltage, resulting in an arc flash and/or arc blast. Such an expanding arc can ignite clothing and/or cause severe burns at a distance from centimeters to meters. The flash protection boundary is defined to characterize the distance at which this injury mechanism is severe.

**Arc Blast Hazards**

A rapid delivery of electrical energy into an arc can cause additional hazards not covered by arc flash hazards. The acoustical shock wave, or arc blast pressure wave, can burst eardrums at lower levels and can cause cardiac arrest at high enough levels. In addition, high currents (> 100 kA) can cause strong magnetic forces on current-carrying conductors, which can lead to equipment destruction, or the whipping of conductors. Such arc blast hazards are of particular concern in high-energy facility power circuits.
Thermal Contact Burns
Thermal contact burns are those that occur when skin comes into contact with the hot surfaces of overheated electrical conductors, including conductive tools and jewelry. This injury requires proximity to a high-current source with a conductive object. Thermal burns can occur from low-voltage/high-current systems that do not present shock or arc flash hazards, and controls should be considered. The controls to prevent injury from shock and arc flash will also protect against thermal contact burn.

Delayed Effects
Damage to the internal tissues may not be apparent immediately after contact with electrical current. Delayed swelling and irritation of internal tissues are possible. In addition, imperceptible heart arrhythmia can progress to ventricular fibrillation. In some cases, workers have died two to four hours after what appeared to be a mild electrical shock. Immediate medical attention may prevent death or minimize permanent injury. All electrical shocks should be reported immediately to the medical department.

Battery Hazards
During maintenance or other work on batteries and battery banks, there are electrical and physical hazards that shall be considered. In addition, when working near or on flooded lead-acid storage batteries additional chemical and explosion hazards shall be considered.

Other Hazards
Low-voltage circuits, which are not hazardous themselves, are frequently used adjacent to hazardous circuits. A minor shock can cause a worker to rebound into the hazardous circuit. Such an involuntary reaction may also result in bruises, bone fractures, and even death from collisions or falls. The hazard is due to the secondary effects of the reflex action.

An arc may form when a short circuit occurs between two conductors of differing potential, or when two conductors carrying current are separated, such as a safety switch attempting to interrupt the current. If the current involved is high enough, the arc can cause injury, ignite flammable materials or initiate an explosion in combustible or explosive atmospheres.

Injury to personnel can result from the arc flash, or arc blast, resulting in severe burns to exposed skin, or ignition of clothing. Equipment or conductors overheated due to overload may ignite flammable materials. Extremely high-energy arcs can cause an arc blast that sends shrapnel flying in all directions.

Research and development equipment is often unique. An uncommon or unique design can be difficult to analyze for hazard identification. The hazard analysis should include shock, potential arc or thermal sources. Acoustic shock wave, pressure shock wave and shrapnel are potential hazards. Once the hazards have been identified, a risk mitigation plan should be developed. Personnel working on unique research and development equipment must be specifically qualified through training specific to the work to be done. The scope of such additional training depends on the hazards associated with the equipment.
b. Describe the general safety precautions for operations and maintenance of electrical systems and components.

The following is taken from DOE-HDBK-1092-2004.

An analysis of high-voltage circuits should be performed by a qualified person before work begins unless all exposed energized parts are guarded as required for high-voltage work. The analysis must include fault conditions where circuit current could rise above the nominal rated value. Depending on the results of the analysis, any of the following may apply:

- If the analysis concludes that the current is above 5 mA or energy is above 10 joules, then the work is considered to be energized work and should be performed in accordance with DOE-HDBK-1092-2004, section 2, General Requirements and/or section 7, Work In Excess of 600 Volts.
- If the analysis concludes that the current is between 0.5 mA and 5 mA and between 0.25 and 1 joules, then the worker may be exposed to a secondary hazard (e.g., startle reaction) that must be mitigated.
- If the analysis concludes that the current is below 0.5 mA and below 0.25 joules, then the worker exposure is minimal and no special precautions are required, even for high voltage circuits.

High-voltage supplies that use rated connectors and cables where there are no exposed energized parts are not considered hazards. Connections shall not be made or broken with the power supply energized unless they are designed and rated for this type of duty (e.g., load-break elbows). Inspect cables and connectors for damage and do not use if they are damaged. Exposed high-voltage parts must be guarded to avoid accidental contact.

Lockout/Tagout

The following is taken from DOE-STD-1186-2004.

A tagout program includes the placement of a tagout device on an energy-isolating device, in accordance with an established procedure, to indicate that the energy-operating device and the equipment being controlled may not be operated until the tagout device is removed. Similarly, a lockout program includes the placement of a lockout device (e.g., a lock or hasp with a lock in place) on an energy-isolating device in accordance with an established procedure ensuring that the energy-isolating device and the equipment being controlled cannot be operated until the lockout device is removed.

An effective lockout/tagout program is developed by each facility and should include detailed administrative procedures, training of personnel, and uniquely identifiable tags. The program should also exercise appropriate control over lockout/tagout preparation, approval, placement, and removal; provide for adequate documentation; and be consistent with the requirements of 29 CFR 1910, “Occupational Safety and Health Standards.”

c. Discuss the safety precautions specific to batteries.

The following is taken from DOE-HDBK-1092-2004.
During maintenance or other work on batteries and battery banks, there are electrical and physical hazards that shall be considered. In addition, when working near or on flooded lead-acid storage batteries additional chemical and explosion hazards shall be considered.

The hazards associated with various types of batteries and battery banks include:
- electric shock
- burns and shrapnel-related injuries from a short circuit
- chemical burns from electrolyte spills or from battery surface contamination
- fire or explosion due to hydrogen
- physical injury from lifting or handling the cells
- fire from overheated electrical components

**d. Describe the safety precautions specific to breaker operations.**

The following is taken from SLAC ESG-2010.

Breakers and disconnect switches at 50V to 240V are to be treated as arc hazard category 0 when they are operated. From National Fire Protection Association (NFPA)-70E, the proper personal protective equipment (PPE) includes a natural fiber long sleeve shirt/jacket, natural fiber long pants, and safety glasses that must all be worn to operate these devices.

For circuit breakers and disconnect switches above 240V and up to and including 480V, additional PPE must be used:
- Where the upstream transformer is 1 megavolt ampere (MVA) or less and there is at least one molded case circuit breaker in a different enclosure between the circuit breaker or disconnect switch to be operated and the upstream transformer, then operation of that circuit breaker or disconnect switch with enclosure covers on may be treated as arc hazard category 0. From NFPA-70E, PPE includes a natural fiber long sleeve shirt/jacket, natural fiber long pants, and safety glasses that must all be worn to operate these devices.
- Where the upstream transformer is larger than 1 MVA and there is at least one additional molded case circuit breaker in a different enclosure between the circuit breaker or disconnect switch to be operated and the upstream transformer, then operation of that circuit breaker or disconnect switch with enclosure covers on may be treated as arc hazard category 1. From NFPA-70E, the proper PPE includes a fire retardant rated long sleeve shirt and fire retardant rated long pants, hard hat, and safety glasses that must all be worn to operate these devices.

Operating other circuit breakers or disconnect switches, at voltages that are above 480V, requires that an arc hazard analysis be done, and, that hazard warning circuit diagrams and field hazard signage be provided before work is accomplished. Typically qualified electricians and/or engineers will perform the hazard analysis and documentation necessary to comply with the requirements of NFPA-70E for the specific situation.
17. A facility representative must demonstrate a familiarity level knowledge of process instrumentation.

a. List the three basic functions that temperature, pressure, flow, and fluid level detectors provide.

The following is taken from DOE-HDBK-1013/1-92.

Although the parameters that are monitored vary slightly depending on the details of facility design, detectors are used to provide three basic functions: indication, alarm, and control. The parameters 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 detectors may have control functions associated with them so that equipment is started or stopped to support a given condition or so that a protective action occurs.

b. For the temperature detection devices listed, discuss how the instrument provides an output representative of the temperature being measured:
   - Thermocouple (TC)
   - Resistance temperature detector (RTD)

The following is taken from DOE-HDBK-1013/1-92.

Thermocouple (TC)
Thermocouples will cause an electric current to flow in the attached circuit when subjected to changes in temperature. The amount of current that will be produced is dependent on the temperature difference between the measurement and reference junction, the characteristics of the two metals used, and the characteristics of the attached circuit. Heating the measuring junction of the TC produces a voltage which is greater than the voltage across the reference junction. The difference between the two voltages is proportional to the difference in temperature and can be measured on the voltmeter (in millivolts). For ease of operator use, some voltmeters are set up to read out directly in temperature through use of electronic circuitry.

A TC is constructed of two dissimilar wires joined at one end and encased in a metal sheath. The other end of each wire is connected to a meter or measuring circuit. Heating the measuring junction of the TC produces a voltage that is greater than the voltage across the reference junction. The difference between the two voltages is proportional to the difference in temperature and can be measured on a voltmeter.

Resistance Temperature Detector (RTD)
The resistance of an RTD varies directly with temperature:
   - As temperature increases, resistance increases.
   - As temperature decreases, resistance decreases.

Resistance Temperature Detectors are constructed using a fine, pure, metallic, spring-like wire surrounded by an insulator and enclosed in a metal sheath. A change in temperature will cause an RTD to heat or cool, producing a proportional change in resistance. The change in
resistance is measured by a precision device that is calibrated to give the proper temperature reading.

c. For the pressure detection devices listed, discuss how the instrument provides an output representative of the pressure being measured:
   - Bellows type
   - Bourdon tube type

The following is taken from DOE-HDBK-1013/1-92.

Bellows Type
The bellows is a one-piece, collapsible, seamless metallic unit that has deep folds formed from very thin-walled tubing. The diameter of the bellows ranges from 0.5 to 12.9 inch (in.) and may have as many as 24 folds. System pressure is applied to the internal volume of the bellows. As the inlet pressure to the instrument varies, the bellows will expand or contract. The moving end of the bellows is connected to a mechanical linkage assembly. As the bellows and linkage assembly moves, either an electrical signal is generated or a direct pressure indication is provided. The flexibility of a metallic bellows is similar in character to that of a helical, coiled compression spring. Up to the elastic limit of the bellows, the relation between increments of load and deflection is linear. However, this relationship exists only when the bellows is under compression. It is necessary to construct the bellows such that all of the travel occurs on the compression side of the point of equilibrium. Therefore, in practice, the bellows must always be opposed by a spring, and the deflection characteristics will be the resulting force of the spring and bellows.

The following apply to a bellows-type detector:
   - System pressure is applied to the internal volume of a bellows and mechanical linkage assembly.
   - As pressure changes, the bellows and linkage assembly move to cause an electrical signal to be produced or to cause a gauge pointer to move.

Bourdon Tube Type
The bourdon tube consists of a thin-walled tube that is flattened diametrically on opposite sides to produce a cross-sectional area elliptical in shape, having two long, flat sides and two short, round sides. The tube is bent lengthwise into an arc of a circle of 270 to 300 degrees. Pressure applied to the inside of the tube causes distention of the flat sections and tends to restore its original round cross-section. This change in cross-section causes the tube to straighten slightly.

Since the tube is permanently fastened at one end, the tip of the tube traces a curve that is the result of the change in angular position with respect to the center. Within limits, the movement of the tip of the tube can then be used to position a pointer or to develop an equivalent electrical signal (which is discussed later in the text) to indicate the value of the applied internal pressure.

The following apply to a bourdon tube-type detector:
- System pressure is applied to the inside of a slightly flattened arc-shaped tube. As pressure increases, the tube tends to restore to its original round cross-section. This change in cross-section causes the tube to straighten.
- Since the tube is permanently fastened at one end, the tip of the tube traces a curve that is the result of the change in angular position with respect to the center. The tip movement can then be used to position a pointer or to develop an electrical signal.

d. For the fluid level detection devices listed, discuss how the instrument provides an output representative of the level being measured:
   - Gauge-glass type
   - Conductive probe type
   - Magnetic bond type
   - Differential pressure type
   - Ball float type
   - Sonic type
   - Radar type

The following definitions are taken from DOE-HDBK-1013/1-92.

**Gauge-Glass Type**
In the gauge-glass method of fluid level detection, a transparent tube is attached to the bottom and top of the tank that is monitored (however, a top connection is not needed in a tank open to atmosphere). The height of the liquid in the tube will be equal to the height of water in the tank.

**Conductive Probe Type**
A 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 that 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. A typical system has three probes: a low-level probe, a high-level probe, and a high-level alarm probe.

**Magnetic Bond Type**
The magnetic bond method of fluid level detection was developed to overcome the problems of cages and stuffing boxes. The magnetic bond mechanism consists of a magnetic float which 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.

**Differential Pressure Type**
The differential pressure (DP) detector method of liquid level measurement uses a DP detector connected to the bottom of the tank being monitored. The higher pressure, caused by the fluid in the tank, is compared to a lower reference pressure (usually atmospheric). This comparison takes place in the DP detector.
In an open tank, only the high-pressure connection to the DP transmitter is used; the low-pressure side is vented to the atmosphere. Therefore, the pressure differential is the hydrostatic head, or weight, of the liquid in the tank. The maximum level that can be measured by the DP transmitter is determined by the maximum height of liquid above the transmitter; the point where the transmitter is connected to the tank determines the minimum level measured.

Many tanks are totally enclosed to prevent vapors or steam from escaping or to allow pressurizing the contents of the tank. When measuring the level in a tank that is pressurized, or where level can become pressurized by vapor pressure from the liquid, both the high- and low-pressure sides of the DP transmitter must be connected.

The high-pressure connection is connected to the tank at or below the lower range value to be measured, and the low-pressure side is connected to a reference leg that is connected at or above the upper range value to be measured. The reference leg is pressurized by the gas or vapor pressure; no liquid is permitted to remain in the reference leg so that there is no liquid head pressure on the low-pressure side of the transmitter. The high-pressure side is exposed to the hydrostatic head of the liquid plus the gas or vapor pressure exerted on the liquid’s surface. Since the gas or vapor pressure is equally applied to the low- and high-pressure sides, the output of the DP transmitter is directly proportional to the hydrostatic head pressure (i.e., the liquid level in the tank).

**Ball Float Type**

The ball float method of fluid level detection is a direct reading liquid level mechanism. The most practical design for the float is a hollow metal ball or sphere. However, there are no restrictions to the size, shape, or material used. The design consists of a ball float attached to a rod, which in turn is connected to a rotating shaft which indicates level on a calibrated scale. 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 will change the position of the pointer attached to the rotating shaft.

**Sonic Type**

The following is taken from National Instruments, The Principles of Level Measurement.

Ultrasonic and sonic level instruments operate on the basic principle of using sound waves to determine fluid level. The frequency range for ultrasonic methods is ~ 20–200 kHz, and sonic types use a frequency of 10 kHz. A top-of-tank mounted transducer directs waves downward in bursts onto the surface of the material whose level is to be measured. Echoes of these waves return to the transducer, which performs calculations to convert the distance of wave travel into a measure of level in the tank. A piezoelectric crystal inside the transducer converts electrical pulses into sound energy that travels in the form of a wave at the established frequency and at a constant speed in a given medium. The medium is normally air over the material’s surface but it could be a blanket of nitrogen or some other vapor. The sound waves are emitted in bursts and received back at the transducer as echoes. The instrument measures the time for the bursts to travel down to the reflecting surface and return. This time will be proportional to the distance from the transducer to the surface and
can be used to determine the level of fluid in the tank. For practical applications of this method, you must consider a number of factors. A few key points are

- The speed of sound through the medium varies with the medium’s temperature. The transducer may contain a temperature sensor to compensate for changes in operating temperature that would alter the speed of sound and hence the distance calculation that determines an accurate level measurement.
- The presence of heavy foam on the surface of the material can act as a sound absorbent. In some cases, the absorption may be sufficient to preclude use of the ultrasonic technique.
- Extreme turbulence of the liquid can cause fluctuating readings. Use of a damping adjustment in the instrument or a response delay may help overcome this problem.

To enhance performance where foam or other factors affect the wave travel to and from the liquid surface, some models can have a beam guide attached to the transducer.

Ultrasonic or sonic methods can also be used for point level measurement, although it is a relatively expensive solution. An ultrasonic gap technique is an alternative way to measure point level with low-viscosity liquids. A transmit crystal is activated on one side of a “measurement gap” and a receive crystal listens on the opposite side. The signal from the receive crystal is analyzed for the presence or absence of tank contents in the measurement gap.

Radar Type
The following is taken from National Instruments, The Principles of Level Measurement.

Radar methods of level measurement are sometimes referred to as microwave types. Both use electromagnetic waves, typically in the microwave X-band range. Most applications have been designed for continuous level measurement.

Basically, all types operate on the principle of beaming microwaves downward from a sensor located on top of the vessel. The sensor receives back a portion of the energy that is reflected off the surface of the measured medium. Travel time for the signal is used to determine level. For continuous level measurement, there are two main types of noninvasive systems, as well as one invasive type that uses a cable or rod as a wave guide and extends down into the tank’s contents to near its bottom.

One type of noninvasive system uses a technology called frequency-modulated continuous wave (FMCW). From an electronic module on top of the tank, a sensor oscillator sends down a linear frequency sweep, at a fixed bandwidth and sweep time. The reflected radar signal is delayed in proportion to the distance to the level surface. Its frequency is different from that of the transmitted signal, and the two signals blend into a new frequency proportional to distance. That new frequency is converted into a very accurate measure of liquid level.

The sensor outputs a frequency-modulated (FM) signal that varies from 0 to ~200 Hz as the distance ranges from 0 to 200 ft. An advantage of this technique is that the level-measurement signals are FM rather than amplitude modulation (AM), affording the same advantages that radio waves offer. Most tank noise is in the AM range and does not affect the FM signals.
The second noninvasive technology, pulsed radar or pulsed time-of-flight, operates on a principle very similar to that of the ultrasonic pulse method. The radar pulse is aimed at the liquid’s surface and the transit time of the pulse’s return is used to calculate level. Because pulse radar is lower power than FMCW, its performance can be affected by obstructions in the tank as well as foam and low-dielectric materials.

Antennas for the noninvasive methods come in two designs: parabolic dish and cone. The choice of one or the other, and its diameter, depends on application factors such as tank obstructions that may serve as reflectors, the presence of foam, and turbulence of the measured fluid.

Guided-wave radar (GWR) is an invasive method that uses a rod or cable to guide the micro wave as it passes down from the sensor into the material being measured and all the way to the bottom of the vessel. The basis for GWR is time-domain reflectometry (TDR), which has been used for years to locate breaks in long lengths of cable that are underground or in building walls. A TDR generator develops more than 200,000 pulses of electromagnetic energy that travel down the waveguide and back. The dielectric of the measured fluid causes a change in impedance that in turn develops a wave reflection. Transit time of pulses down and back is used as a measure of level.

The waveguide affords a highly efficient path for pulse travel so that degradation of the signal is minimized. Thus, extremely low dielectric materials can be effectively measured. Further, because the pulse signals are channeled by the guide, turbulence, foams, or tank obstructions should not affect the measurement. GWR can handle varying specific gravity and media buildup or coatings. It is an invasive method, though, and the probe or guide may be damaged by the blade of an agitator or the corrosiveness of the material being measured.

e. For the flow detection devices listed, discuss how the instrument provides an output representative of the flow being measured:
   - Orifice plate type
   - Venturi tube type
   - Pitot tube type
   - Displacement type
   - Dall flow tube type
   - Ultrasonic type
   - Electromagnetic

The following definitions are taken from DOE-HDBK-1013/1-92.

Orifice Plate Type
The orifice plate is the simplest of the flow path restrictions used in flow detection, as well as the most economical. Orifice plates are flat plates 1/16 to 1/4 inch thick. They are normally mounted between a pair of flanges and are installed in a straight run of smooth pipe to avoid disturbance of flow patterns from fittings and valves. Three kinds of orifice plates are used: concentric, eccentric, and segmental. Flow through a sharp-edged orifice plate is characterized by a change in velocity. As the fluid passes through the orifice, the fluid converges, and the velocity of the fluid increases to a maximum value. At this point, the pressure is at a minimum value. As the fluid diverges to fill the entire pipe area, the velocity decreases back to the original value. The pressure increases to about 60 to 80 percent of the
original input value. The pressure loss is irrecoverable; therefore, the output pressure will always be less than the input pressure. The pressures on both sides of the orifice are measured, resulting in a DP that is proportional to the flow rate.

**Venturi Tube Type**
The venturi tube is the most accurate flow-sensing element when properly calibrated. The venturi tube has a converging conical inlet, a cylindrical throat, and a diverging recovery cone. It has no projections into the fluid, no sharp corners, and no sudden changes in contour. The inlet section decreases the area of the fluid stream, causing the velocity to increase and the pressure to decrease. The low pressure is measured in the center of the cylindrical throat since the pressure will be at its lowest value, and neither the pressure nor the velocity is changing.

**Pitot Tube Type**
The pitot tube is another primary flow element used to produce a DP for flow detection. In its simplest form, it consists of a tube with an opening at the end. The small hole in the end is positioned such that it faces the flowing fluid. The velocity of the fluid at the opening of the tube decreases to zero. This provides for the high-pressure input to a DP detector. A pressure tap provides the low-pressure input. In a displacement flow meter, all of the fluid passes through the meter in almost completely isolated quantities. The number of these quantities is counted and indicated in terms of volume or weight units by a register. The most common type of displacement flow meter is the nutating disk, or wobble plate meter. As the fluid flows through the chamber, the disk wobbles, or executes a nutating motion. Since the volume of fluid required to make the disc complete one revolution is known, the total flow through a nutating disc can be calculated by multiplying the number of disc rotations by the known volume of fluid.

**Displacement Type**
The rotameter is an area flow meter so named because a rotating float is the indicating element. The rotameter consists of a metal float and a conical glass tube, constructed such that the diameter increases with height. When there is no fluid passing through the rotameter, the float rests at the bottom of the tube. As fluid enters the tube, the higher density of the float will cause the float to remain on the bottom, and the space between the float and the tube allows for flow past the float. As flow increases in the tube, the pressure drop increases; when the pressure drop is sufficient, the float will rise to indicate the amount of flow. The higher the flow rate, the greater the drop in pressure, and the higher the pressure drop, the farther up the tube the float will rise. This type of flow meter is usually used to measure low flow rates.

**Dall Flow Tube Type**
The dall flow tube has a higher ratio of pressure developed to pressure lost than the venturi flow tube. It is more compact and is commonly used in large flow applications. The tube consists of a short, straight inlet section followed by an abrupt decrease in the inside diameter of the tube. This section, called the inlet shoulder, is followed by the converging inlet cone and a diverging exit cone. The two cones are separated by a slot or gap between the two cones. The low pressure is measured at the slotted throat (the area between the two cones). The high pressure is measured at the upstream edge of the inlet shoulder.
**Ultrasonic Type**

Ultrasonic flow equipment uses the Doppler frequency shift of ultrasonic signals reflected from discontinuities in the fluid stream to obtain flow measurements. These discontinuities can be suspended solids, bubbles, or interfaces generated by turbulent eddies in the flow stream. The sensor is mounted on the outside of the pipe, and an ultrasonic beam from a piezoelectric crystal is transmitted through the pipe wall into the fluid at an angle to the flow stream. A second piezoelectric crystal located in the same sensor detects signals reflected off flow disturbances. Transmitted and reflected signals are compared in an electrical circuit, and the corresponding frequency shift is proportional to the flow velocity.

**Electromagnetic Flowmeter**

The electromagnetic flowmeter is similar in principle to the generator. The rotor of the generator is replaced by a pipe placed between the poles of a magnet so that the flow of the fluid in the pipe is normal to the magnetic field. As the fluid flows through this magnetic field, an electromotive force is induced in it that will be mutually normal (perpendicular) to both the magnetic field and the motion of the fluid. This electromotive force may be measured with the aid of electrodes attached to the pipe and connected to a galvanometer or an equivalent. For a given magnetic field, the induced voltage will be proportional to the average velocity of the fluid. However, the fluid should have some degree of electrical conductivity.

**f. For the position detection devices listed, discuss how the detector provides an output representative of the position being represented:**

- **Synchronous type**
- **Limit switches**
- **Reed switches**
- **Potentiometer**
- **Linear variable differential transformer (LVDT) types**

The following definitions are taken from DOE-HDBK-1013/1-92.

**Synchronous Type**

Remote indication or control may be obtained by the use of self-synchronizing motors, called synchro equipment. Synchro equipment consists of synchro units that electrically govern or follow the position of a mechanical indicator or device. An electrical synchro has two distinct advantages over mechanical indicators: 1) greater accuracy, and 2) simpler routing of remote indication. The transmitter, or synchro generator, consists of a rotor with a single winding and a stator with 3 windings placed 120 degrees apart. When the mechanical device moves, the mechanically attached rotor moves. The rotor induces a voltage in each of the stator windings based on the rotor’s angular position. Since the rotor is attached to the mechanical device, the induced voltage represents the position of the attached mechanical device. The voltage produced by each of the windings is utilized to control the receiving synchro position. The receiver, or synchro motor, is electrically similar to the synchro generator. The synchro receiver uses the voltage generated by each of the synchro generator windings to position the receiver rotor. Since the transmitter and receiver are electrically similar, the angular position of the receiver rotor corresponds to that of the synchro transmitter rotor. When the transmitter’s shaft is turned, the synchro receiver’s shaft turns such that its electrical position is the same as the transmitter’s. What this means is that when the
transmitter is turned to electrical zero, the synchro receiver also turns to zero. If the transmitter is disconnected from the synchro receiver and then reconnected, its shaft will turn to correspond to the position of the transmitter shaft.

**Limit Switches**
A limit switch is a mechanical device which 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 from 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**
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.

**Potentiometer**
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.

Potentiometer valve position indicators use an extension which 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.

**Linear Variable Differential Transformer (LVDT) Types**
An LVDT uses the extension shaft or control rod as a movable core of a transformer. Moving the extension between the primary and secondary windings of a transformer causes the inductance between the two windings to vary, thereby varying the output voltage proportional to the position of the valve or control rod extension.

18. A facility representative must demonstrate a familiarity level knowledge of control system principles of operation and uses.

a. Define and discuss the application of each of the following:
   - Control system
   - Control system input
   - Control system output
   - Open-loop control system
   - Closed-loop control system
   - Control system feedback
The following definitions are taken from DOE-HDBK-1013/2-92.

Control System
A control system is a system of integrated elements whose function is to maintain a process variable at a desired value or within a desired range of values. The control system monitors a process variable or variables, and then causes some action to occur to maintain the desired system parameter. In a central heating unit, the system monitors the temperature of the house using a thermostat. When the temperature of the house drops to a preset value, the furnace turns on, providing a heat source. The temperature of the house increases until a switch in the thermostat causes the furnace to turn off.

Control System Input and Control System Output
Two terms which help define a control system are input and output. Control system input is the stimulus applied to a control system from an external source to produce a specified response from the control system. In the case of the central heating unit, the control system input is the temperature of the house as monitored by the thermostat.

Control system output is the actual response obtained from a control system. In the example above, the temperature dropping to a preset value on the thermostat causes the furnace to turn on, providing heat to raise the temperature of the house. In the case of nuclear facilities, the input and output are defined by the purpose of the control system. Knowledge of the input and output of the control system enables the components of the system to be identified. A control system may have more than one input or output.

Control systems are classified by the control action, which is the quantity responsible for activating the control system to produce the output. The two general classifications are open-loop and closed-loop control systems.

Open-Loop Control System
An open-loop control system is one in which the control action is independent of the output. An example of an open-loop control system is a chemical addition pump with a variable speed control. The feed rate of chemicals that maintain proper chemistry of a system is determined by an operator, who is not part of the control system. If the chemistry of the system changes, the pump cannot respond by adjusting its feed rate (speed) without operator action.

Closed-Loop Control System
A closed-loop control system is one in which control action is dependent on the output. Figure 45 shows an example of a closed-loop control system. The control system maintains water level in a storage tank. The system performs this task by continuously sensing the level in the tank and adjusting a supply valve to add more or less water to the tank. The desired level is preset by an operator, who is not part of the system.
Control System Feedback
Feedback is information in a closed-loop control system about the condition of a process variable. This variable is compared with a desired condition to produce the proper control action on the process. Information is continually fed back to the control circuit in response to control action. In figure 45, the actual storage tank water level, sensed by the level transmitter, is feedback to the level controller. This feedback is compared with a desired level to produce the required control action that will position the level control as needed to maintain the desired level.

b. Referring to a basic block diagram, describe an automatic control system, including the four functions required for an automatic control system to operate.

The following is taken from DOE-HDBK-1013/2-92.

An automatic control system is a preset closed-loop control system that requires no operator action. This assumes the process remains in the normal range for the control system. An automatic control system has two process variables associated with it: a controlled variable and a manipulated variable.

A controlled variable is the process variable that is maintained at a specified value or within a specified range. In figure 45, the storage tank level is the controlled variable.

A manipulated variable is the process variable that is acted on by the control system to maintain the controlled variable at the specified value or within the specified range. In the previous example, the flow rate of the water supplied to the tank is the manipulated variable.

In any automatic control system, the four basic functions that occur are as follows:
- Measurement
- Comparison
- Computation
- Correction

Source: DOE-HDBK-1013/2-92

Figure 45. Closed-loop control system
In the water tank level control system in figure 45, the level transmitter measures the level within the tank. The level transmitter sends a signal representing the tank level to the level control device which compares it to a desired tank level. The level control device then computes how far to open the supply valve to correct any difference between actual and desired tank levels.

The three functional elements needed to perform the functions of an automatic control system are:
- A measurement element
- An error detection element
- A final control element

Relationships between these elements and the functions they perform in an automatic control system are shown in figure 46. The measuring element performs the measuring function by sensing and evaluating the controlled variable. The error detection element first compares the value of the controlled variable to the desired value, and then signals an error if a deviation exists between the actual and desired values. The final control element responds to the error signal by correcting the manipulated variable of the process.

Source: DOE-HDBK-1013/2-92

Figure 46. Relationship of functions and elements in an automatic control system
c. Discuss the following associated with programmable logic controllers (PLCs):
   - Purpose
   - Advantages of a PLC system
   - Components and their functions
   - Basic sequence of operation
   - Input/output addressing
   - Equipment used to program the PLC

The following is taken from All About Circuits, Programmable Logic Controllers.

The purpose of a PLC was to directly replace electromechanical relays as logic elements, substituting instead a solid-state digital computer with a stored program, able to emulate the interconnection of many relays to perform certain logical tasks.

A PLC has many input terminals, through which it interprets high and low logical states from sensors and switches. It also has many output terminals, through which it outputs high and low signals to power lights, solenoids, contactors, small motors, and other devices lending themselves to on/off control. In an effort to make PLCs easy to program, their programming language was designed to resemble ladder logic diagrams. Thus, an industrial electrician or electrical engineer accustomed to reading ladder logic schematics would feel comfortable programming a PLC to perform the same control functions.

PLCs are industrial computers, and as such their input and output signals are typically 120 volts AC, just like the electromechanical control relays they were designed to replace. Although some PLCs have the ability to input and output low-level DC voltage signals of the magnitude used in logic gate circuits, this is the exception and not the rule.

Figure 47 shows a simple PLC, as it might appear from a front view. Two screw terminals provide connection to 120 volts AC for powering the PLC’s internal circuitry, labeled L1 and L2. Six screw terminals on the left-hand side provide connection to input devices, each terminal representing a different input channel with its own X label. The lower-left screw terminal is a common connection that generally connected to L2 (neutral) of the 120 VAC power source.

Source: All About Circuits, Programmable Logic Controllers

Figure 47. Simple PLC
d. Discuss the following associated with distributed control systems (DCSs).

- 
  - Purpose
  - Components and their functions
  - Functions of DSC consoles
  - Basic operation of components
  - Error indications (DCS and/or component)

The following is taken from Kettering University, Dependability of Distributed Control System Fault Tolerant Units.

**Purpose**

Distributed control systems involve a set of control systems implemented in a distributed fashion using an appropriate communication protocol. A real-time DCS’s functions are partitioned into separate modules each implemented in a distributed fashion on separate nodes interconnected by a real-time computer network. Each node in the computer network must perform computations in a bounded amount of time to meet sampling constraints of the control system. The computing system and the communication network has a number of features designed to meet the requirements and constraints of the control system.

**Components and Their Functions**

A control system is characterized by one or more feedback control loops, and associated control algorithms, sensors, and actuators. The various controllers, sensors, and actuators can reside in different nodes of the communication network and communicate among one another using the network services. Thus in a DCS the applications involve controllers, sensing functions, actuation functions, and communication functions in the context of control loops.

**Functions of DCS Consoles**

A DSC is a system that includes the following:

- Multiple control loops
- Wide range of activation frequencies or control periods for each loop
- Multiple sensors and actuators
- Variables of small size

Each control loop is characterized by a set of controllers, a set of reference signals, a set of output signals, and a set of state signals. The controllers are implemented in the host portion of the nodes of the communication system. The various signals are encoded as messages for transmission on the network. It is further assumed that the control systems have stable and high performing control algorithms organized in modules, implemented as tasks with worst case execution times to meet stringent requirements involving determinist, dependable, and flexible behavior. In a traditional control system the functions of sensing, control computation, and actuation are strictly sequential. In a DCS such functions can be performed in parallel or in an overlap fashion thus introducing a synchronization problem that must be properly addressed at the design phase. Perhaps the main impact on the use of a communication system within a control system is the need of such synchronization mechanism so that the functions of sensing, control computation, and actuation are performed and communicated to the physical locations they are needed in a sequence and fashion that is in accordance to control system principles.
Basic Operation of Components
The following is taken from DOE-HDBK-1132-1999.

Input/Output (I/O) Controller
Input/output controllers consist of intelligent modules, each performing a dedicated function. Modules are chosen to meet the specific function, including I/O mix, redundancy, geographic distribution, and process requirements. Controllers perform logic functions that eliminate the need for separate PLCs.

Communications
Communication networks in the system provide high-speed, secure controller information exchange, as well as an open network for standard computing hardware access where appropriate. Communications between individual modules are via local, independent buses that allow complete integration of the family of modules.

Data Highways
Redundant data highways are used in critical applications so that failure of one data highway should not affect system performance (may include an alarm message). Fiber optics may be used for its immunity to noise and electrical fault isolation.

Failure Mode Recovery
Systems are designed so that they are capable of completely recovering from plant power loss without manual intervention. System software necessary for computer reboot and operation is stored in nonvolatile memory.

Operator Workstations
Operator workstations have access to the communications bus so that if one goes out of service, another can assume the functions of the disabled unit.

System Diagnostics
Systems often perform self diagnostics on all circuits (to the smallest replaceable plug-in module or component) and report failures to the operator workstations to indicate the source of the failure.

Error Indications (DCS and/or Component)
The following is taken from Kettering University, Dependability of Distributed Control System Fault Tolerant Units.

Most approaches to fault tolerance rely on extra elements introduced to detect and recover from faults. These elements are redundant in that they are not strictly required for the system to operate. A fault tolerant system typically goes through the following phases: error detection, damage assessment and confinement, error recovery, and fault treatment. No fault tolerant scheme can start to operate until the fault has manifested itself as an error, which can subsequently be detected, thus the need for error detection. Once an error has been detected, the consequences of that error must be assessed through damage assessment and confinement; the longer the time delay between occurrence and detection, the greater the possibility of system corruption. The aim of error recovery is to transform the system into a
state where it can continue to provide full, or degraded, functionality. Finally under fault treatment, errors are viewed as the symptoms of faults that unless the cause is treated, errors may be repeated.

19. A facility representative must demonstrate a familiarity level knowledge of chemistry fundamentals in the areas of theory and the periodic table.

a. Describe the four possible states of matter.

The following is taken from DOE-HDBK-1122-2009.

Matter is anything that has mass and takes up space. All matter is made up of atoms and molecules which are the building blocks used to form all kinds of different substances. These atoms and molecules are in constant random motion. Because of this motion they have thermal energy. The amount of energy depends on the temperature and determines the state or phase of the substance. There are four states of matter: solid, liquid, gas and plasma.

Any substance can exist in any of the first three states, but there is generally one state that predominates under normal conditions (temperature and pressure). Take water for example: at normal temperatures water is in the liquid state; in the solid state water is called ice; and the gaseous state of water is called steam or water vapor. It is all still water, just in different states. Table 2 provides a summary of these three states in terms of shape and volume.

Table 2. States of matter compared

<table>
<thead>
<tr>
<th>State</th>
<th>Shape</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td>Definite</td>
<td>Definite</td>
</tr>
<tr>
<td>Liquid</td>
<td>Indefinite</td>
<td>Definite</td>
</tr>
<tr>
<td>Gas</td>
<td>Indefinite</td>
<td>Indefinite</td>
</tr>
</tbody>
</table>

Source: DOE-HDBK-1122-2009

**Solid State**

A solid state has definite shape and volume. The solid state differs from the liquid and gaseous states in that

- the molecules or ions of a solid are held in place by strong attractive forces.
- the molecules have thermal energy, but the energy is not sufficient to overcome the attractive forces.
- the molecules of a solid are arranged in an orderly, fixed pattern.

The rigid arrangement of molecules causes the solid to have a definite shape and a definite volume.

**Liquid State**

When heat is added to a substance, the molecules acquire more energy, which causes them to break free of their fixed crystalline arrangement. As a solid is heated, its temperature rises until the change of state from solid to liquid occurs. The volume of a liquid is definite since the molecules are very close to each other, with almost no space in between. Consequently, liquids can undergo a negligible amount of compression. However, the attractive forces
between the molecules are not strong enough to hold the liquid in a definite shape. For this reason a liquid takes the shape of its container.

High energy molecules near the surface of a liquid can overcome the attractive forces of other molecules. These molecules transfer from the liquid state to the gaseous state. If energy (heat) is removed from the liquid, the kinetic energy of the molecules decreases and the attractive forces can hold the molecules in fixed positions. When compared with the kinetic energy, the attractive forces are not strong enough to hold the molecules in fixed positions, forming a solid.

**Gaseous State**

If the temperature of a liquid is increased sufficiently, it boils, that is, molecules change to the gaseous state and escape from the surface. Eventually, all of the liquid will become a gas. A gas has both indefinite shape and indefinite volume. A large space exists between gas molecules because of their high thermal energy. This allows for even more compression of a substance in the gaseous state.

**Plasma**

The following is taken from Vision Learning, States of Matter.

Plasmas are hot, ionized gases. Plasmas are formed under conditions of extremely high energy, so high, in fact, that molecules are ripped apart and only free atoms exist. More astounding, plasmas have so much energy that the outer electrons are actually ripped off of individual atoms, thus forming a gas of highly energetic, charged ions. Because the atoms in plasma exist as charged ions, plasmas behave differently than gases, thus representing a fourth state of matter. Plasmas can be commonly seen simply by looking upward; the high energy conditions that exist in stars such as our sun force individual atoms into the plasma state.

b. **Explain the structure of the Bohr atom.**

The following is taken from DOE-HDBK-1019/1-93.

The British physicist Ernest Rutherford postulated that the positive charge in an atom is concentrated in a small region called a nucleus at the center of the atom with electrons existing in orbits around it. Niels Bohr, coupling Rutherford’s postulation with the quantum theory introduced by Max Planck, proposed that the atom consists of a dense nucleus of protons surrounded by electrons traveling in discrete orbits at fixed distances from the nucleus. An electron in one of these orbits or shells has a specific or discrete quantity of energy (quantum). When an electron moves from one allowed orbit to another allowed orbit, the energy difference between the two states is emitted or absorbed in the form of a single quantum of radiant energy called a photon. Figure 48 is Bohr’s model of the hydrogen atom showing an electron as having just dropped from the third shell to the first shell with the emission of a photon that has an energy = $h \nu$. ($h =$ Planck’s constant $= 6.63 \times 10^{-34}$ J-s and $\nu =$ frequency of the photon.) Bohr’s theory was the first to successfully account for the discrete energy levels of this radiation as measured in the laboratory. Although Bohr’s atomic model is designed specifically to explain the hydrogen atom, his theories apply generally to the structure of all atoms.
c. Discuss the following terms:
   - **Element**
   - **Molecule**
   - **Avogadro’s Number**
   - **Mole**

The following definitions are taken from DOE-HDBK-1015/1-93.

**Element**
An atom is classified chemically by the number of protons in its nucleus. Atoms that have the same number of protons in their nuclei have the same chemical behavior. Atoms that have the same number of protons are grouped together and constitute a chemical element.

**Molecule**
Molecules are groups or clusters of atoms held together by means of chemical bonding. There are two types of molecules; molecules of an element and molecules of a compound.

Molecules of an Element
In certain cases, two single atoms of an element can be attracted to one another by a bond to form a molecule. Examples of this are hydrogen, oxygen, and bromine. The molecular formulas for these are H$_2$, O$_2$, and Br$_2$. Most gaseous elements exist as molecules of two atoms.
Molecules of a Compound
Two atoms of different elements held together by a bond form a compound. The molecule is the primary particle of a chemical compound. Some examples of this type of molecule include hydrogen chloride (HCl), water (H₂O), methane (C₄H₄), and ammonia (NH₃).

Molecular Weight
The weight of a molecule, the molecular weight, is the total mass of the individual atoms. Therefore, it is fairly simple to calculate the mass of any molecule if its formula is known (that is, the elements and the number of each that make up the molecule). Note that the terms mass and weight are used interchangeably in chemistry.

Avogadro’s Number
Consider one atom of oxygen and one atom of sulfur, and compare their atomic weights.

Oxygen’s atomic weight = 15.999 amu
Sulfur’s atomic weight = 32.06 amu
The sulfur atom weighs approximately twice as much as the oxygen atom.

(32.06 ÷ 15.99 = 2)

Because the sulfur atom weighs twice as much as an oxygen atom, a one gram sample of oxygen contains twice as many atoms as a one gram sample of sulfur. Thus, a two gram sample of sulfur contains the same number of atoms as a one gram sample of oxygen.

From this example, one might suggest that a relationship exists between the weight of a sample and the number of atoms in the sample. In fact, scientists have determined that there is a definite relationship between the number of atoms in a sample and the sample’s weight.

Experimentation has shown that, for any element, a sample containing the atomic weight in grams contains 6.022 x 10²³ atoms. Thus 15.999 grams of oxygen contains 6.022 x 10²³ atoms, and 32.06 grams of sulfur contains 6.022 x 10²³ atoms. This number (6.022 x 10²³) is known as Avogadro’s number. It represents the number of atoms in X grams of any element, where X is the atomic weight of the element. It permits chemists to predict and use exact amounts of elements needed to cause desired chemical reactions to occur.

Mole
A single atom or a few atoms are rarely encountered. Instead, larger, macroscopic quantities are used to quantify or measure collections of atoms or molecules, such as a glass of water, a gallon of alcohol, or two aspirin. Chemists have introduced a large unit of matter, the mole, to deal with macroscopic samples of matter.

One mole represents a definite number of objects, substances, or particles. A mole is defined as the quantity of a pure substance that contains 6.022 x 10²³ units (atoms, ions, molecules, or elements) of that substance. In other words, a mole is Avogadro’s number of anything.

For any element, the mass of a mole of that element’s atoms is the atomic mass expressed in units of grams. For example, to calculate the mass of a mole of copper atoms, simply express the atomic mass of copper in units of grams. Because the atomic mass of copper is 63.546 amu, a mole of copper has a mass of 63.546 grams. The value for the atomic mass of gold is
196.967 amu. Therefore, a mole of gold has a mass of 196.967 grams. The mass of a mole of atoms is called the gram atomic weight. The mole concept allows the conversion of grams of a substance to moles and vice versa.

Figure 49 contains a ball of gold and a ball of copper. The two balls are of different masses and different sizes, but each contains an identical number of atoms.

![Figure 49](image)

**Source:** DOE-HDBK-1015/1-93

**Figure 49.** A mole of gold compared to a mole of copper

20. A facility representative must demonstrate a familiarity level knowledge of chemistry fundamentals in the areas of chemical bonding and chemical reactions.

a. Discuss the following types of chemical bonds:
   - Ionic
   - Covalent
   - Metallic

The following definitions are taken from DOE-HDBK-1015/1-93.

**Ionic Bond**

An ionic bond is formed when one or more electrons are wholly transferred from one element to another, and the elements are held together by the force of attraction due to the opposing charges. An example of ionic bonding is sodium chloride (table salt).

The sodium atom loses the one electron in its outer shell to the chlorine atom, which uses the electron to fill its outer shell. When this occurs, the sodium atom is left with a +1 charge and the chlorine atom a -1 charge. The ionic bond is formed as a result of the attraction of the two oppositely-charged particles. No single negatively-charged ion has a greater tendency to bond to a particular positively-charged ion than to any other ion. Because of this, the positive and negative ions arrange themselves in three dimensions to balance the charges among several ions. In sodium chloride, for example, each chloride ion is surrounded by as many sodium ions as can easily crowd around it, namely six. Similarly, each sodium ion is surrounded by six chloride ions. Therefore, each chloride ion is bonded to the six nearest
sodium ions and bonded to a lesser extent to the more distant sodium ions. Accordingly, the ionic bond is a force holding many atoms or ions together rather than a bond between two individual atoms or ions.

**Covalent Bonds**

A covalent bond is formed when one or more electrons from an atom pair off with one or more electrons from another atom and form overlapping electron shells in which both atoms share the paired electrons. Unlike an ionic bond, a covalent bond holds together specific atoms. Covalent bonding can be single covalent, double covalent, or triple covalent, depending on the number of pairs of electrons shared.

Two double covalent bonds result when carbon dioxide, which consists of one carbon atom and two oxygen atoms, is formed. Four pairs of electrons are shared by the carbon atom, two from each of the two oxygen atoms. A combination of two electrons forms a lower energy than their energy when separated. This energy difference represents the force that binds specific atoms together. When both shared electrons in a covalent bond come from the same atom, the bond is called a coordinate covalent bond. Although both shared electrons come from the same atom, a coordinate covalent bond is a single bond similar in properties to a covalent bond.

Covalent bonds can be either polar or non-polar. When the shared pair of electrons is not shared equally, one end of the bond is positive and the other end is negative. This produces a bond with two poles called a polar covalent bond.

Molecules having polar covalent bonds are called dipolar or polar molecules. Water is an example of a polar molecule. When two atoms of the same element share one or more pairs of electrons (such as H or N), each atom exerts the same attraction for the shared electron pair or pairs. When the electron pairs are distributed or shared equally between the two like atoms, the bond is called a non-polar covalent bond. If all the bonds in a molecule are of this kind, the molecule is called a non-polar covalent molecule.

**Metallic Bonds**

Another chemical bonding mechanism is the metallic bond. In the metallic bond, an atom achieves a more stable configuration by sharing the electrons in its outer shell with many other atoms. Metallic bonds prevail in elements in which the valence electrons are not tightly bound with the nucleus, namely metals, thus the name metallic bonding. In this type of bond, each atom in a metal crystal contributes all the electrons in its valence shell to all other atoms in the crystal.

Another way of looking at this mechanism is to imagine that the valence electrons are not closely associated with individual atoms, but instead move around amongst the atoms within the crystal. Therefore, the individual atoms can slip over one another, yet remain firmly held together by the electrostatic forces exerted by the electrons. This is why most metals can be hammered into thin sheets (malleable) or drawn into thin wires (ductile). When an electrical potential difference is applied, the electrons move freely between atoms, and a current flows.
b. Discuss how elements combine to form chemical compounds.

The number of electrons in the outer (valence) shell determines the relative activity of the element. The arrangement of electrons in the outer shell explains why some elements are chemically very active, some are not very active, and others are inert. In general, the fewer electrons an element must lose, gain, or share to reach a stable shell structure, the more chemically active the element is.

The likelihood of elements forming compounds is strongly influenced by the completion of the valence shell and by the stability of the resulting molecule. The more stable the resulting molecules are, the more likely these molecules are to form. For example, an atom that needs two electrons to completely fill the valence shell would rather react with another atom that must give up two electrons to satisfy its valence.

Atoms are joined or bonded together through this interaction of their electrons. There are several types of chemical bonds that hold atoms together, the most common being ionic, covalent, and metallic.

c. Discuss the following terms:
   - Mixture
   - Solvent
   - Solubility
   - Solute
   - Solution
   - Equilibrium
   - Normality
   - Density
   - Molarity
   - Parts per million (ppm)

The following definitions are taken from DOE-HDBK-1015/1-93.

*Mixture*
A mixture is defined as two substances placed together in a container, in any ratio and the composition is not of fixed proportion.

*Solvent*
A solvent is defined as the material that dissolves the other substance(s) in a solution. It is the dissolving medium.

*Solubility*
Solubility is defined as the maximum amount of a substance which will dissolve in a given amount of solvent at a specific temperature.

*Solute*
A solute is defined as the substance that dissolves in a solution.
Solution
A solution is a homogeneous mixture of two or more substances.

Equilibrium
Equilibrium is the point at which the rates of the forward and reverse reactions are exactly equal for a chemical reaction if the conditions of reaction are constant.

Normality
The normal concentration is another method for expressing the concentration of solutions. Normality (N) is defined as the number of equivalents of solute dissolved in one liter of solution.

\[
\text{Normality (N)} = \frac{\text{equivalents of solute}}{\text{liter of solution}}
\]

One equivalent of acid is the amount of acid necessary to give up one mole of hydrogen ions in a chemical reaction. One equivalent of base is the amount of base that reacts with one mole of hydrogen ions. When expressing the concentrations of bases, normality refers to the number of available hydroxyl ions. Because hydrogen and hydroxyl ions combine on a one-to-one basis, one OH\(^-\) is equivalent to one H\(^+\) ion.

Density
Density is the measure of the mass per unit volume of a material (density = mass/volume). Density is a characteristic of a substance; mass and volume are not. Mass and volume vary with size but density will remain constant. Temperature will affect the density of a substance and the temperature at which density for that substance was determined is usually reported along with the density value.

Molarity
A useful way to express exact concentrations of solutions is molarity. Molarity is defined as moles of solute per liter of solution. Molarity is symbolized by the capital letter M. It can be expressed mathematically as follows.

\[
\text{Molarity (M)} = \frac{\text{moles of solute (n)}}{\text{liters of solution (V)}}
\]

The moles of solute are divided by the liters of solution not solvent. One liter of one molar solution will consist of one mole of solute plus enough solvent to make a final volume of one liter.

Parts per Million
Another term used to describe the specific concentration of a solution is parts per million or ppm. The term ppm is defined as the concentration of a solution in units of one part of solute to one million parts solvent. One ppm equals one milligram of solute per liter of solution. Another term, parts per billion (ppb), is defined as one part solute per one billion parts
solvent. One ppb is equal to one microgram solute per liter of solution. These two terms are usually used for very dilute solutions.

d. Given an unbalanced chemical equation, explain how to balance the equation.

The following is taken from DOE-HDBK-1015/1-93.

The number of atoms or molecules of each substance is shown by the coefficients in the equation. Because atoms cannot be created or destroyed in a chemical reaction, a chemical equation must be balanced so that there is exactly the same number of atoms of each element on each side of the equation.

Example:

Explain the following chemical equation.

\[ 2\text{Fe} + 3\text{H}_2\text{O} \rightarrow \text{Fe}_2\text{O}_3 + 3\text{H}_2 \uparrow \]

Solution:

This chemical equation shows that iron reacts with water to form ferric oxide and hydrogen gas (the vertical arrow indicates a gas). This chemical equation also shows that for every two atoms of iron that react, three molecules of water are used to form one molecule of ferric oxide and three molecules of hydrogen gas. This is a balanced chemical equation. There are two iron atoms on each side of the equation; there are six hydrogen atoms on each side; and there are three oxygen atoms on each side.

There are no fixed rules for balancing chemical equations. Learning how is a matter of practice.

The balancing of most equations can be accomplished by following the guidelines explained below:

- Once the correct chemical formula for a compound is written in an equation, do not modify it.
- Select the compound with the greatest number of atoms. Then begin by balancing the element in that compound with the most atoms. There must be the same number of atoms of an element on each side of the equation. As a rule of thumb, this first element should not be hydrogen, oxygen, or a polyatomic ion.
- Balance the atoms of each element in the compound by placing the appropriate coefficient in front of the chemical symbol or formula.
- Next, balance the polyatomic ions. In some cases, the coefficient assigned may have to be changed to balance the polyatomic ion.
- Balance the hydrogen atoms next, then the oxygen atoms. If these elements appear in the polyatomic ion it should not be necessary to balance them again.
- All coefficients will be whole numbers. The coefficients should be reduced to the lowest possible ratios.
- As simple as it sounds, check off each element as it is accounted for since this will prevent double inclusion or a missed atom.
e. Define the following terms:

- **Acid**
- **Base**
- **Salt**
- **pH**
- **pOH**

The following definitions are taken from DOE-HDBK-1015/1-93.

**Acid**
Acids are substances that dissociate in water to produce hydrogen. Examples of acids are sulfuric acid, vinegar, aspirin, and lemon juice. These substances share the following common properties:
- Acid solutions taste sour (acid means sour in Latin).
- Acids react with many metals to form hydrogen gas.
- Acids turn litmus paper red.
- Acid solutions conduct electricity.
- Acids react with bases to form a salt and water.

**Base**
Bases are substances that produce hydroxide ions (OH\(^-\)) in water solutions. Examples of bases are sodium hydroxide (NaOH), household ammonia, most soaps, and lye. The following are four characteristic properties of bases:
- Basic solutions taste bitter and feel slippery to the touch.
- Bases turn litmus paper blue.
- Basic solutions conduct electricity.
- Bases neutralize acids.

**Salt**
When an acid reacts with a base, two products are formed: water and a salt. A salt is an ionic compound composed of positive ions and negative ions. The ionic bond is what keeps salts in their molecular form.

**pH**

ph is defined as the negative logarithm of the hydrogen concentration, represented as \([H^+]\) in moles/liter:

\[
\text{pH} = - \log [H^+] \\
[H^+] = 10^{-\text{pH}}
\]

**pOH**
The pOH of a solution is defined as the negative logarithm of the hydroxyl concentration, represented as \([OH^-]\) in moles/liter:

\[
\text{pOH} = - \log [OH^-] \\
[OH^-] = 10^{-\text{pOH}}
\]
For water solutions, the product of the hydrogen ion concentration and the hydroxyl concentration is always $1 \times 10^{-14}$ at 25°C. This means that the sum of pH and pOH is equal to 14 under these conditions.

$$[H^+] \times [OH^-] = 1 \times 10^{-14}$$

$$pH + pOH = 14$$

21. **A facility representative must demonstrate a familiarity level knowledge of chemistry fundamentals in the areas of corrosion and water treatment.**

**a. Discuss the process of general corrosion of iron and steel when exposed to water.**

The following is taken from DOE-HDBK-1015/1-93.

General corrosion is the process whereby the surface of a metal undergoes a slow, relatively uniform, removal of material. The two conditions typically required for a metal to undergo general corrosion are: (1) metal and water in the same environment, and (2) a chemical reaction between the metal and water that forms an oxide.

**Corrosion of Iron**

The oxidation and reduction half-reactions in the corrosion of iron (Fe) are as follows.

$$Fe \rightarrow Fe^{+2}+2e^- \text{ (oxidation)}$$
$$H_3O^++e^- \rightarrow H^+H_2O \text{ (reduction)}$$

The overall reaction is the sum of these half-reactions.

$$Fe+2H_3O^+ \rightarrow Fe^{+2}+2H^++2H_2O$$

The Fe$^{+2}$ ions readily combine with OH$^-$ ions at the metal surface, first forming Fe(OH)$_2$ which decomposes to ferrous oxide (FeO).

$$Fe^{+2}+2OH^- \rightarrow Fe(OH)_2 \rightarrow FeO+H_2O$$

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.

$$2FeO+ H_2O \rightarrow Fe_2O_3+2H$$

Atomic hydrogen then reacts to form molecular hydrogen and a layer of ferric oxide (Fe$_2$O$_3$) builds up on the FeO layer. Between these two layers is another layer that has the apparent composition Fe O . It is believed that Fe$_3$O$_4$ is a distinct crystalline state composed of O$^2-$, Fe$^{+2}$, and Fe$^{+3}$ in proportions so that the apparent composition is Fe$_3$O$_4$.

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
Fe\textsuperscript{2+} ions and electrons then diffuse through the oxide layer toward the oxide-water interface. Eventually, Fe\textsuperscript{2+} ions encounter OH\textsuperscript{-} 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\textsuperscript{+}, OH\textsuperscript{-} and H\textsubscript{2}O 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.

**Factors Affecting General Corrosion**

Like most other chemical reactions, corrosion rates increase as temperature increases. Temperature and pressure of the medium govern the solubility of the corrosive species in the fluid, such as oxygen, carbon dioxide, chlorides, and hydroxides. A rule of thumb is that the reaction rate doubles with a 20 °F to 50 °F temperature rise. This linear increase with temperature does not continue indefinitely due, in part, to a change in the oxide film.

When water velocity is extremely high, the impact of the water tends to remove the protective oxide layer and some of the metal under it (erosion); thus exposing more metal to corrosion. Water velocities of 30 to 40 ft per second are usually considered to cause erosion.

The presence of oxygen in water to which iron is exposed increases the corrosion rate. The reason for this increase is the rapid reaction between oxygen and the polarizing layer of atomic hydrogen absorbed on the oxide layer. The following reaction rapidly removes the polarizing layer.

\[
\text{O}_2 + 4\text{H} \rightarrow 2\text{H}_2\text{O}
\]

The controlling step is believed to be diffusion of O\textsubscript{2} to the metal surface where it can react directly with iron or with FeO.

Oxygen, therefore, has two effects: it removes the polarizing layer of atomic hydrogen, and it can react directly with the metal or metal oxide; thus the corrosion rate increases. Substances, such as O\textsubscript{2} in this case, that remove the absorbed atomic hydrogen are called depolarizers.

The effect of the pH of water to which iron or steel is exposed is influenced by temperature in the following manner. The potential of hydrogen or symbol (pH) is defined as the negative logarithm of the hydrogen concentration, represented as [H\textsuperscript{+}] in moles/liter.

\[
pH = -\log[H^+] 
\]

The pH value is used to represent the acidity of a solution.

Consider the exposure of iron to aerated water at room temperature (aerated water will contain dissolved oxygen). In the range of pH 4 to pH 10, the corrosion rate of iron is relatively independent of the pH of the solution. In this pH range, the corrosion rate is
governed largely by the rate at which oxygen reacts with absorbed atomic hydrogen, thereby depolarizing the surface and allowing the reduction reaction to continue. For pH values below 4.0, ferrous oxide (FeO) is soluble. Thus, the oxide dissolves as it is formed rather than depositing on the metal surface to form a film. In the absence of the protective oxide film, the metal surface is in direct contact with the acid solution, and the corrosion reaction proceeds at a greater rate than it does at higher pH values. It is also observed that hydrogen is produced in acid solutions below a pH of 4, indicating that the corrosion rate no longer depends entirely on depolarization by oxygen, but on a combination of the two factors (hydrogen evolution and depolarization). For pH values above about pH 10, the corrosion rate is observed to fall as pH is increased. This is believed to be due to an increase in the rate of the reaction of oxygen with Fe(OH)$_2$ (hydrated FeO) in the oxide layer to form the more protective Fe$_3$O$_4$.

The hydrogen normally dissolved in reactor coolant does not have any detectable direct effect upon the corrosion rate of the iron and steels exposed to reactor coolant. It does, however, have an important indirect effect by preventing the accumulation of dissolved oxygen in reactor coolant, which would accelerate corrosion. Dissolved oxygen reacts with the protective hydrogen gas layer at the cathode to form water.

The condition and composition of the metal surfaces affects the corrosion rate. Deposits, scale, or irregular surfaces create areas on the metal where local corrosion can initiate and proceed at a faster rate than normal. Certain alloys of metals have higher corrosion resistance than others.

When iron or steel is exposed to high temperature water, the rate of corrosion of the metal is observed to decrease with exposure time during the early period of exposure. After a few thousand hours, the corrosion rate becomes relatively constant at a low value. During the early period of exposure, while the corrosion rate is decreasing, the oxide film on the surface of the metal grows in thickness. However, the rate at which the film grows decreases with time. The thickness of the oxide film soon reaches a relatively constant value, and thereafter film thickness does not change appreciably with further exposure. As might be expected, a relatively constant corrosion rate and oxide film thickness are attained at about the same time. Because a tightly adhering corrosion film inhibits further corrosion, great care is taken during the initial fill of reactor plants to promote formation of the best possible corrosion film. This process, referred to as pretreatment, or pickling, involves careful control of reactor coolant water chemistry and temperature during the pretreatment period.

b. Discuss the two 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 the electrochemical cells described previously 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 such as impurity inclusions, grains of different sizes, difference in composition of grains, or 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.

c. Discuss the following types of specialized corrosion:
   - Pitting corrosion
   - Stress corrosion cracking
   - Crevice

The following descriptions are taken from DOE-HDBK-1015/1-93.

*Pitting Corrosion*

Pitting corrosion is a form of extremely localized corrosion that leads to the creation of small holes in the metal. The driving power for pitting corrosion is the lack of oxygen around a small area. This area becomes anodic, while the area with an excess of oxygen becomes cathodic.

*Stress Corrosion Cracking*

Stress corrosion cracking (SCC) is the cracking induced from the combined influence of tensile stress and a corrosive environment. The required tensile stresses may be in the form of directly applied stresses or in the form of residual stresses.

The impact of SCC on a material usually falls between dry cracking and the fatigue threshold of that material. 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.

*Crevice Corrosion*

Crevice corrosion is a localized form of pitting corrosion usually associated with a stagnant solution on the micro-environmental level. Such stagnant microenvironments tend to occur in crevices (shielded areas) such as those formed under gaskets, washers, insulation material, fastener heads, surface deposits, threads, lap joints, and clamps. Crevice corrosion is initiated by changes in local chemistry within the low-flow region of a crevice.

d. Discuss the reasons for removing impurities from water prior to use in nuclear and non-nuclear systems.

The following is taken from DOE-HDBK-1015/2-93.

There are three general reasons to treat water for its impurities:
   - To minimize corrosion, which is enhanced by impurities
e. Discuss the ion exchange process.

The following is taken from DOE-HDBK-1015/2-93.

Ion exchange is a process used extensively in nuclear facilities to control the purity and pH of water by removing undesirable ions and replacing them with acceptable ones. Specifically, it is the exchange of ions between a solid substance (called a resin) and an aqueous solution (reactor coolant or makeup water). Depending on the identity of the ions that a resin releases to the water, the process may result in purification of water or in control of the concentration of a particular ion in a solution. An ion exchange is the reversible exchange of ions between a liquid and a solid. This process is generally used to remove undesirable ions from a liquid and substitute acceptable ions from the solid (resin).

The devices in which ion exchange occurs are commonly called demineralizers. This name is derived from the term demineralize, which means the process whereby impurities present in the incoming fluid (water) are removed by exchanging impure ions with H⁺ and OH⁻ ions, resulting in the formation of pure water. H⁺ and OH⁻ are present on the sites of resin beads contained in the demineralizer tank or column.

f. Discuss the safety concerns of the “red oil” phenomenon.

The following is taken from the Defense Nuclear Facility Safety Board, DNFSB/Tech-33, Control of Red Oil Explosions in Defense Nuclear Facilities.

Red oil is defined as a substance of varying composition formed when an organic solution, typically tri-n-butyl phosphate (TBP) and its diluent, comes in contact with concentrated nitric acid at a temperature above 120°C. Red oil is relatively stable below 130 °C, but it can decompose explosively when its temperature is raised above 130°C.

Controls for prevention or mitigation of a red oil explosion are generally categorized as controls for temperature, pressure, mass, and concentration. Maintaining a temperature of less than 130°C is generally accepted as a means to prevent red oil explosions. Sufficient venting serves to keep pressure from destroying the process vessel, while also providing the means for evaporative cooling to keep red oil from reaching the runaway temperature. Mass controls utilize decanters or hydrocyclones to remove organics from feed streams entering process equipment capable of producing red oil. Limiting the total available TBP is another mass control that mitigates the consequence of a red oil explosion by limiting its maximum available explosive energy. Finally, concentration control can be utilized to keep the nitric acid below 10 M (moles/liter). A conclusion of this study is that none of the controls should be used alone; rather, they should be used together to provide effective defense-in-depth for prevention of a red oil explosion.
22. A facility representative must demonstrate a working level knowledge of chemistry fundamentals in the area of safety.

a. Describe the hazards associated with the use of corrosives (acids and alkalies).

The following is taken from DOE-HDBK-1015/2-93.

The hazards of acids are listed below:
- High concentrations of acids can destroy body tissue. The eyes are especially susceptible to permanent damage, and exposure can result in loss of sight.
- Inhalation of acidic vapors can irritate the respiratory system.
- Ingestion can destroy the stomach and throat lining, and if the concentration is strong enough, ingestion can be fatal.
- Aqueous solutions can become explosive if combined with other chemicals or combustible materials.
- If reacting with metal, hydrogen gas, which is very explosive, may be a byproduct.

The hazards of alkalies are listed below:
- Alkalies are more destructive than the acids.
- Alkali dusts, mists, and sprays can cause irritation of nasal passages, eyes, and the respiratory tract.
- When in contact with the tissue, strong alkalies will cause ulcers, severe burns, and eventual scarring.
- Ingestion of alkalies causes perforations of the mucous membrane and deeper tissues. Death may result if penetration is in vital areas.

b. Describe the hazards associated with the use of pyrophorics.

The following is taken from DOE-HDBK-1081-94.

Pyrophoric substances ignite instantly upon exposure to air (atmospheric oxygen). A pyrophoric substance may be a solid, liquid, or gas. Most materials are not pyrophoric unless they are in a very finely divided state. Although there are some pyrophoric liquids and gases, most pyrophoric materials are metals. Pyrophoricity is a special case of a hypergolic reaction because the oxidizing agent is restricted to atmospheric oxygen. Where pyrophoricity is concerned only with the spontaneous combustion of a material when exposed to air (atmospheric oxygen), a hypergolic reaction describes a material’s ability to spontaneously ignite or explode upon contact with any oxidizing agent.

Spontaneous heating of hydrocarbons usually involves a combustible liquid hydrocarbon in contact with combustible materials. An example of this would be combustible rags impregnated with oils or solvents. Some solid hydrocarbons, such as coal, can react directly with atmospheric oxygen. Whether spontaneous heating leads to ignition depends on several items:
- The rate at which heat is generated and removed from the material being oxidized
- The ignition temperature of the fibrous combustible material, hydrocarbon, or any gases liberated by oxidation
- The specific area of the hydrocarbon exposed to an oxidizer
- The amount of moisture present in the atmosphere and the fibrous material
For spontaneous ignition to occur, the rate of heat being generated through oxidation must exceed the rate of heat removal by conduction, convection, and radiation (thermal). As the temperature of the material begins to rise, the rate of heat generation will often increase.

The result is a runaway reaction that ultimately causes ignition. If the rate of heat removal exceeds the rate of generation, the material will cool and will not ignite. The rate of heat removal may be increased through physical contact with a thermally conductive surface, by rotating piles of combustibles to cool hot spots, and by circulating inert gases through the piles to cool hot spots and displace oxygen.

The ignition temperature of the materials is obviously of concern and varies widely among materials. Much more stringent controls must be placed on materials which have lower ignition temperatures and those which liberate explosive gases. Although most materials with high ignition temperatures are of lesser concern, some are more explosive than those with lower ignition temperatures.

The specific area of a combustible substance is a measure of the surface area of the material exposed to an oxidizing atmosphere per gram of material and is expressed in units of cm²/g. Materials that have a high specific area are more prone to heat and ignite spontaneously. For example, it was mentioned earlier that combustible liquids on fibrous material pose a spontaneous fire hazard. This is because the fibers of the material allow the liquid to spread out over a larger surface area, allowing more contact with oxygen. Therefore, porous combustible materials are more likely to ignite than tightly packed solid materials.

It is important to keep potentially spontaneously heating compounds as dry as possible. High ambient temperatures compound moisture problems. As the ambient temperature rises, the rate of spontaneous heat generation will also rise. High ambient temperatures also reduce the rate of heat removal, bringing the hydrocarbon closer to its ignition temperature.

The following housekeeping steps will help minimize the threat of spontaneous heating and ignition of hydrocarbon or organic compounds:

- Keep potentially spontaneously heating materials in a cool environment. The heat transfer resulting from a cooler atmosphere or circulating air will lower the temperature of the materials.
- Know all of the chemicals and their potential self-heating hazards and their ignition temperatures. Consult the chemical manufacturer’s material safety data sheets.
- Reduce the amount of fibrous materials used with combustible liquid hydrocarbons. Fibers allow liquid hydrocarbons to increase in specific areas, thereby increasing the likelihood of self-heating.
- Keep combustible materials away from existing spontaneous heating hazards. Many fires have been started as the result of a self-heating material coming in contact with a combustible with a low ignition temperature. This practice is also important from a fire loss minimization aspect.
- Keep appropriate fire extinguishing equipment near potential areas of ignition. Type A extinguishing agents are appropriate for most nonhazardous, combustible materials (rags, wood, textiles), whereas a type B agent is necessary in the presence of quantities of combustible liquids.
c. Describe the general safety precautions necessary for the handling, storage, and disposal of corrosives.

The following is taken from DOE-HDBK-1015/1-93.

Handling
The following precautions apply to the handling of corrosives:

- Pouring acids into small containers by hand, except by use of a cradle, is prohibited.
- The safest type of cradle should hold the acid container securely and should return to the upright position by gravity, with the provision for locking when not in use. A slow, steady motion should be used to operate the cradle.
- When pipettes are used to remove small quantities of acids from carboys, drawing acid into the pipette should be by suction bottle and never by mouth.
- When mixing acids and water, always add acid to water. Never add water to acid.
- Plastic carriers should be used to move acids from one location to another.

Storage
The following precautions apply to the storage of corrosives:

- Store large bottles of acids on low shelves or in acid storage cabinets.
- Segregate oxidizing acids from organic acids and flammable and combustible liquids.
- Segregate acids from bases and active metals such as sodium, potassium, and magnesium.
- Use bottle carriers for transporting acid bottles, and have spill-neutralizing agent available in case of acid spills.

Disposal
The following precautions apply to the disposal of corrosives:

- Corrosives should be disposed of in an approved container.
- Never pour corrosives down the drain.
- Always wear proper safety equipment when handling acids.

d. Describe the general safety precautions regarding toxic compounds.

The following is taken from DOE-HDBK-1015/2-93.

There are some general precautions that should be universally employed regarding toxic compounds. Proper ventilation, appropriate hygienic practices, housekeeping, protective clothing, and training on safe handling and storage will diminish many of the hazards that exist. Each toxic compound has a material safety data sheet identifying its hazards.

e. Describe the criteria used to determine if a compound is a health hazard and discuss the methods by which toxic compounds may enter the body.

The following is taken from DOE-HDBK-1015/2-93.

The following criteria are used to determine if a compound is a health hazard:

- The toxicity of the materials used
- The physical properties of the compound
The absorption probabilities of these materials by individuals
- The extent and intensity of exposure to these materials
- The control measures used

The methods by which toxic compounds may enter the body are as follows:
- Ingestion
- Inhalation
- Absorption

In general, industrial poisonings usually result from inhalation, ingestion, and absorption. The inhalation and absorption of toxic agents by the lungs depends on the solubility in body fluids, the diffusion through the lungs, the volume of inhalation, the volume of blood in the lungs, and the concentration gradient of vapors between the inhaled air and the blood.

Ingestion of the toxic agent can occur to some extent; however, there would generally be considerable inhalation of the material where such conditions exist.

Absorption through the skin can occur upon exposure to some toxic agents. Some liquids and vapors are known to pass through the skin in concentrations high enough such that respiratory protection is not adequate. For example, hydrogen cyanide is known to pass through unbroken skin.

Consideration should be given to the type of work clothes being worn. If the clothes become saturated with solvents, they will act as a reservoir to bathe the body continually with the harmful material.

f. Describe the general safety precautions regarding the use, handling, and storage of compressed gases, including specifically hydrogen, oxygen, and nitrogen.

The following is taken from DOE-HDBK-1015/2-93.

Compressed and liquefied 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 that can warn of their presence in air. Others, however, like the atmospheric gases, have no odor or color. For this reason, warning labels are required for compressed and liquefied-gas shipping containers, and similar warning signs are placed at the approaches to areas in which the gases are regularly stored and used.
Some gases can have a toxic effect on the human system, either by inhalation, through high-vapor concentrations, or by liquefied 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.

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 from any flammable substance, including grease and oil, and should be stored no closer than 10 feet from 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 be moved by a hand truck, not dragged or rolled across the floor. 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 the outside surface exceeds a temperature of 125°F, and they should never be heated with a torch or other open flame.

**Hydrogen**

Hydrogen is the lightest of all elements. Its presence cannot be detected by any of the senses. It is flammable in oxygen or air, and has a flammable range of from 4.1 percent to 74.2 percent by volume in air. A mixture of 10 to 65 percent hydrogen by volume in air will explode if ignited. Pure hydrogen burns quietly in air with an almost invisible flame, and when burned with pure oxygen, a very high temperature may be reached. Hydrogen will burn readily in chlorine gas, and under proper conditions, will combine with nitrogen, forming ammonia. Some chemical reactions produce hydrogen as a byproduct. A lead-acid battery will produce hydrogen when it is being charged. Metallic sodium and potassium are examples of some chemicals that react violently when exposed to water, producing hydrogen, which may flame spontaneously due to the heat of the reaction. Many electroplating processes produce hydrogen. Some chemicals used to remove scale from the water side of boilers give off hydrogen. Whatever the operation, it is important to know whether hydrogen will be produced, and if so, precautions must be taken to prevent its accumulation and ignition. The precautions to take include adequate ventilation to prevent its accumulation and the elimination of possible sources of ignition. Hydrogen is classified as an asphyxiant.

**Nitrogen**

Nitrogen makes up more than 78 percent of the earth’s atmosphere. It will not burn or support combustion. It cannot be detected by any of the senses and it is not toxic. Although it is often referred to as an inert gas because it does not oxidize readily, it nevertheless forms many compounds. It is frequently used to inert systems that contain, or have contained, flammable liquids or gases. Inerting a system means replacing the oxygen with an inert gas to reduce the possibility of fire or explosion.
Nitrogen is fairly soluble in the blood, and a considerable amount will dissolve in the blood of a person when the air pressure is increased, as in diving, caisson, and some tunnel work. If these employees are not properly decompressed, the dissolved nitrogen escapes from the blood in the form of small bubbles in the bloodstream causing intense pain and is often fatal. This disorder is commonly known as the bends.

If a large amount of nitrogen were released into the air of an enclosed space, it could cause a serious oxygen deficiency. Nitrogen is an asphyxiant.

**Oxygen**

Oxygen supports combustion, but does not burn. Even so, it must be considered a potentially hazardous element from a fire hazard standpoint. The results of an enriched oxygen atmosphere include a lowered ignition temperature, an increased flammable range, and an acceleration of the burning rate. Oxygen readily combines with other elements and compounds, with spontaneous ignition in some cases. When oxygen comes in contact with oil, grease, or fuel oils, it may ignite violently. Every possible precaution must be taken to prevent this combination.

Oxygen sustains life, but if pure oxygen were inhaled continuously for extended periods, the reactions in the body would be too rapid and would cause harmful effects. Oxygen should always be referred to as oxygen, and not air, to prevent confusion. It should never be used to run pneumatic equipment because of the possibility of coming in contact with oil that may be inside the equipment. Finally, oxygen valves should be operated slowly. Abruptly starting and stopping oxygen flow may ignite contaminants in the system.

g. **Describe the safety precautions for working with cryogenic liquids.**

The following is taken from DOE-HDBK-1015/2-93.

Always handle cryogenic liquids carefully as 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.

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 un-insulated pipes or vessels that contain cryogenic fluids because 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.

h. Explain the difference between a flammable liquid and a combustible liquid.

According to DOE-HDBK-1015/2-93, flammable liquids are liquids that have a flash point below 100 °F and a vapor pressure not exceeding 40 psia at 100°F. Combustible liquids are liquids with flash points at or above 100°F, but below 200°F.

i. Describe the general safety precautions regarding the use, handling, and storage of flammable and combustible liquids.

The following is taken from DOE-HDBK-1015/2-93.

Avoid accidental mixture of flammable and combustible liquids. A small amount of a highly volatile substance may lower the flash point of a less volatile substance and form a more flammable mixture. In addition, the lower flash point liquid can act as a fuse to ignite the higher flash point material in the same manner as if it were a flammable mixture.

Fill and discharge lines and openings, as well as control valves associated with flammable and combustible systems, shall be identified by labels, color coding, or both, to prevent mixing different substances. All storage tanks shall be clearly labeled with the name of its contents, and products stored within shall not be intermixed. Transfer lines from different types and classes of flammable products should be kept separate, and preferably, different pumps should be provided for individual products.

For handling quantities of flammable liquids up to five gallons, a portable Factory Mutual Engineering Corp. or Underwriters Laboratory-approved container should be used. The container should be clearly identified by lettering or color code. Smoking, the carrying of strike-anywhere matches, lighters, and other spark-producing devices should not be permitted in a building or area where flammable liquids are stored, handled, or used. The extent of the restricted area will depend on the type of products handled, the design of the building, local codes, and local conditions.

Suitable no smoking signs should be posted conspicuously in those buildings and areas where smoking is prohibited.

Static electricity is generated by the contact and separation of dissimilar material. For example, static electricity is generated when a fluid flows through a pipe or from an orifice into a tank. The principal hazards created by static electricity are fire and explosion, which are caused by spark discharges. A point of great danger from a static spark is where a flammable vapor is present in the air, such as the outlet of a flammable liquid fill pipe, at a delivery hose nozzle, near an open flammable liquid container, and around a tank truck fill opening. In the presence of a mechanism for generating a static charge, a spark between two bodies occurs when there is a poor electrical conductive path between them. Hence,
grounding or bonding of flammable liquid containers is necessary to prevent static electricity from causing a spark.

23. **A facility representative must demonstrate a familiarity level knowledge of basic thermodynamics concepts and theories.**

   a. **Define the following terms:**
   
   - **Specific volume**
   - **Density**
   - **Specific gravity**
   - **Mass**
   - **Weight**

The following definitions are taken from DOE-HDBK-1012/1-92.

**Specific Volume**
Specific volume is the total volume of a substance divided by the total mass of that substance.

**Density**
Density is the total mass of a substance divided by the total volume occupied by that substance. The density of a substance is the reciprocal of its specific volume.

**Specific Gravity**
Specific gravity is a measure of the relative density of a substance as compared to the density of water at a standard temperature. Since the density of a fluid varies with temperature, specific gravities must be determined and specified at particular temperatures.

**Mass**
The mass ($m$) of a body is the measure of the amount of material present in that body.

**Weight**
The weight of a body is the force exerted by that body when its mass is accelerated in a gravitational field.

b. **Describe the thermodynamic properties of temperature and pressure.**

The following is taken from DOE-HDBK-1012/1-92.

Temperature is a measure of the molecular activity of a substance. The greater the movement of molecules, the higher the temperature will be. It is a relative measure of how hot or cold a substance is, and can be used to predict the direction of heat transfer.

Pressure is a measure of the force exerted per unit area on the boundaries of a substance (or system). It is caused by the collisions of the molecules of the substance with the boundaries of the system. As molecules hit the walls, they exert forces that try to push the walls outward. The forces resulting from all of these collisions cause the pressure exerted by a system on its surroundings. Pressure is frequently measured in units of lbf/in$^2$ (psi).
c. Discuss the Fahrenheit, Celsius, Kelvin, and Rankine temperature scales, and discuss the concept of absolute zero.

The following is taken from DOE-HDBK-1012/1-92.

The two temperature scales normally employed for measurement purposes are the Fahrenheit (F) and Celsius (C) scales. These scales are based on a specification of the number of increments between the freezing point and boiling point of water at standard atmospheric pressure. The C scale has 100 units between these points, and the Fahrenheit scale has 180 units. The zero points on the scales are arbitrary.

It is necessary to define an absolute temperature scale having only positive values. The absolute temperature scale that corresponds to the C scale is called the Kelvin (K) scale, and the absolute scale that corresponds to the F scale is called the Rankine (°R) scale. The zero points on both absolute scales represent the same physical state. This state is where there is no molecular motion of individual atoms. The relationships between the absolute and relative temperature scales are shown in the following equations:

\[ °R = F + 460 \] (1-7)

\[ K = C + 273 \]

Absolute zero = -460 °F or -273 °C

Freezing point of water = 32 °F or 0 °C

Boiling point of water = 212 °F or 100 °C

Conversions between the different scales can be made using the following formulas.

\[ F = 32 + \left( \frac{9}{5} \right)C \]

\[ C = \left( °F - 32 \right)\left( \frac{5}{9} \right) \]

\[ °R = F + 460 \]

\[ K = C + 273 \]

d. Describe the relationship between absolute pressure, gauge pressure, and vacuum.

The following is taken from DOE-HDBK-1012/1-92.

When pressure is measured relative to a perfect vacuum, it is called absolute pressure (psia); when measured relative to atmospheric pressure (14.7 psi), it is called gauge pressure (psig). The latter pressure scale was developed because almost all pressure gauges register zero when open to the atmosphere. Therefore, pressure gauges measure the difference between the pressure of the fluid to which they are connected and that of the surrounding air. If the pressure is below that of the atmosphere, it is designated as a vacuum. A perfect vacuum would correspond to absolute zero pressure. All values of absolute pressure are positive,
because a negative value would indicate tension, which is considered impossible in any fluid. Gauge pressures are positive if they are above atmospheric pressure and negative if they are below atmospheric pressure. Figure 50 shows the relationships between absolute, gauge, vacuum, and atmospheric pressures.

Source: DOE-HDBK-1012/1-92

**Figure 50.** Pressure relationships

Relationships between absolute pressure, gauge pressure, and vacuum can be shown using the following formulas.

\[
P_{\text{abs}} = P_{\text{atm}} + P_{\text{gauge}}
\]

\[
P_{\text{abs}} = P_{\text{atm}} - P_{\text{vac}}
\]

\(P_{\text{atm}}\) is atmospheric pressure, which is also called the barometric pressure. \(P_{\text{gauge}}\) is the gauge pressure, and \(P_{\text{vac}}\) is vacuum.

e. **Discuss the following and describe their relationship:**

- Energy
- Potential energy
- Kinetic energy
- Work
- Heat

The following definitions are taken from DOE-HDBK-1012/1-92.

Energy

Energy is defined as the capacity of a system to perform work or produce heat.

**Potential Energy**

Potential energy is defined as the energy of position.
**Kinetic Energy**

Kinetic energy is the energy of motion.

**Work**

Work is a form of energy, but it is energy in transit. Work is not a property of a system. Work is a process done by or on a system, but a system contains no work. This distinction between the forms of energy that are properties of a system and the forms of energy that are transferred to and from a system is important to the understanding of energy transfer systems.

Work is defined for mechanical systems as the action of a force on an object through a distance. It equals the product of the force (F) times the displacement (d).

\[ W = Fd \]

where:
- \( W \) = work (ft-lbf)
- \( F \) = force (lbf)
- \( d \) = displacement (ft)

In dealing with work in relation to energy transfer systems, it is important to distinguish between work done by the system on its surroundings and work done on the system by its surroundings. Work is done by the system when it is used to turn a turbine and thereby generate electricity in a turbine-generator. Work is done on the system when a pump is used to move the working fluid from one location to another. A positive value for work indicates that work is done by the system on its surroundings; a negative value indicates that work is done on the system by its surroundings.

**Heat**

Heat, like work, is energy in transit. The transfer of energy as heat, however, occurs at the molecular level as a result of a temperature difference. The symbol \( Q \) is used to denote heat. In engineering applications, the unit of heat is the British thermal unit (Btu). Specifically, this is called the 60 degree Btu because it is measured by a one degree temperature change from 59.5 to 60.5 °F.

As with work, the amount of heat transferred depends on the path and not simply on the initial and final conditions of the system. Also, as with work, it is important to distinguish between heat added to a system from its surroundings and heat removed from a system to its surroundings. A positive value for heat indicates that heat is added to the system by its surroundings. This is in contrast to work that is positive when energy is transferred from the system and negative when transferred to the system. The symbol \( q \) is sometimes used to indicate the heat added to or removed from a system per unit mass. It equals the total heat \( (Q) \) added or removed divided by the mass \((m)\). The term specific heat is not used for \( q \) since specific heat is used for another parameter. The quantity represented by \( q \) is referred to as the heat transferred per unit mass.

\[ q = \frac{Q}{m} \]
where:
q = heat transferred per unit mass (Btu/lbm)
Q = heat transferred (Btu)
m = mass (lbm)

Latent heat is the amount of heat added or removed to produce only a phase change.

Sensible heat is the heat added or removed that causes a temperature change.

Heat and work are both transient phenomena. Systems never possess heat or work, but either or both may occur when a system undergoes a change of energy state. Heat and work are boundary phenomena in that both are observed at the boundary of the system. Both represent energy crossing the system boundary.

f. Discuss the following types of thermodynamic systems:
   - Isolated
   - Open
   - Closed

The following descriptions are taken from DOE-HDBK-1012/1-92.

*Isolated*
An isolated system is one that is not influenced in any way by the surroundings. This means that no energy in the form of heat or work may cross the boundary of the system. In addition, no mass may cross the boundary of the system. A thermodynamic system is defined as a quantity of matter of fixed mass and identity upon which attention is focused for study.

*Open*
An open system is one that may have a transfer of both mass and energy with its surroundings.

*Closed*
A closed system has no transfer of mass with its surroundings, but may have a transfer of energy (either heat or work) with its surroundings.

g. Discuss the First Law of Thermodynamics.

The following is taken from DOE-HDBK-1012/1-92.

The first law of thermodynamics states that energy can neither be created nor destroyed, only altered in form. For any system, energy transfer is associated with mass and energy crossing the control boundary, external work and/or heat crossing the boundary, and the change of stored energy within the control volume. The mass flow of fluid is associated with the kinetic, potential, internal, and flow energies that affect the overall energy balance of the system. The exchange of external work and/or heat completes the energy balance.

The first law of thermodynamics is referred to as the conservation of energy principle, meaning that energy can neither be created nor destroyed, but rather transformed into various
forms as the fluid within the control volume is being studied. The energy balance spoken of here is maintained within the system being studied. The system is a region in space (control volume) through which the fluid passes. The various energies associated with the fluid are then observed as they cross the boundaries of the system and the balance is made.

h. Discuss the Second Law of Thermodynamics.

The following is taken from DOE-HDBK-1012/1-92.

The second law of thermodynamics states that it is impossible to construct a device that operates in a cycle and produces no effect other than the removal of heat from a body at one temperature and the absorption of an equal quantity of heat by a body at a higher temperature.

With the second law of thermodynamics, the limitations imposed on any process can be studied to determine the maximum possible efficiencies of such a process, and then a comparison can be made between the maximum possible efficiency and the actual efficiency achieved. One of the areas of application of the second law is the study of energy-conversion systems. For example, it is not possible to convert all the energy obtained from a nuclear reactor into electrical energy. There must be losses in the conversion process. The second law can be used to derive an expression for the maximum possible energy conversion efficiency taking those losses into account. Therefore, the second law denies the possibility of completely converting into work all of the heat supplied to a system operating in a cycle, no matter how perfectly designed the system may be. The concept of the second law is best stated using Max Planck’s description: It is impossible to construct an engine that will work in a complete cycle and produce no other effect except the raising of a weight and the cooling of a heat reservoir.

The second law of thermodynamics is needed because the first law of thermodynamics does not define the energy conversion process completely. The first law is used to relate and to evaluate the various energies involved in a process. However, no information about the direction of the process can be obtained by the application of the first law. Early in the development of the science of thermodynamics, investigators noted that while work could be converted completely into heat, the converse was never true for a cyclic process. Certain natural processes were also observed always to proceed in a certain direction (e.g., heat transfer occurs from a hot to a cold body). The second law was developed as an explanation of these natural phenomena.

24. A facility representative must demonstrate a familiarity level knowledge of basic heat transfer and fluid flow concepts and theories.

a. Using the ideal gas law, discuss the relationship between pressure, temperature, and volume.

The following is taken from DOE-HDBK-1012/1-92.

The ideal gas law can be used to determine how the properties of pressure, temperature, and volume will be related during compression processes.
\[ P_v = R \, T \]

The ideal gas law is used by engineers working with gases because it is simple to use and approximates real gas behavior. Most physical conditions of gases used by man fit the above description. Perhaps the most common use of gas behavior studied by engineers is that of the compression process using ideal gas approximations. Such a compression process may occur at constant temperature (\( pV = \text{constant} \)), constant volume, or adiabatic (no heat transfer). Whatever the process, the amount of work that results from it depends on the process, as brought out in the discussion on the first law of thermodynamics. The compression process using ideal gas considerations results in work performed on the system and is essentially the area under a P-V curve. As can be seen in figure 51 different amounts of work result from different ideal gas processes, such as constant temperature and constant pressure.

**Figure 51.** Pressure volume diagram

b. **Discuss when a fluid may be considered to be incompressible.**

The following is taken from DOE-HDBK-1012/1-92.

Usually a fluid may be considered incompressible when the velocity of the fluid is greater than one-third of the speed of sound for the fluid, or if the fluid is a liquid. The treatment of a fluid that is considered incompressible is easy because the density is assumed to be constant, giving a simple relationship for the state of the substance. The variation of density of the fluid with changes in pressure is the primary factor considered in deciding whether a fluid is incompressible.

c. **Discuss the effects of pressure and temperature changes on confined fluids.**

The following is taken from DOE-HDBK-1012/1-92.

The predominant effect of an increase in pressure in a compressible fluid, such as a gas, is an increase in the density of the fluid. An increase in the pressure of an incompressible fluid will not have a significant effect on the density. For example, increasing the pressure of 100°F
water from 15 psia to 15,000 psia will only increase the density by approximately 6 percent. Therefore, in engineering calculations, it is assumed that the density of incompressible fluids remains constant. An increase in temperature will tend to decrease the density of any fluid. If the fluid is confined in a container of fixed volume, the effect of a temperature change will depend on whether the fluid is compressible.

If the fluid is a gas, it will respond to a temperature change in a manner predicted by the ideal gas laws. A 5 percent increase in absolute temperature will result in a 5 percent increase in the absolute pressure.

If the fluid is an incompressible liquid in a closed container, an increase in the temperature will have a tremendously greater and potentially catastrophic effect. As the fluid temperature increases, it tries to expand, but expansion is prevented by the walls of the container. Because the fluid is incompressible, this results in a tremendous increase in pressure for a relatively minor temperature change. The change in specific volume for a given change in temperature is not the same at various beginning temperatures. Resultant pressure changes will vary. A useful thumb rule for water is that pressure in a water-solid system will increase about 100 psi for every 1°F increase in temperature.

d. **Discuss the difference between heat and temperature, and heat and work.**

The following is taken from DOE-HDBK-1012/2-92.

In describing heat transfer problems, students often make the mistake of interchangeably using the terms heat and temperature. Actually, there is a distinct difference between the two. Temperature is a measure of the amount of energy possessed by the molecules of a substance. It is a relative measure of how hot or cold a substance is and can be used to predict the direction of heat transfer. The symbol for temperature is T. The common scales for measuring temperature are the Fahrenheit, Rankine, Celsius, and Kelvin temperature scales.

Heat is energy in transit. The transfer of energy as heat occurs at the molecular level as a result of a temperature difference. Heat is capable of being transmitted through solids and fluids by conduction, through fluids by convection, and through empty space by radiation. The symbol for heat is Q. Common units for measuring heat are the Btu in the English system of units and the calorie in the SI system (International System of Units).

Distinction should also be made between the energy terms heat and work. Both represent energy in transition. Work is the transfer of energy resulting from a force acting through a distance.

Heat is energy transferred as the result of a temperature difference. Neither heat nor work are thermodynamic properties of a system. Heat can be transferred into or out of a system and work can be done on or by a system, but a system cannot contain or store either heat or work. Heat into a system and work out of a system are considered positive quantities. When a temperature difference exists across a boundary, the second law of thermodynamics indicates the natural flow of energy is from the hotter body to the colder body. The second law of thermodynamics denies the possibility of ever completely converting into work all the heat supplied to a system operating in a cycle.
The second law says that if you draw heat from a reservoir to raise a weight, lowering the weight will not generate enough heat to return the reservoir to its original temperature, and eventually the cycle will stop. If two blocks of metal at different temperatures are thermally insulated from their surroundings and are brought into contact with each other the heat will flow from the hotter to the colder. Eventually the two blocks will reach the same temperature, and heat transfer will cease. Energy has not been lost, but instead some energy has been transferred from one block to another.

e. **Discuss the three modes of heat transfer.**

The following is taken from DOE-HDBK-1012/2-92.

Conduction involves the transfer of heat by the interactions of atoms or molecules of a material through which the heat is being transferred.

Convection involves the transfer of heat by the mixing and motion of macroscopic portions of a fluid.

Radiation, or radiant heat transfer, involves the transfer of heat by electromagnetic radiation that arises due to the temperature of a body.

f. **Discuss how the density of a fluid varies with temperature.**

According to DOE-HDBK-1012/2-92, as the temperature of the fluid increases, the density decreases and the specific volume increases.

g. **Discuss the relationship between the pressure in fluid column and the density and depth of the fluid.**

The following is taken from DOE-HDBK-1012/3-92.

Density and specific volume are the inverse of one another. Both density and specific volume are dependant on the temperature and somewhat on the pressure of the fluid. As the temperature of the fluid increases, the density decreases and the specific volume increases. Since liquids are considered incompressible, an increase in pressure will result in no change in density or specific volume of the liquid. In actuality, liquids can be slightly compressed at high pressures, resulting in a slight increase in density and a slight decrease in specific volume of the liquid.

Anyone who dives under the surface of the water notices that the pressure on the eardrums at a depth of even a few feet is noticeably greater than atmospheric pressure. Careful measurements show that the pressure of a liquid is directly proportional to the depth, and for a given depth the liquid exerts the same pressure in all directions.

As shown in figure 52 the pressure at different levels in the tank varies and this causes the fluid to leave the tank at varying velocities. Pressure was defined to be force per unit area. In the case of this tank, the force is due to the weight of the water above the point where the pressure is being determined.
The pressure exerted by a column of water is directly proportional to the height of the column and the density of the water and is independent of the cross-sectional area of the column. The pressure thirty feet below the surface of a one inch diameter standpipe is the same as the pressure thirty feet below the surface of a large lake.

h. **Discuss the terms mass flow rate and volumetric flow rate.**

The following definitions are taken from DOE-HDBK-1012/3-92.

**Mass Flow Rate**

The mass flow rate ($m$) of a system is a measure of the mass of fluid passing a point in the system per unit time. The mass flow rate is related to the volumetric flow rate as shown in the equation below, where $\rho$ is the density of the fluid and $V$ is the volumetric flow rate.

$$m = \rho V$$

If the volumetric flow rate is in cubic feet per second and the density is in pounds-mass per cubic foot, the above equation results in mass flow rate measured in pounds-mass per second. Other common units for measurement of mass flow rate include kilograms per second and pounds-mass per hour.

**Volumetric Flow Rate**

The volumetric flow rate ($V$) of a system is a measure of the volume of fluid passing a point in the system per unit time. The volumetric flow rate can be calculated as the product of the cross-sectional area ($A$) for flow and the average flow velocity ($v$).

$$V = Av$$

If area is measured in square feet and velocity in feet per second, the above equation results in volumetric flow rate measured in cubic feet per second. Other common units for
volumetric flow rate include gallons per minute, cubic centimeters per second, liters per minute, and gallons per hour.

i. **Discuss the characteristics and flow velocity profiles of laminar flow and turbulent flow.**

The following is taken from DOE-HDBK-1012/3-92.

All fluid flow is classified into one of two broad categories or regimes. These two flow regimes are laminar flow and turbulent flow. The flow regime, whether laminar or turbulent, is important in the design and operation of any fluid system. The amount of fluid friction, which determines the amount of energy required to maintain the desired flow, depends upon the mode of flow. This is also an important consideration in certain applications that involve heat transfer to the fluid.

*Laminar Flow*
Laminar flow is also referred to as streamline or viscous flow. These terms are descriptive of the flow because, in laminar flow, 1) layers of water flow over one another at different speeds with virtually no mixing between layers, 2) fluid particles move in definite and observable paths or streamlines, and 3) the flow is characteristic of viscous (thick) fluid or is one in which viscosity of the fluid plays a significant part.

*Turbulent Flow*
Turbulent flow is characterized by the irregular movement of particles of the fluid. There is no definite frequency as there is in wave motion. The particles travel in irregular paths with no observable pattern and no definite layers.

j. **Discuss the property of viscosity.**

The following is taken from DOE-HDBK-1012/3-92.

Viscosity is a fluid property that measures the resistance of the fluid to deforming due to a shear force. Viscosity is the internal friction of a fluid that makes it resist flowing past a solid surface or other layers of the fluid. Viscosity can also be considered to be a measure of the resistance of a fluid to flowing. Thick oil has a high viscosity; water has a low viscosity.

k. **Discuss the terms head, head loss, and frictional loss, with respect to its use in fluid flow.**

The following definitions are taken from DOE-HDBK-1012/3-92.

*Head*
The term head is used by engineers in reference to pressure. It is a reference to the height, typically in feet, of a column of water that a given pressure will support. Each of the energies possessed by a fluid can be expressed in terms of head. The elevation head represents the potential energy of a fluid due to its elevation above a reference level. The velocity head represents the kinetic energy of the fluid. It is the height in feet that a flowing fluid would rise in a column if all of its kinetic energy were converted to potential energy. The pressure head
represents the flow energy of a column of fluid whose weight is equivalent to the pressure of the fluid. The sum of the elevation head, velocity head, and pressure head of a fluid is called the total head. Thus, Bernoulli’s equation states that the total head of the fluid is constant.

**Head Loss**
Head loss is a measure of the reduction in the total head (sum of elevation head, velocity head, and pressure head) of the fluid as it moves through a fluid system. Head loss is unavoidable in real fluids. It is present because of: the friction between the fluid and the walls of the pipe; the friction between adjacent fluid particles as they move relative to one another; and the turbulence caused whenever the flow is redirected or affected in any way by such components as piping entrances and exits, pumps, valves, flow reducers, and fittings.

**Frictional Loss**
Frictional loss is that part of the total head loss that occurs as the fluid flows through straight pipes. The head loss for fluid flow is directly proportional to the length of pipe, the square of the fluid velocity, and a term accounting for fluid friction called the friction factor. The head loss is inversely proportional to the diameter of the pipe.

25. A facility representative must demonstrate a familiarity level knowledge of basic material science in the areas of concepts, theories, and principles.

a. **State the five types of bonding that occur in materials and their characteristics.**
   
   The following is taken from DOE-HDBK-1017/1-93.

   The types of bonds in a material are determined by the manner in which forces hold matter together. The five types of bonds and their characteristics are:
   - **Ionic bond**—In this type of bond, one or more electrons are wholly transferred from an atom of one element to the atom of the other, and the elements are held together by the force of attraction due to the opposite polarity of the charge.
   - **Covalent bond**—A bond formed by shared electrons. Electrons are shared when an atom needs electrons to complete its outer shell and can share those electrons with its neighbor. The electrons are then part of both atoms and both shells are filled.
   - **Metallic bond**—In this type of bond, the atoms do not share or exchange electrons to bond together. Instead, many electrons (roughly one for each atom) are more or less free to move throughout the metal, so that each electron can interact with many of the fixed atoms.
   - **Molecular bond**—When the electrons of neutral atoms spend more time in one region of their orbit, a temporary weak charge will exist. The molecule will weakly attract other molecules. This is sometimes called the van der Waals or molecular bond.
   - **Hydrogen bond**—This bond is similar to the molecular bond and occurs due to the ease with which hydrogen atoms are willing to give up an electron to atoms of oxygen, fluorine, or nitrogen.

b. **Discuss the characteristics of the following crystal structures:**
   - **Body-centered cubic structure**
   - **Face-centered cubic structure**
   - **Hexagonal close-packed structure**
The following descriptions are taken from DOE-HDBK-1017/1-93.

*Body-Centered Cubic Structure*
In a body-centered cubic (BCC) arrangement of atoms, the unit cell consists of eight atoms at the corners of a cube and one atom at the body center of the cube.

*Face-Centered Cubic Structure*
In a face-centered cubic (FCC) arrangement of atoms, the unit cell consists of eight atoms at the corners of a cube and one atom at the center of each of the faces of the cube.

*Hexagonal Close-Packed Structure*
In a hexagonal close-packed arrangement of atoms, the unit cell consists of three layers of atoms. The top and bottom layers contain six atoms at the corners of a hexagon and one atom at the center of each hexagon. The middle layer contains three atoms nestled between the atoms of the top and bottom layers, hence, the name close-packed.

c. **Identify and describe the crystalline structure of a metal.**

The following is taken from DOE-HDBK-1017/1-93.

In a crystalline structure, the atoms are arranged in a three-dimensional array called a lattice. The lattice has a regular repeating configuration in all directions. A group of particles from one part of a crystal has exactly the same geometric relationship as a group from any other part of the same crystal.

d. **Define the following terms:**
   - Grain
   - Grain structure
   - Grain boundary
   - Creep
   - Polymorphism
   - Alloy

The following definitions are taken from DOE-HDBK-1017/1-93.

*Grain*
Grain is the region of space occupied by a continuous crystal lattice.

*Grain Structure*
Grain structure is the arrangement of grains in a metal, with a grain having a particular crystal structure.

*Grain Boundary*
Grain boundary is the outside area of grain that separates it from other grains.

*Creep*
Creep is the permanent deformation that increases with time under constant load or stress.
Polymorphism
Polymorphism is the property or ability of a metal to exist in two or more crystalline forms depending on temperature and composition. Most metals and metal alloys exhibit this property.

Alloy
An alloy is a mixture of two or more materials, at least one of which is a metal. Alloys can have a microstructure consisting of solid solutions, where secondary atoms are introduced as substitutionals or interstitials in a crystal lattice. An alloy might also be a crystal with a metallic compound at each lattice point. In addition, alloys may be composed of secondary crystals imbedded in a primary polycrystalline matrix. This type of alloy is called a composite (although the term composite does not necessarily imply that the component materials are metals).

e. Discuss the three possible alloy microstructures and their two main characteristics as compared to pure metals.

The following is taken from DOE-HDBK-1017/1-93.

Alloy microstructures include the following:
- Solid solutions, where secondary atoms are introduced as substitutionals or interstitials in a crystal lattice
- Crystal with metallic bonds
- Composites, where secondary crystals are imbedded in a primary polycrystalline matrix

Alloys are usually stronger than pure metals, but alloys generally have lower electrical and thermal conductivities than pure metals.

f. Compare and contrast the properties, characteristics, and applications of stainless steel to those of carbon steel.

The following is taken from DOE-HDBK-1017/1-93.

Heat treatment of large carbon steel components is done to take advantage of crystalline defects and their effects and thus obtain certain desirable properties or conditions. During manufacture, by varying the rate of cooling (quenching) of the metal, grain size and grain patterns are controlled. Grain characteristics are controlled to produce different levels of hardness and tensile strength. Generally, the faster a metal is cooled, the smaller the grain sizes will be. This will make the metal harder. As hardness and tensile strength increase in heat-treated steel, toughness and ductility decrease.

The cooling rate used in quenching depends on the method of cooling and the size of the metal. Uniform cooling is important to prevent distortion. Typically, steel components are quenched in oil or water. Because of the crystal pattern of type 304 stainless steel in the reactor tank (tritium production facility), heat treatment is unsuitable for increasing the hardness and strength.
Welding can induce internal stresses that will remain in the material after the welding is completed. In stainless steels, such as type 304, the crystal lattice is FCC (austenite). During high temperature welding, some surrounding metal may be elevated to between 500°F and 1000°F. In this temperature region, the austenite is transformed into a BCC lattice structure (bainite). When the metal has cooled, regions surrounding the weld contain some original austenite and some newly formed bainite. A problem arises because the packing factor is not the same for FCC crystals as for BCC crystals.

The bainite that has been formed occupies more space than the original austenite lattice. This elongation of the material causes residual compressive and tensile stresses in the material. Welding stresses can be minimized by using heat sink welding, which results in lower metal temperatures, and by annealing.

Annealing is another common heat treating process for carbon steel components. During annealing, the component is heated slowly to an elevated temperature and held there for a long period of time, then cooled. The annealing process is done to obtain the following effects:

- To soften the steel and improve ductility
- To relieve internal stresses caused by previous processes such as heat treatment, welding, or machining
- To refine the grain structure

**g. Identify the three types of microscopic imperfections found in crystalline structures.**

The following is taken from DOE-HDBK-1017/1-93.

Microscopic imperfections are generally classified as point, line, or interfacial imperfections:

- Point imperfections have atomic dimensions, and are in the size range of individual atoms.
- Line imperfections or dislocations are generally many atoms in length. They can be of the edge type, screw type, or mixed type, depending on lattice distortion. Line imperfections cannot end inside a crystal; they must end at crystal edge or other dislocation, or close back on themselves.
- Interfacial imperfections are larger than line imperfections and occur over a two-dimensional area. Interfacial imperfections exist at free surfaces, domain boundaries, grain boundaries, or inter-phase boundaries.

**h. Discuss the following terms:**

- Compressibility
- Stress
- Shear stress
- Tensile stress
- Compressive stress

The following definitions are taken from DOE-HDBK-1017/1-93.

*Compressibility*

Compressibility is the ability of a material to react to compressive stress or pressure.
**Stress**
Stress is an applied force (or system of forces) that tends to strain or deform a body.

**Shear Stress**
Shear stress is the internal resistance of a material to the distorting effects of an external force or load.

**Tensile Stress**
Tensile stress is a type of stress in which the two sections of material on either side of a stress plane tend to pull apart or elongate.

**Compressive Stress**
Compressive stress is the reverse of tensile stress; adjacent parts of the material tend to press against each other through a typical stress plane.

i. **Define the following terms:**
- Strain
- Proportional limit
- Plastic deformation

The following definitions are taken from DOE-HDBK-1017/1-93.

**Strain**
In the use of metal for mechanical engineering purposes, a given state of stress usually exists in a considerable volume of the material. Reaction of the atomic structure will manifest itself on a macroscopic scale. Therefore, whenever a stress is applied to a metal, a proportional dimensional change or distortion must take place.

Such a proportional dimensional change is called strain and is measured as the total elongation per unit length of material due to some applied stress.

The following equation illustrates this proportion or distortion.

\[
\text{Strain} = \varepsilon = \frac{\delta}{L}
\]

where
- \(\varepsilon\) = strain
- \(\delta\) = total elongation
- \(L\) = original length

Strain is the proportional dimensional change, or the intensity or degree of distortion, in a material under stress.

**Proportional Limit**
Proportional limit is the amount of stress just before the point (threshold) at which plastic strain begins to appear or the stress level and the corresponding value of elastic strain.
Plastic Deformation

Plastic deformation (or plastic strain) is a dimensional change that does not disappear when the initiating stress is removed. It is usually accompanied by some elastic strain.

The phenomenon of elastic strain and plastic deformation in a material are called elasticity and plasticity, respectively.

At room temperature, most metals have some elasticity that manifests itself as soon as the slightest stress is applied. Usually, they also possess some plasticity, but this may not become apparent until the stress has been raised appreciably. The magnitude of plastic strain, when it does appear, is likely to be much greater than that of the elastic strain for a given stress increment. Metals are likely to exhibit less elasticity and more plasticity at elevated temperatures.

A few pure unalloyed metals show little, if any, elasticity when stressed in the annealed (heated and then cooled slowly to prevent brittleness) condition at room temperature, but do exhibit marked plasticity. Some unalloyed metals and many alloys have marked elasticity at room temperature, but no plasticity.

The state of stress just before plastic strain begins to appear is known as the proportional limit, or elastic limit, and is defined by the stress level and the corresponding value of elastic strain.

The proportional limit is expressed in psi. For load intensities beyond the proportional limit, the deformation consists of both elastic and plastic strains.

Strain measures the proportional dimensional change with no load applied. Such values of strain are easily determined and only cease to be sufficiently accurate when plastic strain becomes dominant.

When metal experiences strain, its volume remains constant. Therefore, if volume remains constant as the dimension changes on one axis, then the dimensions of at least one other axis must change also. If one dimension increases, another must decrease. There are a few exceptions. For example, strain hardening involves the absorption of strain energy in the material structure, which results in an increase in one dimension without an offsetting decrease in other dimensions. This causes the density of the material to decrease and the volume to increase.

If a tensile load is applied to a material, the material will elongate on the axis of the load perpendicular to the tensile stress plane. Conversely, if the load is compressive, the axial dimension will decrease. If volume is constant, a corresponding lateral contraction or expansion must occur. This lateral change will bear a fixed relationship to the axial strain. The relationship, or ratio, of lateral to axial strain is called Poisson’s ratio after the name of its discoverer.

j. Identify the two common forms of strain and discuss the differences.

The following is taken from DOE-HDBK-1017/1-93.
Strain may take two forms: elastic strain and plastic deformation.

Elastic strain is a transitory dimensional change that exists only while the initiating stress is applied and disappears immediately upon removal of the stress. Elastic strain is also called elastic deformation. The applied stresses cause the atoms in a crystal to move from their equilibrium position. All the atoms are displaced the same amount and still maintain their relative geometry. When the stresses are removed, all the atoms return to their original positions and no permanent deformation occurs.

Elastic strain is a transitory dimensional change that exists only while the initiating stress is applied and disappears immediately upon removal of the stress.

Plastic strain (plastic deformation) is a dimensional change that does not disappear when the initiating stress is removed.

k. Discuss Hooke’s Law.

The following is taken from DOE-HBK-1017/1-93.

If a metal is lightly stressed, a temporary deformation takes place, presumably permitted by an elastic displacement of the atoms in the space lattice; removal of the stress results in a gradual return of the metal to its original shape and dimensions. Hooke provided data that showed that in the elastic range of a material, strain is proportional to stress. The elongation of the bar is directly proportional to the tensile force and the length of the bar and inversely proportional to the cross-sectional area and the modulus of elasticity.

I. Discuss what is meant by the terms “bulk modulus” and “fracture point.”

The following is taken from DOE-HDBK-1017/1-93.

The bulk modulus of elasticity is the elastic response to hydrostatic pressure and equilateral tension or the volumetric response to hydrostatic pressure and equilateral tension. It is also the property of a material that determines the elastic response to the application of stress.

Fracture point is the point where the material fractures due to plastic deformation.

m. Given the stress-strain curves for ductile and brittle material, identify the following points on the curve:
   - Proportional limit
   - Ultimate strength
   - Yield point
   - Fracture point

This is a performance-based competency. The Qualifying Official will evaluate its completion. The following information from DOE-HDBK-1017/1-93 may be helpful.

Stress and strain, as computed here, are sometimes called “engineering stress and strain.” They are not true stress and strain, which can be computed on the basis of the area and the gage length that exist for each increment of load and deformation. For example, true strain is the natural log of the elongation (ln (L/Lo)), and true stress is P/A, where A is area. The latter
values are usually used for scientific investigations, but the engineering values are useful for determining the load-carrying values of a material. Below the elastic limit, engineering stress and true stress are almost identical.

Source: DOE-HDBK-1017/1-93

Figure 53. Typical ductile stress-strain curve

The graphic results, or stress-strain diagram, of a typical tension test for structural steel is shown in figure 53. The ratio of stress to strain, or the gradient of the stress-strain graph, is called the modulus of elasticity or elastic modulus. The slope of the portion of the curve where stress is proportional to strain (between points 1 and 2) is referred to as Young’s Modulus and Hooke’s Law applies.

The following observations are illustrated in figure 53:
- Hooke’s Law applies between points 1 and 2.
- Hooke’s Law becomes questionable between points 2 and 3 and strain increases more rapidly.

n. Discuss the following terms:
- Strength
- Malleability
- Ductility
- Toughness
- Yield strength
- Hardness
- Ultimate tensile strength

The following definitions are taken from DOE-HDBK-1017/1-93.
**Strength**

Strength is the ability of a material to resist deformation. The strength of a component is usually considered based on the maximum load that can be borne before failure is apparent. If under simple tension the permanent deformation (plastic strain) that takes place in a component before failure, the load-carrying capacity, at the instant of final rupture, will probably be less than the maximum load supported at a lower strain because the load is being applied over a significantly smaller cross-sectional area. Under simple compression, the load at fracture will be the maximum applicable over a significantly enlarged area compared with the cross-sectional area under no load.

This obscurity can be overcome by utilizing a nominal stress figure for tension and shear. This is found by dividing the relevant maximum load by the original area of cross section of the component. Thus, the strength of a material is the maximum nominal stress it can sustain. The nominal stress is referred to in quoting the strength of a material and is always qualified by the type of stress, such as tensile strength, compressive strength, or shear strength.

**Malleability**

Where ductility is the ability of a material to deform easily upon the application of a tensile force, malleability is the ability of a metal to exhibit large deformation or plastic response when being subjected to compressive force.

**Ductility**

Ductility is more commonly defined as the ability of a material to deform easily upon the application of a tensile force, or as the ability of a material to withstand plastic deformation without rupture. Ductility may also be thought of in terms of bendability and crushability.

Ductile materials show large deformation before fracture. The lack of ductility is often termed brittleness. Usually, if two materials have the same strength and hardness, the one that has the higher ductility is more desirable. The ductility of many metals can change if conditions are altered. An increase in temperature will increase ductility. A decrease in temperature will cause a decrease in ductility and a change from ductile to brittle behavior. Ductility is desirable in high-temperature and high-pressure applications.

**Toughness**

The quality known as toughness describes the way a material reacts under sudden impacts. It is defined as the work required to deform one cubic inch of metal until it fractures. Toughness is measured by the Charpy test or the Izod test.

**Yield Strength**

A number of terms have been defined for the purpose of identifying the stress at which plastic deformation begins. The value most commonly used for this purpose is the yield strength. The yield strength is defined as the stress at which a predetermined amount of permanent deformation occurs. The graphical portion of the early stages of a tension test is used to evaluate yield strength. To find yield strength, the predetermined amount of permanent strain is set along the strain axis of the graph, to the right of the origin (zero).
**Hardness**

Hardness is the property of a material that enables it to resist plastic deformation, penetration, indentation, and scratching. Therefore, hardness is important from an engineering standpoint because resistance to wear by either friction or erosion by steam, oil, and water generally increases with hardness.

Hardness tests serve an important need in industry even though they do not measure a unique quality that can be termed hardness. The tests are empirical, based on experiments and observation, rather than fundamental theory. Its chief value is as an inspection device, able to detect certain differences in material when they arise even though these differences may be indefinable. For example, two lots of material that have the same hardness may or may not be alike, but if their hardness is different, the materials certainly are not alike.

Several methods have been developed for hardness testing. Those most often used are Brinell, Rockwell, Vickers, Tukon, Sclerscope, and the files test. The first four are based on indentation tests and the fifth on the rebound height of a diamond-tipped metallic hammer. The file test establishes the characteristics of how well a file takes a bite on the material.

**Ultimate Tensile Strength**

The ultimate tensile strength is the maximum resistance to fracture. It is equivalent to the maximum load that can be carried by one square inch of cross-sectional area when the load is applied as simple tension. It is expressed in psi.

If the complete engineering stress-strain curve is available, the ultimate tensile strength appears as the stress coordinate value of the highest point on the curve. Materials that elongate greatly before breaking undergo such a large reduction of cross-sectional area that the material will carry less load in the final stages of the test. A marked decrease in cross-section is called necking. Ultimate tensile strength is often shortened to tensile strength or even to ultimate.

**o. Describe the adverse effects of welding on metal including the types of stress.**

The following is taken from DOE-HDBK1017/1-93.

Welding can induce internal stresses that will remain in the material after the welding is completed. In stainless steels, such as type 304, the crystal lattice is FCC (austenite). During high-temperature welding, some surrounding metal may be elevated to between 500°F and 1000°F. In this temperature region, the austenite is transformed into a BCC lattice structure (bainite). When the metal has cooled, regions surrounding the weld contain some original austenite and some newly formed bainite. A problem arises because the packing factor is not the same for FCC crystals as for BCC crystals; the bainite that has been formed occupies more space than the original austenite lattice. This elongation of the material causes residual compressive and tensile stresses in the material. Welding stresses can be minimized by using heat sink welding, which results in lower metal temperatures, and by annealing.
p. Discuss the phenomenon of thermal shock.

Thermal shock can lead to excessive thermal gradients on materials, which lead to excessive stresses. These stresses can be comprised of tensile stress, which is stress arising from forces acting in opposite directions tending to pull a material apart, and compressive stress, which is stress arising from forces acting in opposite directions tending to push a material together. These stresses, cyclic in nature, can lead to fatigue failure of the materials. Thermal shock is caused by non-uniform heating or cooling of a uniform material, or uniform heating of non-uniform materials. Suppose a body is heated and constrained so that it cannot expand. When the temperature of the material increases, the increased activity of the molecules causes them to press against the constraining boundaries, thus setting up thermal stresses.

If the material is not constrained, it expands, and one or more of its dimensions increases. The thermal expansion coefficient \( \alpha \) relates the fractional change in length \( \frac{\Delta l}{l} \), called thermal strain, to the change in temperature per degree \( \Delta T \).

\[
\alpha = \frac{\Delta l}{l \Delta T}
\]

\[
\frac{\Delta l}{l} = \alpha \Delta T
\]

where
- \( l \) = length
- \( \Delta l \) = change in length
- \( \alpha \) = linear thermal expansion coefficient
- \( \Delta T \) = change in temperature

q. Discuss the following terms and discuss their relationship to material failure:

- **Ductile fracture**
- **Brittle fracture**
- **Nil-ductility transition (NDT) temperature**

The following definitions are taken from DOE-HDBK-1017/2-93.

**Ductile Fracture**

Metals can fail by ductile or brittle fracture. Metals that can sustain substantial plastic strain or deformation before fracturing exhibit ductile fracture. Usually, a large part of the plastic flow is concentrated near the fracture faces.

**Brittle Fracture**

Metals that fracture with a relatively small or negligible amount of plastic strain exhibit brittle fracture. Cracks propagate rapidly. Brittle failure results from cleavage (splitting along definite planes). Ductile fracture is better than brittle fracture because ductile fracture occurs over a period of time, where as brittle fracture is fast and can occur (with flaws) at lower stress levels than a ductile fracture.
Nil-Ductility Transition (NDT) Temperature
The NDT temperature, which is the temperature at which a given metal changes from ductile to brittle fracture, is often markedly increased by neutron irradiation. The increase in the NDT temperature is one of the most important effects of irradiation from the standpoint of nuclear power system design.

r. Discuss the phenomenon of brittle fracture.

The following is taken from DOE-HDBK-1017/2-93.

Metals that fracture with a relatively small or negligible amount of plastic strain exhibit brittle fracture. Cracks propagate rapidly. Brittle failure results from cleavage (splitting along definite planes). Ductile fracture is better than brittle fracture, because ductile fracture occurs over a period of time, where as brittle fracture is fast, and can occur (with flaws) at lower stress levels than a ductile fracture. Figure 54 shows the basic types of fracture.

Source: DOE-HDBK-1017/2-93.

Figure 54. Basic fracture types

Brittle cleavage fracture is of the most concern. Brittle cleavage fracture occurs in materials with a high strain-hardening rate and relatively low cleavage strength or great sensitivity to multi-axial stress.

Many metals that are ductile under some conditions become brittle if the conditions are altered. The effect of temperature on the nature of the fracture is of considerable importance. Many steels exhibit ductile fracture at elevated temperatures and brittle fracture at low temperatures. The temperature above which a material is ductile and below which it is brittle is known as the NDT temperature. This temperature is not precise, but varies according to prior mechanical and heat treatment and the nature and amounts of impurity elements. It is determined by some form of drop-weight test.
Ductility is an essential requirement for steels used in the construction of reactor vessels; therefore, the NDT temperature is of significance in the operation of these vessels. Small grain size tends to increase ductility and results in a decrease in NDT temperature. Grain size is controlled by heat treatment in the specifications and manufacturing of reactor vessels. The NDT temperature can also be lowered by small additions of selected alloying elements such as nickel and manganese to low-carbon steels.

Of particular importance is the shifting of the NDT temperature to the right (figure 55), when the reactor vessel is exposed to fast neutrons.

![Stress-temperature diagram for crack initiation and arrest](https://via.placeholder.com/150)

*Source:* DOE-HDBK-1017/2-93.

**Figure 55.** Stress-temperature diagram for crack initiation and arrest

The reactor vessel is continuously exposed to fast neutrons that escape from the core. Consequently, during operation the reactor vessel is subjected to an increasing fluence (flux) of fast neutrons, and as a result the NDT temperature increases steadily. It is not likely that the NDT temperature will approach the normal operating temperature of the steel. However, there is a possibility that when the reactor is being shut down or during an abnormal cool down, the temperature may fall below the NDT value while the internal pressure is still high. The reactor vessel is susceptible to brittle fracture at this point. Therefore, special attention must be given to the effect of neutron irradiation on the NDT temperature of the steels used in fabricating reactor pressure vessels. The NRC requires that a reactor vessel material surveillance program be conducted in water-cooled power reactors in accordance with American Society for Testing and Materials (ASTM) standards.
Pressure vessels are also subject to cyclic stress. Cyclic stress arises from pressure and/or temperature cycles on the metal. Cyclic stress can lead to fatigue failure. Fatigue failure can be initiated by microscopic cracks and notches and even by grinding and machining marks on the surface. The same (or similar) defects also favor brittle fracture.

s. Discuss fatigue failure and work hardening with respect to material failure.

The following is taken from DOE-HDBK-1017/2-93.

The majority of engineering failures are caused by fatigue. Fatigue failure is defined as the tendency of a material to fracture by means of progressive brittle cracking under repeated alternating or cyclic stresses of an intensity considerably below the normal strength. Although the fracture is of a brittle type, it may take some time to propagate, depending on the intensity and frequency of the stress cycles. Nevertheless, there is very little, if any, warning before failure if the crack is not noticed. The number of cycles required to cause fatigue failure at a particular peak stress is generally quite large, but it decreases as the stress is increased. For some mild steels, cyclical stresses can be continued indefinitely provided the peak stress (sometimes called fatigue strength) is below the endurance limit value.

A good example of fatigue failure is breaking a thin steel rod or wire with your hands after bending it back and forth several times in the same place. Another example is an unbalanced pump impeller resulting in vibrations that can cause fatigue failure.

t. Discuss the effects of the following types of radiation on the structural integrity of metals:
   - Alpha
   - Beta
   - Gamma
   - Fast neutron
   - Slow neutron

The following is taken from DOE-HDBK-1017/2-93.

Alpha and Beta

Alpha particles, being the largest particles of radiation and having a +2 charge, interact with matter more readily than other types of radiation. Each interaction results in a loss of energy. This is why the alpha has the shortest range of all the types of radiation. Alpha particles generally are stopped by a thin sheet of paper. As a comparison, a 4 mega electron-V (MeV) alpha particle will travel about 1 inch in air, whereas a 4 MeV beta particle will travel about 630 inches in air.

Because it deposits all of its energy in a very small area, the alpha particle travels only a short distance.

The beta particle is more penetrating than the alpha. However, because of the -1 charge, the beta particle interacts more readily than a non-charged particle. For this reason, it is less penetrating than uncharged types of radiation such as the gamma or neutron. The beta particle can generally be stopped by a sheet of aluminum. Because the beta travels farther than the alpha, it deposits its energy over a greater area and is, therefore, less harmful than...
the alpha if taken internally. All materials described under neutron and gamma radiation are also effective at attenuating beta radiation.

Since alpha and beta particles can be easily shielded against, they do not present a major problem in the nuclear reactor plant.

Gamma
Ionization and excitation of electrons in metals is produced by beta and gamma radiation. The ionization and excitation dissipates much of the energy of heavier charged particles and does very little damage. This is because electrons are relatively free to move and are soon replaced. The net effect of beta and gamma radiation on metal is to generate a small amount of heat. Heavier particles, such as protons, a-particles, fast neutrons, and fission fragments, will usually transfer sufficient energy through elastic or inelastic collisions to remove nuclei from their lattice (crystalline) positions. This addition of vacancies and interstitial atoms causes property changes in metals. This effect of nuclear radiation is sometimes referred to as radiation damage.

Fast Neutron
If a target or struck nucleus gains about 25 eV of kinetic energy (25 eV to 30 eV for most metals) in a collision with a radiation particle (usually a fast neutron), the nucleus will be displaced from its equilibrium position in the crystal lattice, as shown in figure 56.

The target nucleus (or recoiling atom) that is displaced is called a knocked-on nucleus or just a knock-on (or primary knock-on). When a metal atom is ejected from its crystal lattice the vacated site is called a vacancy. The amount of energy required to displace an atom is called displacement energy. The ejected atom will travel through the lattice causing ionization and heating. If the energy of the knock-on atom is large enough, it may in turn produce additional collisions and knock-ons. These knock-ons are referred to as secondary knock-ons. The process will continue until the displaced atom does not have sufficient energy to eject another atom from the crystal lattice. Therefore, a cascade of knock-on atoms will develop from the initial interaction of a high energy radiation particle with an atom in a solid.
This effect is especially important when the knock-on atom (or nucleus) is produced as the result of an elastic collision with a fast neutron (or other energetic heavy particle). The energy of the primary knock-on can then be quite high, and the cascade may be extensive. A single fast neutron in the greater than or equal to 1 MeV range can displace a few thousand atoms. Most of these displacements are temporary. At high temperatures, the number of permanently displaced atoms is smaller than the initial displacement.

During a lengthy irradiation many of the displaced atoms will return to normal (stable) lattice sites.

The permanently displaced atoms may lose their energy and occupy positions other than normal crystal lattice sites, thus becoming interstitials. The presence of interstitials and vacancies makes it more difficult for dislocations to move through the lattice. This increases the strength and reduces the ductility of a material.

At high energies, the primary knock-on (ion) will lose energy primarily by ionization and excitation interactions as it passes through the lattice, as shown in figure 56. As the knock-on loses energy, it tends to pick up free electrons which effectively reduces its charge. As a result, the principal mechanism for energy losses progressively changes from one of ionization and excitation at high energies to one of elastic collisions that produce secondary knock-ons or displacements. Generally, most elastic collisions between a knock-on and a nucleus occur at low kinetic energies below ‘A’ kilo-electron-V (KeV), where ‘A’ is the mass number of the knock-on. If the kinetic energy is greater than ‘A’ KeV, the probability is that the knock-on will lose much of its energy in causing ionization.
Slow Neutron

The following is taken from DOE-HDBK-1017/2-93.

The effects of neutrons on materials arise largely from the transfer of kinetic energy to atomic nuclei in one way or another. Thus, highly energetic recoil nuclei may be indirectly produced by the absorption of a neutron and the subsequent emission of a γ. If the energy of the recoil nucleus is sufficient to permit it to be displaced from its normal (or equilibrium) position in the crystal lattice of a solid, physical changes of an essentially permanent nature will be observed. This damage is commonly referred to as radiation damage. The absorption or capture of lower energy thermal (slow) neutrons can produce two effects:

- Introduction of an impurity atom (this is used in the electronics industry to uniformly dope semiconductors) due to the transmutation of the absorbing nucleus
- Atomic displacement caused by recoil atoms or knock-ons

Atomic displacement is the result of (n, p) and (n, α) reactions and (n, γ) reactions followed by radioactive decay. Thermal (slow) neutrons cannot produce atomic displacements directly, but they can do so indirectly as the result of radioactive capture (n, γ) and other neutron reactions or elastic scattering.

Radioactive capture, or thermal (slow) neutron capture, produces many gamma rays in the 5 MeV to 10 MeV energy range. When a gamma-ray photon is emitted by the excited compound nucleus formed by neutron capture, the residual atom suffers recoil. This recoil energy is often large enough to displace the atom from its equilibrium position and produce a cascade of displacements, or Frenkel defects, with a resultant property change of the material.

In a thermal reactor, in which the thermal (slow) neutron flux generally exceeds the fast neutron flux, the radiation damage caused by recoil from (n γ) reactions may be of the same order as (or greater than) that due to the fast neutrons in a material having an appreciable radioactive capture cross section for thermal neutrons. Other neutron reactions will also produce recoil atoms, but these reactions are of little significance in thermal reactors. Thermal (slow) neutron capture effects are generally confined to the surface of the material because most captures occur there, but fast-neutron damage is likely to extend through most of the material.

26. A facility representative must demonstrate a working level knowledge of engineering prints and drawings.

a. Given an engineering print, read and interpret the following information:
   - Title block
   - Notes
   - Legend
   - Revision block
   - Drawing grid

b. Given an engineering piping and instrument drawing (P&ID), identify the symbols used for:
   - Types of valves
   - Types of valve operators
- Types of eductors and ejectors
- Basic types of instrumentation
- Types of instrument signal controllers and modifiers
- Types of system components (pumps, etc.)
- Types of lines

c. Identify the symbols used on engineering piping and engineering diagrams to denote the location of instruments, indicators, and controllers.

d. Identify how valve conditions are depicted.

e. Determine system flow path(s) for a given valve lineup.

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

27. A facility representative must demonstrate a working level knowledge of electrical prints, diagrams, and schematics.

a. Identify the symbols used on engineering electrical drawings.

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

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

d. Identify the power sources and/or loads and their status, given simple electrical schematics and initial conditions.

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

28. A facility representative must demonstrate a familiarity level knowledge of engineering fabrication, construction, and architectural drawings.

a. State the purpose of engineering fabrication, construction, and architectural drawings.

The following is taken from DOE-HDBK-1016/2-93.

Fabrication, construction, and architectural drawings differ from P&IDs, electrical prints, and logic diagrams in that they are drawn to scale and provide the component’s physical dimensions so that the part, component, or structure can be manufactured or assembled. Although fabrication and construction drawings are presented as separate categories, both supply information about the manufacture or assembly of a component or structure. The only real difference between the two is the subject matter. A fabrication drawing provides information on how a single part is machined or fabricated in a machine shop, whereas a construction drawing provides the construction or assembly of large multi-component structures or systems.

Fabrication drawings, also called machine drawings, are principally found in and around machine and fabrication shops where the actual machine work is performed. The drawing
usually depicts the part or component as an orthographic projection with each view containing the necessary dimensions. Figure 57 is an example of a fabrication drawing. In this case, the drawing is a centering rest that is used to support material as it is being machined.

Source: DOE-HDBK-1016/2-93

Figure 57. Example of a fabrication drawing

Construction drawings are found principally at sites where the construction of a structure or system is being performed. These drawings usually depict each structure/system or portion of a structure/system as an orthographic projection with each view containing the necessary dimensions required for assembly. Figure 58 provides an example of a construction print for a section of a steel roof truss.
Architectural drawings are used by architects in the conceptual design of buildings and structures. These drawings do not provide detailed information on how the structure or building is to be built, but rather they provide information on how the designer wants the building to appear and how it will function. Examples of this are location-size-type of doors, windows, rooms, flow of people, storage areas, and location of equipment. These drawings can be presented in several formats, including orthographic, isometric, plan, elevation, or perspective. Figure 59 provides an example of an architectural drawing, of a county library.

Source: DOE-HDBK-1016/2-93

Figure 58. Example of a construction drawing
b. **Given an engineering fabrication, construction, or architectural drawing, identify the specified dimensions of an object.**

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

c. **Discuss the methods used to specify a dimension’s allowable tolerance.**

The following is taken from DOE-HDBK-1016/2-93.

For any engineering fabrication, construction, or architectural drawing to be of value, exact information concerning the various dimensions and their tolerances must be provided by the drawing. Drawings usually denote dimensions and tolerances per the American National Standards Institute (ANSI) standards.

Dimensions on a drawing can be expressed in one of two ways. In the first method, the drawing is drafted to scale and any measurement is obtained by measuring the drawing and correcting for the scale. In the second method, the actual dimensions of the component are specified on the drawing. The second method is the preferred method because it reduces the chances of error and allows greater accuracy and drawing flexibility. Because even the simplest component has several dimensions that must be stated (and each dimension must have a tolerance), a drawing can quickly become cluttered with dimensions. To reduce this problem, the ANSI standards provide rules and conventions for dimensioning a drawing.
When actual dimensions are specified on a print, the basic line symbols that are illustrated by figure 60 are used.

**Visible Outline (Full Line)**
- Shows the shape of the part and all visible features.

**Hidden Line (Dashed Line)**
- Shows hidden features of objects.

**Center Line**
- Used to locate the centers of holes and round features.

**Extension Line**
- Extends from the object to locate dimension lines.

**Dimension Line**
- Used to show the size of the object.

**Cutting Plane**
- Used to show the part "cut away" when making a section.

**Section Line**
- Shows that part of the object is not visible; that it has been sectioned.

*Source: DOE-HDBK-1016/2-93*

**Figure 60.** Types of dimensioning lines

Figure 61 provides examples of the various methods used on drawings to indicate linear, circular and angular dimensions.
When a drawing is dimensioned, each dimension must have a tolerance. In many cases, the tolerance is not stated, but is set to an implied standard. An example is the blueprint for a house. The measurements are not usually given stated tolerances, but it is implied that the

Source: DOE-HDBK-1016/2-93.

**Figure 61.** Examples of dimensioning notation

When a drawing is dimensioned, each dimension must have a tolerance. In many cases, the tolerance is not stated, but is set to an implied standard. An example is the blueprint for a house. The measurements are not usually given stated tolerances, but it is implied that the
The last method is to state the tolerance for a specified dimension with the measurement. This method is usually used in conjunction with one of the other two tolerancing methods. This type of notation is commonly used for a dimension that requires a higher level of accuracy than the remainder of the drawing. Figure 62 provides several examples of how this type of tolerance notation can appear on a drawing.

Tolerances are applied to more than just linear dimensions, such as 1 ± 0.1 inches. They can apply to any dimension, including the radius, the degree of out-of-round, the allowable out-of-square, the surface condition, or any other parameter that affects the shape and size of the

Source: DOE-HDBK-1016/2-93

Figure 62. Symbology used in tolerance drawings
object. These types of tolerances are called geometric tolerances. Geometric tolerances state the maximum allowable variation of a form or its position from the perfect geometry implied on the drawing. The term geometry refers to various forms, such as a plane, a cylinder, a cone, a square, or a hexagon. Theoretically these are perfect forms, but because it is impossible to produce perfect forms, it may be necessary to specify the amount of variation permitted. These tolerances specify either the diameter or the width of a tolerance zone within which a surface or the axis of a cylinder or a hole must be if the part is to meet the required accuracy for proper function and fit. The methods of indicating geometric tolerances by means of geometric characteristic symbols are shown in figure 62. Examples of tolerance symbology are shown in figure 63.
Figure 63. Examples of tolerance symbology

Source: DOE-HDBK-1016/2-93
Because tolerances allow a part or the placement of a part or feature to vary or have a range, all of an object’s dimensions cannot be specified. This allows the unspecified, and therefore non-toleranced, dimension to absorb the errors in the critical dimensions. As illustrated in Figure 64 (A) for example, all of the internal dimensions plus each dimension’s maximum tolerance adds up to more than the specified overall dimension and its maximum tolerance. In this case the length of each step plus its maximum tolerance is 1 1/10 inches, for a maximum object length of 3 3/10 inches. However the drawing also specifies that the total length of the object cannot exceed 3 1/10 inches. A drawing dimensioned in this manner is not correct, and one of the following changes must be made if the part is to be correctly manufactured.

To prevent this type of conflict, the designer must either specify different tolerances for each of the dimensions so that the length of each smaller dimension plus its maximum error adds up to a value within the overall dimension plus its tolerance, or leave one of the dimensions off, as illustrated in figure 64 (B) (the preferred method).

Source: DOE-HDBK-1016/2-93

Figure 64. Example of tolerancing
d. Given an engineering fabrication, construction, or architectural drawing, identify the specific dimension’s allowable tolerance.

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

29. A facility representative must demonstrate working level knowledge of lasers in the area of safety.


The following is taken from *OSHA Technical Manual*, section III, chapter VI, “Laser Hazards.”

In some laser operations, particularly in the research laboratory, general safety and health guidelines should be considered.

*Industrial Hygiene*

Potential hazards associated with compressed gases, cryogenic materials, toxic and carcinogenic materials and noise should be considered. Adequate ventilation shall be installed to reduce noxious or potentially hazardous fumes and vapors, produced by laser welding, cutting and other target interactions, to levels below the appropriate threshold limit value (TLVs), (e.g., American Conference of Governmental Industrial Hygienists (ACGIH) TLV’s) or Occupational Safety and Health Administration’s (OSHA) permissible exposure limits (PELs).

*Explosion Hazards*

High-pressure arc lamps and filament lamps or laser welding equipment shall be enclosed in housings which can withstand the maximum pressures resulting from lamp explosion or disintegration. The laser target and elements of the optical train which may shatter during laser operation shall also be enclosed.

*Nonbeam Optical Radiation Hazards*

This relates to optical beam hazards other than laser beam hazards. Ultraviolet radiation emitted from laser discharge tubes, pumping lamps and laser welding plasmas shall be suitably shielded to reduce exposure to levels below the ANSI Z136.1, *Safe Use of Lasers*, (extended source), OSHA PELs, and/or ACGIH TLVs.

*Collateral Radiation*

Radiation, other than laser radiation, associated with the operation of a laser or laser system, (e.g., radio frequency [RF] energy associated with some plasma tubes), x-ray emission associated with the high voltage power supplies used with excimer lasers, shall be maintained below the applicable protection guides. The appropriate protection guide for RF and microwave energy is that given in the American National Standard, ANSI C95.1, *Safety Levels With Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kilohertz (kHz) to 100 gigahertz (GHz)*; the appropriate protection guides for exposure to X-ray emission is found in the Department of Labor Occupational Safety and Health Standards, 29 CFR 1910.1096, “Ionizing Radiation,” and the applicable state codes. Lasers and laser
systems which, by design, would be expected to generate appreciable levels of collateral radiation, should be monitored.

**Electrical Hazards**

The intended application of the laser equipment determines the method of electrical installation and connection to the power supply circuit (e.g., conduit versus flexible cord). All equipment shall be installed in accordance with the National Electrical Code and the Occupational Safety and Health Act. (Additional specific recommendations can be found in section 7.4 of ANSI Z136.1.)

**Flammability of Laser Beam Enclosures**

Enclosure of class IV laser beams and terminations of some focused class IIIB lasers, can result in potential fire hazards if the enclosure materials are exposed to irradiances exceeding 10 watts per square centimeter (W/cm²). Plastic materials are not precluded as an enclosure material, but their use and potential for flammability and toxic fume release following direct exposure should be considered. Flame-resistant materials and commercially available products specifically designed for laser enclosures should also be considered.

**Biological Effects of the Laser Beam.**

**Eye Injury**

Because of the high degree of beam collimation, a laser serves as an almost ideal point source of intense light. A laser beam of sufficient power can theoretically produce retinal intensities at magnitudes that are greater than conventional light sources, and even larger than those produced when directly viewing the sun. Permanent blindness can be the result.

**Thermal Injury**

The most common cause of laser-induced tissue damage is thermal in nature, where the tissue proteins are denatured due to the temperature rise following absorption of laser energy.

The thermal damage process (burns) is generally associated with lasers operating at exposure times greater than 10 microseconds and in the wavelength region from the near ultraviolet to the far infrared. Tissue damage may also be caused by thermally induced acoustic waves following exposures to sub-microsecond laser exposures.

With regard to repetitively pulsed or scanning lasers, the major mechanism involved in laser-induced biological damage is a thermal process wherein the effects of the pulses are additive. The principal thermal effects of laser exposure depend upon the following factors:

- The absorption and scattering coefficients of the tissues at the laser wavelength
- Irradiance or radiant exposure of the laser beam
- Duration of the exposure and pulse repetition characteristics, where applicable
- Extent of the local vascular flow
- Size of the area irradiated

**Other**

Other damage mechanisms have also been demonstrated for other specific wavelength ranges and/or exposure times. For example, photochemical reactions are the principal cause of
threshold level tissue damage following exposures to either actinic ultraviolet radiation for any exposure time or blue light visible radiation when exposures are greater than 10 seconds.

To the skin, ultra-violet (UV)-A (0.315 micrometers(µm)-0.400 µm) can cause hyperpigmentation and erythema.

Exposure in the UV-B range is most injurious to skin. In addition to thermal injury caused by ultraviolet energy, there is the possibility of radiation carcinogenesis from UV-B (0.280 mm-0.315 mm) either directly on deoxyribonucleic acid or from effects on potential carcinogenic intracellular viruses.

Exposure in the shorter UV-C (0.200 µm-0.280 µm) and the longer UV-A ranges seems less harmful to human skin. The shorter wavelengths are absorbed in the outer dead layers of the epidermis (stratum corneum) and the longer wavelengths have an initial pigment-darkening effect followed by erythema if there is exposure to excessive levels.

The hazards associated with skin exposure are of less importance than eye hazards; however, with the expanding use of higher-power laser systems, particularly ultraviolet lasers, the unprotected skin of personnel may be exposed to extremely hazardous levels of the beam power if used in an unenclosed system design.

b. Describe types and classifications of lasers (ANSI Z136.1, Safe Use of Lasers).

The following is taken from OSHA Technical Manual, section III, chapter 6, Laser Hazards.

Lasers and laser systems are assigned one of four broad classes (I to IV) depending on the potential for causing biological damage.

Class I cannot emit laser radiation at known hazard levels (typically continuous wave: cw 0.4 µW at visible wavelengths). Users of class I laser products are generally exempt from radiation hazard controls during operation and maintenance (but not necessarily during service).

Since lasers are not classified on beam access during service, most class I industrial lasers will consist of a higher class (high power) laser enclosed in a properly interlocked and labeled protective enclosure. In some cases, the enclosure may be a room (walk-in protective housing) which requires a means to prevent operation when operators are inside the room.

Class I.A is a special designation that is based upon a 1000-second exposure and applies only to lasers that are not intended for viewing such as a supermarket laser scanner. The upper power limit of class I.A. is 4.0 MW. The emission from a class I.A. laser is defined such that the emission does not exceed the class I limit for an emission duration of 1000 seconds.

Class II are low-power visible lasers that emit above class I levels but at a radiant power not above 1 MW. The concept is that the human aversion reaction to bright light will protect a person. Only limited controls are specified.

Class IIIA are intermediate power lasers (1-5 MW). Only hazardous for intra-beam viewing. Some limited controls are usually recommended.
There are different logotype labeling requirements for class IIIA lasers with a beam irradiance that does not exceed 2.5 MW/cm² (caution logotype) and those where the beam irradiance does exceed 2.5 MW/cm² (danger logotype).

Class IIIB are moderate power lasers (5-500 MW, pulsed: 10 J/cm² or the diffuse reflection limit, whichever is lower). In general class IIIB lasers will not be a fire hazard, nor are they generally capable of producing a hazardous diffuse reflection. Specific controls are recommended.

Class IV: High power lasers (500 MW, pulsed: 10 J/cm² or the diffuse reflection limit) are hazardous to view under any condition (directly or diffusely scattered) and are a potential fire hazard and a skin hazard. Significant controls are required of class IV laser facilities.

c. Describe engineering controls and use of personnel protective equipment for laser safety:

- Laser control area
- Protective housing, barriers, and curtains
- Beam attenuators and stops
- Interlocks
- Key control
- Eyewear

The following descriptions are taken from OSHA Technical Manual, section III, chapter 6, Laser Hazards.

*Laser Control Area*

When the entire beam path from a class IIIB or class IV laser is not sufficiently enclosed and/or baffled to ensure that radiation exposures will not exceed the maximum permissible exposure (MPE), a laser-controlled area is required. During periods of service, a controlled area may be established on a temporary basis. The controlled area will encompass the nominal hazard zone (NHZ).

*Protective Housing, Barriers and Curtains*

A laser shall have an enclosure around it that limits access to the laser beam or radiation at or below the applicable MPE level (the level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin). A protective housing is required for all classes of lasers except, of course, at the beam aperture. In some cases, the walls of a properly enclosed room can be considered as the protective housing for an open beam laser. The barrier will be described with a barrier threshold limit: the beam will penetrate the barrier only after some specified exposure time, typically 60 seconds.

Area control can be affected in some cases using special barriers specifically designed to withstand either direct or diffusely scattered beams. It is essential that the barrier also not support combustion or be itself consumed by flames during or following a laser exposure.
Beam Attenuators and Stops

Class IV lasers require a permanently attached beam stop or attenuator which can reduce the output emission to a level at or below the appropriate MPE level when the laser system is on standby. Such a beam stop or attenuator is also recommended for Class IIA and Class IIB lasers.

Interlocks

Interlocks, which cause beam termination or reduction of the beam to MPE levels, must be provided on all panels that are intended to be opened during operation and maintenance of all Class IIIA, Class IIB, and Class IV lasers. The interlocks are typically electrically connected to a beam shutter. The removal or displacement of the panel closes the shutter and eliminates the possibility of hazardous exposures.

All Class IV lasers or laser systems must have a remote interlock connector to allow electrical connections to an emergency master disconnect (panic button) interlock or to room, door, or fixture interlocks. When open circuited, the interlock shall cause the accessible laser radiation to be maintained below the appropriate MPE level. The remote interlock connector is also recommended for Class IIB lasers.

Key Control

All Class IV lasers and laser systems require a master switch control. The switch can be operated by a key or computer code. When disabled (key or code removed), the laser cannot be operated. Only authorized system operators are to be permitted access to the key or code. Inclusion of the master switch control on Class IIB lasers and laser systems is also recommended but not required.

Eyewear

Eye-protection devices designed to protect against radiation from a specific laser system shall be used when engineering controls are inadequate to eliminate the possibility of potentially hazardous eye exposure (i.e., whenever levels of accessible emission exceed the appropriate MPE levels). This generally applies only to Class IIB and Class IV lasers. All laser eyewear shall be clearly labeled with the optical density value (a logarithmic expression for the attenuation produced by an attenuating medium, such as an eye protection filter) and wavelengths for which protection is afforded.

d. Describe administrative controls and the role of the laser safety officer:
   - Training
   - Authorized personnel
   - Operating and alignment procedures

The following descriptions are taken from OSHA Technical Manual, section III, chapter 6, Laser Hazards.

Training

The laser safety officer (LSO) should receive detailed training that includes laser fundamentals, laser biological effects, exposure limits, classifications, NHZ computations,
control measures (including area controls, eye wear, barriers, etc.), and medical surveillance requirements.

**Authorized Personnel**
Only qualified and authorized personnel operate lasers. Training of the individuals in aspects of laser safety is required for class IIIB and class IV laser installations.

**Operating and Alignment Procedures**
Many laser eye accidents occur during alignment. The procedures require extreme caution. A written standard operating procedure is recommended for all recurring alignment tasks.

e. **Describe requirements of laser warning signs, labels, and postings.**

The following descriptions are taken from OSHA Technical Manual, section III, chapter 6, Laser Hazards.

Class IIA, class IIIB, and class IV lasers require the ANSI danger sign (figure 65) format: a white background and a red laser symbol with black outlining and black lettering. Note that under ANSI Z136.1 criteria, area posting is required only for class IIIB and class IV lasers.

![Figure 65. ANSI danger sign](image)

*Source: OSHA Technical Training Manual*

In class II or class IIA areas (if area warning is deemed unnecessary by the LSO), all signs (and labels) associated with these lasers (when beam irradiance for class IIA does not exceed 2.5 MW/cm²) use the ANSI caution format (figure 66): a yellow background with a black symbol and black lettering.
During times of service and other times when a temporary laser-controlled area is established, an ANSI notice sign (figure 67) format is required: a white background and a red laser symbol with a blue field and black lettering. This sign is posted only during the period of time that service is in progress.

Source: OSHA Technical Training Manual

Figure 66. ANSI caution sign

Source: OSHA Technical Training Manual

Figure 67. ANSI notice sign
30. A facility representative must demonstrate a working level knowledge of the purpose, scope, and application of applicable Federal regulations to include:

- 10 CFR 820, “Procedural Rules for DOE Nuclear Activities”
- 10 CFR 830, “Nuclear Safety Management”
- 10 CFR 835, “Occupational Radiation Protection”
- 10 CFR 851, “Worker Safety and Health Program”

a. Discuss the purpose, scope, and application of the listed Federal regulations. Include in this discussion the key terms, essential elements, and personnel responsibilities and authorities.

10 CFR 820, Procedural Rules for DOE Nuclear Activities

Purpose. The DOE has adopted procedural rules in 10 CFR 820 to provide for the enforcement of violations of DOE nuclear safety requirements for which civil and criminal penalties can be imposed under the Price-Anderson Amendments Act (PAAA) of 1988. Appended to the rule is a general statement of enforcement policy (Enforcement Policy). The Enforcement Policy sets forth the general framework through which DOE would seek to enforce compliance with DOE’s nuclear safety rules, regulations, and Orders by a DOE contractor, subcontractor, or a supplier.

Refer to 10 CFR 820 for information related to key terms, essential elements, and personnel responsibilities and authorities.

10 CFR 830, Nuclear Safety Management

Purpose. Title 10 CFR 830 governs the conduct of DOE contractors, DOE personnel, and other persons conducting activities, including providing items and services that affect, or may affect, the safety of DOE nuclear facilities.

Refer to 10 CFR 830 for information related to key terms, essential elements, and personnel responsibilities and authorities.

10 CFR 835, Occupational Radiation Protection

Purpose. The rules in 10 CFR 835 establish radiation protection standards, limits, and program requirements for protecting individuals from ionizing radiation resulting from the conduct of DOE activities.

Refer to 10 CFR 835 for information related to key terms, essential elements, and personnel responsibilities and authorities.

10 CFR 851, Worker Safety and Health Program

Purpose. The worker safety and health requirements in this part govern the conduct of contractor activities at DOE sites. This part establishes the

- requirements for a worker safety and health program that reduces or prevents occupational injuries, illnesses, and accidental losses by providing DOE contractors and their workers with safe and healthful workplaces at DOE sites; and
Procedures for investigating whether a violation of a requirement of this part has occurred, for determining the nature and extent of any such violation, and for imposing an appropriate remedy.

Refer to 10 CFR 851 for information related to key terms, essential elements, and personnel responsibilities and authorities.

**b. Discuss what constitutes acceptable contractor work performance in categories as defined by the above Rules.**

The following is taken from 48 CFR 970.5223.1.

In performing work under a contract, the contractor shall perform work safely, in a manner that ensures adequate protection for employees, the public, and the environment, and shall be accountable for the safe performance of work. The contractor shall exercise a degree of care commensurate with the work and the associated hazards. The contractor shall ensure that management of environment, safety, and health (ES&H) functions and activities becomes an integral but visible part of the contractor’s work planning and execution processes. The contractor shall, in the performance of work, ensure the following:

- Line management is responsible for the protection of employees, the public, and the environment. Line management includes those contractor and subcontractor employees managing or supervising employees performing work.
- Clear and unambiguous lines of authority and responsibility for ensuring ES&H are established and maintained at all organizational levels.
- Personnel possess the experience and KSAs that are necessary to discharge their responsibilities.
- Resources are effectively allocated to address ES&H, programmatic, and operational considerations. Protecting employees, the public, and the environment is a priority whenever activities are planned and performed.
- Before work is performed, the associated hazards are evaluated and an agreed-upon set of ES&H standards and requirements are established which, if properly implemented, provide adequate assurance that employees, the public, and the environment are protected from adverse consequences.
- Administrative and engineering controls to prevent and mitigate hazards are tailored to the work being performed and associated hazards. Emphasis should be on designing the work and/or controls to reduce or eliminate the hazards and to prevent accidents and unplanned releases and exposures.
- The conditions and requirements to be satisfied for operations to be initiated and conducted are established and agreed-upon by DOE and the contractor. These agreed-upon conditions and requirements are requirements of the contract and binding upon the contractor. The extent of documentation and level of authority for agreement shall be tailored to the complexity and hazards associated with the work and shall be established in a safety management system.

The contractor shall manage and perform work in accordance with a documented safety management system that fulfills all of the requirements. Documentation of the system shall describe how the contractor will:

- define the scope of work;
• identify and analyze hazards associated with the work;
• develop and implement hazard controls;
• perform work within controls; and
• provide feedback on adequacy of controls and continue to improve safety management.

The system shall describe how the contractor will establish, document, and implement safety performance objectives, performance measures, and commitments in response to DOE program and budget execution guidance while maintaining the integrity of the system. The system shall also describe how the contractor will measure system effectiveness.

The contractor shall submit to the contracting officer (CO) documentation of its system for review and approval. Dates for submittal, discussions, and revisions to the system will be established by the CO. Guidance on the preparation, content, review, and approval of the system will be provided by the CO. On an annual basis, the contractor shall review and update, for DOE approval, its safety performance objectives, performance measures, and commitments consistent with and in response to DOE’s program and budget execution guidance and direction. Resources shall be identified and allocated to meet the safety objectives and performance commitments as well as maintain the integrity of the entire system. Accordingly, the system shall be integrated with the contractor’s business processes for work planning, budgeting, authorization, execution, and change control.

The contractor shall comply with, and assist DOE in complying with, ES&H requirements of all applicable laws and regulations, and applicable directives identified in the clause of a contract entitled “Laws, Regulations, and DOE Directives.” The contractor shall cooperate with Federal and non-Federal agencies having jurisdiction over ES&H matters under this contract.

The contractor shall promptly evaluate and resolve any noncompliance with applicable ES&H requirements and the system. If the contractor fails to provide resolution or if, at any time, the contractor’s acts or failure to act causes substantial harm or an imminent danger to the environment or health and safety of employees or the public, the CO may issue an order stopping work in whole or in part. Any stop work order issued by a CO shall be without prejudice to any other legal or contractual rights of the Government. In the event that the CO issues a stop work order, an order authorizing the resumption of the work may be issued at the discretion of the CO. The contractor shall not be entitled to an extension of time or additional fee or damages by reason of, or in connection with, any work stoppage ordered in accordance with this clause.

Regardless of the performer of the work, the contractor is responsible for compliance with the ES&H requirements applicable to this contract. The contractor is responsible for flowing down the ES&H requirements applicable to this contract to subcontracts at any tier to the extent necessary to ensure the contractor’s compliance with the requirements.

c. Describe the methods by which Rule noncompliance is determined and communicated to contractor and DOE management.

The following is taken from 48 CFR 970.5223.1
The contractor shall promptly evaluate and resolve any noncompliance with applicable ES&H requirements and the system. If the contractor fails to provide resolution or if, at any time, the contractor’s acts or failure to act causes substantial harm or an imminent danger to the environment or health and safety of employees or the public, the CO may issue an order stopping work in whole or in part. Any stop work order issued by a CO shall be without prejudice to any other legal or contractual rights of the Government. In the event that the CO issues a stop work order, an order authorizing the resumption of the work may be issued at the discretion of the CO. The contractor shall not be entitled to an extension of time or additional fee or damages by reason of, or in connection with, any work stoppage ordered in accordance with this clause.

31. A facility representative must demonstrate a working level knowledge of the purpose, scope, and application of applicable DOE Orders to include:

- DOE O 151.1C, Comprehensive Emergency Management System
- DOE O 231.1A, Chg 1, Environment, Safety and Health Reporting
- DOE O 420.1B, Facility Safety
- DOE O 420.2B, Safety of Accelerator Facilities
- DOE O 425.1D, Start-Up and Restart of Nuclear Facilities
- DOE O 435.1, Chg 1, Radioactive Waste Management
- DOE O 440.1B, Worker Protection Management for DOE (Including the National Nuclear Security Administration) Federal Employees
- DOE O 442.1A, Department of Energy Employee Concerns Program
- DOE O 451.1B, Chg. 1, National Environmental Policy Act Compliance Program
- DOE O 460.1C, Packaging and Transportation Safety

a. Discuss the purpose, scope, and application of the listed DOE Orders. Include in this discussion the key terms, essential elements, and personnel responsibilities and authorities.

**DOE O 151.1C, Comprehensive Emergency Management**

The purpose, scope, and objectives of this Order are

- to establish policy and to assign and describe roles and responsibilities for the DOE emergency management system. The emergency management system provides the framework for development, coordination, control, and direction of all emergency planning, preparedness, readiness assurance, response, and recovery actions. The emergency management system applies to DOE and to the NNSA.

- to establish requirements for comprehensive planning, preparedness, response, and recovery activities of emergency management programs or for organizations requiring DOE/NNSA assistance.

- to describe an approach to effectively integrate planning, preparedness, response, and recovery activities for a comprehensive, all-emergency management concept.

- to integrate public information and emergency planning to provide accurate, candid, and timely information to site workers and the public during all emergencies.

- to promote more efficient use of resources through greater flexibility (i.e., the graded approach) in addressing emergency management needs consistent with the changing missions of the Department and its facilities.

- to ensure that the DOE emergency management system is ready to respond promptly, efficiently, and effectively to any emergency involving DOE/NNSA facilities, activities, or operations, or requiring DOE/NNSA assistance.
to integrate applicable policies and requirements, including those promulgated by other Federal agencies (e.g., stockpiling stable iodine for possible distribution as a radiological protective prophylaxis), and interagency emergency plans into the Department’s emergency management system.

- to eliminate duplication of emergency management efforts within the Department.

**DOE O 231.1A, Chg 1, Environment, Safety and Health Reporting**

The objectives of this Order are to ensure timely collection, reporting, analysis, and dissemination of information on ES&H issues as required by law or regulations or as needed to ensure that the DOE/NNSA are kept fully informed on a timely basis about events that could adversely affect the health and safety of the public or the workers, the environment, the intended purpose of DOE facilities, or the credibility of the Department.

**DOE O 420.1B, Facility Safety**

The objectives of this Order are to establish facility and programmatic safety requirements for DOE/NNSA for

- nuclear and explosives safety design criteria
- fire protection
- criticality safety
- natural phenomena hazards mitigation
- the System Engineer Program

**DOE O 420.2B, Safety of Accelerator Facilities**

The objective of this Order is to establish accelerator-specific safety requirements which, when supplemented by other applicable safety and health requirements, will serve to prevent injuries and illnesses associated with DOE/NNSA accelerator operations.

**DOE O 425.1D, Start-Up and Restart of Nuclear Facilities**

The objective of this Order is to establish the requirements for DOE/NNSA for startup of new nuclear facilities and for the restart of existing nuclear facilities that have been shut down. Nuclear facilities are activities or operations that involve radioactive and/or fissionable materials in such form or quantity that a nuclear hazard potentially exists to the employees or the general public. The requirements specify a readiness review process that must, in all cases, demonstrate that it is safe to start (or restart) the applicable facility. The facility must be started (or restarted) only after documented independent reviews of readiness have been conducted and the approvals specified in this Order have been received. The readiness reviews are not intended to be tools of line management to achieve readiness. Rather, the readiness reviews provide an independent confirmation of readiness to start or restart operations.

**DOE O 435.1, Chg. 1, Radioactive Waste Management**

The objective of this Order is to ensure that all DOE radioactive waste is managed in a manner that is protective of worker and public health and safety and the environment.
**DOE O 440.1B, Worker Protection Management for DOE (Including the National Nuclear Security Administration) Employees**

The objective of this Order is to establish the framework for an effective worker protection program that will reduce or prevent injuries, illnesses, and accidental losses by providing DOE Federal and contractor workers with a safe and healthful workplace.

**DOE O 442.1A, Department of Energy Employee Concerns Program**

As a service to all departmental elements, this Order will establish a DOE Employee Concerns Program that ensures employee concerns related to such issues as the environment, safety, health, and management of DOE and the NNSA programs and facilities are addressed through

- prompt identification, reporting, and resolution of employee concerns regarding DOE facilities or operations in a manner that provides the highest degree of safe operations;
- free and open expression of employee concerns that results in an independent, objective evaluation; and
- supplementation of existing processes with an independent avenue for reporting concerns.

**DOE O 451.1B, Chg. 1, National Environmental Policy Act Compliance Program**

The purpose of this Order is to establish DOE internal requirements and responsibilities for implementing the National Environmental Policy Act of 1969 (NEPA), the Council on Environmental Quality (40 Parts 1500-1506), and the DOE NEPA Implementing Procedures (10 CFR 1021). The goal of establishing the requirements and responsibilities is to ensure efficient and effective implementation of DOE’s NEPA responsibilities through teamwork. A key responsibility for all participants is to control the cost and time spent on the NEPA process while maintaining its quality.

**DOE O 460.1C, Packaging and Transportation Safety**

The objective of DOE O 460.1C is to establish safety requirements for the proper packaging and transportation of DOE/NNSA offsite shipments and onsite transfers of hazardous materials and for modal transport. (Offsite is any area within or outside a DOE site to which the public has free and uncontrolled access; onsite is any area within the boundaries of a DOE site or facility to which access is controlled.)

**DOE O 151.1C, Comprehensive Emergency Management System**

Contractors must develop and implement a comprehensive emergency management system designed to

- minimize the consequences of all emergencies involving or affecting departmental facilities and activities (including transportation operations/activities);
- protect the health and safety of all workers and the public from hazards associated with DOE/NNSA operations and those associated with decontamination, decommissioning, and environmental restoration;
- prevent damage to the environment;

b. Discuss what constitutes acceptable contractor work performance in categories as defined by the listed Orders.
promote effective and efficient integration of all applicable policies, recommendations, and requirements, including Federal interagency emergency plans.

**DOE O 231.1A, Chg 1, Environment, Safety and Health Reporting**

Contractors are not covered in this DOE Order.

**DOE O 420.1B, Facility Safety**

Contractors must ensure that any work done is consistent with any other safety, design, or other analysis or requirements applicable to the affected facility. In particular, work must be performed in accordance with the integrated safety management (ISM) requirements of 48 CFR 970.5223-1, “Integration of Environment, Safety, and Health into Work Planning and Execution,” and the quality assurance (QA) requirements of either subpart A of 10 CFR 830, or DOE O 414.1C, *Quality Assurance*, or successor document, as applicable. All new construction, at a minimum, must comply with national consensus industry standards and the model building codes applicable for the state or region, supplemented in a graded manner with additional safety requirements for the associated hazards in the facility that are not addressed by the codes.

**DOE O 420.2B, Safety of Accelerator Facilities**

The following items are required of the contractor organization:

A safety assessment document (SAD). An SAD must

- identify hazards and associated onsite and offsite impacts to workers, the public, and the environment from the facility for both normal operations and credible accidents;
- contain sufficient descriptive information and analytical results pertaining to specific hazards and risks identified during the safety analysis process to provide an understanding of risks presented by the proposed operations;
- provide appropriate documentation and detailed descriptions of engineered controls and administrative measures taken to eliminate, control, or mitigate hazards from operation;
- include or reference a description of facility function, location, and management organization in addition to details of major facility components and their operation;
- be prepared as a single document addressing the hazards of the entire accelerator facility or as separate SADs prepared for discrete modules of the facility such as injectors, targets, experiments, experimental halls, or other types of modules;
- be maintained current and consistent with the administrative control measures and physical configuration of the facility and major safety equipment.

An accelerator safety envelope (ASE). A documented ASE must define the physical and administrative bounding conditions for safe operations based on the safety analysis documented in the SAD. Any activity violating the ASE must be terminated immediately, and the activity must not recommence before DOE/NNSA has been notified.

Unreviewed safety issues. Activities that involve unreviewed safety issues must not be performed if significant safety consequences could result from either an accident or a malfunction of equipment that is important to safety and for which a safety analysis has not been performed. Activities involving identified unreviewed safety issues must not commence before DOE/NNSA has provided written approval.
Accelerator readiness reviews (ARRs). ARRs must be performed before approval for commissioning and routine operation and as directed by the DOE cognizant Secretarial Officer/NNSA Deputy Administrator or a DOE/NNSA field manager.

Training and qualification. Requirements must be established for each individual at an accelerator facility whose activities could affect safety and health conditions or whose safety and health could be affected by facility activities. Training and qualification must be documented and kept current. Only appropriately trained and qualified personnel, or trainees under the direct supervision of trained and qualified personnel, are permitted to perform tasks that may affect safety and health. All personnel assigned to or using the accelerator facility (including emergency response personnel) must be trained in the safety and health practices and emergency plans consistent with their involvement and the hazards present.

Written procedures. Written procedures and instructions for conducting activities safely must be maintained; must be clear, current, and consistent with management systems and the configuration of the facility and equipment; and must be approved by a facility contractor’s senior line manager who is actively involved in the day-to-day operation of the facility. Procedures must include descriptions of the tasks to be performed; appropriate safety and health precautions and controls; and requirements for initial conditions to be verified, operating conditions to be maintained, and data to be recorded, as applicable. At a minimum, the contractor must prepare procedures for:

- operation startup
- normal operation
- emergency conditions
- conduct of maintenance
- approval and conduct of experiments
- review and approval of facility modifications
- management of safety-related changes
- control of facility access

An internal safety review system. An internal safety review system must be established and maintained to periodically assess and document the condition of the facility, equipment, and engineered safety systems. Appropriateness and implementation of procedures, administrative controls, and personnel training and qualifications must be periodically reviewed and documented by the internal safety review system.

A shielding policy. The contractor must approve and implement a written statement of the shielding policy for ionizing and non-ionizing radiation.

DOE O 425.1D, Startup and Restart of Nuclear Facilities
Contractor management must determine if operational readiness reviews are required for startup or restart of nuclear facilities. Contractors must conduct an operational readiness review when any of the following conditions occur:

- Initial startup of a new hazard category 1, 2, or 3 nuclear facility
- Restart after a DOE management official directs the unplanned shutdown of a nuclear facility for safety or other appropriate reasons
• Restart after an extended shutdown for hazard categories 1 and 2 nuclear facilities
  (Extended shutdown for a hazard category 1 nuclear facility is 6 months. Extended
  shutdown for a hazard category 2 nuclear facility is 12 months.)
• Restart of hazard categories 1 and 2 nuclear facilities after substantial process,
  system, or facility modifications (The restart authority must determine if the
  modifications are substantial based on the impact of the changes on the safety basis
  and the extent and complexity of changes; this would not necessarily be determined
  by the unreviewed safety question (USQ) process.)
• Restart after a nuclear facility shutdown because of operations outside the safety basis
• When deemed appropriate by DOE management officials, including restarts of hazard
  category 3 nuclear facilities

**DOE O 435.1, Radioactive Waste Management**

In the performance of this contract, the contractor is required to

• systematically plan, document, execute, and evaluate the management of DOE
  radioactive waste, and assist the government in planning, executing and evaluating
  the management of DOE radioactive waste in accordance with the requirements of
  DOE O 435.1, Radioactive Waste Management.
• assist the government in managing DOE radioactive waste so as to
  o protect the public from exposure to radiation from radioactive materials;
  o protect the environment;
  o protect workers, including following requirements for radiation protection.
• assist DOE in meeting its obligations and responsibilities under Executive Order
  12856, “Federal Compliance with Right-to-Know Laws and Pollution Prevention
  Requirements,” and Executive Order 13101, “Greening the Government through
  Waste Prevention, Recycling, and Federal Acquisition, and The Pollution Prevention
  Act of 1990.”
• comply with the requirements in DOE M 435.1-1, Radioactive Waste Management
  Manual, unless such activities are specifically exempted by DOE O 435.1, section 3.d.
• incorporate these requirements into the contracts of all sub-contractors which are
  involved in the management of DOE radioactive waste.

**DOE O 440.1B, Worker Protection Management for DOE (Including the National Nuclear
Security Administration) Federal Employees**

Contractors are not covered in this DOE Order.

**DOE O 442.1A, Department of Energy Employee Concerns Program**

Contractors are not covered in this DOE Order.

**DOE O 451.1B, Chg. 1, National Environmental Policy Act Compliance Program**

Contractors are not covered in this DOE Order.

**DOE O 460.1C. Packaging and Transportation Safety**

Offsite shipment of hazardous materials on vehicles operated by contractors that are not
otherwise subject to U.S. Department of Transportation (DOT) jurisdiction shall follow the
hazardous materials regulations of DOT and the applicable tribal, state, and local regulations
not otherwise preempted by DOT.
Each contractor subject to the hazardous materials regulations (49 CFR 171-180, “Pipeline and Hazardous Materials Safety Administration, Department of Transportation”) with a non-compliant package or shipment shall apply for a DOT exemption through the field element to the Office of Environmental Management or the NNSA for processing to DOT. Applications shall follow the directions in 49 CFR 107.105, “Application for Special Permit.” Each contractor, who is not subject to DOT jurisdiction but who must comply with the 49 CFR requirements specified in the contractor requirements document (CRD), must prepare the package or shipment in accordance with a valid DOE exemption.

For specific radioactive material packagings, follow the regulations listed in the CRD.

Each contractor who participates in the design, fabrication, procurement, use, or maintenance of hazardous materials packaging, shall have an approved quality assurance program (QAP) that, for type B and fissile radioactive materials packagings, satisfies the applicable requirements of 10 CFR 71, “Packaging and Transportation of Radioactive Materials,” subpart H.

Each contractor who uses a type B, fissile, or plutonium packaging shall implement operating controls and procedures that satisfy the requirements of 10 CFR 71, subpart G.

Each contractor may follow international packaging and transportation regulations for domestic segments of transportation by air, vessel, rail, or highway of shipments in international traffic as authorized by the DOT regulations, as appropriate. In all instances, adherence to 49 CFR 171.12, “North American Shipments,” is required when using the International Maritime Dangerous Goods Code.

Each contractor shall comply with 49 CFR 171-180 for onsite hazardous materials transfers, or comply with an approved site- or facility-specific transportation safety document that describes the methodology and compliance process to meet equivalent safety for any deviation from 49 CFR 171-180. For multiple-tenant sites, safety documents for several contractor organizations may be combined into a single document. Approval shall be by the cognizant operations office or field office/field manager for field operations, NNSA. Approved transportation safety documents shall be in effect no later than one year from the incorporation of the CRD into the contractor’s contract.

Each contractor shall implement and/or expand lessons learned programs to include sharing transportation and packaging safety successes and problems throughout the site and with other DOE contractors. This information will be provided to the responsible head of operations office or field office/site office manager, NNSA.

Each contractor who offers for transportation, or transports or transfers hazardous materials, substances, and wastes, shall develop and implement a training program and procedures for the safe packaging, transfer, and transportation of hazardous materials; assure that all personnel who support and/or perform packaging, transfer, and transportation operations are appropriately trained and qualified; and maintain auditable training records in accordance with site record retention requirements.
c. Describe the methods by which Order noncompliance is determined and communicated to contractor and DOE management.

The following is taken from DOE-HDBK-1085-95.

The DOE enforcement policy sets forth DOE’s strong commitment to positively support contractor efforts to establish effective compliance assurance programs. DOE may substantially mitigate or refrain from issuing a civil penalty or a notice of violation if the contractor demonstrates an effective process of self identification, prompt reporting to DOE, and correction of noncompliances with nuclear safety requirements.

DOE has established a noncompliance tracking system (NTS) that will be typically used as the source of information for identification of the most safety significant potential violations with nuclear safety requirements. DOE contractors can report noncompliances into the NTS that meet established thresholds. Noncompliances below the threshold should be reported and tracked in the contractor’s self-tracking process. Noncompliances should be reported into the appropriate reporting system to obtain consideration for mitigation of enforcement sanctions according to the DOE enforcement policy criteria. The thresholds are based on a determination of the actual or potential safety significance associated with the noncompliance. The NTS is accessible to all DOE personnel who are registered users, and DOE program and operations offices are encouraged to monitor contractor reports on the system. The NTS reporting process can use selected information reported in the Occurrence Reporting and Processing System (ORPS) with some additional information required to be input directly into the NTS.

Potential noncompliances identified by DOE personnel should be communicated to the contractor for appropriate reporting, either into the NTS (if the noncompliance meets the threshold for NTS reporting, or in the contractor’s self-tracking process if below the NTS threshold). If the contractor declines to report a potential noncompliance that meets the threshold for reporting into NTS and DOE believes further review is necessary to resolve the issue, the DOE PAAA Coordinator should communicate the issue directly to the enforcement and investigation staff for entry into the NTS and subsequent evaluation.

DOE field and operations office personnel are routinely involved with the contractor operations on a day-to-day basis. Part of their responsibilities may include mentoring the contractor and as such they may feel a conflict in the support of enforcement activities. However, their roles should not be viewed as being in conflict with the enforcement activities. All DOE personnel have always had an obligation to identify significant noncompliances with regulatory requirements to the contractor and the operations office and to ensure that appropriate corrective actions are taken. To the extent that such matters involve Price-Anderson enforcement issues, the contractor would then be responsible to formally report the noncompliances to DOE through NTS for evaluation.
32. A facility representative must demonstrate a working level knowledge of DOE-STD-1063-2006, *Facility Representatives*.

a. Discuss the purpose, scope, and application. Include in this discussion the key terms, essential elements, and personnel responsibilities and authorities.

The Facility Representative Program ensures that competent DOE staff personnel are assigned to oversee the day-to-day contractor operations at DOE’s hazardous nuclear and non-nuclear facilities. Oversight performed by facility representatives provides DOE line managers with accurate objective information on the effectiveness of contractor work performance and practices, including implementation of the integrated safety management system (ISMS).

DOE-STD-1063-2006 defines the duties, responsibilities, and qualifications for DOE facility representatives based on facility hazard classification; risks to workers, the public, and the environment; and the operational activity level. This standard provides the guidance necessary to ensure that DOE’s hazardous nuclear and non-nuclear facilities have sufficient staffing of technically qualified facility representatives to provide day-to-day oversight of contractor operations.

DOE-STD-1063-2006 helps ensure that DOE facility representatives are selected based on consistently high standards and from the best qualified candidates available, that they receive the training required for them to function effectively, and that their expected duties, responsibilities, and authorities are well understood and accurately documented. To this end, this guidance provides the following practical information:

- The duties, responsibilities, and authorities expected of a facility representative and other personnel relative to the facility representative program
- An approach for use in determining the required facility coverage
- The training and qualifications expected of a facility representative
- Elements necessary for successful facility representative programs at DOE field offices

b. Discuss the process by which DOE line management determines an appropriate level of coverage by an FR. Include in this discussion factors that may be considered to adjust the established level of coverage.

Field element managers shall evaluate each hazardous facility to determine an appropriate level of facility representative coverage. Appendix C, Process to Determine Facility Representative Staffing, provides a detailed process to determine appropriate facility coverage and assignment, and is the expected methodology to be used. The field element manager, or designee, should prepare staffing plans to document these assignments and supporting rationale.

Field element managers shall assign one or more full-time facility representatives to each hazard category 1 facility, unless the field element manager and cognizant Secretarial Officer agree that less coverage is necessary. For nuclear hazard category 2 or 3 facilities, radiological facilities, and hazardous non-nuclear facilities, field element managers may assign a facility representative to two or more facilities. In unusual situations, when it is impractical to assign a sufficient number of facilities to occupy a person full-time, the field element manager may assign the duties of a facility representative to be performed part-time as a collateral function.
It is important that a facility representative’s primary duty of providing DOE an onsite presence not be diminished. Field element managers should make assignments so that facility representatives spend a significant portion of their time in their assigned facility(ies). It is preferable that facility representative offices be located within the facility of primary responsibility. Field element managers should make assignments so that administrative work does not prevent facility representatives from performing their primary function of monitoring the performance of the facility and its operations.

To the degree that facility representatives are advanced or otherwise lost from the program, field element managers should take necessary steps to ensure departing facility representatives are replaced in a timely manner. The goal of the field element manager should be to recruit and hire technically capable personnel to fill facility representative vacancies in an expeditious manner. Recognizing the lengthy average time for a new facility representative candidate to achieve full qualifications (i.e., approximately 18 months), field element managers should strive to recruit experienced candidates from technically rigorous programs, both from within DOE and from external sources, to minimize time in qualification. Such potential sources include DOE safety system oversight personnel, DOE subject matter expert (SME) personnel, and personnel from directly related fields such as naval nuclear power, commercial nuclear power, radioactive waste management, nuclear weapons, nuclear research, industrial safety, chemical safety, or accelerator facility programs.

As part of the overall staffing strategy, field element managers should also consider making use of existing DOE and NNSA technical intern programs to provide a source of prospective facility representative candidates, especially for sites that have experienced historically high attrition rates.

Field element managers should review staffing plans and assignments of facility representatives at least annually to ensure that coverage assignments and responsibilities are appropriate to the hazards and level of activity involved.

Field element managers may also establish provisions for changing coverage. For example, as the degree of hazard, complexity, or other governing factors is reduced, the field element managers may increase the number of processes, facilities, buildings or areas covered by a single facility representative. Field element managers may use special coverage assignments for a facility that operates only intermittently. Also, field element managers should consider periodically rotating facility representatives to different facilities to maintain objective oversight, to broaden each facility representative’s experience base, and to provide flexibility for backup coverage during periods when facility representatives are absent.

Field element managers should make facility representative assignments to optimize effective interaction with the facility operating organization line management responsible for ensuring safe and efficient performance at the facility. For example, field element managers may make assignments based on facility and/or operating organization subdivisions. If the contractor has established a building or facility manager concept, the field element manager may assign facility representatives on a similar basis.
c. Describe the FR’s role with respect to performance of oversight of government-owned contractor operated facilities.

Table 4 lists the activities that count as time spent performing contractor oversight.
### Table 3. Facility representative oversight activities

<table>
<thead>
<tr>
<th>Activities that count as time spent in the plant/field</th>
<th>Activities that count as time spent performing contractor oversight</th>
<th>Activities that should not be counted in numerator</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COLUMN 1</strong></td>
<td><strong>COLUMN 2</strong></td>
<td><strong>COLUMN 3</strong></td>
</tr>
<tr>
<td>Goal: Greater than 40%</td>
<td>Goal: Greater than 65%</td>
<td></td>
</tr>
<tr>
<td>Plant walkthrough/walkdowns</td>
<td>Field time activities fro column 1 included</td>
<td>Training (mandatory refresher, regulatory, continuing, facility access, requalification, etc.) authorized by DOE management as being pertinent for performing FR and Federal employee duties.</td>
</tr>
<tr>
<td>Surveillances</td>
<td>Researching requirements</td>
<td></td>
</tr>
<tr>
<td>Assessments of the contactor</td>
<td>Occurrence report reviews</td>
<td></td>
</tr>
<tr>
<td>Verifying completion of corrective actions in the field or with the contractor</td>
<td>Supporting facility related programmatic needs and special projects</td>
<td></td>
</tr>
<tr>
<td>Observing operator activities and maintenance actions</td>
<td>Reviewing DSAs, SERs, Abs, and other safety documentation at desk</td>
<td></td>
</tr>
<tr>
<td>Reviewing contractor documents and procedures at the job site</td>
<td>Reviewing contractor documents and procedures at desk</td>
<td>Non facility-related special projects</td>
</tr>
<tr>
<td>Facility grounds and property tours</td>
<td>Attending facility meetings</td>
<td>Administrative/collateral duties</td>
</tr>
<tr>
<td>Completing facility condition assessments</td>
<td>Communications involving issues requiring DOE oversight</td>
<td></td>
</tr>
<tr>
<td>Commute time between facilities or driving tours within facility</td>
<td>Discussions of actions required for addressing issues</td>
<td></td>
</tr>
<tr>
<td>Attending contractor pre-job briefings or other facility activity briefings</td>
<td>Commute time between oversight activities</td>
<td></td>
</tr>
<tr>
<td>Plan of the day/plan of the week meetings</td>
<td>Briefing management on facility issues</td>
<td></td>
</tr>
<tr>
<td>Shift turnovers</td>
<td>Providing feedback to the contractor</td>
<td></td>
</tr>
<tr>
<td>Response to facility/lab events</td>
<td>PAAA corrective action validations</td>
<td></td>
</tr>
<tr>
<td>Observing or participating in facility drills or lab exercises</td>
<td>Preparing reports for activities in column 1</td>
<td></td>
</tr>
<tr>
<td>Emergency operations center assignments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performing facility review activities in a facility at the FRs site</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: DOE-STD-1063-2006*

**d. Describe the assessment requirements and limitations associated with the FR’s interface with contractor employees.**

The following is taken from DOE O 226.1A.

DOE line management oversight must perform the following oversight activities:

- Ensure contractor compliance with requirements. DOE line management must periodically examine contractor programs and their implementation at the work-activity level to assess that DOE requirements and external regulatory requirements are met effectively. Deficiencies must be brought to the attention of contractor management and addressed in a timely manner.
- Ensure the adequacy of contractor assurance systems. DOE line management must review contractor assurance systems periodically to ensure that: required assessments by applicable DOE directives are being performed; the effectiveness of safety management programs, including programs that are credited in the safety basis for nuclear facilities are being assessed adequately; deficiencies are being self-identified; and corrective actions are being taken in a timely and effective manner.
- Evaluate contractor performance. DOE line management must periodically evaluate contractor performance in accordance with the provisions of their contracts.
- Ensure compliance with requirements applicable to DOE line management. DOE line management organizations must establish and implement oversight processes for monitoring their internal operations and completing required activities, such as reviewing and approving safety analysis reports and security plans, performing emergency management functions, adjudicating security clearances, implementing computer security programs at DOE office buildings, operating classified and sensitive information identification and protection programs, and operating employee concerns programs and other such functions.

**e. Describe the relationship and interface of FRs with other DOE oversight personnel.**

The following is taken from DOE-STD-1063-2006.

Facility representatives oversee the day-to-day contractor operations at DOE’s most hazardous facilities. Oversight performed by facility representatives provides DOE line managers with accurate objective information on the effectiveness of contractor work performance and practices, including implementation of the ISMS.

For each major facility or group of lesser facilities, a facility representative is assigned responsibility for monitoring the safety performance of the facility and its operations; this individual is the primary point of contact with the contractor for operational and safety oversight, and is responsible to the facility’s DOE line manager.

DOE facility representatives perform 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 operations and implementing ISM objectives, principles, and functions;
- DOE line/program managers are cognizant of the operational performance of facility contractors;
- 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.

The facility representative is assigned to monitor the performance of facility operations and management. The facility representative is a direct safety oversight extension of DOE line management to each respective facility.
f. Describe the FR’s role in contractor oversight.

The following is taken from DOE-STD-1063-2006.

Facility representatives occupy a unique position in the transmission of information between DOE and its contractors. Facility representatives should be able to communicate effectively with all levels of the contractor organization. They should be familiar with the contractor chain of command for facility operations. The FR should always strive to work constructively and effectively with contractor personnel to meet the shared goals of safe and efficient facility operations, in accordance with relevant DOE and contractual expectations. Facility representatives should represent DOE to the contractor and ensure the contractor carries out DOE operational safety policies in a manner consistent with DOE Program Office and field element expectations, relevant contract requirements, and the contractor’s ISMS description. In defining the relationship between an FR and contractor, the following points are emphasized:

- The FR functions as a part of DOE line management, and therefore should exercise authority consistent with specific program and management guidance established by the field element.
- The FR is the primary point of contact for the contractor to notify DOE of reportable occurrences as prescribed in DOE M 231.1-2.
- The contractor is responsible for the safe and efficient operation of the facility. The contractor is accountable to DOE to perform its operations in a manner that ensures the safety and health of personnel and protection of the environment. No FR activity or inactivity can diminish the contractor’s responsibility.
- The FR is responsible for determining that the contractor is operating the facility in a safe and efficient manner, consistent with the established safety expectations and requirements. Facility representatives fulfill this responsibility by assessing the contractor’s performance and discussing identified deficiencies and corrective action with contractor management.
- Field element managers should identify processes or procedures within the field element for FR to use to track identified issues or discrepancies to satisfactory closure.
- Although the FR identifies deficiencies, the ultimate responsibility for identifying and correcting deficiencies rests with the operating contractor. Field element managers should ensure that the contractor does not rely solely on the FR to identify or correct deficiencies.
- Minor events or problems are frequently clues that indicate more general problems in the contractor’s organization, management, personnel abilities, or practices. Therefore, attention to detail in the identification and correction of minor problems can result in significant improvements in the contractor’s performance. When corrective actions are called for, DOE line/program managers should initiate formal action with the operating contractor. Additionally, the FR should also provide input to formal mechanisms such as confirmation of actions or orders, if necessary.
- The FR shall adhere to certain rules of conduct, or protocol, while performing assigned duties, including the facility’s approved conduct of operations procedures. Formal protocols should be established to include the following:
  - Facility representatives should avoid interrupting operators in their work. The FR should wait for opportune times to deal with facility operators. If the FR is
observing operations or activities, the FR should perform observations unobtrusively. Operators carry the true burden of safety, and a diversion from their duties could adversely affect plant operations.

- The FR should maintain frequent contact with facility management. When FRs observe something that raises a safety concern, they should discuss their concerns with the facility management. If the contractor response is deemed unsatisfactory, the FR should discuss the concern with DOE line management for appropriate action.
- Facility representatives should use established chains of command for all requests for action, except when exercising “Stop Work” authority.
- Facility representatives shall keep a record of their activities and observations. Facility representatives should periodically review their records to determine if a systemic or recurring problem exists with contractor activities at one or more facilities. This record is subject to review in audits or appraisals and may be used by the field element manager as a source of information for the contractor evaluation process.

**g. Compare and contrast the following:**
- Department of Energy’s expectations of the operating contractor
- Operating contractor’s expectations of the Department of Energy

The following is taken from DOE-STD-1063-2006.

Facility representatives occupy a unique position in the transmission of information between DOE and its contractors. Facility representatives should be able to communicate effectively with all levels of the contractor organization. They should be familiar with the contractor chain of command for facility operations. The facility representative should always strive to work constructively and effectively with contractor personnel to meet the shared goals of safe and efficient facility operations, in accordance with relevant DOE and contractual expectations. Facility representatives should represent DOE to the contractor and ensure the contractor carries out DOE operational safety policies in a manner consistent with DOE program office and field element expectations, relevant contract requirements, and the contractor’s ISMS description.

**MANAGEMENT, ASSESSMENT, AND OVERSIGHT**

**33. A facility representative must demonstrate a working level knowledge of event investigation principles and techniques necessary to:** identify problems, determine causes, determine conclusions, and develop judgments of need (corrective actions).

**a. Discuss the techniques associated with identifying the events, facts, and conditions (known and assumed) necessary to perform causal analysis.**

The following is taken from DOE G 231.1-2.

The causal analysis process is an integral part of the ORPS model and supports the required performance analysis process described in DOE G 231.1-1. When implementing the causal analysis process, apparent cause(s) are identified as the most probable cause(s) of an event or condition that management has the control to fix and for which effective recommendations
for corrective actions can be generated. A model for the causal analysis process is provided below. There are three basic steps in the process: 1) identifying causal factors, 2) selecting ISM core functions, and 3) using the causal analysis tree (CAT), which is reproduced in figure 68, to identify apparent causes/cause codes.

Source: DOE G 231.1-2

Figure 68. Causal analysis tree

1. Identify causal factors. Use one of the contractor’s supported/recommended methodologies to determine causal factors.
2. Select applicable ISM core function(s). Select all of the ISM core function(s) necessary to identify any observed weakness(es) in the facility’s implementation of the ISM program. Deficient ISM core functions are considered to be causal factors and processed in the same manner as the causal factors determined in step 1.
3. Use the tree to identify apparent causes/cause codes and to determine the appropriate cause(s) for each causal factor identified. Causal analysis node descriptions that are in attachment 7 to DOE G 231.1-2, Occurrence Reporting Causal Analysis Guide can be used, as needed, to determine the appropriate cause(s). Additionally, the logic
provided below will ensure that all possible cause(s) are considered during the analysis.

- Use the design/engineering (A1) branch and the equipment/material (A2) branch to codify any design/equipment related deficiencies.
- Use the human performance (A3) branch to codify errors by personnel. If any human performance codes are determined to be applicable, use attachment 6 to determine applicable C level apparent cause codes in the other branches that may have caused the resultant human error. These codes coupled together describe the cause of the human error.
- Use the management problem (A4), communications LTA (A5), training deficiency (A6), and other problem (A7) branches to determine other cause codes.
- Repeat this process with remaining causal factors until all causal factors have been addressed.

b. Discuss the principles and techniques associated with the following analytical techniques:

- Event and causal factors analysis
- Root cause analysis
- Barrier analysis
- Change analysis
- Factual analysis

The following is taken from DOE-NE-STD-1004-92 (archived).

*Event and Causal Factors Analysis*

Event and causal factors analysis is a method in which personnel conduct a step-by-step reenactment of their actions for the observer without carrying out the actual function. If appropriate, it may be possible to use a simulator for performing the walk-through rather than the actual work location.

Objectives include:

- determining how a task was really performed;
- identifying problems in human-factors design, discrepancies in procedural steps, training, etc.

Preconditions are that participants must be the people who actually do the task.

Steps in event and causal factor analysis are as follows:

1. Obtain preliminary information to determine what the person was doing when the problem or inappropriate action occurred.
2. Decide on a task of interest.
3. Obtain necessary background information:
   - Obtain relevant procedures.
   - Obtain system drawings, block diagrams, P&IDs etc.
   - Interview personnel who have performed the task (but not those who will be observed) to obtain understanding of how the task should be performed.
4. Produce a guide outlining how the task will be carried out. A procedure with key items underlined is the easiest way of doing this. The guide should indicate steps in performing task and key controls and displays so that
   o you will know what to look for
   o you will be able to record actions more easily.

5. Thoroughly familiarize yourself with the guide and decide exactly what information you are going to record and how you will record it.

   You may want to check off each step and controls or displays used as they occur. Discrepancies and problems may be noted in the margin or in a space provided for comments, adjacent to the step.

6. Select personnel who normally perform the task. If the task is performed by a crew, crew members should play the same role they fulfill when carrying out the task.

7. Observe personnel walking through the task and record their actions and use of displays and controls. Note discrepancies and problem areas.

   You should observe the task as it is normally carried out; however, if necessary, you may stop the task to gain full understanding of all steps. Conducting the task as closely to the conditions that existed when the event occurred will provide the best understanding of the event causal factors.

8. Summarize and consolidate any problem areas noted. Identify probable contributors to the event.

Cause and Effect Chart

Figure 69 shows the conceptual process of cause and effect charting. Figure 70 shows a sample cause and effect chart. The primary effect given on the chart is the problem you are trying to prevent from recurring. To complete the cause and effect chart, follow these steps:

1. Identify the cause and effect starting with the primary effect. For each effect, there is a cause that then becomes the next effect for which you need to identify the cause. Each block is an effect and a cause, except for the first block, which is the primary effect and the last block in each series, which is the root cause.

2. For each cause, list in a block just below the cause two ways you know it to be true. If only one way is known or not firm, all possible causes should be evaluated as potential causes, and the bases for rejected and accepted causes should be stated.

3. When this process gets to the point where a cause can be corrected to prevent recurrence in a way that allows meeting your objectives and is within your control, you have found the root cause or causes.
Source: DOE-NE-STD-1004-92

Figure 69. Conceptual process of cause and effect charting
Root Cause Analysis

Every root cause investigation and reporting process should include five phases. While there may be some overlap between phases, every effort should be made to keep them separate and distinct.
Phase I. Data Collection
It is important to begin the data collection phase of root cause analysis immediately following the occurrence identification to ensure that data are not lost. (Without compromising safety or recovery, data should be collected even during an occurrence.) The information that should be collected consists of conditions before, during, and after the occurrence; personnel involvement (including actions taken); environmental factors; and other information having relevance to the occurrence.

Phase II. Assessment
Any root cause analysis method may be used that includes the following steps:
- Identify the problem.
- Determine the significance of the problem.
- Identify the causes (conditions or actions) immediately preceding and surrounding the problem.
- Identify the reasons why the causes in the preceding step existed, working back to the root cause (the fundamental reason that, if corrected, will prevent recurrence of these and similar occurrences throughout the facility). This root cause is the stopping point in the assessment phase.

Phase III. Corrective Actions
Implementing effective corrective actions for each cause reduces the probability that a problem will recur and improves reliability and safety.

Phase IV. Inform
Entering the report on the ORPS is part of the inform process. Also included is discussing and explaining the results of the analysis, including corrective actions, with management and personnel involved in the occurrence. In addition, consideration should be given to providing information of interest to other facilities.

Phase V. Follow-up
Follow-up includes determining whether corrective action has been effective in resolving problems. An effectiveness review is essential to ensure that corrective actions have been implemented and are preventing recurrence.

Barrier Analysis
The following is taken from DOE-NE-STD-1004-92 (archived).

Barrier analysis is a systematic process that can be used to identify physical, administrative, and procedural barriers or controls that should have prevented the occurrence. This technique should be used to determine why these barriers or controls failed and what is needed to prevent recurrence.

Change Analysis
The following is taken from DOE-NE-STD-1004-92 (archived).

Change analysis is used when the problem is obscure. It is a systematic process that is generally used for a single occurrence and focuses on elements that have changed. It
compares the previous trouble-free activity with the occurrence to identify differences. These differences are subsequently evaluated to determine how they contributed to the occurrence.

Change analysis looks at a problem by analyzing the deviation between what is expected and what actually happened. The evaluator essentially asks what differences occurred to make the outcome of this task or activity different from all the other times this task or activity was successfully completed.

This technique consists of asking the questions: What? When? Where? Who? How? Answering these questions should provide direction toward answering the root cause determination question: Why?

Primary and secondary questions included within each category will provide the prompting necessary to thoroughly answer the overall question. Some of the questions will not be applicable to a given condition. Some amount of redundancy exists in the questions to ensure that all items are addressed.

Several key elements are as follows:
- Consider the event resulting in the undesirable consequences.
- Consider a comparable activity that did not have the undesirable consequences.
- Compare the condition having the undesirable consequences with the reference activity.
- Set down all known differences whether they appear to be relevant or not.
- Analyze the differences for their effects in producing the undesirable consequences. This must be done with careful attention to detail, ensuring that obscure and indirect relationships are identified (e.g., a change in color or finish may change the heat transfer parameters and consequently affect system temperature).
- Integrate into the investigative process any information relevant to the causes of, or the contributors to, the undesirable consequences.

Change analysis is a good technique to use whenever the causes of the condition are obscure, you do not know where to start, or you suspect a change may have contributed to the condition.

Not recognizing the compounding of change (e.g., a change made 5 years previously combined with a change made recently) is a potential shortcoming of change analysis. Not recognizing the introduction of gradual change as compared with immediate change is also possible.

This technique may be adequate to determine the root cause of a relatively simple condition. In general, though, it is not thorough enough to determine all the causes of more complex conditions.

Figure 71 shows the six steps involved in change analysis.
**Figure 71. Six steps of change analysis**

*Factual Analysis*

The following is taken from All Experts, Reid Technique, Factual Analysis.

Both an interview as well as an interrogation are facilitated by analysis of investigative findings. Proper factual analysis assists the investigator in the following ways:

- Eliminate improbable suspects
- Develop possible suspects or leads
- Increase confidence in identifying truthful or guilty suspects through the interview process
- Identify proper interrogational strategies

**c. Discuss the process associated with forming conclusions based on the results of the analytical process.**

The following is taken from the DOE Workbook: Accident Investigation.

Conclusions and judgments of need are key elements of the investigation that must be developed.

Conclusions are significant deductions derived from the investigation’s analytical results. They are derived from and must be supported by the facts plus the results of testing and the various analyses conducted.
Conclusions may
- include concise statements of the causal factors of the accident determined by analysis of facts
- be statements that alleviate potential confusion on issues that were originally suspected causes
- address significant concerns arising out of the accident that are unsubstantiated or inconclusive
- be used to highlight positive aspects of performance revealed during the investigation, where appropriate.

When developing conclusions, the analyst should
- organize conclusions sequentially, preferably in chronological order, or in logical sets;
- base conclusions on the facts and the subsequent analysis of the facts;
- include only substantive conclusions that bear directly on the event, and that reiterate significant facts and pertinent analytical results leading to the event’s causes
- keep conclusions as short as possible and, to the extent possible, limit reference citations to one per conclusion.

d. Discuss the process associated with developing judgments of need.

The following is taken from DOE Workbook: Accident Investigation.

Judgments of need are the managerial controls and safety measures determined to be necessary to prevent or minimize the probability or severity of a recurrence. Judgments of need should be linked to causal factors and logically flow from the conclusions. They should be:
- stated in a clear, concise, and direct manner
- based on the facts/evidence
- stated so that they can be the basis for corrective action plans.

Judgments of need
- should not be prescriptive corrective action plans or recommendations, nor should they suggest punitive actions
- should not include process issues unless these issues have a direct impact on the event. These concerns should be noted in a separate memorandum to the appointing official, with a copy to site management.

An interactive process is the preferred approach for generating judgments of need. That is, board members should work together to review causal factors and then begin generating a list of judgments of need.

These judgments should be linked directly to causal factors, which are derived from facts and analyses.

One method for ensuring that all significant facts and analytical results are addressed in the judgments of need is to develop displays linking judgments of need with facts, analyses, and causal factors. It is useful to display these elements on the walls of the conference room.
e. Explain the necessity for and differences between the immediate, short term, and long term actions taken as the result of a problem identification or 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:
1. Immediate corrective actions that are taken by the organization managing the site where the accident occurred to prevent a second or related accident.
2. 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.
3. 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.
4. DOE Headquarters corrective actions that result from discussions with senior management. These actions usually address DOE policy.

f. Conduct an interview representative of one that would be conducted during an occurrence investigation.

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

g. Describe the following types of investigations and discuss an example of the application of each:
   - Type A
   - Type B
   - Limited scope

DOE O 225.1A, Accident Investigations, provides an accident investigation categorization algorithm as attachment 2. This algorithm provides the criteria for categorizing an accident investigation as either a type A or a type B investigation. Table 5 breaks the criteria into four different categories of effects: human, environmental, property, and other.

A limited scope investigation is an accident investigation, chartered by the Assistant Secretary for Environment, Safety and Health, that is reduced in scope, duration, and resources from that normally associated with a Type A or Type B investigation.
Table 4. Accident investigation categorization

<table>
<thead>
<tr>
<th><strong>Type A Investigation</strong></th>
<th><strong>Type B Investigation</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Effects</td>
<td></td>
</tr>
<tr>
<td>Any fatal, or likely to be fatal, injury or chemical or biological exposure to an employee or a member of the public</td>
<td>Any one or series of injuries, chemical exposures, or biological exposures that results in hospitalization of one or more employees or members of the public for more than five continuous days</td>
</tr>
<tr>
<td>Any one accident that requires the hospitalization for treatment of three or more individuals</td>
<td>Any one or series of injuries, chemical exposures, or biological exposures that results in permanent partial disability of one or more employees or members of the public</td>
</tr>
<tr>
<td>Any one accident that has a high probability of resulting in the permanent total disability due to injuries, chemical exposures, or biological exposures of DOE, contractor, or subcontractor employees or members of the public</td>
<td>Any one accident or series of accidents within a one-year time period resulting in five or more lost-workday cases, or any series of similar or related accidents involving five or more persons, one or more of which is a lost-workday case</td>
</tr>
<tr>
<td>A single radiation exposure to an individual resulting in</td>
<td>A single radiation exposure to an individual resulting in</td>
</tr>
<tr>
<td>a. a total effective dose equivalent &gt;25 rem</td>
<td>a. a total effective dose equivalent &gt;10 but &lt;25 rem</td>
</tr>
<tr>
<td>b. a dose equivalent to the lens of the eye &gt;75 rem</td>
<td>b. a dose equivalent to the lens of the eye &gt;30 but &lt;75 rem</td>
</tr>
<tr>
<td>c. a shallow dose equivalent to an extremity of skin &gt;250 rem</td>
<td>c. a shallow dose equivalent to an extremity of skin &gt;100 but &lt;250 rem</td>
</tr>
<tr>
<td>d. the sum of the deep dose equivalent for external exposure and the committed dose equivalent to any organ or tissue other than the lens of the eye &gt;250 rem</td>
<td>d. the sum of the deep dose equivalent for external exposure and the committed dose equivalent to any organ or tissue other than the lens of the eye &gt;00 rem but &lt;250 rem</td>
</tr>
<tr>
<td>e. a dose equivalent to the embryo or fetus of a declared pregnant worker &gt;2.5 rem</td>
<td>e. a dose equivalent to the embryo or fetus of a declared pregnant worker &gt;1.0 but &lt;2.5 rem</td>
</tr>
</tbody>
</table>

Environmental Effects

<table>
<thead>
<tr>
<th><strong>Type A Investigation</strong></th>
<th><strong>Type B Investigation</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Release of a hazardous substance, material, waste, or radionuclide from a DOE facility (onsite or offsite) in an amount greater than five times the reportable quantities specified in 40 CFR 302 that results in serious environmental damage</td>
<td>Release of a hazardous substance, material, waste, or radionuclide from a DOE facility (onsite or offsite) in an amount greater than or equal to two times but less than five times the reportable quantities specified in 40 CFR 302 that results in serious environmental damage</td>
</tr>
<tr>
<td><strong>Type A Investigation</strong></td>
<td><strong>Property Effects</strong></td>
</tr>
<tr>
<td>-------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Estimated loss of, or damage to, DOE or other property, including aircraft damage, greater than or equal to $2.5 million or requiring estimated costs greater than or equal to $2.5 million for cleaning, decontaminating, renovating, replacing, or rehabilitating structures, equipment, or property</td>
<td></td>
</tr>
<tr>
<td>Any apparent loss, explosion, or theft involving radioactive or hazardous material under the control of DOE, contractors or subcontractors in such quantities and under such circumstances as to constitute a hazard to human health and safety or private property</td>
<td></td>
</tr>
<tr>
<td>Any unplanned nuclear criticality</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Type B Investigation</strong></th>
<th><strong>Property Effects</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated loss of, or damage to, DOE or other property, greater than or equal to $1 million but less than $2.5 million, including aircraft damage, and costs of cleaning, decontaminating, renovating, replacing, or rehabilitating structures, equipment, or property</td>
<td></td>
</tr>
<tr>
<td>The operation of a nuclear facility beyond its authorized limits</td>
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<tr>
<th><strong>Other Effects</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Any accident or series of accidents for which a Type A investigation is deemed appropriate by the Secretary or the Assistant Secretary of Environment, Safety, and Health</td>
</tr>
<tr>
<td>Any accident or series of accidents for which a Type B investigation is deemed appropriate by the Secretary or the Assistant Secretary of Environment, Safety, and Health; the associate deputy secretary for field management; the cognizant Secretarial Officer; or the head of the field element (This includes departmental crosscutting issues and issues warranting the attention of local news or interest groups.)</td>
</tr>
</tbody>
</table>

*Source: DOE O 225.1A*
34. A facility representative must demonstrate a working knowledge of the DOE oversight process as defined by DOE O 226.1A, *Implementation of DOE Oversight Policy*, such as the essential elements of an oversight program, the contractor assurance system, and DOE line management oversight responsibilities and functions.

a. **Explain the four essential elements of an effective oversight program, including a comprehensive and rigorous contractor assurance system, the DOE field element line management oversight process, DOE headquarters line management oversight process and independent oversight processes.**

The four essential elements of an effective oversight program are listed below:

1. A comprehensive and integrated contractor assurance system must be established, consistent with the hazards and the risks associated with the work performed, to identify and address program and performance deficiencies, opportunities for improvement, provide the means and requirements to report deficiencies to the responsible managers and authorities, establish and effectively implement corrective and preventive actions, and share lessons learned across all aspects of operations.

The contractor assurance system must include self-evaluations of compliance with applicable laws, regulations, national standards, DOE directives, DOE-approved plans and program documents (e.g., security plans, authorization basis documents, and QAP, site-specific procedures/manuals, criteria review and approach documents, contractual performance objectives, and other contractually mandated requirements.

2. DOE field element line management oversight processes should include inspections, reviews, surveillances, surveys, operational awareness, and walkthroughs that evaluate programs and management systems and the effectiveness of the site assurance system. DOE field elements must prepare documented program plans and annual schedules for both planned assessments and focus areas for operational oversight.

3. DOE Headquarters line management oversight processes are focused primarily on the DOE field elements and also look at contractor activities to the extent necessary, in order to evaluate the implementation and effectiveness of field element line management oversight. DOE Headquarters elements must prepare documented program plans and annual schedules for both planned assessments and focus areas for operational oversight.

4. Independent oversight processes are performed by DOE organizations that do not have line management responsibility for the management of the activity and thus provide an independent perspective for senior management on the effectiveness of programs and activities at all organizational levels (Headquarters, field, and contractor).

b. **Describe the DOE oversight model.**

The following is taken from DOE P 226.1A.

The four elements of oversight are designed to work as a comprehensive system to provide oversight model (figure 72) assurance that DOE activities are safe and secure.
Oversight of high consequence activities, such as high hazard nuclear operations, requires additional rigor, such as instituting Central Technical Authorities for core nuclear safety functions. The assurance system puts responsibility and accountability at the appropriate organizational level to implement comprehensive and rigorous processes that ensure adequate protection of the public, workers, environment, and national security assets and effective and efficient operations. The DOE Headquarters and field element line management oversight processes put responsibility and accountability on line management to determine the effectiveness, on an ongoing and regular basis, of site operations and to ensure timely corrective actions if performance does not meet expectations. The independent oversight processes determine whether Headquarters, field, and contractor line management are effectively implementing their responsibilities and provide an additional basis for credibility throughout the system. These assurance systems and oversight activities will be tailored to meet the needs and unique differences of each site or activity. Consistent with QA objectives, thorough, rigorous assessments and corrective actions are required to ensure performance and quality improvement.

c. Explain the six required elements of a contractor assurance system, and list the four aspects of operations that are required in a contractor assurance system.

The following is taken from DOE O 226.1A.

The contractor assurance system will address the criteria described in appendix A to DOE O 226.1A, or other comparably effective criteria established by responsible DOE line management, for activities such as the following:

- Assessments,
- Event reporting,
- Worker feedback mechanisms,
- Issues management,
- Lessons learned,
- Performance measures.
Assessments
A rigorous and credible assessment program is the cornerstone of effective, efficient management of programs such as ES&H; safeguards and security; cyber security; and emergency management. Contractors will be responsible for developing, implementing, and performing comprehensive assessments of all facilities, systems, and organizational elements, including subcontractors, on a recurring basis. The scope and frequency of assessments must be specified in site plans and program documents (e.g., the QAP) and must ensure that required assessments by applicable DOE directives are being performed; the effectiveness of safety management programs, including programs that are credited in the safety basis for nuclear facilities are being assessed adequately; deficiencies are being self-identified; and corrective actions are being taken in a timely and effective manner. External peers or SMEs may be utilized to support assessment activities.

Event Reporting
Formal programs will be established and effectively implemented to identify issues and report, analyze, and address operational events, accidents, and injuries:
- Reportable occurrences that meet ORPS thresholds and associated corrective actions will be evaluated, documented, and reported as required.
- For activities covered by the PAAA, nuclear and worker safety and health issues (e.g., noncompliance) meeting DOE reporting thresholds should be self-reported through the DOE-wide Noncompliance Tracking System to mitigate the severity level of the violation and potential financial penalties.
- Trending analysis of events, accidents, and injuries is performed in accordance with structured/formal processes.

Worker Feedback
In addition to structured assessments, DOE contractors will establish and implement processes to solicit feedback from workers and work activities.

Common feedback mechanisms are described in site plans/program documents and include the following:
- Employee concerns programs
- Telephone or intranet “hotline” processes for reporting concerns or questions
- Pre-job briefs
- Job hazard walk-downs by workers prior to work
- Post-job reviews
- Employee suggestion forms
- Safety meetings
- Employee participation in committees and working groups
- Labor organization input

Issues Management
Contractors must ensure that a comprehensive, structured issues management system is in place. This system must provide for the timely and effective resolution of deficiencies, and be an integral part of effective contractor assurance system
Program and performance deficiencies, regardless of their source, must be captured in a system or systems that provide for effective analysis, resolution, and tracking. Issues management must include structured processes for:

- determining the risk, significance, and priority of deficiencies;
- evaluating the scope and extent of the condition or deficiency;
- determining event reportability under applicable requirements;
- identifying root causes;
- identifying and documenting suitable corrective actions and recurrence controls, based on analyses, to correct the conditions and prevent recurrence;
- identifying individuals/organizations responsible for implementing corrective actions;
- establishing appropriate milestones for completion of corrective actions, including consideration of significance and risk;
- tracking progress toward milestones such that responsible individuals and managers can ensure timely completion of actions and resolution of issues;
- verifying that corrective actions are complete;
- validating that corrective actions are effectively implemented and accomplish their intended purposes, using a graded approach based on risk; and
- ensuring that individuals and organizations are accountable for performing their assigned responsibilities.

Lessons Learned

Formal programs must be established to communicate lessons learned during work activities, process reviews, and event analyses to potential users and applied to future work activities. Contractors must identify, apply, and exchange lessons learned with the rest of the DOE complex. Contractors must review and apply lessons learned identified by other DOE organizations and external sources to prevent similar occurrences.

Performance Measures

Contractors must identify, monitor, and analyze data measuring the performance of facilities, programs, and organizations. The data must be used to demonstrate performance improvement or deterioration relative to identified goals. Using a program to analyze and correlate data, contractors must suggest further improvements and identify good practices and lessons learned. To accomplish these objectives, contractors must establish programs that identify, gather, verify, analyze, trend, disseminate, and make use of performance indicators.

Performance indicator data must be considered in allocating resources, establishing goals, identifying performance trends, identifying potential problems, and applying lessons learned and good practices. Quantitative performance indicators/Measures also may be considered in evaluating performance and establishing oversight priorities. However, quantitative performance measures provide only a partial indication of system effectiveness and must be considered in combination with other appraisal and operational awareness results.

Aspects of Operations for a Contractor Assurance System

The contractor must submit, for DOE review and approval, detailed contractor assurance system program descriptions to address the following aspects of operations: 1) ES&H; 2) safeguards and security; 3) emergency management; and 4) cyber security. If existing processes provide adequate descriptions of the contractor assurance system, or if such
processes can be modified to provide adequate descriptions, submittals under these processes can be used to meet this requirement. Depending on the complexity and hazards associated with the work, the contractor may choose not to require the subcontractor to submit a contractor assurance system program description for the contractor’s review and approval. However, contractors are still required to ensure that work performed by subcontractors meets the requirements of the existing QAPs and ISM systems.

d. Identify the key elements and features of an effective DOE and operating contractor relationship, including communications and dispute resolution.

The following is taken from DOE O 226.1A.

DOE line management must have effective processes for communicating line oversight results and other issues up the DOE line management chain, using a graded approach based on the hazards and risks. The processes must provide sufficient technical basis to allow senior DOE managers to make informed decisions and must include provisions for communicating and documenting dissenting opinions. Processes for resolving disputes about oversight findings and other significant issues must also be implemented and include provisions for independent technical reviews of significant issues.

e. Explain “balanced approach” as it relates to a DOE O 226.1A compliant DOE oversight program.

The following is taken from DOE O 226.1A.

The oversight program will provide a balance between reviews of documentation (e.g., plans, procedures, and records) and adequacy of implementation through performance tests and observation of actual work activities at the facilities.

Oversight program activities will provide for a similar balance between evaluations of systems (such as the DOE ISMS and integrated safeguards and security management system), programs (e.g., radiation protection), facilities, and implementation of individual elements of those systems (e.g., specific work activities).

f. Explain the following DOE oversight processes, including the reason for conducting each process and types of activities involved in completing each process:
   - Operational awareness
   - Assessment of facilities, operations, and programs
   - Assessment of contractor assurance systems
   - Evaluations of contractor performance
   - Self-assessments of DOE line management functions and performance

The following explanations are taken from DOE O 226.1A.

*Operational Awareness*

Operational awareness refers to those activities taken by DOE line personal to maintain cognizance of overall facility or activity status, major changes planned, and overall safety
posture. The expected degree of operational awareness varies based on distance from the work.

- DOE line management must rigorously review and critique contractor processes and performance in identifying, evaluating, and reporting events and safety issues that are required to be reported by laws, regulations, or DOE directives to determine whether issues are properly screened, evaluated, and reported.
- DOE line management must evaluate and monitor the contractor evaluations and corrective actions for events and issues and assess whether effective recurrence controls are identified and implemented.
- Operational awareness activities must be documented either individually or in periodic summaries.
- Deficiencies in programs or performance identified during operational awareness activities must be communicated to the contractor for resolution through a structured issues management process, which can be managed by the DOE field organization or the contractor.

**Assessments of Facilities, Operations, and Programs**

DOE line management must establish and implement assessment programs to determine contractor compliance with requirements.

- DOE line management assessments will be planned and scheduled based on requirements, analysis of hazards and risks, past performance, and effectiveness of contractor assurance systems for organizations, facilities, operations, and programs.
- In addition to scheduled assessments, “for cause” reviews will be performed when circumstances warrant.
- Assessments will be performed in support of facility startup and restart and will review and approve required program documents.
- Assessments must include reviews of site qualification standard programs, training programs, and individual training and qualifications as they relate to ES&H; safeguards and security; emergency management; and cyber security.
- Assessment results, including findings, must be documented and provided to the contractor for timely resolution.
- Deficiencies identified by DOE assessments or other DOE reviews must be addressed in a structured issues management process. DOE verifies that contractor corrective actions are complete and effective in addressing deficiencies before they are closed out in the issues management system.
- DOE line management must maintain a baseline assessment program that provides assurance that DOE managers have an accurate picture of the status and effectiveness of site programs and that deficiencies are identified in a timely manner.
- Oversight must include structured and rigorous processes for validating the accuracy of information collected during assessments. DOE line management requires that findings must be tracked and resolved through structured and formal processes, including provisions for review of corrective action plans.
- DOE line management must verify that corrective actions are complete and performed in accordance with requirements before findings identified by DOE assessments or reviews are closed, and requires that deficiencies are analyzed both individually and collectively to identify causes and prevent recurrences.
**Assessments of Contractor Assurance Systems**

DOE requires that contractor assurance systems address all organizations, facilities, and program elements.

DOE line management must assess implementation and effectiveness of contractor assurance systems for ES&H; safeguards and security; emergency management; and cyber security systems and their sub-elements by examining the following:

- Assessment methods
- The frequency, breadth, and depth of self-assessments
- Line management involvement in self-assessments
- Evaluators’ technical expertise and qualifications
- The number and nature of findings identified
- The degree of rigor applied to self-assessment

DOE line management must regularly assess the effectiveness of contractor issues management and corrective action processes, lessons learned processes, and other feedback mechanisms. DOE line management must also evaluate contractor processes for communicating information, including dissenting opinions, up the management chain.

DOE line management must validate that contractor corrective actions have been implemented and are effective in resolving deficiencies and preventing recurrence.

DOE line management must also regularly assess the contractor’s reporting processes and performance to assess that contractors meet reporting requirements for events and incidents of security, environment, safety, health, cyber security, and emergency management concern and take effective actions to prevent recurrence of deficiencies or findings.

For sites where contractors report the results of performance measures to DOE, DOE must regularly assess the effectiveness of processes for collecting, evaluating, and reporting performance data to ascertain the accuracy, completeness, and validity of the performance measures.

**Evaluations of Contractor Performance**

As COs, DOE line management must periodically evaluate contractor performance in meeting contractual requirements and expectations.

A combination of DOE line management oversight, contractor self-assessments, and other performance indicators must be used to evaluate contractor performance.

DOE line management must evaluate the effectiveness of management programs, including ES&H; safeguards and security; cyber security; and emergency management. Poor performance in these areas must have significant negative consequences on evaluations and fee determination. In accordance with contract provisions, evaluations must be used to reward significant accomplishments and/or performance improvements.

Quantitative performance indicators and measures may be used to support the evaluation of a contractor; however, such indicators provide only a partial indication of system effectiveness and must be considered in combination with assessment results.
Evaluations must be based on an analysis of the results of relevant information obtained or developed during the performance period, including contractual performance measures and objectives, DOE line management oversight, contractor self-assessments, operational history/events, and reviews by DOE and external organizations.

**Self-Assessments of DOE Line Management Functions and Performance**

DOE Headquarters and field organizations must have a structured, documented self-assessment program for ES&H; safeguards and security; cyber security; and emergency management to comply with DOE requirements. DOE organizations must perform self-assessments of programmatic and line management oversight processes and activities to assess whether requirements and management expectations are met. The frequency of assessments of these functions must be commensurate with the hazards and risks related to the activity being assessed. Continuous improvement mechanisms must be in place to improve the effectiveness and efficiency of oversight programs and site operations.

g. **Conduct a minimum of three assessments of contractor or Federal employee (as appropriate) work performance.**

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

35. **A facility representative must demonstrate a working level knowledge of conduct of maintenance principles and DOE requirements to ensure maintenance is performed in a safe and efficient manner.**

a. **Explain the DOE’s role in the oversight of contractor maintenance operations.**

The following is taken from DOE O 433.1A.

DOE has the following responsibilities for the oversight of contractor maintenance operations:

- Ensure that maintenance activities and programs at nuclear facilities under their purview are conducted in compliance with the requirements of DOE O 433.1A, *Maintenance Management Program for DOE Nuclear Facilities*.
- Review contractor maintenance implementation plan (MIP) every 2 years and forward to the appropriate approval authority approval.
- Ensure that sufficient resources are budgeted in a timely manner to provide DOE with the highest confidence in the reliable performance of mission critical and safety structures, systems, and components (SSCs) through proactive maintenance practices.
- Ensure that cost-effective maintenance management programs are developed and implemented for all hazard category 1, 2 and 3 nuclear facilities consistent with DOE’s mission, safety and health, reliability, quality, and environmental protection objectives.
- Ensure that maintenance responsibility, authority, and accountability are clearly defined, appropriately assigned and executed.
- Where maintenance requirements or accepted maintenance standards cannot be met, ensure that such instances are appropriately documented and acknowledged by the appropriate Secretarial Officer, including the granting of exemptions by DOE/NNSA, as appropriate, when requested.
• Ensure that the requirements for maintenance of nuclear facilities are incorporated into contracts, subcontracts, and support services contracts as appropriate.
• Ensure that descriptions of maintenance management program requirements of DOE O 433.1A which ensure safe operation are conveyed accurately by contractors operating hazard category 1, 2 and 3 nuclear facilities and contained in the DSAs for the facilities as required by 10 CFR 830-204, “Documented Safety Analysis.”
• Notify COs when contracts are affected by DOE O 433.1A.
• Coordinate with COs the revisions of contracts to comply with requirements of DOE O 433.1A and require contractors to appropriately flow down requirements to subcontractors.
• Ensure that procurement requests include applicable requirements in the CRD for DOE O 433.1A to be applied to awards or sub-awards.
• If delegated by the Secretarial Officer, review and approve exemption requests after resolving comments from the Director, Office of Health, Safety and Security at non-NNSA facilities and after considering such requests, for NNSA facilities. If not delegated, forward requests for exemptions to the Secretarial Officer.
• Conduct comprehensive self assessments and assessments of contractor maintenance management programs periodically with appropriate frequency and follow-up.
• Ensure that all procurement requests for work within the scope of DOE O 433.1A, including work requests to be performed through subcontracts, include the appropriate requirements of the CRD.

b. Explain the application of DOE O 433.1B, Maintenance Management Program for DOE Nuclear Facilities and DOE O 430.1B, Chg 1, Real Property Asset Management.

The following is taken from DOE G 433.1-1.

DOE O 433.1A, Maintenance Management Program for DOE Nuclear Facilities, requires DOE contractors to develop and implement a maintenance management program for each nuclear facility under DOE cognizance.

DOE O 433.1A further requires that each DOE contractor develop a MIP defining the SSCs the nuclear facility comprises. Functional areas within the ISMS program and life-cycle asset management that overlap with functional areas within 10 CFR 830, 29 CFR 1910.119, “Process Safety Management of Highly Hazardous Chemicals;” DOE Order 5400.5, Radiation Protection of the Public and the Environment; and 10 CFR 835 are intended to be complementary to one another, not duplicative efforts. Similar relationships exist with other nuclear safety requirements, such as conduct of operations and QA. It is important to recognize that these complementary areas should not be developed and implemented as independent programs, but should be developed in concert with each other to ensure harmonious integration.

The following is taken from DOE O 430.1B.

The management of real property assets must take a corporate, holistic, and performance-based approach to real property life-cycle asset management that links real property asset planning, programming, budgeting, and evaluation to program mission projections and
performance outcomes. Acquisitions, sustainment, recapitalization, and disposal must be balanced to ensure real property assets are available, used, and in a suitable condition to accomplish DOE missions. DOE O 430.1B, *Real Property Asset Management*, sets the requirements for the major real property asset management functional components of planning, real estate, acquisition, maintenance and recapitalization, disposition and long-term stewardship, value engineering, and performance goals and measures.

c. Define each of the following maintenance related terms and explain their relationship to each other:

- **Corrective**
- **Preventive**
- **Predictive**
- **Periodic**
- **Planned**
- **Reliability-centered**
- **Troubleshooting**

The following definitions are taken from DOE G 433.1-1.

**Corrective**
Corrective maintenance involves the repair of failed or malfunctioning equipment, system, or facilities to restore the intended function or design condition. This maintenance does not result in a significant extension of the expected useful life.

**Preventive**
Preventive maintenance (PM) includes all those planned, systematic, periodic, and seasonal maintenance actions taken to prevent SSC or facility failures, to maintain designed-in operating conditions, and to extend operating life. The PM process takes into account the inevitability of failures in any simple or complex piece of equipment, although the consequences of failures can be controlled by careful design and effective maintenance. The reason for the failure incident can be apparent if basic differences between expected behaviors and the actual behaviors of SSCs are considered. These differences can be translated into possible failure modes. Preventive maintenance identifies any differences between actual and expected behavior of SSCs. Generally, regulatory and code requirements, DOE TSR for surveillances, in-service inspection and testing, vendor recommendations, and other forms of maintenance action and frequency selection based on engineering judgment or analytical methods are the pursuit of proactive planned maintenance.

**Predictive**
Predictive maintenance in the actions necessary to monitor; find trends; and analyze parameters, properties, and performance characteristics or signatures associated with SSCs, facilities, or pieces of equipment to discern whether a state or condition may be approaching that is indicative of deteriorating performance or impending failure, where the intended function of the SSCs, facilities, or pieces of equipment may be compromised. Predictive maintenance activities involve continuous or periodic monitoring and diagnosis to forecast component degradation so that “as-needed” planned maintenance can be initiated before failure. Not all SSC, facility, or equipment conditions and failure modes can be monitored and diagnosed in advance; therefore, predictive maintenance should be selectively applied.
To the extent that predictive maintenance can be relied on without large uncertainties, it is normally preferable to activities such as periodic internal inspection or equipment overhauls.

**Periodic**

Periodic maintenance includes preventive, predictive, or seasonal maintenance activities performed on a routine basis that may include any combination of external inspections, alignments or calibrations, internal inspections, overhauls, and SSC replacements.

**Planned**

Planned maintenance includes preventive or seasonal maintenance activities performed before SSC failure that may be initiated by predictive or periodic maintenance results, through vendor recommendations, or by experience/lessons learned. These include actions such as scheduled cold weather protection, valve repacking, replacement of bearings as indicated from vibration analysis, major or minor overhauls based on experience factors or vendor recommendations, and replacement of known life-span components. For example, repacking a valve because of packing leakage would be corrective maintenance, but scheduled repacking before leakage would be planned maintenance.

**Reliability-Centered**

Reliability-centered maintenance is a proactive systematic decision logic tree approach to identify or revise PM tasks or plans to preserve or promptly restore operability, reliability and availability of facility SSCs; or to prevent failures and reduce risk through types of maintenance action and frequency selection to ensure high performance.

Reliability-centered maintenance is the performance of scheduled maintenance for complex equipment, quantified by the relationship of PM to reliability and the benefits of reliability to safety and cost reduction through the optimization of maintenance task/frequency intervals. The concept relies on empirical maintenance task/frequency intervals to make determinations about real applicable data suggesting an effective interval for task accomplishment. The approach taken to establish a logical path for each functional failure is that each functional failure, failure effect, and failure cause be processed through the logic so that a judgment can be made as to the necessity of the task, and includes 1) reporting PM activities, plans, and schedules; 2) optimizing/calculating the PM interval by balancing availability, reliability, and cost; 3) ranking PM tasks; 4) accessing PM information from P&IDs; 5) accessing PM and other maintenance data; 6) listing recurring failure modes/parts, including failure to start and failure to run; 7) calculating and monitoring SSC availability; 8) accessing PM procedures, and 9) keeping track of PM cost.

**Troubleshooting**

The process of locating and identifying SSC malfunctions through deductive and inductive reasoning and/or testing. The process may include activities such as taking readings, pulling fuses, stroking valves, changing electronic modules, partial or complete disassembly of a component, etc.

**d. Explain the purpose and content of a master equipment list.**

The following is taken from DOE G 433.1-1.
A master equipment list (MEL) is a detailed master list of equipment, components, and structures to be included in the maintenance program.

An MEL of all controlled M&TE should be maintained. If separate organizations control their own M&TE, each should maintain or have access to a list of its own equipment. Equipment lists should include the following at a minimum:

- Generic description, trade or marketing name, manufacturer, model, and serial number
- Unique identification number
- Range(s) and accuracy
- Calibration procedure
- Calibration frequency
- Calibration interval
- Expiration date
- Date of last calibration
- Systems/stations number (this identifies a specific document which establishes parameters, range, precision, accuracy and other requirements for application of the individual item listed)
- Responsible organization or person
- Normal storage location(s)

e. Observe a contractor preventive maintenance activity and describe the preventive maintenance factors to be considered as the activity is planned.

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

f. Observe post-maintenance testing and discuss the activity, including several examples of maintenance activities to which post-maintenance testing would be applied.

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

g. Explain the purpose of maintaining good facility condition and housekeeping.

The following is taken from DOE G 433.1-1.

Properly used, a facility condition and housekeeping inspection program is an effective means for identifying and correcting deficiencies. The following elements should be included in the inspection program:

- Facility managers should set high facility condition and housekeeping standards and communicate them to all personnel to promote a clear understanding of these standards.
- Appropriate personnel should receive training in inspection techniques.
- Facility managers and supervisors should personally participate in inspections.
- Inspection areas should be assigned to ensure that the entire facility is periodically inspected, including areas with difficult access.
- An inspection coordinator should be assigned to implement, schedule, and monitor the effectiveness of the inspection program.
Deficiencies identified should be reported and corrected promptly, thus allowing personnel to see the positive results of the inspection program.

A condition assessment survey with assigned risk assessment code could be used to prioritize schedules for repair.

Instructions could be prepared to establish the program and define responsibilities for conducting inspections, correcting deficiencies, and accomplishing other tasks associated with the program, such as on-the-spot correction of minor deficiencies. What are considered minor deficiencies, who is allowed to correct them, and the limitations and documentation associated with this type of work should be clearly defined.

Inspection guidelines and criteria could be prepared to assist the assigned inspectors in performing their inspections.

h. **Conduct a facility observation walk through and identify any deficiencies often found with respect to material, housekeeping, industrial safety, and radiological areas.**

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

i. **Describe configuration control and its relationship to the maintenance work control process and the maintenance history file.**

The following is taken from DOE G 433.1-1.

**Configuration Control**

Configuration Management (CM) is a discipline that applies technical and administrative direction and surveillance to identify and document the physical characteristics of a facility. It is a method of doing business that maintains consistency among design requirements, physical configuration, and facility documentation. It audits to verify conformance to specifications and related documentation. Basically, continually manage and control physical and functional items at a facility. Such a program can be broken down into five basic programmatic elements:

1. Program management
2. Design requirements
3. Document control
4. Change control
5. Assessments

An important aspect of a CM program is the assurance that the design basis of a DOE nuclear facility is established, documented, and maintained. The facility SSCs, and computer software should conform to approved design requirements, and any changes to them must be minimized through an integrated management review process, with established approval criteria. This will help to establish that the operations of the facility are reliable if personnel operating the facility are knowledgeable about changes through timely review and training. Proposed changes should be thoroughly evaluated to determine their impact on other hardware and documents. Such changes should be reviewed and approved by appropriate, responsible managers before implementation. This way, the program maintains a consistency between the documents of all departments and organizations. Safety, mission, economic
impact, and benefit can be fully analyzed through the full range of review and approval contained in the program.

Maintenance History File
A maintenance history file should be kept for all M&TE. This file should include the following, as appropriate:

- Manufacturers’ data, including model serial numbers
- Facility-unique identification number
- Calibration interval and specifications
- History of calibrations, repairs, restrictions on use, and other appropriate data
- Calibration nonconformance evaluations
- Usage record
- Nonscheduled actions

Records for lost, destroyed, unavailable, or removed-from-use M&TE should be maintained in the history file.

Manufacturers’ information manuals and supplemental bulletins should be filed in accordance with document control procedures.

j. **Explain the intent of a maintenance problem analysis program and discuss a maintenance problem where this program has been recently employed.**

The following is taken from DOE G 433.1-1.

Systematic analysis should be used to determine and correct root causes of unplanned occurrences related to maintenance. Maintenance history that has been collected and trended to reduce recurring or persistent equipment failures should be reviewed by the analysis program. Incident reports, post-trip reviews, and other similar operating experience review documents and methods supplement the maintenance history program and provide data, including human error data, which should be reviewed by the analysis program.

The intent of an analysis program is to reduce recurring maintenance problems by identifying and resolving their root causes.

k. **Explain facility management’s role in facility maintenance.**

The following is taken from DOE G 433.1-1.

DOE contracts with individual companies to manage, operate, and maintain the facilities and sites in a safe, efficient manner. Senior management ensures the obligations and schedules defined in the contract are met. The first-line supervisor and/or team leader is responsible for executing these obligations in the field.

The first-line supervisor/team leader is accountable to senior management for the quality of work performed in the following areas:

- Understanding and ensuring the correct use of appropriate DOE, site, facility, and Department policies and procedures
- Selecting qualified people to perform work
Identifying and controlling job hazards
Following an integrated work schedule to manage time and resources effectively
Periodically observing work-in-progress, while providing job-site coordination and supervision
Ensuring proper return to service of equipment, including job-site cleanliness and post-maintenance testing
Maintaining the quality of the completed work packages to adequately record the work actions performed

I. Describe the principles of instrument calibration to ensure safe and efficient operation.

The following is taken from DOE G 433.1-1.

The program for control and calibration of M&TE should be consistent with QA requirements of 10 CFR 830, and should ensure the accurate performance of facility instrumentation and equipment for testing, calibration, and repair. Measuring and test equipment devices include all tools, gauges, instruments, devices, or systems used to inspect, test, calibrate, measure, or troubleshoot to control or acquire data for verifying the conformance of an instrument or piece of equipment to specified requirements. Devices do not include permanently installed facility process or control instrumentation, nor does the category include test equipment used for preliminary checks where data obtained will not be used to determine acceptability or verify conformance to established criteria.

The M&TE selected for use should have the precision necessary to ensure that facility instrumentation and equipment will operate within design accuracy requirements and be durable enough for their intended applications. Control and calibration requirements for M&TE apply to onsite and offsite calibration facilities and nonnuclear facility contractor or subcontractor groups that are engaged in maintenance activities.

The control and calibration of M&TE used on safety-class items, safety-related SSCs, or SSCs that affect critical facility performance and reliability play an important role in maintenance and the safe operation of DOE nuclear facilities. Ensuring that properly calibrated measuring, tooling and test equipment performs as intended is essential to a comprehensive maintenance program, and is an important factor in enabling facilities to move from corrective maintenance to effective PM. A computer based system should be considered as necessary for the establishment of an M&TE program to allow for frequent updates of M&TE status and permit personnel access to current information as quickly as possible.

Operators depend on installed facility instrumentation for accurate indications, process control actions, and trip functions to operate the facility safely and reliably. The accuracy of the installed instrumentation is established and maintained through the M&TE control and calibration program. Such a comprehensive M&TE program should include the following elements:

- Unique identification numbers on all M&TE that accurately identify the specific devices and provide traceability
- A current MEL identifying all M&TE
Calibration standards that are traceable to a national standard or that themselves are recognized as standards
- Procedures for calibrating M&TE to help control the performance of calibration and to provide repeatable calibrations and acceptance criteria
- Establishment of a calibration frequency that helps maintain M&TE accuracy and availability
- Provision for checking the function of M&TE, when applicable
- Provision of facilities to control storage, issue, and calibration of M&TE
- Segregation and marking of M&TE devices with suspected or actual deficiencies to prohibit their use
- Clear marking to indicate limitations of M&TE devices that are not fully calibrated or usable
- Records for accountability and traceability of use. A recall system should be developed for recalibrations
- A maintenance policy that minimizes contamination of M&TE
- Timely evaluations of M&TE devices found out of calibration or defective to determine the validity of all measurements and/or calibrations for which they were used
- Trending of M&TE reliability problems to determine if any corrective actions are needed
- Periodic reviews to determine whether the control of M&TE is effective

m. Conduct an assessment of maintenance activities.

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

36. A facility representative must demonstrate a working level knowledge of the Occurrence Reporting and Processing System necessary to ensure that occurrences are properly reported and processed in accordance with DOE M 231.1-2, Occurrence Reporting and Processing of Operations Information.

a. Define the term reportable occurrence.

According to DOE M 231.1-2, reportable occurrences are events or conditions to be reported in accordance with the criteria defined in DOE M 231.1-2.

b. Discuss the FR and operating contractor’s (facility manager) responsibilities.

The following is taken from DOE M 231.1-2.

Facility Representative

Facility representatives are responsible for the following:
- Evaluating facility implementation of the notification and reporting process to ensure it is compatible with and meets the requirements of DOE M 231.1-2
- Maintaining day-to-day operational oversight of contractor activities, as described in DOE-STD-1063-2006
- Ensuring that occurrences that may have generic or programmatic implications are identified and elevated to the head of the field element for appropriate action.
Ensuring that facility personnel act to minimize and prevent recurrence of significant events
Reviewing and assessing reportable occurrence information from facilities under their cognizance to determine the acceptability of the facility manager’s evaluation of the significance, causes, generic implications, and corrective action implementation and closeout, and to ensure that facility personnel involved in these operations perform the related functions
Ensuring that occurrence reports are prepared and transmitted in accordance with DOE information security requirements
Interacting with facility personnel and field element oversight organizations as necessary and informing and advising their respective managements of their findings
Elevating any unresolved issues regarding actions or determinations on a reportable occurrence to the program manager for resolution and direction
Being available at all times to satisfy the requirements of DOE M 231.1-2

Facility Managers
Facility managers are responsible for the following:
Ensuring procedures are implemented for notification and reporting that meet the requirements of DOE M 231.1-2
Actively monitoring day-to-day operations and performance of facilities/activities under their cognizance
Identifying and sharing with others lessons learned and generic or programmatic implications from occurrences and taking actions to minimize or prevent recurrence
Determining causes and generic implications, and implementing corrective actions and closeout activities for reportable occurrences
Reviewing and assessing reportable occurrence information for their facility(ies) to assess generic implications and corrective action(s) implementation, closeout, and effectiveness, as required; to identify and report recurring events, and to ensure that facility personnel involved in these operations perform the related functions
Ensuring that occurrence reports and operations information from other organizations are disseminated to appropriate facility personnel within their cognizance, are reviewed for generic implications, and are used to improve operations
Preparing and transmitting occurrence reports in accordance with DOE information security requirements
Being available at all times to satisfy the requirements of DOE M 231.1-2

c. Describe the intent and contents of DOE M 231.1-2 requirements of occurrence reporting, including the following:
   Reporting philosophy, including the purpose of the occurrence reporting model
   Event or condition identification
   Event or condition categorization
   DOE HQ operations center prompt notifications
   Written notification report
   Occurrence investigation and analysis, including the purpose of the causal analysis tree
   Occurrence report closure
   Short form reports
Performance analysis and identification of recurring occurrences
Training

The following descriptions are taken from DOE M 231.1-2.

Reporting Philosophy, Including the Purpose of the Occurrence Reporting Model
To implement the occurrence categorization, notification, reporting, and processing system, the key responsible personnel must be identified and procedures developed, approved, and implemented to ensure that all of the occurrence reporting requirements, as delineated in DOE M 231.1-2, are met. The facility manager must be available at all times to carry out the responsibilities for the categorization, notification, and reporting requirements. Facility operators are required to ensure that occurrences resulting from activities performed by subcontractors in support of facility operation are reported in accordance with the provisions of DOE M 231.1-2.

The occurrence reporting model summarizes the various time limits, levels of investigation and analysis, corrective action development and tracking, approvals, and lessons learned development by significance category.

Event or Condition Identification
Occurrences may be identified by direct observation of equipment or process malfunctions, log or record reviews, operator recognition of their own or others’ errors, or other means.

Operations personnel must take appropriate immediate action to stabilize and/or place the facility/operation in a safe condition and ensure that any potential environmental effects are stabilized and workers are treated for injuries sustained. Also, actions should be taken to preserve conditions for continued investigation; however, these actions are not to interfere with establishing a safe condition.

The facility staff and operators must, upon identification of an abnormal or suspected abnormal event or condition, promptly notify the appropriate line management and the facility manager of the event status and record and/or archive all pertinent information, including details concerning the discovery of the occurrence and actions taken to stabilize or place the facility/operation in a safe condition.

Event or Condition Categorization
The facility manager must categorize all occurrences, except operational emergencies, within 2 hours of discovery by the cognizant facility staff following the site/facility-specific procedures developed in accordance with DOE M 231.1-2. The significance categories, as outlined in the occurrence reporting model are for those occurrences of interest for complex-wide occurrence reporting.

Occurrences should be assigned a category based on the following requirements:

Operational Emergencies. Operational emergencies are defined in DOE O 151.1C, Comprehensive Emergency Management System. Operational emergency occurrences are the most serious occurrences and require an increased alert status for onsite personnel and, in specified cases, for offsite authorities. The prompt notification requirements, definitions,
criteria, and classifications of operational emergencies and appropriate responses are provided in DOE O 151.1C. Written occurrence reports must be completed in accordance with DOE M 231.1-2.

Significance category 1. Occurrences in this category are those that are not operational emergencies and that have a significant impact on safe facility operations, worker or public safety and health, regulatory compliance, or public/business interests.

Significance category R. Occurrences in this category are those identified as recurring, as determined from the periodic performance analysis of occurrences across a site.

Significance category 2. Occurrences in this category are those that are not operational emergencies and that have a moderate impact on safe facility operations, worker or public safety and health, regulatory compliance, or public/business interests.

Significance category 3. Occurrences in this category are those that are not operational emergencies and that have a minor impact on safe facility operations, worker or public safety and health, regulatory compliance, or public/business interests.

Significance category 4. Occurrences in this category are those that are not operational emergencies and that have some impact on safe facility operations, worker or public safety and health, public/business interests.

**DOE HQ Operations Center Prompt Notifications**

**Operational Emergencies**

The requirements for the prompt and follow-up notifications to DOE (including NNSA) and other agencies and the appropriate emergency responses to be taken are provided in DOE O 151.1C. The specific procedures on how these events are categorized and how and when DOE is notified are included in the site/facility-specific emergency response plans or procedures. If an event has been declared an operational emergency, the facility manager will be responsible for the written notification report and for the completion of all other occurrence reporting requirements, as described below.

**Prompt Notifications for Significance Category 1, 2, 3, and 4 Reportable Occurrences**

The facility manager must notify the DOE facility representative and the DOE Headquarters Operations Center (DOE HQ OC) as required, of the following reportable occurrences as soon as practical, but no later than 2 hours after categorization:

- All significance category 1 occurrences require a prompt notification to the facility representative and DOE HQ OC.
- All significance category 2 occurrences require a prompt notification to the facility representative and, if directed by the facility representative, to the DOE HQ OC.
- All significance category 3 occurrences require a prompt notification to the facility representative.
- Additionally, specific significance category 2, 3, and 4 occurrences require prompt notification to the facility representative and DOE HQ OC.

The DOE HQ OC will relay notifications to the appropriate HQ-level program manager and make any further notifications, as required.
The facility manager may use the local field/site emergency operations center (EOC) to expedite establishing the communication link required and to record and archive conversations. The prompt notification process is as follows:

- The facility manager must e-mail the prompt notification of the reportable occurrence to the DOE HQ OC, and follow up with a phone call to the DOE HQ OC to ensure receipt of the e-mail.
- The prompt notification must clearly state/select the significance category (1, R, 2, 3, or 4) and identify the specific reporting criteria associated with the occurrence.
- Prompt notification to the DOE HQ OC must include information on the following items:
  - Occurrence significance category
  - Location and description of the event
  - Date and time of discovery
  - Damage and casualties
  - Impact of event on other activities and operations
  - Protective actions taken or recommended
  - Weather conditions at the scene
  - Level of media interest at scene/facility/site
  - Other notifications made

All information should be clear and succinct. Avoid jargon. Uncommon or site/facility-specific abbreviations and acronyms should be fully described.

The facility manager must follow the appropriate security procedures if the notification to DOE may contain classified or sensitive information.

If the occurrence is re-categorized, then the occurrence must be reconsidered for prompt notification. If appropriate, the facility manager must notify the facility representative and the DOE HQ OC as soon as practical, but within the prompt notification time requirements of the new significance category for the re-categorized occurrence and provide the occurrence report number. The DOE HQ OC will make any required internal DOE HQ notifications.

Follow-up notifications must be made to DOE for any further degradation in the level of safety or impact on the environment, health, or operations of the facility or other worsening conditions subsequent to the previous notification. If a degradation results in upgrading the event to an operational emergency, the DOE HQ OC must be notified in accordance with DOE O 151.1C.

Written Notification Report

The facility manager must prepare the written notification report and distribute it. Direct entry into the computerized ORPS satisfies this requirement. Any changes in the reporting criteria of the occurrence, which result in a change, either lower or higher, to the significance category, must be documented in an update report and submitted within the timeframe required for the notification report under the new significance category. A discussion on the change in categorization must be included in the description of occurrence field in the update report.
Occurrence Investigation and Analysis, Including the Purpose of the Causal Analysis Tree

The following steps describe an acceptable process for submitting update reports and conducting the investigation and analysis of a specific occurrence. DOE Order 5480.19, Conduct of Operations Requirements for DOE Facilities, and DOE-STD-1045-93, Guide to Good Practices for Notifications and Investigation of Abnormal Events, should be considered when establishing a program for investigation of occurrences. In cases of conflict between DOE Order 5480.19 or DOE-STD-1045-93 and DOE M 231.1-2, the requirements of DOE M 231.1-2 must be followed.

In general, the investigative process is used to gain an understanding of the occurrence, its causes, and the corrective actions necessary to prevent recurrence or only remedy the problem, based on the significance of the occurrence. If DOE is doing a type A or B investigation, the facility manager is not required to perform an identical investigation. However, the facility manager is still required to do the preliminary assembly of information to turn over to the DOE accident investigation board, in accordance with DOE O 225.1A.

The facility manager should use the graded approach described in the occurrence reporting model when determining the level of effort required for the investigation into the causes of the occurrence. The graded approach is based on the significance, severity, or risk associated with the event or condition.

For operational emergencies, in general, the investigation, problem analysis, and corrective action process should parallel the process for significance category 1 occurrences. However, the facility manager should consider a graded approach when determining the level of effort for the investigation into the cause of the operational emergency. The graded approach is based on whether the operational emergency was directly caused by DOE operations or resulted from non-DOE operations or natural phenomena.

All causes must be identified as required in the occurrence reporting model and included in the occurrence report. The cause codes to be used for reporting are provided in the CAT. Guidance on selecting the appropriate cause code is provided in DOE G 231.1-2. The cause description field should include a brief discussion to clearly link the event to the cause code(s).

For those occurrences that require a formal root cause analysis, any of the site approved root cause analysis methodologies are permitted. The methodology used must be included in the cause description field of the occurrence report.

In addition to determining the causes of the occurrence, any weaknesses in the facility’s implementation of the ISM program must be identified and entered in the ISM field.

In addition to submitting an update report when the significance category of the occurrence has been changed, the facility manager must submit and distribute an update report for all occurrences, with the exception of significance category 4 occurrences, if there is any significant and new information about the occurrence. The status of the investigation, recurring consequences, and the identification of additional component defects are activities associated with the occurrence and must be included in update reports.
Using a graded approach as described in the occurrence reporting model, the facility manager should consult in a timely manner with the facility representative and the program manager, as appropriate, for their assessment, if any, of the occurrence.

**Occurrence Report Closure**

The following steps describe an acceptable process for closing out the final report for all occurrences except those categorized as significance category 4:

The final report must be prepared by the facility manager and submitted as soon as practical but within 45 calendar days after initial categorization of the occurrence. The final report must be prepared using the writing instructions listed in section 5.4.1 of DOE M 231.1-2 and must document the following:

- The significance, nature, and extent of the event or condition
- The causes of the event or condition using the codes provided in the causal analysis tree
- The immediate actions taken and the corrective action(s) to be taken, as required by the occurrence reporting model
- The lessons learned

If the required analysis cannot be completed within 45 calendar days after initial categorization, an update report must be submitted within the 45 days. The update report must provide a detailed explanation of the delay and provide an estimated date for submittal of the final report. This information must be reported in the evaluation block of the occurrence report. It is expected that the analysis of most occurrences will be completed and the final report submitted within the 45 calendar days. However, for certain occurrences, such as those requiring an accident investigation, it is understood that the information required for the final report may not be available within this time. For occurrences resulting in an accident investigation, all causes identified in the accident investigation report, as well as the corrective actions developed in response to the judgments of need, must be included in the final report.

For operational emergencies and significance category 1, R, and 2 final reports, the facility representative must review, approve, and add any comments, as necessary, within 14 calendar days after receipt of the report. For operational emergencies and significance category 1 final reports, after the facility representative has approved the occurrence report, the program manager must review, approve, and add any comments to the final report within 14 calendar days. If the ORPS database is being used, the facility representative and program manager’s comments should be provided through ORPS. Facility representative and program manager comments are not required for their approval of the report.

If the final report is not approved by the facility representative or the program manager, the facility representative or program manager who is rejecting the report must provide the reason for disapproval in the comment section of the report at the time the action is taken. The revised final report must be resubmitted within 21 calendar days of the disapproval. If it cannot be resubmitted within this time, an update report must be submitted within the 21 calendar days explaining the delay and providing an estimated date for re-submittal of the final report. This information must be reported in the evaluation block of the occurrence report.
All occurrence reports must be distributed as soon as practical to the following:

- Facility representative
- Program manager
- Heads of all field organizations
- Office of Environment, Safety and Health and Administrator (NNSA) and
- DOE management and operations or integrating contractors

If the occurrence reports are entered into the ORPS database, the distribution requirement is automatically satisfied.

As prescribed on the occurrence reporting model and depending on the significance category, the facility manager must track all corrective actions to closure, including independent verification or sampling at the facility level and also evaluate the effectiveness of the corrective actions to prevent recurrence (if applicable). Site/contractor corrective action programs must include management of significance category 4 occurrences, whose corrective actions are not managed through ORPS.

The cognizant facility manager may use the ORPS database to track the status of final report corrective actions. For those facilities that do not choose to use ORPS to track the status of their corrective actions, the specific corrective action tracking number from the local corrective action tracking system must be entered into ORPS. Any changes made to the corrective actions tracked in the local corrective action system must follow the site’s approved change process and should be updated in ORPS. For significance category 2 and higher reports, any text change to a corrective action previously entered in ORPS must be updated in ORPS with facility representative approval. A status report of all incomplete occurrence reports and incomplete corrective actions will be available at any time from the ORPS database. Retain all supporting information pertaining to each occurrence or report in accordance with departmental records disposition schedules.

**Short Form Reports**

A short form report must be prepared and submitted for all significance category 4 occurrences no later than 2 business days after categorization of the occurrence. This report will satisfy all of the written reporting requirements for these occurrences.

**Performance Analysis and Identification of Recurring Occurrences**

Each contractor at a site and managers at DOE-owned and operated sites must perform ongoing, but as a minimum quarterly, analyses of events during a 12-month period to look for trends. This periodic performance analysis must evaluate occurrences of all significance categories plus contractor-/operator-determined non-reportable events to prevent serious events from occurring. Quarterly performance analysis results must be reported to contractor and DOE line management to achieve improvements.

Occurrences identified as recurring require a new occurrence report to be submitted for notification of the recurring issue, with investigation, root cause analysis, and corrective actions subsequently required. Previous individual occurrence report numbers associated with the recurring issue must be provided in the similar occurrence report numbers field. The reporting organization should select the appropriate reporting criteria associated with the
recurring issue. If no specific reporting criteria can be identified, the reporting criteria should be listed as group 10, criteria #2.

Recurring occurrences must be categorized and reported collectively as a significance category R occurrence, even if each individual occurrence had been originally categorized at a higher or lower significance level. See the occurrence reporting model to learn the requirements for a significance category R occurrence.

**Training**
Specific training programs for the requirements of DOE M 231.1-2 must be established for DOE and contractor personnel for facilities under their cognizance. These training programs must include

- indoctrination in the objectives and process of occurrence reporting as defined in the occurrence reporting requirements documents;
- identification of reportable occurrences and their categorization, notification, and associated reporting requirements; analysis, determination, and coding of causes; identification of generic implications; and management of corrective actions;
- use of ORPS, including input of occurrence reports and obtaining information from the database;
- use of the CAT;
- where applicable, the preparation of occurrence reports that may include classified information or unclassified controlled information, including the sanitization of the report for entry into ORPS.

**d. Discuss the following:**
- Categorizing instructions
- Occurrence reporting criteria

The following is taken from DOE M 231.1-2.

**Categorizing Instructions**
An event can meet multiple reporting criteria that establish it as an occurrence. All of the specific reporting criteria applicable for an occurrence must be identified. Some criteria are secondary in that they complement other reporting criteria that require occurrence reporting. In these cases, all of the applicable criteria must be recorded. Each criterion is denoted by its group, subgroup (if applicable), and sequence number.

The reporting criteria presented below list a specific significance category (SC) for each criterion, between the sequence number and the criterion text.

Significance categories are designated as OE for operational emergencies, R for recurring occurrences, or 1, 2, 3, or 4. Thus, for example, the significance category for a stop work order issued by a DOE office, criterion 4B(1), is SC 2.

Operational emergencies, significance category 1, and some other occurrences in lesser significance categories require prompt notification to the DOE HQ OC.
Asterisks (*) next to the significance categories denote those occurrences requiring prompt notification to the DOE HQ OC.

DOE O 151.1C describes initiating events that are considered operational emergencies. DOE O 225.1A defines when type A or B accident investigations should be initiated. While some operational emergencies and some other ORPS occurrences involve conditions that would be sufficient to initiate accident investigations, criterion 10(1) will report the actual initiation of type A or B accident investigations.

**Occurrence Reporting Criteria**

The reporting criteria are categorized into 10 major groups and appropriate subgroups related to DOE operations. The list, which is in DOE M 231.1-2 provides a minimum set of requirements necessary to develop local procedures and report occurrences applicable to local operations.

Categorization of occurrences must be done at the criterion level. Site/contractor corrective action programs will manage actions for important events that do not meet the ORPS reporting.

**e. Discuss information security requirements for ORPS reports.**

The following is taken from DOE M 231.1-2.

Occurrence reports containing any classified information, unclassified controlled nuclear information (UCNI), or other controlled information must not be entered into the ORPS database. Facility managers must ensure that a review is performed prior to ORPS data entry to preclude contamination of the database with classified, UCNI, official use only, or other controlled information.

Any ORPS report determined to be classified or controlled by current classification or control guidance must be submitted using the appropriate secure transmission means. However, with the exception of entry into the ORPS database, all other reporting requirements identified in DOE M 231.1-2 must be met. In addition, an unclassified version of the occurrence report that has been sanitized of all controlled information must be submitted to ORPS within the required time frames.

Implementing procedures should identify the requirements for distribution of reports containing classified or controlled information. In those instances where UCNI data may still be present in the ORPS database, appropriate security procedures related to the handling of such data need to be followed.

[Note: Occurrence reports involving incidents of counterintelligence concern (e.g., foreign persons, governments, organizations, entities or influence) will not be entered or referenced in the ORPS database.]

**f. Discuss how DOE and contractors should utilize reportable occurrence information, particularly as a feedback mechanism.**

The following is taken from DOE M 231.1-2.
Each facility manager must collect and disseminate to their personnel information from occurrences related to their facilities and similar DOE facilities.

This information includes both lessons learned and good practices. Each facility manager should use this information for trending and analysis and for early identification and correction of deteriorating conditions.

One of the major purposes of this reporting system is to provide feedback of safety and operational information identified in the occurrence reports to other DOE facilities. In addition, Headquarters oversight and assessment organizations should use ORPS information to prepare safety notices and other feedback documents.

These uses are dependent on the quality of the information reported, which means the information should be thorough and accurate. To this end, occurrence reports should contain sufficient information about the facility operations and the occurrence to facilitate action by other personnel who are unfamiliar with details of the facility, equipment, process, or procedures.

Operations and engineering units, as well as other support organizations, should be involved in the identification and assessment of reportable occurrences. Site information, such as operations logs and engineering evaluations, should be used in this process.

Engineering judgment should be used during the review of events and conditions to ensure that precursors to occurrences are identified and reported. An occurrence that is not serious, given the conditions under which it happened, might under different initial conditions be a precursor to a serious event at the same or other facilities.

g. Given an actual occurrence report, determine the accuracy of categorization, adequacy of the review process used, that causes were appropriately defined, that corrective actions are appropriate (addressed causes), that the lessons learned were communicated, and verify that corrective actions have been completed.

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

h. Explain the difference between the ORPS notification requirements and emergency management systems event classification and notification requirements.

The ORPS classification and notification requirements are described in 36 c and j. The following is the emergency management systems event classification and notification as described in DOE O 151.1C.

**Event Classification**

Hazardous material emergencies involving DOE/NNSA facilities must be classified operational emergencies as either an alert, site area emergency, or general emergency, in order of increasing severity, when events occur that represent a specific threat to workers and the public due to the release or potential release of significant quantities of hazardous materials. Classification aids in the rapid communication of critical information and the initiation of appropriate time-urgent emergency response actions.
**Notification**

Initial emergency notifications must be made promptly, accurately and effectively to workers and emergency response personnel/organizations, appropriate DOE/NNSA elements, and other Federal, tribal, state, and local organizations and authorities. Accurate and timely follow-up notifications must be made when conditions change, when the emergency classification level is upgraded, or when the emergency is terminated. Continuous, effective, and accurate communication among response components and/or organizations must be reliably maintained throughout an operational emergency.

The contractor at all DOE/NNSA facilities must perform the following:

- Provide prompt initial notification of workers, emergency response personnel, and response organizations, including DOE/NNSA elements and state, tribal, and local organizations;
- Notify state and local officials and the cognizant field element emergency operations center (EOC) and HQ OC within 15 minutes and all other organizations within 30 minutes of the declaration of an alert, site area emergency, or general emergency;
- Notify the cognizant field element EOC and HQ OC within 30 minutes of the declaration of an operational emergency not requiring classification; and
- Notify local, state, and tribal organizations within 30 minutes or as established in mutual agreements for declaration of an operational emergency not requiring classification.
- Make a phone call to HQ OC providing as much information as is known at the time. The same information must be provided by e-mail or a fax, either immediately prior to or following the phone call.
- Provide for continuing effective communication among response organizations throughout an emergency.
- Establish effective communications methods between event scene responders, emergency managers, and response facilities.
- Forward emergency status reports to the next-higher emergency management team on a continuing basis until the emergency is terminated.
- Submit a final report on the emergency response to the emergency manager for submission to the Director, Office of Emergency Operations, following termination of emergency response, and in conjunction with the final occurrence report.
- Review all reports and releases for classified or unclassified controlled information prior to being provided to personnel not authorized access to such information, entered into databases not authorized for such information, or transmitted using non-secure communications equipment.

37. A facility representative must demonstrate a working level knowledge of the Department’s philosophy and approach to implementing integrated safety management (ISM).

a. Using DOE M 450.4-1, Integrated Safety Management System Manual, review the history of ISM implementation within DOE, and identify DOE’s primary ISM directives and related programs.

The following is taken from DOE M 450.4-1.
The Department developed and began implementation of ISM in 1996. Since that time, the Department has gained significant experience with its implementation. This experience has shown that the basic framework and substance of the Department’s ISM program remains valid. The experience also shows that substantial variances exist across the complex regarding familiarity with ISM, commitment to implementation, and implementation effectiveness. The experience also shows that more clarity on DOE’s role in effective ISM implementation is needed. Contractors and DOE alike have reported that clearer expectations and additional guidance on annual ISM maintenance and continuous improvement processes are needed.

Since 1996, external organizations that are also performing high-hazard work, such as commercial nuclear organizations, Navy nuclear organizations, National Aeronautics and Space Administration, and others, have also gained significant experience and insight relevant to safety management. The ISM core function of feedback and improvement calls for DOE to learn from available feedback and make changes to improve. This concept applies to the ISM program itself. Lessons learned from internal and external operating experience are reflected in DOE M 450.4-1 to update the ISM program. Two significant sources of external lessons learned have contributed to DOE M 450.4-1: 1) the research and conclusions related to high-reliability organizations (HROs), and 2) the research and conclusions related to the human performance improvement (HPI) initiatives in the commercial nuclear industry, the U.S. Navy, and other organizations. HRO and HPI tenets are very complementary with ISM and serve to extend and clarify the program’s principles and methods.

As part of the ISM revitalization effort, the Department wants to address known opportunities for improvement based on DOE experience, and integrate the lessons learned from HRO organizations and HPI implementation into the Department’s existing ISM infrastructure. The Department wants to integrate the ISM core functions, ISM principles, HRO principles, HPI principles and methods, lessons learned, and internal and external best safety practices into a proactive safety culture where: facility operations are recognized for their excellence and high-reliability; everyone accepts responsibility for their own safety and the safety of others; organization systems and processes provide mechanisms to identify systematic weaknesses and assure adequate controls; and continuous learning and improvement is expected and consistently achieved. The revitalized ISM system is expected to define and drive desired safety behaviors, to help DOE and its contractors create a world-class safety culture, and ultimately to result in achievement of performance excellence.

DOE M 450.4-1 is being issued to assist the Department in re-vitalizing ISM implementation. The Department recognizes that the existing ISM directives and Department of Energy Acquisition Regulations (DEAR) clause contain some differences in comparison to DOE M 450.4-1. Every attempt was made to keep these inconsistencies to a minimum. As the Department gains experience in implementing the new DOE requirements contained in DOE M 450.4-1, it is expected that DOE M 450.4-1 will need to be revisited and revised within two years to incorporate experience, best practices, and lessons learned. In the same timeframe, it is also expected that the full suite of ISM directives will be reviewed in parallel and adjusted as needed to bring them into full alignment. The Department’s primary ISM directives are the following:
• **DOE P 450.4, Safety Management System Policy**—The ISM policy establishes the ISM program, its objective, its guiding principles and core functions, and its implementing mechanisms. This policy defines the ISM program that the requirements and responsibilities in DOE M 450.4-1 are targeted for implementing.

• **DOE G 450.4-1B, Integrated Safety Management System Guide for Use with Safety Management System Policies; the Functions, Responsibilities, and Authorities Manual; and the DOE Acquisition Regulation**—The ISM guide provides guidance for contractors who are developing, implementing, and maintaining ISM systems. It also provides guidance for DOE to facilitate development, implementation and maintenance of contractor ISM systems. Much of the guidance in the ISM guide may be useful to DOE offices that are developing ISM systems in response to the requirements in DOE M 450.4-1.

• **DOE-HDBK-3027-99, Integrated Safety Management Systems Verification Team Leader’s Handbook**—The ISM Verification Team Leader’s Handbook provides guidance on the planning, conduct, and reporting of ISM verification reviews. The requirements and guidance of DOE M 450.4-1 should be considered by ISM verification team leaders in addition to the guidance in the Team Leader’s Handbook.

• **DEAR 970.5223-1, Integration of Environment, Safety, and Health into Work Planning and Execution**—The ISM DEAR clause provides requirements for DOE contractors regarding the development, implementation, and maintenance of ISM systems. The CRD in DOE M 450.4-1 is intended to supplement the requirements in the DEAR clause and only apply to those contractors for which the DEAR clause is already applicable.

Other DOE directives, such as the Oversight Order, the Quality Assurance Order, the Environmental Protection Program Order, the Nuclear Safety Management rule, and the Worker Health and Safety Program rule contain related and overlapping requirements and responsibilities with the ones contained in DOE M 450.4-1.

**b. Identify the field element manager’s responsibilities for ISM.**

The following is taken from DOE M 450.4-1.

The field element manager’s responsibilities for ISM include the following:

• Develop, approve, maintain, and implement field office ISM systems, as described in ISMS descriptions, which are complete, accurate and up-to-date; provide field office ISMS descriptions to the applicable secretarial office for information.

• Integrate an environmental management system and QAP into the field office ISMS, pursuant to DOE O 450.1A, Environmental Protection Program, and DOE O 414.1C.

• Review and approve the contractor’s ISMS descriptions and updates, as needed. This review includes verifying that the contractor’s ISMS effectively coordinates with the DOE field office ISMS as a condition of approval. If the contractor states that changes are not needed, then review and approve the rationale for that decision. Conduct line oversight of the field office’s contractor implementation of ISM, consistent with the requirements and guidance of DOE O 226.1.

• Perform an annual ISM effectiveness review and using the results of this review, make an annual declaration in writing of the status and effectiveness of ISM
implementation within the field office and the contractor’s organizations, and submit this declaration to the applicable secretarial office.

- Prepare annual field office safety performance objectives, measures, and commitments, and provide to the applicable DOE secretarial office.
- Designate an ISM champion to support ISM implementation activities as directed.
- Use the results of the annual ISM effectiveness review and the annual ISM declaration to drive ownership and improvement. Communicate implementation and improvement expectations through clear, timely, and accurate feedback to DOE personnel and to contractor organizations.
- Provide direction, including reporting dates, to contractors for annual ISM effectiveness reviews, annual ISM declarations, and annual safety performance objectives, measures, and commitments.
- Determine whether and when to conduct full ISM verifications of field office ISM activities, encompassing Federal and contractor implementation of ISM, consistent with the guidance in attachment 4 of DOE M 450.4-1.

c. **Discuss field office ISM system descriptions.**

The following is taken from DOE M 450.4-1.

ISM descriptions for DOE secretarial offices must be approved by the responsible DOE Headquarters Secretarial Officer. These system descriptions must describe:

- how the secretarial office defines its work activities related to achieving the ISM objective of safe mission accomplishment, as defined in DOE P 450.4;
- The ISM implementing mechanisms, processes and methods by which the secretarial office implements the ISM guiding principles to create an effective environment for ISM implementation;
- the ISM implementing mechanisms, processes and methods by which the secretarial office implements the ISM core functions;
- how environmental management systems, QAP, and other management processes and systems are integrated into the ISMS;
- how the secretarial office will measure ISM effectiveness, perform annual ISM effectiveness reviews, prepare annual ISM declarations, and continuously improve the effectiveness of the ISMS;
- how the secretarial office will establish, document, and implement relevant safety performance objectives, measures, and commitments in response to Secretarial direction and budget execution guidance while maintaining the integrity of the system;
- how the secretarial office will maintain its ISM system description so that it is accurate and up-to-date, and demonstrate continuous improvement in its performance of safe work activities; and
- the ISM implementing mechanisms and processes that will be used to meet the Secretarial Office responsibilities delineated in DOE M 450.4-1.

d. **Discuss the attributes of each of the ISM guiding principles and the supplemental safety cultural elements.**

The following is taken from DOE M 450.4-1.
Line Management Responsibility for Safety

Attributes include:

- Line managers understand and accept their safety responsibilities inherent in mission accomplishment. Line managers do not depend on supporting organizations to build safety into line management work activities.
- Line managers have a clear understanding of their work activities and their performance objectives, and how they will conduct their work activities safely and accomplish their performance objectives.
- Line managers demonstrate their commitment to safety. Top-level line managers are the leading advocates of safety and demonstrate their commitment in both word and action. Line managers periodically take steps to reinforce safety, including personal visits and walkthroughs to verify that their expectations are being met.
- Line managers spend time on the floor. Line managers practice visible leadership in the field by placing eyes on the problem, coaching, mentoring, and reinforcing standards and positive behaviors. Deviations from expectations are corrected promptly and, when appropriate, analyzed to understand why the behaviors occurred.
- Line managers maintain a strong focus on the safe conduct of work activities. Line managers maintain awareness of key performance indicators related to safe work accomplishment, watch carefully for adverse trends or indications, and take prompt action to understand adverse trends and anomalies.
- Line managers throughout the organization set an example for safety through their direct involvement in continuous learning by themselves and their followers on topics related to technical understanding and safety improvement.
- Line managers are skilled in responding to employee questions in an open, honest manner. They encourage and appreciate the reporting of safety issues and errors. They do not discipline employees for the reporting of errors. They encourage a vigorous questioning attitude toward safety, and constructive dialogues and discussions on safety matters.
- Credibility and trust are present and continuously nurtured. Line managers reinforce perishable values of trust, credibility, and attentiveness. The organization is just—that is, the line managers demonstrate an understanding that humans are fallible and when mistakes are made, the organization seeks first to learn as opposed to blame. The system of rewards and sanctions is aligned with strong safety policies and reinforces the desired behaviors and outcomes.
Clear Roles and Responsibilities

Attributes include:

- Responsibility and authority for safety are well defined and clearly understood as an integral part of performing work.
- Organizational safety responsibilities are sufficiently comprehensive to address the work activities and hazards involved.
- The line of authority and responsibility for safety is defined from the Secretary to the individual contributor. Each of these positions has clearly defined roles, responsibilities, and authorities, designated in writing and understood by the incumbent.
- Ownership boundaries and authorities are clearly defined at the institutional, facility, and activity levels, and interface issues are actively managed.
- Organizational functions, responsibilities, and authorities documents are maintained current and accurate.
- Reporting relationships, positional authority, staffing levels and capability, organizational processes and infrastructure, and financial resources are commensurate with and support fulfillment of assigned or delegated safety responsibilities.
- All personnel understand the importance of adherence to standards.
- Line managers provide ongoing reviews of performance of assigned roles and responsibilities to reinforce expectations and ensure that key safety responsibilities and expectations are being met.
- Personnel at all levels of the organization are held accountable for shortfalls in meeting standards and expectations related to fulfilling safety responsibilities. Accountability is demonstrated both by recognition of excellent safety performers as well as identification of less-than-adequate performers. In holding people accountable, in the context of a just culture, managers consider individual intentions and the organizational factors that may have contributed.

Competency Commensurate with Responsibility

Attributes include:

- People and their professional capabilities, experiences, and values are regarded as the organization’s most valuable assets. Organizational leaders place a high personal priority and time commitment on recruiting, selecting, and retaining an excellent technical staff.
- The organization maintains a highly knowledgeable workforce to support a broad spectrum of operational and technical decisions. Technical and safety expertise is embedded in the organization. Outside expertise is employed when necessary.
- Individuals have in-depth understanding of safety and technical aspects of their jobs. Technical qualification standards are defined and personnel are trained accordingly. Technical support personnel have expert-level technical understanding. Managers have strong technical backgrounds in their area of expertise.
- Assignments of safety responsibilities and delegations of associated authorities are made to individuals with the necessary technical experience and expertise. In rare cases, if this is not possible, corrective and compensatory actions are taken.
- The organization values and practices continuous learning, and requires employees to participate in recurrent and relevant training and encourages educational experiences.
to improve knowledge, skills, and abilities. Professional and technical growth is formally supported and tracked to build organizational capability.

- Training to broaden individual capabilities and to support organizational learning is available and encouraged—to appreciate the potential for unexpected conditions; to recognize and respond to a variety of problems and anomalies; to understand complex technologies and capabilities to respond to complex events; to develop flexibility at applying existing knowledge and skills in new situations; to improve communications; to learn from significant industry and DOE events.

- Mental models, practices, and procedures are updated and refreshed based on new information and new understanding.

- Training effectively upholds management’s standards and expectations. Beyond teaching knowledge and skills, trainers are adept at reinforcing requisite safety values and beliefs.

- Managers set an example for safety through their personal commitment to continuous learning and by their direct involvement in high-quality training that consistently reinforces expected worker behaviors.

- Managers encourage informal opinion leaders in the organization to model safe behavior and influence peers to meet high standards.

**Balanced Priorities**

Attributes include:

- Organization managers frequently and consistently communicate the safety message, both as an integral part of the mission and as a stand-alone theme.

- Managers recognize that aggressive mission and production goals can appear to send mixed signals on the importance of safety. Managers are sensitive to detect and avoid these misunderstandings, or to deal with them effectively if they arise.

- The organization demonstrates a strong sense of mission and operational goals, including a commitment to highly reliable operations, both in production and safety. Safety and productivity are both highly valued.

- Safety and productivity concerns both receive balanced consideration in funding allocations and schedule decisions. Resource allocations are adequate to address safety. If funding is not adequate to ensure safety, operations are discontinued.

- Staffing levels and capabilities are consistent with the expectation of maintaining safe and reliable operations.

- The organizational staffing provides sufficient depth and redundancy to ensure that all important safety functions are adequately performed.

- The organization is able to build and sustain a flexible, robust technical staff and staffing capacity. Pockets of resilience are established through redundant resources so that adequate resources exist to address emergent issues. The organization develops sufficient resources to rapidly cope and respond to unexpected changes.

- Key technical officials are assigned for long terms of service to provide institutional continuity and constancy regarding safety requirements and expectations. Organizational knowledge is valued and efforts are made to preserve it when key players move on.

- Systems of checks and balances are in place and effective at all levels of the organization to make sure that safety considerations are adequately weighed and prioritized.
- Safety and QA positions have adequate organizational influence.
- Adequate resources are allocated for safety upgrades and repairs to aging infrastructure. Modern infrastructure and new facility construction are pursued to improve safety and performance over the long term.

**Identification of Safety Standards and Requirements**

**Attributes include:**
- Facilities are designed, constructed, operated, maintained, and decommissioned using consensus industry codes and standards, where available and applicable, to protect workers, the public, and the environment.
- Applicable requirements from laws, statutes, rules and regulations are identified and captured so that compliance can be planned, expected, demonstrated, and verified.
- Clear, concise technical safety directives are centrally developed, where necessary, and are based on sound engineering judgment and data. DOE directives and technical standards are actively maintained up to date and accurate.
- A clearly-defined set of safety requirements and standards is invoked in management contracts, or similar agreements. An accepted process is used for identification of the appropriate set of requirements and standards. This set of requirements is comprehensive and includes robust QA safety, and radiological and environmental protection requirements.
- Implementing plans, procedures and protocols are in place to translate requirements into action by the implementing organization.
- Technical and operational safety requirements clearly control the safe operating envelope. The safety envelope is clearly specified and communicated to individuals performing operational tasks.
- Exemptions from applicable TSRs are rare and specific, provide an equivalent level of safety, have a compelling technical basis, and are approved at an appropriate organizational level.
- Compliance with applicable safety and technical requirements is expected and verified.
- Willful violations of requirements are rare, and personnel and organizations are held strictly accountable in the context of a just culture. Unintended failures to follow requirements are promptly reported, and personnel and organizations are given credit for self-identification and reporting of errors.
- The organization actively seeks continuous improvement to safety standards and requirements through identification and sharing of effective practices, lessons learned, and applicable safety research. The organization is committed to continuously rising standards of excellence.

**Hazard Controls Tailored to Work Being Performed**

**Attributes include:**
- Work hazards are identified and controlled to prevent or mitigate accidents, with particular attention to high consequence events with unacceptable consequences. Workers understand hazards and controls before beginning work activities.
- The selection of hazard controls considers the type of hazard, the magnitude of the hazard, the type of work being performed, and the life-cycle of the facility. Controls
are designed and implemented commensurate with the inherent level and type of hazard.

- Safety analyses identifying work hazards are comprehensive and based on sound engineering judgment and data.
- Defense-in-depth is designed into highly-hazardous operations and activities, and includes independent, redundant, and diverse safety systems, which are not overly complex. Defense-in-depth controls include engineering controls, administrative processes, and personnel staffing and capabilities.
- Emphasis is placed on designing the work and/or controls to reduce or eliminate the hazards and to prevent accidents and unplanned releases and exposures.
- The following hierarchy of defense-in-depth is recognized and applied: 1) elimination or substitution of the hazards, 2) engineering controls, 3) work practices and administrative controls, and 4) PPE. Inherently safe designs are preferred over ones requiring engineering controls. Prevention is emphasized in design and operations to minimize the use of, and thereby possible exposure to, toxic or hazardous substances.
- Equipment is consistently maintained so that it meets design requirements.
- Safety margins are rigorously maintained. Design and operating margins are carefully guarded and changed only with great thought and care. Special attention is placed on maintaining defense-in-depth.
- Organizations implement hazard controls in a consistent and reliable manner. Safety is embedded in processes and procedures through a functioning formal ISMS. Facility activities are governed by comprehensive, efficient, high-quality processes and procedures.
- Hazard controls are designed with an understanding of the potential for human error. Error-likely situations are identified, eliminated, or mitigated. Existence of known error-likely situations is communicated to workers prior to commencing work along with planned mechanisms to assure their safety.

**Operations Authorization**

Attributes include:

- Formal facility authorization agreements are in place and maintained between owner and operator.
- Readiness at the facility level is verified before hazardous operations commence. Pre-operational reviews confirm that controls are in place for known hazards.
- Facility operations personnel maintain awareness of all facility activities to ensure compliance with the established safety envelope.
- Work authorization is defined at the activity level. The work authorization process verifies that adequate preparations have been completed so that work can be performed safely. These preparations include verifying that work methods and requirements are understood; verifying that work conditions will be as expected and not introduce unexpected hazards; and verifying that necessary controls are implemented.
- The extent of documentation and level of authority for work authorization is based on the complexity and hazards associated with the work.
Supplemental Safety Culture Elements

Based on experience and learning over the past ten years since the inception of ISM, the Department has identified the following four supplemental safety culture elements to be used, along with the existing ISM guiding principles, to help develop the appropriate context or environment for effective implementation of ISM systems within DOE and at its sites and facilities in the future:

Individual Attitude and Responsibility for Safety
Every individual accepts responsibility for safe mission performance. Individuals demonstrate a questioning attitude by challenging assumptions, investigating anomalies, and considering potential adverse consequences of planned actions. All employees are mindful of work conditions that may impact safety, and assist each other in preventing unsafe acts or behaviors.

Operational Excellence
Organizations achieve sustained, high levels of operational performance, encompassing all DOE and contractor activities to meet mission, safety, productivity, quality, environmental, and other objectives. High-reliability is achieved through a focus on operations, conservative decision making, open communications, deference to expertise, and systematic approaches to eliminate or mitigate error-likely situations.

Oversight for Performance Assurance
Competent, robust, periodic and independent oversight is an essential source of feedback that verifies expectations are being met and identifies opportunities for improvement. Performance assurance activities verify whether standards and requirements are being met. Performance assurance through conscious, directed, independent reviews at all levels brings fresh insights and observations to be considered for safety and performance improvement.

Organizational Learning For Performance Improvement
The organization demonstrates excellence in performance monitoring, problem analysis, solution planning, and solution implementation. The organization encourages openness and trust, and cultivates a continuous learning environment.

38. A facility representative must demonstrate a familiarity level knowledge of the Department’s philosophy and approach to implementing quality assurance programs.

a. Identify the purpose and key elements of quality assurance programs.

The following is taken from DOE O 414.1C.

The purpose of QA programs is to ensure that the quality of DOE/NNSA products and services meet or exceed customers’ expectations.

Quality assurance for all work is based on the following principles:
- Quality is assured and maintained through a single, integrated, effective QAP.
- Management support for planning, organization, resources, direction, and control is essential to QA.
Performance and quality improvement require thorough, rigorous assessment and corrective action.

Workers are responsible for achieving and maintaining quality.

Environmental, safety, and health risks and impacts associated with work processes can be minimized, while maximizing reliability and performance of work products.

DOE endorses the use of a single, integrated QAP to satisfy the requirements for the regulated work, QA drivers, any additional quality requirements imposed by DOE elements, and the requirements of DOE O 414.1C. Quality process requirements are implemented under a QAP for the control of S/CI and safety issue corrective actions. The quality management system is intended to support the Department’s ISMS.

**b. Describe performance measures for measuring the effectiveness of quality assurance programs.**

The following is taken from DOE O 414.1C.

The QAP must address the following management, performance, and assessment criteria.

- **Management/Criterion 1—Program.**
  - Establish an organizational structure, functional responsibilities, levels of authority, and interfaces for those managing, performing, and assessing work.
  - Establish management processes, including planning, scheduling, and providing resources for work.

- **Management/Criterion 2—Personnel Training and Qualification.**
  - Train and qualify personnel to be capable of performing assigned work.
  - Provide continuing training to personnel to maintain job proficiency.

- **Management/Criterion 3—Quality Improvement.**
  - Establish and implement processes to detect and prevent quality problems.
  - Identify, control, and correct items, services, and processes that do not meet established requirements.
  - Identify the causes of problems, and include prevention of recurrence as a part of corrective action planning.
  - Review item characteristics, process implementation, and other quality-related information to identify items, services, and processes needing improvement.

- **Management/Criterion 4—Documents and Records.**
  - Prepare, review, approve, issue, use, and revise documents to prescribe processes, specify requirements, or establish design.
  - Specify, prepare, review, approve, and maintain records.

- **Performance/Criterion 5—Work Processes.**
  - Perform work consistent with technical standards, administrative controls, and hazard controls adopted to meet regulatory or contract requirements using approved instructions, procedures, etc.
  - Identify and control items to ensure their proper use.
  - Maintain items to prevent their damage, loss, or deterioration.
  - Calibrate and maintain equipment used for process monitoring or data collection.

- **Performance/Criterion 6—Design.**
Design items and processes using sound engineering/scientific principles and appropriate standards.

Incorporate applicable requirements and design bases in design work and design changes.

Identify and control design interfaces.

Verify/validate the adequacy of design products using individuals or groups other than those who performed the work.

Verify/validate work before approval and implementation of the design.

- Performance/Criterion 7—Procurement.
  - Procure items and services that meet established requirements and perform as specified.
  - Evaluate and select prospective suppliers on the basis of specified criteria.
  - Establish and implement processes to ensure that approved suppliers continue to provide acceptable items and services.

- Performance/Criterion 8—Inspection and Acceptance Testing.
  - Inspect and test specified items, services, and processes using established acceptance and performance criteria.
  - Calibrate and maintain equipment used for inspections and tests.

- Assessment/Criterion 9—Management Assessment.
  - Ensure that managers assess their management processes and identify and correct problems that hinder the organization from achieving its objectives.

- Assessment/Criterion 10—Independent Assessment.
  - Plan and conduct independent assessments to measure item and service quality and the adequacy of work performance and to promote improvement.
  - Establish sufficient authority and freedom from line management for independent assessment teams.
  - Ensure that persons conducting independent assessments are technically qualified and knowledgeable in the areas to be assessed.

c. Contrast quality assurance and quality control.

The following is taken from Yucca Mountain QA 101, by Kristi Hodges.

Quality assurance aims to assure that quality is built into work; QC aims to confirm that quality was built into work. QA has auditors; QC has inspectors. QA auditors evaluate implementation and effectiveness of processes used to complete work; QC inspectors evaluate completed work for conformance to specifications and drawings.

d. Explain the factors applicable to and methods of implementing the graded approach to quality.

The following is taken from DOE G 414.1-2A.

The graded approach must be used to evaluate hazards or risks and to determine the appropriate controls to address those hazards or risks. This process is accomplished by ensuring the level of analyses, documentation, and actions used to comply with requirements are commensurate with the following:
- Relative importance to safety, safeguards, and security
- Magnitude of any hazard involved
- Life-cycle stage of a facility or item
- Programmatic mission of a facility
- Particular characteristics of a facility or item
- Relative importance of radiological and non-radiological hazards
- Any other relevant factors

The first step in the grading process is to identify the consequences and probability of a failure. The second step is to identify the specific requirements to be applied. The third step is to determine the depth, extent, and degree of rigor necessary to comply with the requirements. The final step is to communicate and implement the requirements using documented procedures and controls.

e. **Explain the intent of 10 CFR 830, Subpart A “Quality Assurance Requirements,” and DOE O 414.1C, Quality Assurance.**

The following is taken from 10 CFR 830, subpart A.

This subpart establishes QA requirements for contractors conducting activities, including providing items or services that affect, or may affect, nuclear safety of DOE nuclear facilities.

The following is taken from DOE O 414.1C.

The intent of DOE O 414.1C is
- to ensure that DOE/NNSA products and services meet or exceed customers’ expectations; and
- to achieve QA for all work based on the following principles.
  - Quality is assured and maintained through a single, integrated, effective QA program.
  - Management support for planning, organization, resources, direction, and control is essential to QA.
  - Performance and quality improvement require thorough, rigorous assessment and corrective action.
  - Workers are responsible for achieving and maintaining quality.
  - 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 QAP for the control of suspect/counterfeit items, safety issue corrective actions, and safety software.
f. **Describe methods for assessing the implementation of quality assurance program elements.**

The following is taken from DOE G 414.1-1B.

Assessments are tools for improvement. DOE’s QA Rule and QA Order establish distinct requirements for management and independent assessments. DOE O 226.1A, refers to contractor self-assessment programs that include line and independent evaluations. In this context, the assessments are those that a contractor conducts on its own ES&H performance. Management and independent assessments will satisfy the requirements of DOE O 226.1A.

Contractors should clearly describe in writing how their self-assessment programs satisfy the requirements for management and/or independent assessment.

Management and independent assessments may be performed on the same functions or organizations; however, each has a specific focus defined by the QA Rule and QA Order as described below. For some organizations, the only difference between management and independent assessments may be the actual performer of the assessment.

It is essential to clearly define the criteria and/or objectives intended for the assessment through the assessment planning process and in the criteria review and approach documents.

**Management Assessment**

Managers perform management assessments to comply with the QA Rule and QA Order and to improve performance. In general, the purpose of this type of assessment is to identify the management systems, processes, and programs that affect performance and to make improvements. Management assessments look at the total picture:

- How well the management systems and processes meet the customer’s requirements
- Compliance with standards and requirements
- Meeting the expectations for safely performing work
- Clarity of the organizational mission, goals, and objectives
- Identifying and correcting problems that hinder the organization from achieving its objectives.

The emphasis of management assessment is on issues that affect performance, strategic planning, personnel qualification and training, staffing and skills mix, communication, cost control, organizational interfaces, and mission objectives.

Management assessment is a periodic introspective self-analysis to determine whether the organization’s activities are properly focused on achieving desired results. This includes reviewing the processes, systems, and programs that are important to the organization’s mission and objectives. Results of management as well as independent assessments can be used, in addition to formulating approaches and corrective actions for improvements, to develop plans for the subsequent management assessments. Additionally, independent assessment results may also be used as the basis for determining the focus and frequency of management assessments. It should be noted that effective management assessments could result in less frequent independent assessments, and independent assessment findings could affect the frequency and rigor of management assessments. In general, management and
Independent assessments are complementary; however, management assessments are generally performed at a greater frequency and cover a broader spectrum than independent assessments.

**Independent Assessment**

An independent assessment may be an audit, surveillance, “for cause” review or inspection conducted by individuals within the organization or company but independent from the work or process being evaluated, or by individuals from an external organization or company. In general, the purpose of this assessment is to perform the following:

- Evaluate compliance with standards and requirements.
- Evaluate the performance of work.
- Measure the quality of the item or service.
- Examine process effectiveness/adequacy.
- Promote improvement.

**g. Explain facility management’s and the individual’s role in quality assurance.**

The following is taken from DOE G 414.1-2A.

It is the role of senior management to establish and cultivate principles that integrate quality requirements into daily work. Management is responsible for leadership and commitment to quality achievement and improvement within a framework of public, worker, and environmental safety. Management retains the primary responsibility and accountability for the scope and implementation of the quality management system. However, every individual in the organization is responsible for achieving quality in his or her activities. Senior management should require and cultivate the achievement and improvement of quality at all levels.

**39. A facility representative must demonstrate a working level knowledge in the area of industrial safety programs.**

**a. Identify the purpose and key elements of industrial safety programs.**

The following is taken from DOE G 440.1-8.

DOE contractors must comply with contractually mandated industrial safety laws, codes, standards, regulations, and the applicable portions of mandated DOE Orders relating to industrial safety.

The following criteria apply:

- An industrial safety management program is in place that ensures compliance with mandated codes, standards, and regulations.
- An effective and efficient safety and health self assessment process or an integrated set of processes is implemented to identify, fix less than acceptable safety and health conditions, and provide feedback.
- Design modifications are evaluated for compliance with applicable codes and mandated DOE Orders.
Management is actively involved in oversight and evaluation of safe working conditions and actions. The safety and health organization is staffed and structured to support management.

Upper-level management actively and positively reinforces proper safety behavior and practices through the management observing and promoting safety program, or substantially equivalent programs, and maintains a visible safety and health presence in plant and facility operating areas.

Third parties are effectively used in the primary evaluation of safety program performance.

Oral notifications and written submission of incident reports and injury/illness notifications are accomplished in accordance with mandated requirements.

b. Describe performance measures for measuring the effectiveness of industrial safety programs.

The following is taken from DOE M 450.4-1.

Performance measures are used to track progress and monitor achievement of performance objectives and commitments. The most useful performance measures provide information that directly reflects how safely the operational work is being performed. A combination of leading (process or behavioral) and lagging (outcome or results) indicators is desirable. The measures are changed as necessary to address the performance objectives, and significant identified weaknesses and areas for improvement. Annual performance expectations should be established for most of these measures.

The following are sample performance measures:

- Exposures of personnel to chemical, physical, and biological hazards are adequately controlled.
- Accident and injury rates, lost workday case rates, and the DOE injury cost index are adequately controlled. Perform better than comparable industry statistics and exhibit a downward trend.
- Exposures of personnel to ionizing radiation are adequately controlled. ORPS-reportable occurrences, intakes of radioactivity, and skin contaminations are managed and minimized.
- Radioactive material is adequately controlled.
- The fire department response time and the rate of completion of required fire protection is adequately controlled and accomplished.
- Environmental violations and releases are adequately controlled.
- Reduce the amount of waste generated and the amount of pollutants emitted.
- Manage hazardous and radioactive wastes in a manner that meets regulatory requirements and is cost effective.
- Identify and control number of error-likely situations.
- Include behavioral and process measures – such as the number of near-misses, the number of error reports, the number of behavioral observations, the number of safe acts, etc.
c. Explain facility management’s and the individual’s role in industrial safety.

The following is taken from 29 CFR 1960.10.

Facility management’s roles are to furnish employees a place of employment that is free from recognized hazards that cause or are likely to cause death or serious physical harm, and to comply with the occupational safety and health standards applicable to their agency and with all rules, regulations, and orders issued by the head of the agency with respect to the agency occupational safety and health program.

The individual’s roles in industrial safety are to
- comply with the standards, rules, regulations, and orders issued by his/her agency;
- use safety equipment, PPE, and other devices and procedures provided or directed by the agency and necessary for the individual’s protection;
- have the right to report unsafe and unhealthful working conditions to appropriate officials;
- receive authorized official time to participate in the activities provided for in the agency’s occupational safety and health program.

d. Describe the basic requirements for the following elements of industrial safety programs:
- Hearing protection
- Eye protection
- Fall protection (including scaffolding)
- Machine guarding
- Lockout/tagout
- Confined spaces
- Non-radiological respirator protection
- Hoisting and rigging

Hearing Protection
The following is taken from 29 CFR 1910.95.

The employer shall administer a continuing, effective hearing conservation program whenever employee noise exposures equal or exceed an 8-hour time-weighted average sound level of 85 decibels measured on the A scale (slow response) or, equivalently, a dose of fifty percent.

For purposes of the hearing conservation program, employee noise exposures shall be computed in accordance with appendix A and table G–16a of 29 CFR 1910.95, “Occupational Noise Exposure,” and without regard to any attenuation provided by the use of PPE.

Eye Protection
The following is taken from 29 CFR 1910.133.

The employer shall ensure that each affected employee uses appropriate eye or face protection when exposed to eye or face hazards from flying particles, molten metal, liquid
chemicals, acids or caustic liquids, chemical gases or vapors, or potentially injurious light radiation.

The employer shall ensure that each affected employee uses eye protection that provides side protection when there is a hazard from flying objects. Detachable side protectors meeting the pertinent requirements of 29 CFR 1910.133, “Eye and Face Protection” are acceptable.

The employer shall ensure that each affected employee who wears prescription lenses while engaged in operations that involve eye hazards wears eye protection that incorporates the prescription in its design, or wears eye protection that can be worn over the prescription lenses without disturbing the proper position of the prescription lenses or the protective lenses.

Eye and face PPE shall be distinctly marked to facilitate identification of the manufacturer.

The employer shall ensure that each affected employee uses equipment with filter lenses that have a shade number appropriate for the work being performed for protection from injurious light radiation.

*Fall Protection*

The following is taken from 29 CFR 1910.23.

Every stairway floor opening shall be guarded by a standard railing. The railing shall be provided on all exposed sides. For infrequently used stairways where traffic across the opening prevents the use of fixed standard railing, the guard shall consist of a hinged floor opening cover of standard strength and construction and removable standard railings on all exposed sides.

Every ladder-way floor opening or platform shall be guarded by a standard railing with standard toe board on all exposed sides, with the passage through the railing either provided with a swinging gate or so offset that a person cannot walk directly into the opening.

Every hatchway and chute floor opening shall be guarded by one of the following:

- Hinged floor opening cover of standard strength and construction equipped with standard railings or permanently attached thereto so as to leave only one exposed side. When the opening is not in use, the cover shall be closed or the exposed side shall be guarded at both top and intermediate positions by removable standard railings.

- A removable railing with toe board on not more than two sides of the opening and fixed standard railings with toe boards on all other exposed sides. The removable railings shall be kept in place when the opening is not in use. Where operating conditions necessitate the feeding of material into any hatchway or chute opening, protection shall be provided to prevent a person from falling through the opening.

Every skylight floor opening and hole shall be guarded by a standard skylight screen or a fixed standard railing on all exposed sides.
Every pit and trapdoor floor opening, infrequently used, shall be guarded by a floor opening cover of standard strength and construction. While the cover is not in place, the pit or trap opening shall be constantly attended by someone or shall be protected on all exposed sides by removable standard railings.

Every manhole floor opening shall be guarded by a standard manhole cover which need not be hinged in place. While the cover is not in place, the manhole opening shall be constantly attended by someone or shall be protected by removable standard railings.

Every temporary floor opening shall have standard railings, or shall be constantly attended by someone.

Every floor hole into which persons can accidentally walk shall be guarded by either
- a standard railing with standard toe board on all exposed sides, or
- a floor hole cover of standard strength and construction. While the cover is not in place, the floor hole shall be constantly attended by someone or shall be protected by a removable standard railing.
- Every floor hole into which persons cannot accidentally walk shall be protected by a cover that leaves no openings more than 1 inch wide. The cover shall be securely held in place to prevent tools or materials from falling through.

Machine Guarding
The following is taken from 29 CFR 1910.212.

One or more methods of machine guarding shall be provided to protect the operator and other employees in the machine area from hazards such as those created by point of operation, ingoing nip points, rotating parts, flying chips and sparks.

Guards shall be affixed to the machine where possible and secured elsewhere if for any reason attachment to the machine is not possible. The guard shall be such that it does not offer an accident hazard in itself.

Point of operation is the area on a machine where work is actually performed upon the material being processed.

Revolving drums, barrels, and containers shall be guarded by an enclosure that is interlocked with the drive mechanism, so that the barrel, drum, or container cannot revolve unless the guard enclosure is in place.

When the periphery of the blades of a fan is less than 7 feet above the floor or working level, the blades shall be guarded. The guard shall have openings no larger than one-half inch.

Lockout/Tagout
The following is taken from 29 CFR 1910.147.

Employers are required to establish a program and use procedures for affixing appropriate lockout devices or tagout devices to energy isolating devices, and to otherwise disable
machines or equipment to prevent unexpected energization, start-up or release of stored energy to prevent injury to employees.

If an energy isolating device is not capable of being locked out, the employer’s energy control program will use a tagout system.

If an energy isolating device is capable of being locked out, the employer’s energy control program will use lockout, unless the employer can demonstrate that the use of a tagout system will provide full employee protection.

When a tagout device is used on an energy isolating device that is capable of being locked out, the tagout device will be attached at the same location that the lockout device would have been attached, and the employer shall demonstrate that the tagout program will provide a level of safety equivalent to that obtained by using a lockout program.

Confined Spaces
The following is taken from 29 CFR 1910.146.

The employer will evaluate the workplace to determine if any spaces are permit-required confined spaces.

If the workplace contains permit spaces, the employer will inform exposed employees, by posting danger signs or by any other equally effective means, of the existence and location of and the danger posed by the permit spaces.

If the employer decides that its employees will not enter permit spaces, the employer shall take effective measures to prevent its employees from entering the permit spaces.

If the employer decides that its employees will enter permit spaces, the employer will develop and implement a written permit space program. The written program will be available for inspection by employees and their authorized representatives.

When there are changes in the use or configuration of a non-permit confined space that might increase the hazards to entrants, the employer will reevaluate that space and, if necessary, reclassify it as a permit-required confined space.

Non-Radiological Respirator Protection
The following is taken from 29 CFR 1910.134.

In the control of those occupational diseases caused by breathing air contaminated with harmful dusts, fogs, fumes, mists, gases, smokes, sprays, or vapors, the primary objective shall be to prevent atmospheric contamination. This will be accomplished as far as feasible by accepted engineering control measures. When effective engineering controls are not feasible, or while they are being instituted, appropriate respirators shall be used.

Employers will provide respirators when such equipment is necessary to protect the health of the employee. The employer will provide the respirators that are applicable and suitable for the purpose intended.
The employer will be responsible for the establishment and maintenance of a respiratory protection program.

In any workplace where respirators are necessary to protect the health of the employee or whenever respirators are required by the employer, the employer will establish and implement a written respiratory protection program with worksite-specific procedures. The program will be updated as necessary to reflect those changes in workplace conditions that affect respirator use. The employer will include in the program the following provisions as applicable:

- Procedures for selecting respirators for use in the workplace
- Medical evaluations of employees required to use respirators
- Fit-testing procedures for tight-fitting respirators
- Procedures for proper use of respirators in routine and reasonably foreseeable emergency situations
- Procedures and schedules for cleaning, disinfecting, storing, inspecting, repairing, discarding, and otherwise maintaining respirators
- Procedures to ensure adequate air quality, quantity, and flow of breathing air for atmosphere-supplying respirators
- Training of employees in the respiratory hazards to which they are potentially exposed during routine and emergency situations
- Training of employees in the proper use of respirators, including putting on and removing them, any limitations on their use, and their maintenance
- Procedures for regularly evaluating the effectiveness of the program

_Hoisting and Rigging_

The following is taken from 29 CFR 1926.753.

A qualified rigger should inspect riggings prior to each shift.

The headache ball, hook, or load shall not be used to transport personnel. However, cranes or derricks may be used to hoist employees on a personnel platform when work is being conducted.

Safety latches on hooks shall not be deactivated or made inoperable.

Routes for suspended loads will be pre-planned to ensure that no employee is required to work directly below a suspended load.

A multiple lift shall only be performed if the following criteria are met:

- A multiple lift rigging assembly is used
- A maximum of five members are hoisted per lift
- Only beams and similar structural members are lifted
- All employees engaged in the multiple lift have been trained
- No crane is permitted to be used for a multiple lift where such use is contrary to the manufacturer’s specifications and limitations.
Components of the multiple lift rigging assembly shall be specifically designed and assembled with a maximum capacity for total assembly and for each individual attachment point.

This capacity, certified by the manufacturer or a qualified rigger, will be based on the manufacturer’s specifications with a 5 to 1 safety factor for all components.

The total load shall not exceed
- the rated capacity of the hoisting equipment specified in the hoisting equipment load charts;
- the rigging capacity specified in the rigging rating chart.

The multiple lift rigging assembly shall be rigged with members
- attached at their center of gravity and maintained reasonably level;
- rigged from top down;
- rigged at least 7 feet apart.

The members on the multiple lift rigging assembly will be set from the bottom up.

Controlled load lowering will be used whenever the load is over the connectors.

40. A facility representative must demonstrate a working level knowledge of the safety authorization basis, including the documented safety analysis, technical safety requirements, and safety evaluation reports.

a. Explain DOE’s role in the oversight of the safety authorization basis.

The following is taken from 10 CFR 830.3 and the associated regulations indicated in table 6.

DOE must review and approve safety basis documents prepared by the contractor. According to 10 CFR 830.3, “Definitions,” DOE must prepare a safety evaluation report (SER) to document the following:
- The sufficiency of the DSA for a hazard category 1, 2, or 3 nuclear facility
- The extent to which the contractor has satisfied the requirements of 10 CFR 830, subpart B
- The basis for approval by DOE of the safety basis for the facility, including any conditions for approval

To do this, DOE must be prepared to perform the actions identified in table 6.
Table 5. DOE Actions to approve a DSA

<table>
<thead>
<tr>
<th>Action</th>
<th>Requirement</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Determine if the contractor methodology used to prepare the DSA is appropriate.</td>
<td>10 CFR 830.204</td>
</tr>
<tr>
<td>2.</td>
<td>Review and approve the nuclear safety design criteria to be used in preparing the preliminary documented safety analysis (PDSA).</td>
<td>10 CFR 830.206</td>
</tr>
<tr>
<td>3.</td>
<td>Review and approve the PDSAs for any new facilities or for major modifications to hazard category 1, 2, or 3 facilities.</td>
<td>10 CFR 830.206</td>
</tr>
<tr>
<td>4.</td>
<td>Determine if the contractor may perform limited procurement and construction activities without approval of the PDSA for a new hazard category 1, 2, or 3 facility</td>
<td>10 CFR 830.207</td>
</tr>
<tr>
<td>5.</td>
<td>Issue an SER for any new hazard category 1, 2, or 3 facility before operations or modification can begin.</td>
<td>10 CFR 830.207</td>
</tr>
<tr>
<td>6.</td>
<td>Review and approve the contractor TSR(s) and any changes to the TSR(s).</td>
<td>10 CFR 830.205</td>
</tr>
<tr>
<td>7.</td>
<td>Review the safety basis for an existing hazard category 1, 2, or 3 facility and issue a SER.</td>
<td>10 CFR 830.207</td>
</tr>
<tr>
<td>8.</td>
<td>Review and approve the contractor’s USQ procedure and any revisions thereafter.</td>
<td>10 CFR 830.203</td>
</tr>
<tr>
<td>9.</td>
<td>Review and approve USQs submitted by the contractor, including those for facility changes and discovery conditions.</td>
<td>10 CFR 830.203</td>
</tr>
</tbody>
</table>

Source: 10 CFR 830

b. Explain the application of 10 CFR 830 subpart B “Safety Basis Requirements,” and associated implementation guides and standards.

The safety basis requirements of 10 CFR 830 require the contractor responsible for an NNSA 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 NNSA 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.


The contractor responsible for a hazard category 1, 2, or 3 NNSA nuclear facility must establish and maintain the safety basis for the facility. In establishing the safety basis for a hazard category 1, 2, or 3 NNSA nuclear facility, the contractor responsible for the facility
must categorize the facility in a manner consistent with DOE-STD-1027-92, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports.*

The contractor responsible for a DOE nuclear explosive facility may prepare its DSA by developing a safety analysis report according to DOE-STD-3009-94 and a hazards analysis report according to DOE-STD-3016-2006, *Hazards Analysis Reports for Nuclear Explosive Operations.*

DOE G 423.1-1, *Implementation Guide for Use in Developing Technical Safety Requirements*, is used to develop TSRs. TSRs define the performance requirements of safety SSCs and identify the safety management programs that 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 analyses of the activities and through identification of the potential sources of safety issues.

DOE G 424.1-1, *Implementation Guide for Use in Addressing Unreviewed Safety Question Requirements*, provides guidance on the USQ process. The USQ process allows contractors to make physical and procedural changes and to conduct tests and experiments without prior NNSA 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. Title 10 CFR 830.203, “Unreviewed Safety Question Process,” requires NNSA approval of the procedure to implement the USQ process.

DOE-STD-1104-2009 *Review and Approval of Nuclear Facility Safety Basis Documents (DSAs and TSRs)*, is used to standardize the process of reviewing and approving DSAs and TSRs. Certain benefits are gained by standardizing fundamental elements of the review and approval process. To that end, this standard establishes NNSA guidelines for the review and approval of these documents, including preparation of SERs for nuclear facilities.

c. Define each of the following terms and explain their relationship to each other:
   - Authorization agreement
   - Documented safety analysis (DSA)
   - Technical safety requirements (TSR): This should include safety limit, limiting control settings (LCSs), limiting conditions for operation (LCOs), and administrative controls (specific, procedural, or key element)
   - Unreviewed safety question (USQ) process
   - Safety evaluation report (SER)
   - Safety structures, systems and components (safety SSC)
   - Defense-in-depth

**Authorization Agreement**

An authorization agreement is a documented agreement between DOE and the contractor for high-hazard facilities, incorporating the results of DOE’s review of the contractor’s proposed authorization basis for a defined scope of work. The authorization agreement contains key terms and conditions under which the contractor is authorized to perform the work.
Documented Safety Analysis (DSA)
A DSA reviews the extent to which a nuclear facility can be operated with respect to workers, the public, and the environment, including a description of the conditions, safe boundaries, and hazard controls that provide the basis for ensuring safety.

Technical Safety Requirements (TSRs)
The following definitions related to TSRs are taken from DOE-STD-3009-94.

TSRs include the limits, controls, and related actions that establish the specific parameters and requisite actions for the safe operation of a nuclear facility and include, as appropriate for the work and the hazards identified in the DSA for the facility: safety limits, operating limits, surveillance requirements, administrative and management controls, use and application provisions, and design features, as well as a bases appendix.

Safety Limit
Safety limits are limits on process variables associated with those safety-class physical barriers, generally passive, that are necessary for the intended facility functions and which are required to guard against the uncontrolled release of radioactive materials.

Limiting Control Settings
Limiting control settings are the settings on process variables associated with safety systems that control the facility function and will prevent exceeding the associated safety limits.

Limiting Conditions for Operation
Limiting conditions for operation are the limits that represent the lowest functional capability or performance level of one or more safety-related items required for the safe operation of a facility.

Administrative Control
Administrative controls are the provisions relating to organization and management, procedures, record keeping, assessment, and reporting necessary to ensure the safe operation of a facility.

Unreviewed Safety Question (USQ) Process
10 CFR 830.203 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. The USQ process is primarily applicable to the DSA. The rule references only the DSA, and includes conditions of approval in SERs and facility-specific commitments made in compliance with DOE rules, Orders, or policies.

Safety Evaluation Report (SER)
According to DOE G 421.1-2, the SER is primarily a management document that provides the approval authority, the basis for the extent and detail of the DSA review, and the basis for any conditions of DSA approval.
Safety Structures, Systems, and Components (SSC)
According to DOE-STD-3009-94, SSCs are the set of safety-class structures, systems, and components, and safety-significant structures, systems, and components for a given facility.

Defense-in-Depth
The following is taken from DOE-STD-3009-94.

Defense-in-depth as an approach to facility safety has extensive precedent in nuclear safety philosophy. It builds in layers of defense against release of hazardous materials so that no one layer by itself, no matter how good, is completely relied upon. To compensate for potential human and mechanical failures, defense-in-depth is based on several layers of protection with successive barriers to prevent the release of hazardous material to the environment. This approach includes protection of the barriers to avert damage to the plant and to the barriers themselves. It includes further measures to protect the public, workers, and the environment from harm in case these barriers are not fully effective.

The defense-in-depth philosophy is a fundamental approach to hazard control for nonreactor nuclear facilities even though they do not possess the catastrophic accident potential associated with nuclear power plants. In keeping with the graded-approach concept, no requirement to demonstrate a generic, minimum number of layers of defense-in-depth is imposed. However, defining defense-in-depth as it exists at a given facility is crucial for determining a safety basis. Operators of DOE facilities need to use the rigorous application of defense-in-depth thinking in their designs and operations. Such an approach is representative of industrial operations with an effective commitment to public and worker safety and the minimization of environmental releases.

For high hazard operations, there are typically multiple layers of defense-in-depth. The inner layer of defense-in-depth relies on a high level of design quality so that important systems, structures, and components will perform their required functions with high reliability and high tolerance against degradation. The inner layer also relies on competent operating personnel who are well trained in operations and maintenance procedures. Competent personnel translate into fewer malfunctions, failures, or errors and, thus, minimize challenges to the next layer of defense.

In the event that the inner layer of defense-in-depth is compromised from either equipment malfunction or operator error and there is a progression from the normal to an abnormal range of operation, the next layer of defense-in-depth is relied upon. It can consist of: (1) automatic systems; or (2) means to alert the operator to take action or manually activate systems that correct the abnormal situation and halt the progression of events toward a serious accident.

Mitigation of the consequences of accidents is provided in the outer layer of defense-in-depth. Passive, automatically or manually activated features, and/or safety management programs minimize consequences in the event that all other layers have been breached. The contribution of emergency response actions to minimizing consequences of a given accident cannot be neglected as they represent a truly final measure of protection for releases that cannot be prevented.
The SSCs that are major contributors to defense-in-depth are designated as safety-significant SSCs. The discipline imposed by safety management programs goes beyond merely supporting the assumptions identified in the hazard analysis and is an integral part of defense-in-depth.

Administrative controls that are major contributors to defense-in-depth are designated as specific administrative controls (SAC) that are required for safety because they are the basis for validity of the hazard or accident analyses, or they provide the main mechanisms for hazard control. The established hierarchy of hazard controls requires that engineering controls with an emphasis on safety-related SSCs be preferable to administrative controls or SACs due to the inherent uncertainty of human performance. SACs may be used to help implement a specific aspect of a program administrative control that is credited in the safety analysis and therefore has a higher level of importance.

d. Using the guidance in DOE-STD-1073-2003, DOE Standard: Configuration Management, discuss the system engineer concept as it applies to FR oversight of safety systems. Specifically address the areas of configuration management, assessment of system status and performance, relationship and interface between the safety system oversight personnel and FRs, and the technical support for operation and maintenance activities.

The following is taken from DOE-STD-1073-2003.

**Configuration Management**

DOE O 420.1B, Facility Safety, requires contractors to designate a cognizant system engineer for each system for DOE category 1, 2, or 3 nuclear facilities. The qualifications for the cognizant system engineer must be consistent with those defined in DOE O 420.1B. In addition the cognizant system engineer has the lead responsibility for the CM of design.

The cognizant system engineer must be knowledgeable of the system and the related safety basis. The cognizant system engineer must also retain a working knowledge of the facility’s operation and the existing condition of the system. Consequently, the cognizant system engineer is also responsible for overseeing the configuration of the assigned system to ensure that it continues to be able to perform its expected functions. The cognizant system engineer should

- be knowledgeable of the system safety functions, requirements, and performance criteria and their bases;
- understand how the system SSCs are designed and how they function to meet the requirements and performance criteria;
- understand system operation;
- be knowledgeable of the testing and maintenance necessary to ensure the system continues to be able to perform its safety functions;
- be responsible for ensuring that documents related to the system are complete, accurate, and up-to-date, including system design descriptions, technical drawings, diagrams, and procedures for surveillance, testing, and maintenance;
- be appropriately involved in the design, review, and approval of changes affecting/impacting system design, operation, and maintenance.
Because the cognizant system engineers are expected to have a thorough understanding of system design expectations, operating requirements, and current configuration, the cognizant system engineers should have a major role in identifying the CM SSCs. Each cognizant system engineer should also participate in the identification of the design requirements for their system and the SSCs within the system. Finally, the cognizant system engineer should participate in the CM review of any changes that are made to the system for which the cognizant system engineer has cognizance responsibility.

System Status
DOE O 420.1B requires contractors to designate a cognizant system engineer for each system for DOE category 1, 2, or 3 nuclear facilities. The duties, responsibilities, and interfaces of each cognizant system engineer need to be clearly defined, documented, communicated to and understood by supporting facility organizations. To facilitate the change control process, each cognizant system engineer should perform the following functions:

- Monitor and track the status of the assigned system, especially during changes (e.g., physical changes in progress and temporary physical changes);
- Conduct and/or observe equipment performance monitoring, evaluating the results of performance monitoring and surveillance, trending important data, and initiating corrective actions;
- Review and approve post-modification, post-maintenance, surveillance, and special test procedures and test results;
- Provide assistance to operations and maintenance, as needed; and
- Identify any situation where the design engineering organization should be consulted for advice or services.

Technical Support for Operation and Maintenance Activities
Cognizant system engineers should maintain cognizance over performance monitoring activities on assigned systems. Their responsibilities should include the identification of performance goals and acceptance criteria consistent with the associated SSC design requirements. Reviewing trend graphs of collected equipment data at specified intervals is a proven, effective approach. For example, if the trend graph indicates that the equipment likely will not meet the acceptance criteria at or before the next scheduled test, an adjustment in the test schedule and other maintenance actions would be necessary. Recognition of interfaces with existing maintenance program requirements is necessary. Surveillance testing is typically performed to satisfy regulatory, code, or other requirements to ensure operability of the equipment within established limits. The results of surveillance testing should be used to detect and correct any deficiencies that cause the equipment to deviate from the design requirements. Surveillance testing techniques are similar in many ways to those used in SSC performance monitoring. The results of surveillance testing should be reviewed and trended, and necessary corrective actions taken to return equipment performance to within the design requirements. The periodic equipment performance monitoring function should take credit for periodic surveillance testing, where appropriate. Periodic testing, beyond that in the TSR surveillance requirements, may be adjusted both in frequency and degree of technical content based on the importance of the SSC or the particular SSC function. The origin of various testing requirements should be documented and maintained in the MIP.
e. Describe configuration control and its relationship to the authorization basis.

Figure 73 illustrates the relationship between the CM equipment database and the design process. Requests for changes to the design of the activity typically include a description of the problem and sometimes include an associated proposed facility configuration change. When a change is requested, the individual preparing the documentation for the proposed change should consult the CM equipment database and assess how the design requirements in that database will be affected. That assessment should be part of the documentation for the proposed change.

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Source: DOE-STD-1073-2003

**Figure 73.** Sample CM equipment database

If it is determined that the proposed change could impact an SSC that is part of the CM equipment database, then the proposed change will need to be processed through the change control process. Furthermore, following review and approval of the proposed change, the CM equipment database will need to be updated as appropriate to reflect the change.

Section 3.2 of DOE-STD-1073-2003 discusses how the safety SSCs identified in the DSA constitute the baseline set of SSCs that are to be controlled under the CM process. It also discusses including other SSCs such as those identified as necessary for

- defense-in-depth,
- critical mission functions,
- environmental protection,
- protection of costly equipment or functions,
- protection of adjacent SSCs, or
- critical software functions.

CM should be used to control and document changes to the safety basis. The relationship of the process of documenting the CM design requirements to the safety basis required by subpart B of 10 CFR 830 for hazard category 1, 2, and 3 nuclear facilities is illustrated in figure 74.
f. Observe a contractor TSR surveillance activity and describe the factors to be considered as the activity is planned and performed.

g. Conduct a facility walkthrough and identify all facility safety SSCs as well as defense-in-depth SSCs.

Elements f and g are performance-based KSAs. The Qualifying Official will evaluate their completion.

h. Discuss the purpose, scope, and application of the following DOE guides and standards:
   - DOE G 423.1-1, *Implementation Guide for Use in Developing Technical Safety Requirements*
   - DOE-STD-1027-92, CN1, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports*

**DOE G 421.1-2, Implementation Guide for Use in Developing Documented Safety Analysis to Meet Subpart B of 10 CFR 830**

**Purpose**

DOE G 421.1-2 elaborates on the DSA development process and the safe harbor provisions of the appendix to 10 CFR 830, subpart B.

**Scope and Application**

The information contained in DOE G 421.1-2 is intended for use by all Department elements, including the NNSA, and all contractors for a DOE-owned or DOE-leased hazard category 1, 2, or 3 nuclear facility or nuclear operation. DOE nuclear activities that are regulated through a license by the NRC or a state under an agreement with the NRC, including activities certified by the NRC under section 1701 of the Atomic Energy Act (Act); activities conducted under the authority of the Director, Naval Nuclear Propulsion, pursuant to Executive Order 12344, as set forth in Public Law 106–65; transportation activities which are regulated by the DOT; and activities conducted under the Nuclear Waste Policy Act of 1982, as amended, and any facility identified under section 202(5) of the Energy Reorganization Act of 1974, as amended; and activities related to the launch approval and actual launch of nuclear energy systems into space are exempt from the DSA rule and therefore do not need to follow this guidance.

Accelerators and their operations are excluded from the safety basis requirements of the rule because their activities normally do not use, store, or form radioactive materials. However, target areas associated with the accelerators and areas associated with the radioactive materials produced by the accelerators are not considered to be part of the accelerator and continue to be subject to the provisions of 10 CFR 830 to the extent that they use, store, or form radioactive materials. Thus, target areas that contain or form radioactive inventories within the DOE-STD-1027-92 limits are subject to 10 CFR 830. DOE G 421.1-2 does not prescribe the format for a DSA.

**DOE G 423.1-1, Implementation Guide for Use in Developing Technical Safety Requirements**

**Purpose**

DOE G 423.1-1 was developed in support of subpart B of 10 CFR 830, and provides guidance in meeting the provisions for TSRs defined in 10 CFR 830.205, “Technical Safety Requirements.” DOE G 423.1-1 provides elaboration for the content of TSRs.

**Scope**

The information contained in DOE G 423.1-1 is intended for use by all Department elements, including NNSA, and all contractors for DOE-owned or DOE-leased, hazard category 1, 2, or 3, nuclear facilities or nuclear operations. DOE G 423.1-1 does not apply to activities that are regulated through a license by the NRC or a state under an agreement with the NRC, including activities certified by the NRC under section 1701 of the Atomic Energy Act (Act); activities conducted under the authority of the Director, Naval Nuclear Propulsion, pursuant to Executive Order 12344, as set forth in Public Law 106–65; transportation activities that
are regulated by the DOT; activities conducted under the Nuclear Waste Policy Act of 1982, as amended, and any facility identified under section 202(5) of the Energy Reorganization Act of 1974, as amended; and activities related to the launch approval and actual launch of nuclear energy systems into space.

Application

DOE G 423.1-1 provides two different formats that are effective in highlighting the important features of TSRs. The older format is described in the attachment to DOE Order 5480.22, Technical Safety Requirements, dated 2-25-92. The newer format, based on the NRC Tech Spec Improvement Program (TSIP), is designed to aid the use of the operations information by the operators. However, neither the older format nor the new TSIP format is required. Other formats may be used as long as they meet the content expectations of the appendix to subpart B of the nuclear safety management rule.

A contractor for an environmental restoration activity may follow the provisions of 29 CFR 1910.120, “Occupational Safety and Health Standards, Hazardous Waste Operations and Emergency Response,” or 1926.65, “Hazardous Waste Operations and Emergency Response” for construction activities to develop the appropriate hazard controls (rather than this TSR guidance) provided the activity involves either (1) work not done within a permanent structure or (2) the decommissioning of a facility with only low-level residual fixed radioactivity. Implicit in this guidance is an understanding that reasonable efforts to remove radioactive systems, components, and stored materials has been completed and that the work does not prudently require the use of active safety systems or components designed to prevent or mitigate the accidental release of hazardous radioactive materials. DOE-STD-1120-2005, Integration of Environment, Safety, and Health into Facility Disposition Activities, also provides guidance that should be considered in the development of TSRs.

DOE G 424.1-1, Implementation Guide for Use in Addressing Unreviewed Safety Question Requirements

Purpose

DOE G 424.1-1A provides information to assist in the implementation of 10 CFR 830.203 of the nuclear safety management rules for category 1, 2, and 3 nuclear facilities owned or operated by the DOE.

Scope and Application

10 CFR 830.203 applies to all category 1, 2 and 3 nuclear facilities. The USQ process applies to all temporary or permanent changes to nuclear facilities unless a decision to request DOE approval already has been made, and to potential inadequacies of safety analyses. Some changes may be such that they can be screened out from a detailed USQ determination.

The applicability of 10 CFR 830.203 is broad. Non-safety-related SSCs are not excluded by the scope of Section 830.203 if they could affect the proper operation of equipment important to safety that is relied on in the safety basis or create the possibility of an accident or malfunction of a different type than previously evaluated in the DSA. For example, losses of certain non-safety-related systems may represent critical operational occurrences identified as initiators in the accident analysis. Therefore, changes to non-safety-related SSCs are evaluated and may be determined to involve a USQ.
Physical interactions may also fall under the purview of Section 830.203. For example, the installation of a non-seismically supported piece of equipment above a seismically qualified component designed to perform a safety function explicitly or implicitly assumed in the existing safety analyses may constitute a USQ and need to be evaluated.

The guide defines types of changes, tests, and experiments and potential inadequacies that the USQ process needs to address to comply with Section 830.203.

DOE-STD-1027-92 CN1, Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports

The purpose of DOE-STD-1027-92 is to establish guidance for the preparation and review of hazard categorization and accident analyses techniques as required in DOE Order 5480.23. This new Order requires further guidance to ensure consistency across all nuclear facilities within the DOE complex. DOE-STD-1027-92 focuses on (1) the definition of the standard identifying nuclear facilities required to have SARs in order to comply with the Order, (2) the SAR implementation plan and schedule, (3) the hazard categorization methodology to be applied to all facilities, and (4) the accident analysis techniques appropriate for the graded approach addressed in the Order. DOE Order 5480.23 and its attached guidance document provide some direction on the use of the graded approach. This report is intended not to supersede that direction, but to supplement and clarify it. Methods other than those suggested in this guide may be considered for applying the graded approach, but they must be justified whenever grading is applied.

DOE-STD-1027-92 is used with DOE Order 5480.23 and may not be applicable to other DOE Orders. Regarding the applicability of other nuclear safety Orders to those facilities which fall below category 3 criteria, as defined by this standard, the PSOs shall provide guidance, as appropriate.

Developed by a working group with contributions from all Secretarial and oversight organizations having nuclear safety responsibilities, with input from several field and contractor organizations, and with clarifying direction from the Senior Nuclear Managers meeting of October 26, 1992, this standard applies to DOE nuclear facilities as defined in the Order and is suitable for DOE nuclear facilities.

DOE-STD-1104-2009, Review and Approval of Nonreactor Nuclear Facility Safety Basis and Safety Design Basis Documents

Purpose

DOE-STD-1104-2009 was prepared to be consistent with 10 CFR 830 and its implementation guides and should be used in conjunction with the Rule and its implementing guidance for safety basis documents. It was also prepared to be consistent with DOE O 413.3A, Chg. 1, Program and Project Management for the Acquisition of Capital Assets and DOE-STD-1189-2008, DOE Standard: Integration Of Safety Into The Design Process and should be used in conjunction with those documents, the Rule, and their implementing guidance for safety design basis documents.
Scope and Application
The following guiding principles pertain to the application and provisions of DOE-STD-1104-2009:

- The documents listed in table 2 of appendix A to 10 CFR 830, subpart B, provide approved methodologies for meeting the DSA requirements of 10 CFR 830. These documents are commonly referred to as safe harbors. Developed consistent with, and as a companion to these documents, DOE-STD-1104-2009 does not generally reiterate the provisions of these documents but may cite specific requirements from these documents, as convenient.

- If a contractor uses a method other than a safe harbor method from table 2 of appendix A of 10 CFR 830, per 10 CFR 830.204, the contractor must obtain DOE approval of the method before developing the DSA. Likewise, if a contractor uses a safe harbor method to develop the DSA, but does not follow the method completely, per 10 CFR 830.204, the contractor must request DOE approval of the method with the specific deviations noted. Requirements and responsibilities for the use of alternative methods or specific deviations from the safe harbor methods are contained in DOE M 411.1-1C, Safety Management Functions, Responsibilities and Authorities Manual, and DOE O 410.1, Central Technical Authorities Responsibilities Regarding Nuclear Safety Requirements.

- DOE O 413.3A, Chg. 1, assigns the authority to designate a safety basis approval authority (SBAA) with the authority to review and approve safety basis and safety design basis documents to the Program Secretarial Officer (PSO). DOE M 411.1-1C defines provisions for delegation of authorities. In accordance with DOE M 411.1-1C, the PSO may establish a new SBAA, but does not relinquish the ultimate responsibility for ensuring adequate performance of that approval authority. In carrying out assigned responsibilities, the approval authority, if not the PSO, is at all times accountable to the PSO.

- Independent review of the safety design basis and safety bases documents facilitates achieving defensible approval. Since the preparation and the review and approval of these documents may fall under the purview of the SBAA, independent review is achieved by designating a review team leader with the responsibility and authority to conduct independent assessments. The review team leader is independent of any responsibility for preparation of the documents under review. The review team members are also independent of any responsibility for preparation of the documents.

- The SBAA is the single point of contact between DOE and the facility contractor for all areas of review and approval of DSAs and TSRs. In this capacity, the SBAA serves as the focal point through which DOE interfaces with the facility contractor and from which directions to the facility contractor originate. This is accomplished through the review team leader and in conjunction with official contractor interfaces and the DOE CO.

- The DOE is responsible for the operation and the regulation of the facilities for which these documents are required. This dual role places fundamental limits on the ability of DOE to completely segregate the processes of preparation and review of these documents. For example, the field element manager typically has responsibility for the operation of the facility and the review and approval of the DSA and TSRs. However, to be as objective as possible in the review process, most of the reviewers of these documents should not be responsible for the design or operation of the
facility, including the preparation of the safety design basis and safety bases documents. It is expected that these reviews will be conducted, to the extent practicable, by individuals and organizations separate from the document preparation. DOE-STD-1104-2009 encourages interface between the two processes to develop familiarity with the facility’s safety basis, to respond to requests from the preparer for early identification and resolution of potential issues, and to establish the scope of subsequent review and the extent of approval documentation required.

- The DOE strives for an effective, streamlined review and approval process for safety design basis and safety basis documents while still achieving an acceptable level of safety assurance. DOE-STD-1104-2009 advocates proper planning for a review and encourages an integrated review process where all parties with vested interest in a facility safety basis coordinate throughout the review and approval process.
- The DOE manages review issues requiring resolution for approval in that reviewers establish and document the safety significance of issues prior to submittal for possible resolution. Guidance is provided to focus facility contractor’s resolution of those issues determined to be necessary for adequately establishing and documenting the facility safety basis.
- DOE-STD-1104-2009 provides guidelines for reviewing the DSA through assessment of the major subject areas of a safety analysis as defined by the following DSA approval bases:
  - Base information
  - Hazard and accident analyses
  - SSCs
  - SACs
  - Derivation of TSRs
  - Safety management program characteristics


Purpose

DOE-STD-3009-94 describes a DSA preparation method that is acceptable to the DOE as delineated for those specific facilities listed in table 2 of appendix A, “General Statement of Safety Basis Policy” to Subpart B, “Safety Basis Requirements” of 10 CFR 830. It was developed to assist hazard category 2 and 3 facilities in preparing DSAs that will satisfy the requirements of 10 CFR 830. Hazard category 1 facilities are typically expected to be category A reactors for which extensive precedents for DSAs already exist.

Scope and Application

The guidance provided in DOE-STD-3009-94 is generally applicable to any facility required to document its safety basis in accordance with 10 CFR 830. For new facilities in which conceptual design or construction activities are in progress elements of this guidance may be more appropriately handled as an integral part of the overall design requirements process. The methodology provided by DOE-STD-3009-94 focuses more on characterizing facility safety with or without well-documented information than on the determination of facility design. Accordingly, contractors for facilities that are documenting conceptual designs for PDSAs should apply the process and format of DOE-STD-3009-94 to the extent it is judged to be of benefit.
Beyond conceptual design and construction, the methodology in DOE-STD-3009-94 is applicable to the spectrum of missions expected to occur over the lifetime of a facility. As the phases of facility life change, suitable methodology is provided for use in updating an existing DSA and in developing a new DSA if the new mission is no longer adequately encompassed by the existing DSA. This integration of the DSA with changes in facility mission and associated updates should be controlled as part of an overall safety management plan.

A unique element of DSA documentation is the required provisions for decontamination and decommissioning (D&D) as discussed in chapter 16 of DOE-STD-3009-94. This forward-looking aspect of facility operations is independent of facility mission and is intended to be a means of ensuring that current facility operations take into account D&D operations that will occur in the future.

For facilities transitioning into D&D, the safety basis of the D&D operations is documented throughout a DSA. This DSA, of which the principal emphasis is on the D&D operations themselves, provides the necessary analysis and supporting information to describe the facilities as they undergo shutdown, deactivation, decontamination, and decommissioning or dismantlement. The facility consists of the physical building, its constituent components, and the actual processes of D&D being performed. Physical buildings and constituent components targeted for D&D are briefly described in chapter 2, “Facility Description.” Detailed descriptions are reserved for the actual D&D processes, which are the focus of evaluation in chapter 3, “Hazard and Accident Analysis,” and chapter 4, “Safety Structures, Systems, and Components,” for each stage of major configuration change. Also included are the temporary engineering and administrative controls used to maintain the safety basis. This description and evaluation would envelop major configurations during the D&D operations for which the authorization basis is sought. This is consistent with the intent of DSAs for operating facilities where all operations conducted are not detailed in the DSA. DSAs for D&D describe in chapter 16, “Provisions for Decontamination and Decommissioning,” assurances that the D&D operations for which approval is being sought are effectively planned and will not result in future, unnecessary D&D activities.

41. A facility representative must demonstrate a working level knowledge of the training and qualification requirements for facility personnel.

a. Describe the five elements of a systematic approach to training described in DOE O 426.2, Personnel Selection, Qualification, and Training Requirements for DOE Nuclear Facilities.

The basic elements of a systematic approach to training include the following:

_A Systematic Analysis of the Jobs to be Performed_

Analysis typically involves the conduct of job analysis, needs analysis, or both; job analysis to determine tasks for training, and needs analysis to distinguish between actual and desired performance and to propose workable solutions. The analysis should include normal and emergency duties. Program goals are then established and the scope of training program content is defined.
A graded approach should be used when analyzing jobs. Experience with the conduct of job and task analysis has shown that detailed methods are rarely needed. Rather, using qualified trainers and SMEs, more simplified methods can produce equivalent results as effectively and more efficiently. One method that can be used to conduct a job analysis is the table-top job analysis method. This is a method where a team of trainers, SMEs, and supervisors meet to identify duty areas involved in a specific job, tasks performed within each duty area, and tasks that should be included in the training program.

The resulting task list typically ranges from the teens to approximately 250 tasks with the average being 125 - 150 for an operator or maintenance program. At non-reactor nuclear facilities where operator positions are sometimes more narrowly defined than a reactor operator job, the average is less. The verification and modification of task lists from similar facilities and jobs has also been found to be an effective method of job analysis.

Similarly, table-top methods can also be used to derive learning objectives from task lists. These methods are less time consuming, more cost effective, and are usually self-validating. Because of varied complexity and scope of job functions, the degree of analysis necessary to define training program content will vary. For example, a job and needs analysis may be appropriate for operations and maintenance personnel, whereas a less formal broad-based assessment of training needs is appropriate for technical staff personnel.

Job analyses need not be conducted for technical staff personnel. Consensus-based content guides should be used to assist with the determination of technical staff training program content. This method may also be sufficient to determine training program content for operating organization positions at many category 3 hazard nuclear facilities.

Learning Objectives Derived From the Analysis of the Job That Describe Desired Performance After Training

Learning objectives define the content of the training program. They are derived from task statements and represent the knowledge and skills necessary to perform the job. The objectives are organized into instructional units and sequenced to aid in the learning process. The objectives form the “blueprint” which guides the development of all training materials, tests, and strategies.

Objectives are determined using one or more content analysis techniques. The most common techniques include verification analysis, document analysis, templating, detailed task analysis, or group brainstorming. In most cases the learning objectives, which address the knowledge and skills necessary to perform the task, can be developed directly from the task list and do not require additional analysis. A graded approach should be used to select the most effective technique for determining the learning objectives. For example, experience has shown that detailed task analysis is not necessary when good operating procedures exist or if improper performance of the task is of low consequence. Group brainstorming or a joint review of the procedure by a trainer and a SME can produce acceptable results.

Training Design, Development, and Implementation Based on the Learning Objectives.

Materials are developed to conduct training. The materials should reflect good instructional design and incorporate methods and activities that maximize knowledge and skill retention.
Development of additional learning objectives, and in some cases, rewording of objectives also occurs. A graded approach should be used to develop training materials. For example, the training materials used to guide discussions with technical staff trainees could include a one-page outline of the lesson content that includes the key points and a student handout to distribute. The level of detail should take into account the job position and experience of the designated instructor. This approach may also be sufficient for much of the training that is conducted at category 3 hazard nuclear facilities. Training/evaluation standards are also developed to provide guidance for on-the-job training (OJT). Additional activities include development of test items and examinations.

Technical and instructional reviews of the products that are developed should be conducted. Recommendations resulting from these reviews should be incorporated as necessary to ensure that program content is both technically and educationally sound.

Program implementation consists of activities related to the actual conduct of training, as well as resource allocation, planning, and scheduling. Implementation requires assigning instructors and support staff, scheduling training and facilities, and conducting training.

**Evaluation of Trainee Mastery of the Objectives During Training.**

Mastery of the learning objectives by the trainees should be evaluated periodically during the training. Evaluation methods include oral questioning, written examinations, and performance of related tasks by the use of evaluation instruments. Evaluations should be content valid, administered consistently, controlled, and documented as appropriate to the level of assurance needed.

Content-valid examinations are examinations that accurately and consistently measure the associated learning objectives. A graded approach should be used during evaluation. For example, structured on-the-job familiarization can be used in lieu of formal on-the-job evaluation for managers, non-certified supervisors, and technical staff personnel. Much of the training for managers, non-certified supervisors, and technical staff personnel occurs in nontraditional settings such as discussions with individual managers. In addition, learning objectives for managers, non-certified supervisors, and technical staff personnel may not be readily adaptable to prescribed standards or quantitative testing. In such instances, qualitative evaluations are acceptable. For example, trainee mastery could be assessed from responses during discussions, behavior during role-playing, or material developed during training exercises. Qualitative evaluations may also be used to assess trainee mastery of learning at category 3 hazard nuclear facilities.

**Evaluation and Revision of the Training Based on the Performance of Trained Personnel in the Job Setting.**

Evaluation provides the critical feedback loop to ensure the training is up to date and reflects the requirements of the job.

Specifically, training programs are evaluated for program and lesson content adequacy, test adequacy, presentation adequacy, documentation adequacy, and post-training job performance. In addition, the operating performance of job incumbents should be monitored to determine individual strengths and weaknesses. The feedback received from the evaluation process is used to modify and improve program content and delivery. Program content
should be periodically monitored and revisions should be made to include changes in areas such as policies and/or procedures, system or component design, job requirements, regulatory requirements, and industry guidelines or commitments.

Adjustments should also be made as a result of reviews of operating experience information such as occurrence reports, inspection reports, information notices, and bulletins. Feedback obtained from instructors, students, and supervisors is also reviewed for its potential impact on future training programs. The results are translated into action items or recommendations which are factored into program content.

b. Discuss the relationship between training, risk, and safe facility operations.

The following is taken from DOE Order 5480.20A.

At those nuclear facilities for which a probabilistic risk assessment has been performed, initial and continuing training programs for operations and technical staff personnel shall include training on the principal results of the probabilistic risk assessment. This training shall address the following:

- The importance of facility systems in preventing damage or severe accidents
- Locations of all significant amounts of radioactive and other hazardous materials, and measures to prevent its release
- The importance of maintaining operational limits and conditions, and the consequences of violating those limits

c. Discuss key elements of an effective on-the-job training program as described in DOE-HDBK-1206-98, Guide to Good Practices for On-the-Job Training.

DOE-HDBK-1206-98 briefly addresses each phase of the systematic approach to training process. Where appropriate, specific guidance for OJT and OJT programs is presented. These processes can normally produce equivalent results more efficiently than the more traditional methods that have been used.

Analysis Phase

Training requirements can be identified by performing needs analysis, job analysis, and/or task analysis. Analyses form the basis for determining training needs, developing and maintaining valid task lists, and selecting tasks that must be trained on. To facilitate tracking and revisions of training materials on the basis of facility or procedural changes, task lists are entered into systems such as task-to-training matrices. Correctly done, these analyses provide assurance that training is appropriate for the expected performance and identify requirements that serve as the basis for the design and development of OJT programs.

Design Phase

Design phase activities include writing of terminal objectives, selection of appropriate training settings, and development of training/evaluation standards (TES) for each task selected for training. It is during the development of the TES that the bulk of the tasks are further analyzed, enabling objectives are written, and decisions are made regarding how training will be conducted and evaluated. On-the-job training may be conducted using...
general instructions and task specific evaluation materials for low-hazard potential facilities or tasks.

When writing a terminal objective, the training setting must be considered. The training setting selected should be consistent with the task, but balanced against available resources and facility constraints.

Training/Evaluation Standards
A TES is developed for each task selected for training. The TES specifies elements, criteria, and conditions required for adequate task performance. Each TES contains two parts: a training standard and an evaluation standard. The training standard contains the task title, the terminal and enabling learning objectives, and any applicable references. The information in the training standard is used to establish entry-level requirements and forms the basis for training development activities. The evaluation standard contains a performance test that includes prerequisites, amplifying conditions and standards, and instructions to the trainee and the evaluator. The evaluation standard defines the conditions that signal a person to perform a specific task, establishes conditions under which actions occur, and establishes standards that measure knowledge and performance. It may be practical to combine the information contained in the training and evaluation standards into one document or include it in a qualification card or checklist.

Instructors and training material designers/developers should design each evaluation standard so that different OJT instructors will administer the test consistently. The test should require actual task performance if possible.

The methods of conducting OJT and the required level of accomplishing performance testing is determined during the TES development process. The acceptable level of accomplishment should be specified in each TES. Certain tasks should require that a trainee demonstrate achievement of the terminal objective through actual task performance. A core of tasks that must be performed should be identified by line and training management. These tasks are typically over-train tasks or those that may be critical to safety.

Ultimately, the training and performance testing an employee receives should lead to qualifying that individual to perform the task. Therefore, the majority of tasks should be performance coded as either perform or simulate. Observe and discuss are primarily used for knowledge assessments.

Development Phase
Development phase activities include the writing of training materials such as OJT checklists, qualification standards, and OJT guides. Additional activities include the selection and training of OJT instructors. The specifications generated in the design phase are used to develop an OJT program and all required training materials. Care should be taken to keep OJT materials simple and usable.

On-the-job training checklists that are specific to an individual OJT program should be developed to document training and performance testing. The OJT checklists should be based on knowledge and skills required by the training and evaluation standards. Required level(s) of accomplishing performance testing should be specified for each task.
While many options exist for the format of an OJT checklist, only two general formats will be discussed. The first, and probably the most common, is simply a list of all the tasks required for qualification and the required level of performance test accomplishment. The OJT checklist is used as a signature record card to document the performance testing for each task. The completion of training for each task should also be documented on the OJT checklist. An OJT checklist should reference the OJT guides used to conduct the training and the evaluation standards used to conduct the performance tests. If the trainee must be trained and performance tested on a number of tasks to become qualified, this format is usually the best.

A second format used by some facilities includes each task’s evaluation standard as a part of the OJT checklist. This format may result in a much larger OJT checklist. If a facility qualifies trainees on a duty area or a task basis, this approach may be workable.

The use of an OJT checklist that has two instructor signatures for each task helps to ensure that OJT is conducted and evaluated as a two-part process. The trainee is taught the task using an OJT guide and is then performance-tested using the evaluation standard.

The OJT checklists may contain tasks that have simulate and perform specified as the acceptable levels of accomplishment. At the time of conducting the OJT and/or the performance test, the OJT instructor should select the highest level of accomplishment that is supported by facility conditions. The OJT guide and the evaluation standard for a task that has multiple levels of accomplishment should be written to support the training and the evaluation at either level of accomplishment.

For tasks with a single level of accomplishment, there may be times that facility conditions do not support performance testing at the specified level of accomplishment. If this is the case, the instructor should inform the OJT program coordinator. The program coordinator may then reschedule the performance test or, with management’s documented concurrence, the specific level of performance test accomplishment may be lowered. This documented concurrence should be attached to, and become a permanent part of, the trainee’s OJT checklist.

Qualification Standards
Qualification standards are documents that contain the knowledge and skill requirements necessary for the successful completion of a training program. A qualification standard should provide explicit guidance to the instructor and to the trainee to aid in the preparation for and the consistent administration of performance tests. A qualification standard should include all program-specific evaluation standards to be used during performance testing. Facilities that qualify employees on a task basis need not develop a qualification standard. In this case, the OJT instructor and the trainee only need the task’s evaluation standard.

A qualification standard should be prepared consistent with the program’s OJT guides and evaluation standards. It should list the specific procedures and training resource materials required for each task. This type of information may also be specified on the qualification card/checklist or in other training documents or procedures. The qualification standard may also include reading assignments, self-study requirements, study questions, problem analysis exercises, figures and diagrams, and amplifying information. Qualification standards should
Trainees in an OJT program that requires self-study should find the qualification standard a very useful document. It provides them with information on what to study, where this information may be found, and guidance on what they need to learn. A qualification standard should contain a section that provides a trainee entering an OJT program with information on how that specific program operates, what will be expected of him/her, and how/where to obtain training-related help. It should provide information regarding the use of the OJT checklist and how to use the qualification standard.

On-the-Job Training Guides
Performance-based training programs should require the use of OJT guides to ensure consistent delivery of training. An OJT guide is a document that outlines instructor and trainee activities, learning objectives, training content, and the resources necessary for the consistent conduct of training. The contents of an OJT guide for a specific task should be based on the training standard portion of the TES. An OJT guide should identify trainee prerequisites, learning activities, training equipment, and materials needed for training and specific guidance for their use. The OJT guides also provide specific direction to the instructor for guiding the learning process.

Some may question the necessity of OJT guides for OJT. However, one of the most frequently asked questions is “How can we ensure consistent training from one instructor to the next?” One way to ensure this is by the use of the OJT guide. It may be a part of the OJT qualification card/checklist or a stand-alone document. In either case it should reference the specific task it supports and should be organized and formatted to enhance the one-on-one learning process.

The OJT guides should not contain copies of facility procedures. Rather, they should reference the appropriate procedures and provide the instructor with task specific guidance that enhances the learning process. It should not include generic instructions that would be more appropriate in a training procedure or other type of guidance document. This practice helps ensure that the system/facility is operated only with approved procedures, rather than with training materials, and will minimize revisions to the OJT guide as facility procedures are revised.

The OJT guides should be prepared with the assistance of the OJT instructor serving as the SME. They should be reviewed by an additional SME who was not directly involved in their development, and should be approved prior to use by supervisory members of the training staff and the management of the work group for which the training was developed.

There are numerous factors that can have a significant influence on a trainee’s learning and motivation during the OJT process. Instructors or training material designers/developers should use these factors as they develop OJT guides.

There are many OJT guide formats that could be successfully used for OJT. The OJT guides normally consist of a cover page, a body, and a conclusion. It should be noted that much of
Instructor Selection and Training
The credibility of a training program (and OJT programs in particular) depends on the quality of the instructors. The OJT instructors should be qualified to deliver OJT and/or conduct performance tests. The selection of OJT instructors is the responsibility of each facility’s line and training management; however, first-line supervisor and senior job incumbents are the recommended first choices for OJT instructors.

Several factors should be considered when selecting OJT instructors. The instructors should be technically competent. They should have the skills necessary to train and evaluate assigned trainees. Additional factors to be considered when selecting OJT instructors include: recognition of responsibilities, professionalism, maturity, judgment, integrity, safety awareness; communication skills, personal standards of performance, and a commitment to quality.

The options normally available for selecting OJT instructors are the first-line supervisors and senior job incumbents or an instructor from the training organization. The supervisors and senior job incumbents are usually SMEs who supervise or perform the job. As such, they have first-hand knowledge of the job. An instructor from training may well be an expert on training but will typically not be as knowledgeable or proficient in the specifics of the job as an SME. It is usually better to train the supervisor or senior incumbent to be an effective instructor than to train the instructor to be a job expert. When OJT is conducted and evaluated using facility equipment, the instructor must be qualified to perform the task.

The OJT instructors should receive instructor training in advance to allow sufficient time to develop instructor competency prior to working with trainees. When instructors have not yet attained the required instructional qualifications or only instruct occasionally, training quality may be maintained through mock training exercises and appropriate supervision and assistance.

All OJT instructors should be given the opportunity to enhance their technical competency and instructional skills. Continuing training that is based on periodic instructor performance evaluations should be provided to all qualified instructors. Instructor evaluations should include direct observation by training and operations supervision during training sessions, and should address technical competency, instructor skills, and overall effectiveness in facilitating the trainee’s achievement of the learning objectives. Announced and unannounced evaluations are appropriate.

Implementation Phase
Implementation phase activities for an OJT program include implementing the OJT program’s administrative guidance, assigning an OJT coordinator, implementing the OJT program, conducting in-training evaluations, and maintaining training records.

Each OJT program at a DOE facility may have many instructors for training and performance testing. However, one person from the line organization staff or the training organization staff should be designated to perform the functions of an OJT program coordinator. These
OJT program coordinator functions may be one part of an individual’s job. An OJT program coordinator may have responsibility for one or more OJT programs.

Implementing an OJT program involves evaluating the knowledge and skills of trainees entering an OJT program to determine if they meet the entry-level requirements for that specific OJT program. When trainees enter the OJT program, they need to learn how the program operates and what will be expected of them. They should be provided with an OJT checklist, a qualification standard, and other supporting self-study materials.

Key factors in successful OJT instruction and performance testing (implementation) include the following:
- The learning objectives should be clearly understood by the instructor and the trainee.
- The standards for successful completion of the training should be clearly understood by the instructor and the trainee.
- The instructor should have the knowledge and the ability to instruct and evaluate the trainee in accordance with the learning objectives and performance tests.
- The training and the performance tests should be documented to meet training record requirements and to provide feedback to the training program.

**Evaluation Phase**

The evaluation phase of performance-based training takes place to determine the effectiveness of training programs and to identify program changes that may be required.

An OJT program’s content should be continuously monitored and revised as a result of changes affecting policies and/or procedures, system or component design, job requirements, regulatory requirements, and industry guidelines or commitments. Facility and industry operating, maintenance, and safety experiences should be monitored to identify employee performance problems.

If training related employee performance problems exist, the solution may involve repeating portions of the analysis, design, and development activities and revision of existing materials. Because of the work and cost involved, the decision to modify the training program should first be based on safety considerations and then on a cost versus benefit basis. To ensure that programs remain effective and efficient, management’s concurrence on all programmatic changes should be required.

d. **Using guidelines provided in the applicable DOE standard or handbook as a reference, observe and evaluate a contractor training evolution (e.g., technical staff training, written or oral examination, on-shift training, etc.).**
   - DOE-STD-1040-93 CN1, *Guide to Good Practices for Control of On-Shift Training*
   - DOE-STD-1070-94, *Guidelines for Evaluation of Nuclear Facility Training Programs*
This is a performance-based KSA. The Qualifying Official will evaluate its completion.

e. Perform an assessment of one element of the contractor training program

This is a performance-based KSA. The Qualifying Official will evaluate its completion. The following taken from DOE-STD-1070-94 may be helpful.

The objectives and criteria for evaluation of training programs describe the expected results of an effective, well-managed training program. The objectives address

- management and administration of training and qualification programs;
- development and qualification of training staff;
- trainee entry-level requirements;
- determination of training program content;
- design and development of training programs;
- conduct of training;
- trainee examinations and evaluations; and
- training program evaluation.

The criteria are principles or methods that support the objectives and are to be applied with judgment. The expectation is that all objectives will be met. However, some criteria may not be applicable to some programs. This situation would prevail when, for example, a particular method such as laboratory training is not used. The evaluator must choose the objective and associated criteria to accomplish the scope of the assessment that is to be performed. The method chosen to meet the objectives and criteria is determined by the contractor.
42. A facility representative must demonstrate a working level knowledge of conduct of operations principles and DOE requirements to ensure facility operations are performed in a safe and efficient manner.

a. Explain the DOE-s role in the oversight and implementation of the contractor’s conduct of operations program.

The following is taken from DOE O 422.1.

DOE’s role is to provide requirements and guidelines for departmental elements to use in developing directives, plans, and/or procedures relating to the conduct of operations at DOE facilities. The implementation of these requirements and guidelines should result in improved quality and uniformity of operations.

It is the policy of the Department that the conduct of operations at DOE facilities be managed with a consistent and auditable set of requirements, standards, and responsibilities consistent with the requirements of this Order:

- Operations at DOE facilities must be managed, organized, and conducted in a manner to assure an acceptable level of safety.
- Operators at facilities must have procedures in place to control the conduct of their operations.
- Line organizations must review existing and planned programs important to safe and reliable facility operations.
- Line organizations must assess the effectiveness of corporate directives, plans, or procedures at facilities under their cognizance.

b. Describe the FR’s role relative to conduct of operations at DOE facilities as is provided in DOE O 422.1, Conduct of Operations.

The following is taken from DOE O 422.1.

The facility representative is an individual assigned responsibility by the field element manager (or designee) for monitoring the safety performance of the facility and its operations. This individual is the primary point of contact with the contractor for operational and safety oversight and is responsible to the facility’s DOE line manager.

c. Describe contractor responsibilities associated with implementing the conduct of operations at DOE facilities.

Each DOE contractor shall use DOE O 422.X, Conduct of Operations, and associated standards in the review and development of existing and proposed directives, plans, or procedures relating to the conduct of operations at DOE facilities.

d. Explain the general and specific requirements of conduct of operations associated with DOE O 422.1:

- Organization and administration
- Shift routines and operating practices
- Control area activities
- Communications
- Operator training
Investigation of abnormal events, conditions, and trends
Notifications
Control of equipment and system status
Lockout and tagouts
Independent verification
Logkeeping
Turnover and assumption of responsibilities
Control of interrelated processes
Required reading
Timely instructions/orders
Procedures
Operator aid postings
Component labeling

Note: For specifics, refer to the DOE Standard that is referenced in DOE O 422.1 for each of the following areas:

Organization and Administration
The contractor must establish policies, programs, and procedures that define an effective operations organization, including
- organizational roles, responsibilities, authority, and accountability;
- adequate material and personnel resources to accomplish operations;
- monitoring and self-assessment of operations;
- management and worker accountability for the safe performance of work;
- management training, qualification, and succession;
- methods for the analysis of hazards and implementation of hazard controls in the work planning and execution process; and
- methods for approving, posting, and controlling access to electronic operations documents if electronic documents are used.

Shift Routines and Operating Practices
The contractor must establish and implement operations practices to ensure that shift operators are alert, informed of conditions, and operate equipment properly, addressing
- prompt notification to operating personnel and supervisors of changes in the facility status, abnormalities, or difficulties encountered in performing assigned tasks;
- operating personnel and other workers’ adherence to established safety requirements;
- operating personnel awareness of the status of equipment;
- procedures for completing round sheets or inspection logs, responding to abnormal conditions, and periodic supervisory reviews of round sheets or inspection logs;
- procedures for protecting operators from personnel hazards;
- prompt response to instrument indications;
- procedures for resetting protective devices;
- authorization to operate facility equipment;
- designating shift operating bases and providing equipment for them; and
- professional and disciplined operator performance of duties.

Control Area Activities
The contractor must establish and implement operations practices that promote orderly, business-like control area operations and address
- control-area access
- formality and discipline in the control and at-the-controls areas
- surveillance of control panels and timely response to determine and correct the cause of abnormalities/out-of-specification conditions
- limitation of the number of concurrent evolutions and duties
- authorization to operate control area equipment

**Communications**

The contractor must establish and implement operations practices that ensure accurate, unambiguous communications among operations personnel and address
- provision of communications systems for emergency and normal operations
- administrative control of communications equipment
- methods for control areas to contact operators and supervisors
- use of abbreviations and acronyms
- use of oral instructions and communications

**Operator Training**

The contractor must establish and implement operations practices that control training of facility operators, prevent inadvertent or incorrect manipulation of equipment, and address
- operator training program
- authorization and documentation of training activities
- supervision and control of personnel under instruction by qualified personnel
- facility conditions and controls for conducting training during operational activities

**Investigation of Abnormal Events, Conditions, and Trends**

The contractor must establish and implement operations practices for investigating events to determine their impact and prevent recurrence, addressing
- specific events requiring investigation, and criteria for identifying other events or conditions to be investigated
- designation of investigators and their training and qualification
- investigation process and techniques
- root cause and corrective action determination
- event investigation reporting, training, and trending
- response to known or suspected sabotage

**Notifications**

The contractor must establish and implement operations practices to ensure appropriate event notification for timely response, addressing
- procedures for internal, DOE/NNSA, and external notifications;
- communications equipment for notifications

**Control of Equipment and System Status**

The contractor must establish and implement operations practices for initial equipment lineups and subsequent changes to ensure facilities operate with known, proper configuration as designed, addressing
- authorization for, and awareness of, equipment and system status changes;
initial system alignment, maintaining control of equipment and system status through startup, operation, and shutdown, and documentation of status;
- use and approval of lockouts and tagouts for administrative control of equipment status;
- operational limits compliance and documentation;
- management of equipment deficiencies, maintenance activities, post-maintenance testing, and return to service;
- awareness and documentation of control panel and local alarm issues;
- evaluation and control of the installation and removal of temporary equipment modifications or temporary systems; and
- configuration control and distribution of engineering documents.

**Lockout and Tagouts**

The contractor must establish and implement operations practices that address the following elements for the installation and removal of lockout/tagouts for the protection of personnel:
- Procedures, roles and responsibilities associated with the development, documentation, review, installation, and removal of a lockout/tagout
- Compliance with Occupational Safety and Health Administration Rules 29 CFR 1910 and/or 29 CFR 1926, “Safety and Health Regulations for Construction” requirements for the protection of workers using lockout/tagout
- Compliance with National Fire Protection Association Standard 70E electrical safety requirements using lockout/tagout
- Description and control of the tags, locks, lockboxes, chains, and other components used for the lockout/tagout program
- Training and qualification in lockout/tagout and special considerations for DOE facilities, i.e. seismic issues and operational limitations

The contractor must establish and implement operations practices that address the following elements for the installation and removal of caution tags for equipment protection or operational control:
- Roles and responsibilities associated with the development, documentation, review, installation, and removal of caution tags to convey operational information or equipment alignments for protection of equipment
- Description and control of the tags
- Measures to prevent relying on caution tags for personnel protection

**Independent Verification**

The contractor must establish and implement operations practices to verify that critical equipment configuration is in accordance with controlling documents, addressing
- SSCs, operations, and programs requiring independent verification;
- situations requiring independent verification;
- methods for performing and documenting independent verification;
- situations, if any, allowing concurrent dual verification; and
- methods for performing concurrent dual verification, if used.
Logkeeping
The contractor must establish and implement operations practices to ensure thorough, accurate, and timely recording of equipment information for performance analysis and trend detection, addressing
- narrative logs at all key positions, as defined by management, for the recording of pertinent information;
- prompt and accurate recording of information;
- type, scope, and format for log entries;
- method for recording late entries and correcting erroneous entries without obscuring the original entry;
- periodic supervisory reviews for accuracy, adequacy, and trends; and
- document retention requirements.

Turnover and Assumption of Responsibilities
The contractor must establish and implement operations practices for thorough, accurate transfer of information and responsibilities at shift or operator relief to ensure continued safe operation, addressing
- definitions for all key positions requiring a formal turnover process;
- turnover of equipment/facility status, duties, and responsibilities that results in the safe and effective transfer of equipment status and in-progress or planned activities from one shift or workgroup to the next;
- process for reliefs during a shift.

Control of Interrelated Processes
The contractor must establish and implement operations practices to ensure that interrelated processes do not adversely affect facility safety or operations, addressing
- defined responsibilities with respect to the control of interrelated processes;
- operator training and qualification to understand interrelated processes, to interpret instrument readings, and provide timely corrective action for process-related problems; and
- established lines of communication between operating personnel, process support personnel, and other interrelated process operators for coordination of activities.

Required Reading
The contractor must establish and implement operations practices for an effective required reading program to keep operators updated on equipment or document changes, lessons learned, or other important information, addressing
- identification of material to be distributed via required reading
- identification of which personnel are required to read specific required reading items
- distribution of required reading to appropriate personnel and documentation of their timely completion

Timely Instructions/Orders
The contractor must establish and implement operations practices for timely written direction and guidance from management to operators, addressing
- appropriate circumstances for the use of timely instructions/orders
- designated levels of review and approval prior to issuance
- configuration control of timely instructions/orders
- distribution of timely instructions/orders to appropriate personnel and documentation of their receipt and understanding

**Procedures**

The contractor must establish and implement operations practices for developing and maintaining accurate, understandable written procedures that ensure safe and effective facility and equipment operation, addressing

- expectations for the use of procedures to perform operations;
- a process for procedure development and validation/verification;
- procedure content, including consistent format and use of terms, detail sufficient for accomplishing the operation, technically accurate procedures capable of performance as written, and procedure conformance with the facility design and manufacturer documentation;
- a process for procedure changes and revisions;
- a process for training personnel on new, revised, or changed procedures;
- a process for approval of new, revised, or changed procedures;
- new-issue and periodic reviews of procedures;
- availability and use of the latest revisions of procedures; and
- specified and defined procedure use requirements.

**Operator Aid Postings**

The contractor must establish and implement operations practices to provide accurate, current, and approved operator aids, addressing

- technical evaluation and management approval of operator aids;
- operator aids that do not obscure equipment, and serve as conveniences, not operational requirements;
- administrative control of installed operational aids; and
- periodic review for adequacy and correctness.

**Component Labeling**

The contractor must establish and implement operations practices for clear, accurate equipment labeling, addressing

- components that require a label;
- label information that uniquely identifies components and is consistent with regulations, standards, and contractor documents;
- durable and securely attached labels that do not interfere with controls or equipment; and
- administrative control of labels, including a process for promptly identifying and replacing lost or damaged labels, preventing unauthorized or incorrect labels, and control of temporary labels.

e. **Explain the relationship between the specific requirements provided in DOE O 422.1 and the associated technical standard or publication:**

- **DOE-STD-1032-92 CN1, Guide to Good Practices for Operations Organization and Administration**
- **National Institute of Standards and Technology Special Publication 800-44, Guidelines on Securing Public Web Servers**
This guide to good practices is written to enhance understanding of, and provide direction for operations organization and administration, as described in DOE O 422.1. The practices in this guide should be considered when planning or reviewing operations organization and administration programs. Contractors are advised to adopt procedures that meet the intent of DOE O 422.1. This standard should be used in conjunction with principles of the ISMS as incorporated in DOE G 450.4-1.

Operations organization and administration is an element of an effective conduct of operations program. The complexity and array of activities performed in DOE facilities dictate the necessity for well-defined standards and requirements for safe and efficient operations.

National Institute of Standards and Technology Special Publication 800-44, Guidelines on Securing Public Web Servers

This document is intended to assist organizations in installing, configuring, and maintaining secure public Web servers. More specifically, this document describes, in detail, the following practices to apply:

- Securing, installing, and configuring the underlying operating system
- Securing, installing, and configuring Web server software
- Deploying appropriate network protection mechanisms, such as firewalls, routers, switches, and intrusion detection and intrusion prevention systems
Maintaining the secure configuration through application of appropriate patches and upgrades, security testing, monitoring of logs, and backups of data and operating system files

Using, publicizing, and protecting information and data in a careful and systematic manner.

**DOE-STD-1041-93 CN1, Guide to Good Practices for Shift Routines and Operating Practices**

This guide to good practices is written to enhance understanding of, and provide direction for, shift routines and operating practices. The practices in this guide should be considered when planning or reviewing shift routines and operating practices. Contractors are advised to adopt procedures that meet the intent of DOE O 422.

Recently, guidance pertaining to this element has been strengthened for nuclear power reactors. This additional guidance is given in appendix C for information purposes. Though this guidance and good practices pertain to nuclear power reactors, DOE sites may choose to use a graded approach for implementing these in nuclear facilities.

The objective and criteria are derived from DOE O 422.1. They are intended to aid each facility in meeting the intent of the Order.

Standards for professional conduct of personnel are established and followed so that personnel performance coincides with the expectations of DOE and facility management.

**Criteria:**

- Supervisors and other appropriate personnel are notified of changes in facility status.
- Personnel follow the facility’s industrial safety program.
- Personnel determine equipment status and area conditions during inspection tours.
- Round sheets are used to record facility parameters during inspection tours.
- Personnel maintain exposure to hazards as low as reasonably achievable.
- Personnel follow specific facility guidance and procedures when responding to abnormal instrument readings.
- Protective devices are reset using specific facility guidance and procedures.
- All power or process rate changes are approved by the cognizant supervisor.
- Personnel have proper authorization before operating any equipment.
- Personnel use an operating base to perform administrative duties and turnovers.
- Personnel read only authorized material.
- Personnel use only devices that relate to the operation of the facility.

**DOE-STD-1042-93 CN1, Guide to Good Practices for Control Area Activities**

The objective and criteria are derived from DOE O 422.1. They are intended to aid each facility in meeting the intent of the order.

Control area activities are conducted in a manner that achieves safe and reliable facility operation.

**Criteria:**

- Control area access is limited to only personnel on official business.
Professional behavior is displayed in the control area.
Main control panels are properly monitored.
Control area equipment is operated only by authorized personnel.
Ancillary duties assigned to control area personnel do not interfere with their ability to monitor facility parameters.

DOE-STD-1031-92 CN1, Guide to Good Practices for Communications
The objective and criteria are derived from DOE O 422.1. They are intended to aid each facility in meeting the intent of the Order.

Communications, both normal and emergency, are highly reliable and provide accurate transmission of information within the facility.

Criteria:
- Communication methods are implemented to ensure timely and reliable contact with essential personnel such as supervisors or on-shift operators.
- Only facility approved abbreviations and acronyms are used in facility communications.
- Communications are clear, concise, and correctly understood.
- Portable radio use is monitored and controlled to prevent electronic interference in sensitive instrument areas.
- A facility paging system is effectively used and controlled to ensure the impact of important announcements is not reduced.
- An emergency communications system is implemented to ensure all facility personnel are promptly alerted to facility emergencies.

DOE-STD-1040-93 CN1, Guide to Good Practices for Control of On-Shift Training
The objective and criteria are derived from DOE O 422.1. They are intended to aid each facility in meeting the intent of the Order.

Facility operation by personnel under instruction is carefully supervised and controlled to avoid mistakes by unqualified personnel, and training activities are conducted to ensure that the time is used effectively.

Criteria:
- The on-shift training process adheres to established training programs.
- Trainees are supervised by on-shift instructors who are currently qualified at the work station.
- Policies directing the use of trainees in support of operations activities are developed to ensure that trainees are effectively and appropriately used.
- The operations supervisor, or equivalent, approves training programs that best meet operations needs.
- On-shift training is appropriately documented.
DOE-STD-1045-93 CN1, Guide to Good Practices for Notifications and Investigation of Abnormal Events

The objective and criteria are derived from DOE O 422.1. They are intended to aid each facility in meeting the intent of the Order.

Notifications
A program is established to provide timely notifications to appropriate DOE personnel and other agencies to ensure that the facility is responsive to public health and safety concerns.

Criteria:
- Facility procedures are developed to ensure appropriate notifications.
- Notifications are appropriately documented.
- Adequate communications equipment is maintained to meet notification requirements.

Investigation of Abnormal Events
An established and thorough review process ensures that all significant aspects of an abnormal event are identified, investigated, and resolved.

Criteria:
- Facility guidelines identify specific events and near-miss situations that require investigation.
- Responsibilities for investigative tasks are understood by personnel.
- Personnel performing investigations are qualified in the facility’s investigative process through experience and training.
- Information required for the investigation is collected as soon as possible during and after the occurrence of the event.
- A structured review is performed to identify the root cause and corrective actions to prevent recurrence of each abnormal event.
- A timely and comprehensive investigative report is prepared and disseminated, including entry into the ORPS.
- Events are evaluated to determine what training is appropriate.
- Follow-up review is performed to evaluate the effectiveness of corrective actions and determine patterns of deficiencies.
- Acts of known or suspected sabotage are immediately investigated.

DOE-STD-1039-93 CN1, Guide to Good Practices for Control of Equipment and System Status

The objective and criteria are derived from DOE O 422.1. They are intended to aid each facility in meeting the intent of the Order.

Facility configuration is properly maintained by methods that control equipment and system status.

Criteria:
- The operations supervisor maintains proper facility configuration.
A system is in place to ensure and document proper alignment of equipment and systems prior to placing them in service.

A lockout/tagout program is in place to provide protection to personnel and equipment and to aid in the control of equipment and system status.

Administrative controls are established to document compliance with operational limits.

Operating personnel receive accurate information reflecting the status of control panel and local panel alarms.

A system is in place to document equipment deficiencies.

All activities on equipment that are important to safety, that affect operations, or that change control indications or alarms, are properly analyzed, documented, and authorized.

Operational testing is performed following maintenance to demonstrate that equipment and systems are capable of performing their intended function.

A system is in place to control temporary modifications to facility equipment or systems.

A document control system is in place that ensures operating personnel have the latest revision to documents necessary for proper control of equipment and systems.


The objective and criteria are derived from DOE O 422.1. They are intended to aid each facility in meeting the intent of the Order.

A lockout/tagout program is implemented to provide protection to personnel and equipment, and to aid in the control of equipment and system status.

Criteria:

- Locks and tags are used when controls must be established to protect personnel, equipment, or the environment.
- The facility lockout/tagout program is implemented through physical and administrative controls on sources of energy and hazardous materials.
- Protective materials and hardware are provided to control sources of energy and hazardous material.
- Procedures are developed and used to control and document the application of lockouts/tagouts.
- Lockout/tagout procedures provide instruction for all aspects of energy control.
- Requirements are specified for temporary or partial removal of a lockout/tagout for testing or equipment positioning.
- Periodic inspection and review of lockout/tagout implementation are performed.
- All personnel receive appropriate training in the safe application, use, and removal of lockouts/tagouts.
- The lockout/tagout program specifies actions that must be taken when other than facility personnel (e.g., vendors, subcontractors, etc.) perform work on equipment.
- The lockout/tagout program identifies any special requirements for maintenance performed under a group lockout/tagout.
- The lockout/tagout program identifies the requirements for transfer of lockout/tagout at shift change.
Caution tags are controlled similarly to tagout devices but are not used for energy isolation.

**DOE-STD-1036-93 CN1, Guide to Good Practices for Independent Verification**

The objective and criteria are derived from DOE O 422.1. They are intended to aid each facility in meeting the intent of the Order.

Independent verification activities are implemented by appropriate policies and procedures to ensure correct operation of facility equipment, and aid in the control of equipment and system status.

Criteria:
- Components critical to safe, reliable operation of the facility are identified as to their requirements for independent verification.
- Occasions requiring independent verification are identified through appropriate policies and procedures.
- Independent verification techniques are identified consistent with facility equipment and operational requirements.

**DOE-STD-1035-93 CN1, Guide to Good Practices for Logkeeping**

The objective and criteria are derived from DOE O 422.1. They are intended to aid each facility in meeting the intent of the Order.

A logkeeping program is in place to provide an accurate history of facility operations and to aid in controlling equipment and system status.

Criteria:
- Logs are established for key shift positions.
- Written guidance defines the type, scope, and format of entries for each log.
- Information is recorded in logs in a timely manner.
- Log entries are precise, legible, and easily understood by the reader.
- A standardized method is used for correcting errors in logs.
- Supervisors periodically review logs for accuracy and adequacy.
- Written guidance is provided for the disposition of completed log.

**DOE-STD-1038-93, Guide to Good Practices for Operations Turnover**

The objective and criteria are derived from DOE O 422.1. They are intended to aid each facility in meeting the intent of the Order.

Turnovers that provide on-coming personnel with an accurate status of their work stations are systematically performed.

Criteria:
- Supervisory personnel and specified work station operators use a checklist in the turnover process.
- On-coming personnel review specified documents prior to assuming responsibility for the work station.
- Walkdowns of appropriate control panels are conducted by on-coming personnel.
A discussion of facility status occurs between off-going and on-coming personnel prior to transferring work station responsibility.
- On-coming supervisors conduct personnel briefings as required.
- Turnovers occurring during the shift are as thorough as necessary to ensure a complete transfer of work station information.

**DOE-STD-1037-93 CN1, Guide to Good Practices for Operations Aspects of Unique Processes**

The objective and criteria are derived from DOE O 422.1. They are intended to aid each facility in meeting the intent of the Order.

A system is in place to ensure that the operation of interrelated processes is properly monitored and controlled.

**Criteria:**
- Personnel responsibilities are defined with respect to unique processes.
- Personnel are knowledgeable of unique processes and process interactions.
- Personnel are able to interpret parameters and provide timely corrective action for process-related problems.
- Lines of communication exist between operators and process support personnel to promote effective coordination of activities.

**DOE-STD-1033-9 CN12, Guide to Good Practices for Operations and Administration Updates Through Required Reading**

The objective and criteria are derived from DOE O 422.1. They are intended to aid each facility in meeting the intent of the Order.

A required reading program is in place to enhance personnel awareness of important information relevant to their job assignments.

**Criteria:**
- A list of the types of documents to be selected for required reading is developed.
- A system is in place that specifies documents to be read by applicable personnel, whose operations are impacted by such documents.
- Required reading documents are assigned a required completion date.
- Completion of reading assignments is documented and that documentation is retained.
- Periodic reviews are performed to ensure required completion dates are met.

**DOE-STD-1034-93 CN1, Guide to Good Practices for Timely Orders to Operators**

The objective and criteria are derived from DOE O 422.1. They are intended to aid each facility in meeting the intent of the Order.

A program is in place for operations management to communicate, in writing, short-term information and administrative instructions to personnel in a timely fashion.

**Criteria:**
- Operator orders are clearly written, dated, and maintained in an accessible location.
Operator orders are issued by the cognizant manager to communicate pertinent and relevant information to personnel.
Operator orders are segregated into daily and long-term orders.
Appropriate personnel periodically review operator orders and document their review.
Operator orders that are no longer applicable or are outdated are removed or cancelled by the cognizant manager.


A primary objective of operations conducted in the DOE complex is safety. Procedures are a critical element of maintaining a safety envelope to ensure safe facility operation.

This DOE Writer’s Guide for Technical Procedures addresses the content, format, and style of technical procedures that prescribe production, operation of equipment and facilities, and maintenance activities.

DOE is providing this guide to assist writers across the DOE complex in producing accurate, complete, and usable procedures that promote safe and efficient operations that comply with DOE Orders, including DOE O 422.1.

Successful procedures assist users by presenting actions clearly, concisely, and in the proper sequence. DOE-STD-1029-92 provides a method for writers to ensure the following key questions are addressed and that procedures contribute to maintaining safe operations:
- What technical and administrative requirements are to be met?
- Who is the user and what is the user's level of experience and training?
- How does this document relate to other procedures for this equipment and facility?
- What materials, equipment, and facilities are to be used?
- What tasks are to be accomplished?
- Why, when, where, and how are the tasks to be accomplished?

**DOE-STD-1043-93 CN1, Guide to Good Practices for Operator Aid Postings**

The objective and criteria are derived from DOE O 422.1. They are intended to aid each facility in meeting the intent of the Order.

An operator aid program is in place to ensure that operator aids are current, correct, and useful.

Criteria:
- Personnel follow guidelines for developing operator aids.
- Operator aids are approved prior to being posted.
- A list of approved operator aids, along with a reference copy of each operator aid, is maintained.
- Placement of operator aids adequately supports their intended use and does not obscure instrumentation or controls.
- Operator aids are a convenience to the individual using them.
- Operator aids are periodically reviewed for currency and relevance.
The objective and criteria are derived from DOE O 422.1. They are intended to aid each facility in meeting the intent of the Order.

An equipment labeling program is established and maintained to ensure that facility personnel are able to positively identify the equipment they operate.

Criteria:

- Equipment, components, and piping that require labeling are identified by the facility.
- Label information meets regulatory requirements and is consistent with facility procedures.
- Label materials and means of attachment are compatible with the components and environment where they are used.
- Labels are properly placed and oriented to enhance readability and component identification.
- Checks to verify that labels are correct are included in designated operating procedures.
- Procedures are established to replace lost or damaged labels and to acquire new labels when needed.
Selected Bibliography and Suggested Reading

**Code of Federal Regulations**

All About Circuits, Programmable Logic Controllers.
All Experts, Reid Technique, Factual Analysis.

**American National Standard Institute**
ANSI C95.1, *Safety Levels With Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz. 1999.*


GlobalSpec, *Pipe Hangers and Pipe Supports.*


HVAC Training Institute, *HVAC Startup, Test & Balance, Commissioning.*

**Integrated Publishing**

*Aviation: Moisture Separators.*

*Engine Mechanics, Pressure Control Valves*


Kettering University, Dependability of Distributed Control System Fault Tolerant Units.


Maintenance World, Drying Your Compressed Air System Will Save Real Money.


**National Fire Protection Association**


U.S. Army Corps of Engineers, Commissioning of Mechanical Systems for Command, Control, Communications, Computer, Intelligence, Surveillance, and Reconnaissance Facilities

**U.S. Congress**


**U.S. Department of Energy (DOE) Guides, and Manuals, Orders, and Policies**


DOE Guide 450.4-1B, *Integrated Safety Management System Guide (volumes 1and 2) for use with Safety Management System Policies (DOE P 450.4, DOE P 450.5, and DOE*
P 450.6); The Functions, Responsibilities, and Authorities Manual; and the DOE Acquisition Regulation. March 1, 2001.
DOE Order 430.1B, Real Property Asset Management. February 8, 2008.

U.S. Department of Energy (DOE) Handbooks and Standards


**Other DOE Documents**

**U.S. Environmental Protection Agency**
*Basic Concepts in Environmental Sciences*.

Vision Learning, *States of Matter*. 