(Part 3 of 5)

ALARA Training for Technical Support Personnel

Student's Guide

Coordinated and Conducted for Office of Safety, Health and Security U.S. Department of Energy

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I. MODULE 101

1. INTRODUCTION TO ALARA

A. Objectives.

Following self-study and classroom review, participants will be able to:

1. Define the acronym ALARA,
2. List the ALARA recommendations outlined in the DOE Radiological Control Standard (RadCon Standard), and
3. Identify which groups should participate in the ALARA design reviews.

2. DEFINITION AND PHILOSOPHY OF ALARA

A. ALARA.

ALARA stands for "As Low As Reasonably Achievable."

B. Definition.

ALARA is defined as an approach to radiation protection to manage and control doses (both individual and collective) to the work force and the general public such that doses are kept as low as is reasonable, taking into account social, technical, economic, practical, and public policy considerations. ALARA is not a dose limit but a process, which has the objective of maintaining dose levels as far below applicable limits of 10 CFR 835 and DOE Order 5400.5, Ch. 2, as is reasonably achievable.

C. Discussion.

The current system of radiological protection reflected in the National Council on Radiation Protection and Measurements (NCRP) Publication 116, *Limitation on Exposure to Ionizing Radiation* (NCRP 1993), is based on three general criteria.

1. The need to justify any activity which involves radiation exposure on the basis that the expected net benefits to society exceed the overall societal cost.

2. The need to ensure that the total societal detriment from such justifiable activities or practices is maintained ALARA, economic and social factors being taken into account.

3. The need to apply individual dose limits to ensure that the procedures of justification and ALARA do not result in individuals or groups of individuals exceeding levels of acceptable risk.

Although DOE has not formally adopted the recommendations of NCRP 116, these criteria are reflected in the RadCon Standard and 10 CFR 835.

D. Linear Nonthreshold Hypothesis.

The linear nonthreshold hypothesis assumes the risk of detriment from radiation is directly proportional to the dose and no threshold exists below which there is no detriment (damage). This theory is controversial because it is derived from extrapolation of low dose and low dose rate effects from high dose and high dose rate data. To ensure adequate protection, national and international groups have recommended, and DOE has adopted, a system of regulatory limits and an emphasis on ALARA to keep exposures as far below the limits as is reasonable.

E. No Fixed Numerical Criteria.

The ICRP states that there is no one set of numerical criteria universally applicable in determining whether a measure or practice is ALARA. Instead, such criteria should be derived on a case-by-case basis. Sometimes the criteria are applicable to one site or facility, and sometimes to a single task. ALARA measures should not be implemented without careful consideration of associated costs and benefits. Failure to evaluate the costs and benefits of a protective measure can be a waste of resources, or even result in unjustifiably increased dose along with its associated risk. An example of such a case is presented in Appendix F.

F. Responsibility.
According to DOE Orders, the responsibility for controlling exposures lies at every organizational level, including management, supervision, engineering, the radiological control department, and individual employees. This includes occupational doses AND doses to the public and the environment from DOE operations.

3. POLICIES, REGULATIONS, AND OTHER GUIDANCE

The principal objective of the ALARA policy is to reduce the dose to facility personnel and the public, and to reduce the levels of radioactive materials released to the environment to the lowest levels in keeping with sound operating and economic practices. DOE directives and technical documents that require that ALARA measures be incorporated into nuclear facility design include:

A. 10 CFR 835, "Occupational Radiation Protection."
Section 835.1001 requires that:

"(a) Measures shall be taken to maintain radiation exposure in controlled areas as low as is reasonably achievable through engineered features and administrative control. The primary methods used shall be engineered features (e.g., confinement, ventilation, remote handling, and shielding). Administrative controls and procedural requirements shall be employed only as supplemental methods to control radiation exposure;

(b) For specific activities where use of engineered features is demonstrated to be impractical, administrative controls and procedural requirements shall be used to maintain radiation exposures ALARA."

Facility design and modification per 835.1002:

1. In areas of continuous occupational occupancy (2,000 hours per year) the design objective shall be to maintain dose rate levels below an average of 0.5 mrem (5 μSv) per hour and as far below this average as is reasonably achievable.

2. The design objectives for exposure to a radiological worker where occupancy differs from that above shall be ALARA and shall not exceed 20 percent of the applicable standards (10 CFR 835).

10 CFR 835.101(c) requires that the Radiological Protection Program shall include formal plans and processes for implementing ALARA. Also, DOE O 420.1, *Facility Safety,* sets ALARA design criteria.

B. DOE Radiological Control (RadCon) Standard.

1. The RadCon Standard recommends the following:

   a. Individual worker dose should be less than 500 mrem/yr;

   b. Discharges of radioactive liquid to the environment are covered by DOE 5400.5 and should not degrade the ground water;

   c. Control of contamination should be achieved by containment of radioactive material (Note: Ventilation is an alternative, if filtered, for control of particulates);

   d. Efficiency of maintenance, decontamination, operations, and decommissioning shall be maximized;

   e. Components should be selected to minimize the buildup of radioactivity;

   f. Support facilities shall be provided for donning and removal of protective clothing and for personnel contamination monitoring, when required; and

2. The RadCon Standard emphasizes engineered controls over administrative controls, especially to minimize the need for respiratory protection.

3. Operational planning and review of work is emphasized.

4. ALARA training for procedure writers, engineers, and planners is specifically recommended.

5. Records of ALARA planning are to be kept.

C. DOE Order 5400.5.

DOE Order 5400.5, Ch. 2, "Radiation Protection of the Public and the Environment," gives specific dose limits for the general public, such as limits on the releases of radioactive materials in airborne and waterborne effluents from DOE nuclear facilities to the environment. This order also requires contractors to implement the ALARA process (i.e., cost-benefit/optimization analysis) for all DOE activities and facilities that cause public doses. The actual doses should be as far below the limits as is reasonably achievable.

D. PNL-6577.

PNL-6577, "Health Physics Manual of Good Practices for Reducing Radiation Exposures to Levels that are ALARA," states that ALARA should be incorporated into the earliest stages of the design of a building or operation and that a radiological engineer or ALARA specialist should be on the design team from the beginning. The design or operation should be reviewed at each of the appropriate stages, and any team reviewing the design or operation should include representatives from:

1. Maintenance,
2. Operations,
3. Research,
4. Safety, and
5. Appropriate engineering disciplines.

PNL-6577 also states that design and operations engineers, as well as other groups, should be trained in the principles of ALARA.

Engineers must be aware of pitfalls or questionable practices to participate intelligently in ALARA reviews, and all disciplines should understand any radiological implications their equipment or operations may have.

Much design time can be saved if the engineer knows some of the good practices in advance, and the engineer trained in ALARA becomes more aware of what is contained in available references regarding good design or operation. Radiological engineers probably will not have the necessary expertise to make ALARA judgments in all engineering areas (e.g., HVAC, electrical, mechanical, architectural); this will most often be a consensus decision of a facility or operational project or a design team.

4. SITE SPECIFIC ALARA DESIGN REQUIREMENTS

Add materials here based on review of site procedures relating to safety reviews and design criteria.

II. MODULE 102

1. TYPES OF RADIATION

A. Objectives.

Following self-study and/or classroom review, participants will be able to define and identify the penetrating abilities in body tissue of:

1. Alpha,
2. Beta,
3. Gamma and X-rays, and
4. Neutron radiation.

2. RADIOACTIVITY AND RADIATION

A. Radioactivity.

Radioactivity may be defined as spontaneous nuclear transformations that result in the formation of new elements. It is this spontaneous decay or disintegration of an unstable nucleus that may result in the emission of ionizing radiation.

B. Radioactive Half-life.

Different radionuclides decay at different rates. The time required for any given radionuclide to decrease to one-half of its original quantity is a measure of the rate with which the radionuclide undergoes radioactive decay. This period of time is called the half-life, and is unique to the individual radionuclide.

C. Radioactive Material.

Radioactive material contains atoms whose nuclei have excess energy (unstable) and reduce their energy by decaying or transforming and releasing the excess energy in the form of ionizing radiation.

D. Ionizing Radiation.

Ionizing radiation is the actual particle or photon (packet of electromagnetic energy) emitted by the nucleus or atom during the process of radioactive decay. These radiations interact with and cause ionizations within the materials through which they pass. In the field of

radiation protection, the primary concern is radiation interacting with the body, causing biological damage to living tissue. Engineers are also concerned with evaluating whether potential radiation damage to materials or equipment may compromise function.

E. Particles and Photon Radiations.

The two general categories of ionizing radiation are particulate (alpha, neutron, beta), which consists of subatomic particles ejected from the nucleus, and photons (X and gamma rays), which also have particle-like properties. Alphas and betas are electrically charged particles, while neutrons and photons have no charge.

3. TYPES OF RADIATION

A. Alpha Particles.

1. Alpha particles are highly energetic helium nuclei that are emitted from the nucleus of a heavy atom (e.g., Uranium-235).

2. They are made up of two protons and two neutrons, giving them a charge of +2 and a mass about four times that of a neutron or proton.

B. Beta Particles.

1. A beta particle is an energetic electron that is ejected from the unstable nucleus.

2. Beta particles carry an electric charge of -1 or +1 and have a mass much smaller than that of a neutron or proton.

C. Gammas and X-Rays.

1. Gammas and X-rays are chargeless and massless waves of electromagnetic energy. They both consist of discrete packets of energy called “photons.”

2. Gammas and X-rays radiation are identical except for where they originate.

   a. Gamma rays come from the nucleus of the atom, and

b. X-rays come from two sources. One is from the movement of an electron from one atomic orbital energy level to another, and the second is from the slowing down of a free electron when it passes close to a large nucleus. In the latter case, the X-rays are called “bremsstrahlung” (braking radiation); these are an important consideration in the shielding of beta particles.

D. Neutron.

1. Neutrons are uncharged particles that reside in the nucleus of the atom along with protons. A neutron has about the same mass as a proton.

2. Sources of neutron radiation include nuclear reactors, accelerators, natural neutron emitters (e.g., transuranic radionuclides) and mixtures of alpha emitters and radionuclides that absorb alpha particles and subsequently emit neutrons.

4. PENETRATING ABILITY IN TISSUE

A. Alphas.

1. Alpha particles will not penetrate the dead layer of skin and are not even considered from an external radiation standpoint. Alphas travel no more than a few inches in air.

2. Alphas are considered to be a hazard only when the radioactivity emitting them is inside the body, where the very localized deposition of the high alpha energy can be significantly damaging.

B. Betas and Electrons

1. A beta particle will travel several feet through the air and through several layers of skin depending on its energy.

2. Beta radiation, therefore, is considered to be both an external (predominantly the skin or eyes) and an internal exposure hazard.

C. Gammas and X-Rays.

1. Primarily because they have no charge, gamma and X- ray radiation are highly penetrating in tissue and are termed “penetrating radiation.”

2. They will pass deeply into or completely through the whole body, possibly causing biological damage to internal organs they interact with.

D. Neutrons.

1. Because they carry no charge, neutrons are very penetrating and may travel long distances in air.

2. Neutrons are more readily stopped by materials that contain hydrogen, such as tissue, and other materials with low atomic mass. Neutrons are generally considered an external hazard.

3. The low-energy neutrons eventually are absorbed by another nucleus, and the resulting nuclide may be radioactive. The latter process is called neutron activation. In the absorption process, excited nuclei are created which subsequently emit gamma radiation. This radiation may also result in added dose.

II. MODULE 103

1. SELECTED TOPICS IN RADIATION PROTECTION

A. Objectives.

Following self-study and/or classroom review, participants will be able to:

1. List four ways radioactive material enters the body.
2. Define the terms “crud” and activation products.
3. Discuss controls for airborne radioactive material.
4. Discuss methods to process radwaste.
5. Define the terms “Controlled Area” and “Radiological Area.” Discuss types of radiological areas.
6. Identify types of contamination control measures.
7. Define scattering and streaming.

2. RADIATION EXPOSURE MODES

A. Radiation Dose.

Radiation interacts with the body by depositing its energy in the cells of the tissue. Deposition of this energy causes chemical alterations which may cause biological damage.

This energy is delivered to the tissue from the decay of radioactive material deposited inside the body or from radiation emitted from external sources.

Appendix C discusses certain dosimetry calculations using the dosimetry quantities provided in 10 CFR 835.

B. External Dose.

All or part of the body can receive dose delivered by a source that is outside the body. Typical sources include radioactive materials in flasks, pipes, and sealed containers, and air or water containing radioactive materials.

C. Internal Dose.

Internal dose is delivered to the body tissue from radioactive material present inside the body. It may involve large or small portions of the whole body or specific organs to which the isotope is attracted. Radionuclides can enter the body in four ways:

1. Inhalation: worker breathes in air containing airborne radioactive materials.

2. Ingestion: worker swallows some radioactive material.

3. Absorption: a few radioactive materials can be absorbed through the skin.

4. Injection: radioactive materials may be carried into the body through wounds or punctures in the skin.

D. Whole-Body Dose.

Whole-body dose normally results from penetrating radiation such as gammas, X-rays, or neutrons. An exception is the whole-body dose delivered by some radioactive material, such as tritiated water, that is dispersed throughout the body. The gammas and X-rays may interact with the body in two ways:

1. They interact with body material and deposit all or part of their energy in local tissues, or

2. They pass through the body without interaction. With no deposition of energy, there is no dose.

E. Skin Dose.

In addition to the dose from penetrating radiation, skin dose may also be delivered by weakly penetrating radiation such as low-energy gamma rays, X- rays, and beta particles.

F. Extremity Dose.

Extremities include hands, arms below the elbow, feet, and legs below the knees. (The head is considered to be part of the whole body). High dose to an extremity without a correspondingly high dose to the body can result from work in nonuniform radiation fields or proximity to a small, strong radiation source. The extremities are not as sensitive to radiation damage as the rest of the whole body and can tolerate higher doses. Due to this fact, extremity dose limits have been established at levels higher than the whole-body limits.

3. CRUD AND OTHER RADIOACTIVE SOURCES

A. Crud.

Originally, crud was considered to be activated debris or fuel bits in the coolant piping of reactors. Because many people apply the term to any contamination in liquid systems that may deposit as solids in unfavorable spots, we will use it for convenience in this expanded

sense as well. Crud deposition problems are thus potentially present for all facilities and equipment that have liquids containing radioactive material circulating in them. Such deposits can be a prime contributor to “hot spots” (small, localized areas with dose rates significantly higher than general area dose rates) in piping, valves, pumps, and tanks.

B. Radiation Levels from Crud.

The radiation from crud does not go away when the facility shuts down. The radiation levels usually decrease over time as a result of radioactive decay, with the rate depending on the half-lives of the radionuclides composing the crud. But, radiation levels may actually increase in cases when the radionuclide decays to a “daughter” nuclide that is also radioactive. The “parent” may be an alpha, beta, or weak gamma emitter, producing little or no dose rate outside the container, but the daughter(s) may emit strong gammas, neutrons, or even betas, producing significant bremsstrahlung.

C. Crud Production.

Crud can be produced in two ways:

1. Corrosion or erosion of equipment in or near a neutron-emitting source (e.g., a reactor core neutron-generating devices) may produce small free bits of steel or other metal that are near or can be carried near the source and activated by the neutron flux. These new radioactive bits (called activation products) can then be transported out of the vicinity of the neutron flux to plate out or be deposited on wet surfaces. Crud can be removed from the liquid by a filtration system.

2. The second method of crud production occurs at production, test, and research reactors. The fuel rods, fuel assemblies, or target materials contain the plutonium or uranium atoms to be fissioned and radioactive fission products. The fission products or activated target materials can leak, allowing some of the uranium and the fission products to escape into the reactor coolant. In nonreactor facilities, a leakage of radioactive materials into fluid transport systems can result in unwanted deposition of contamination.

D. Decontamination.

Advanced decontamination techniques are being studied. Decontamination of inner surfaces may reduce deposits, but they will usually build up again. Anti-deposition measures, such as metal passivation and electro-polishing treatments, inhibit crud from redepositing on surfaces.

E. Reducing Crud.

The best means to reduce the production of crud include:

1. Using low-activation materials.
2. Preventing corrosion and erosion of equipment, and
3. Avoiding crud traps such as low-flow areas,
4. Providing equipment with smooth internal surfaces, and
5. Preventing fuel or target leaks.

4. AIRBORNE RADIOACTIVE MATERIAL

A. Production.

Radioactive materials can become airborne in the following ways:

1. Normally Gaseous Forms: Some radionuclides, such as krypton, xenon, and argon, naturally exist in a gaseous form. Other radionuclides may be chemically combined with other elements to form a gas. Note that most gases mix readily with the air unless contained in some manner.

2. Volatile Liquids, Droplets, and Sprays: Some radionuclides are in the form of volatile liquids, either naturally or as part of a compound. If leaked or exposed to the air, these can also become airborne. Some liquids containing radionuclides, while not volatile, can become airborne in processes that produce droplets or sprays.

3 Airborne Particulates: Radioactive material in a particulate form can become suspended in air and be transported by air currents, sometimes after adhering to dust particles, until they eventually settle. Operations such as grinding, welding, etc., may create airborne particulates.

B. Radiological Protection Against Airborne Radioactivity.

Airborne radioactive materials can deliver both external and internal doses. External doses result from the worker being surrounded by a radioactive cloud; whereas internal dose results from the radioactive material entering the worker's body and organs. Protection measures against airborne radioactive materials include the following:

1. For external doses, a protective plastic suit can be worn as shielding against weakly penetrating radiation from airborne radioactive materials. This shielding will stop alphas and most betas and radioactive material, such as tritium, that can be also absorbed through the skin.

2. For internal doses, one can:
   - Wear a respirator, or
   - Wear a nonporous suit in atmospheres containing absorbable radionuclides.

3. Engineered features, which are the primary defenses against airborne radioactive materials, include:
   - ventilation cleanup systems,
   - liquid filtration and processing systems,
   - containment devices, and
   - airborne radioactive monitoring systems.

C. Derived Air Concentration (DAC).

DOE's limits on airborne radioactivity are expressed in terms of the Derived Air Concentrations (DACs) that are given in 10 CFR 835, Appendices A and C. Breathing 1 DAC for 2,000 working hours (1 year) would result in the annual limit on intake (ALI), corresponding to 5 rem committed effective dose (CED) or 50 rem committed equivalent dose (CED or organ dose), whichever is more limiting. An equivalent DAC for a mixture of radionuclides can also be calculated.

Areas with atmospheres containing a radionuclide or a mixture of radionuclides > the DAC or where an individual present in the area without respiratory protection could receive an intake exceeding 12 DAC-hours in a week must be posted as Airborne Radioactivity Areas.

D. Design Criteria.

The 10 CFR 835 design objective for airborne radiactive material states that “under normal conditions, to avoid releases to the workplace atmosphere, and in any situation, to control the inhalation of such materials to levels that are ALARA.”

If airborne radioactivity cannot be avoided, it is best to design an operation to try to stay below the 10 percent DAC level. At levels >10 percent DAC, more restrictive administrative and/or increased engineered controls may become necessary.

E. Respirator.

The primary method of controlling airborne contamination should be to use reasonable engineering design features. Good work practices and contamination control at the source should also be performed(e.g., flushing a pipeline to remove the radioactive source prior to maintenance).. Only when these features and controls are not feasible or effective (or while they are being evaluated) should respirators be prescribed.

To be ALARA, routine respirator use must be kept to a minimum. Design that requires the constant use of respirators in frequently or regularly occupied areas or during routine work is not acceptable.

F. Time Versus Respirator Usage.

In specific situations, the use of respiratory protection may not be suitable due to physical limitations or the potential for increased external exposure.

It is often generally perceived that personnel should not be allowed to work in an Airborne Radioactivity Area without a respirator. However, brief entries in airborne radioactivity areas may result in doses negligible compared to the risk of heat stress or the risk associated with not doing the job. Also, it has been shown that in Airborne Radioactivity Areas with elevated external dose rates, total doses (i.e., internal plus external) to workers without respirators may be lower than total doses to those workers with respirators. This is due to the extra length of time it takes the worker with respirators to perform tasks as a result of restricted movement, blurred vision, impaired breathing, and limited communication. In such cases, the radiological control staff and the operational supervisor may agree to waive respirator use.

5. DECONTAMINATION

A. Decontamination.

Decontamination is any process or method of removing contamination. Frequently, there is a need for decontamination to reduce the radioactive source, and thus avoid more significant exposures to workers or, if the radioactive material escapes from the facility, to the public. Unfortunately, the process of decontamination itself may involve some dose to workers, e.g. radioactive material may enter the body through broken skin.

B. Design Criteria.

10 CFR 835 has a design Objective that the design or modification of a facility and the selection of materials shall include features that facilitate operations, maintenance, decontamination, and decommissioning.

Provision for decontamination must be made in the design of any component, system, or area where the potential for leakage of radioactive materials exists. Facilities may be released for public use if contamination levels meet established limits (not zero).

C. Planning.

Planning for the likelihood of decontamination should be done for any operation which may involve the spread or generation of significant amounts of radioactive materials.

D. Methods.

Factors that affect the choice of decontamination method include type and quantity of radioactive leakage, item to be decontaminated, expense, practicality, etc.

E. Fixed and Removable Equipment.

Potential decontamination must be considered for fixed and removable equipment. Laundries and decontamination cells may be necessary for such items as respirators, clothing, or removable pumps. For equipment that must be decontaminated in place, provisions must be made for decontamination supplies (water, chemical, air) and electrical power.

6. RADIOACTIVE WASTE (RADWASTE)

A. Definition.

Radwaste is any radioactive material or substance that is not considered useful and must be disposed of. Useful materials that can be decontaminated and reused are not considered radwaste; however, the liquid and solid by-products of the decontamination process may be radwaste, such as rags, cleaning solutions, and filters.

B. Types of Radwaste.

1. Solid dry waste, also called “dry active waste” (DAW),
2. Liquid,
3. Gaseous,
4. Mixed waste,
5. High level radiactive waste, and
6. Transuranic waste.

C. Processing of Radwaste.
Radwaste can be processed in several ways:

1. Filtration: Mechanical removal of radioactive contamination from liquid or gaseous waste.

2. Ion Exchange Processes: Chemical removal of radioactive contamination with demineralizers or filter-demineralizers.

3. Volume Reduction: Methods that reduce the volume of waste that must be disposed of, such as incineration, compaction or evaporation.

4. Decay Tanks: Containers that allow contents to undergo radioactive decay to decrease radioactivity levels before further processing or disposal.

5. Dilution: Radioactive liquids or gases may be mixed with a large volume of air or water upon release (there are many restrictions on such releases).

D. Disposal.
Radwaste, either in its original form or after processing, is placed in tanks, drums, casks, or other appropriate sealed containers and disposed of through storage, burial, or release (when allowed).

E. Segregation.
Wastes containing oil, detergent, and many different chemicals must often be processed separately.

F. Mixed Waste.
Mixed waste is waste containing both radioactive and hazardous components as defined by the Atomic Energy Act and the Resource Conservation and Recovery Act.

Special considerations must be given to reducing generation of mixed waste because of the many restrictions on storage and disposal.

G. Methods of Collecting and Dealing with RadWaste.
(INSERT FACILITY-SPECIFIC INFORMATION)

7. CONTROLLED AREAS

A. Controlled Areas.

For the purposes of radiological access control, a facility can be divided into radiological areas according to the type and extent of the radiological hazard. When designing a new facility, anticipated dose rates are calculated or estimated; then, a radiological engineer or other radiological specialist divides the facility into radiological areas.

1. Controlled Area: Any area to which access is managed to protect individuals from exposure to radiation and/or radioactive material.

   (Insert facility-specific information concerning controlled and uncontrolled areas.)

2. Radioactive Materials Area: Any accessible area within a controlled area, accessible to individuals, in which radioactive material is used, handled, or stored shall be posted with the words "Caution, Radioactive Material." The posting shall meet the requirements of 10 CFR 835.601. The following areas are exempt from this posting requirement:

   (a) Areas may be excepted from the posting requirements of § 835.603 for periods of less than 8 continuous hours when placed under continuous observation and control of an individual knowledgeable of, and empowered to implement, required access and exposure control measures.

   (b) Areas may be excepted from the radioactive material area posting requirements of § 835.603(g) when:

(1) Posted in accordance with § 835.603(a) through (f); or

(2) Each item or container of radioactive material is labeled in accordance with this subpart such that individuals entering the area are made aware of the hazard; or

(3) The radioactive material of concern consists solely of structures or installed components which have been activated (i.e. such as by being exposed to neutron radiation or particles produced in an accelerator).

   (c) Areas containing only packages received from radioactive material transportation labeled and in non-degraded condition need not be posted in accordance with § 835.603 until the packages are monitored in accordance with § 835.405.

B. Area Designations.

The following area designations are defined in 10 CFR 835 and DOE directives:

1. Radiological Area: Any area within a Controlled Area that meets the definition of a Radiation Area, Contamination Area, High Contamination Area, Airborne Radioactivity Area, or High Radiation or Very High Radiation Areas.

   (Insert facility-specific information concerning radiological division of areas by type of hazard.)

2. Radiation Area: Any area accessible to personnel where an individual could receive to a major portion of the whole body an equivalent dose greater than 5 mrem (0.05 mSv) in 1 hour at 30 cm (30 cm is approximately 1 foot) from the radiation source or any surface through which the radiation penetrates.

   (Insert facility-specific information.)

3. High Radiation Area: Any area accessible to personnel where an individual could receive a dose equivalent greater than 0.1 rem (0.001 sievert) in 1 hour at 30 cm (approximately 1 foot) from the radiation source or from any surface through which the radiation penetrates.

4. Very High Radiation Area: Any area accessible to personnel where an individual could receive an absorbed dose in excess of 500 rad (5 grays) in 1 hour at 1 one meter from the radiation source or from any surface through which the radiation penetrates.

5. Radiological Buffer Area: An intermediate area established to prevent the spread of radioactive contamination and to protect personnel from radiation exposure.

6. Contamination Area: Any area, accessible to individuals, where removable surface contamination levels exceed or are likely to exceed the removable surface contamination values specified in appendix D of 10 CFR 835, but do not exceed 100 times those values.

   (Insert facility-specific information concerning areas of potential surface and airborne contamination.)

7. High Contamination: Any area, accessible to individuals, where removable surface contamination levels exceed or are likely to exceed 100 times the removable surface contamination values specified in appendix D of 10 CFR 835.

8. Airborne Radioactivity Area: An area, accessible to individuals, where:
   (1) The concentration of airborne radioactivity, above natural background, exceeds or is likely to exceed the derived air concentration (DAC) values listed in appendix A or appendix C of 10 CFR 835; or
   (2) An individual present in the area without respiratory protection could receive an intake exceeding 12 DAC-hours in a week.

C. Entry Controls.

Some common entry control measures include signs, barricades, control devices on entrances, visible or audible alarms, locks, allowing entry to only necessary personnel, and administrative control procedures. 10 CFR 835 requires special access controls on High Radiation and Very High Radiation Areas.

(Insert facility-specific entry control method.)

D. Contamination Controls.

Some common types of contamination control measures include area posting; step-off pads; protective clothing; containments (such as gloveboxes and hot cells); and effective ventilation cleanup, filters, and flow rates.

(Insert facility-specific information concerning contamination controls.)

E. Potential or Intermittent Radiological Areas.

An area may remain posted as a Radiological Area even when conditions are potential or intermittent. Care must be taken in designing facilities and planning operations that such conditions are identified and appropriate controls (such as alarms, flashing lights, etc.) are specified to alert workers to changes.

8. SCATTER AND STREAMING

A. Scatter.

Scatter is the reflection of a neutron or photon resulting from the interaction of the radiation with matter. Basic concrete can reflect up to 1-3 percent of the gamma rays incident upon it. X-rays and neutrons, also, can be significantly reflected.

B. Skyshine.
Outside air can provide significant scatter, particularly for neutrons. This is referred to as “skyshine.”

C. Streaming.
Streaming results when radiation passes through an opening, void, or low-density region in shielding. Gaps in radiation shielding may exist because of doorways, penetrations, or air pockets. Most shielding installations will require at least some penetrations for electrical power, plumbing, personnel access, remote sensing, ventilation, and/or process fluid transfer.

D. Dose Rates.
Radiation scatter and streaming may create a significant dose rate outside the shield (non-source side). For example, a dose rate may be acceptable if the shield wall goes up to the ceiling, but may be unacceptable - due to scatter off the ceiling - if the wall stops short of the ceiling.

E. Exposure Control.
Scattering and streaming should be considered where applicable.

1. A labyrinth entrance can be a scatter path; so can a penetration.

2. Removable, overlapping block walls may be used to minimize streaming.

3. Shield slabs and plugs may be used to minimize exposure. Pass-through ports should be placed near the floor or ceiling.

4. Proper door or shield slab arrangement can reduce scatter.

(Insert facility-specific information concerning scattering and streaming exposure control.)

IV. MODULE 104

1. ALARA PRINCIPLES

A. Objectives.

Following self-study and classroom review, participants will be able to:

1. Identify the six fundamental principles used to reduce radiation doses and the release and spread of radioactive materials.

2. Identify applications of the fundamental principles.

3. Identify shielding materials used to reduce radiation exposures.

B. Six Fundamental Principles.

Six fundamental principles should be considered for every facet of the design or operation. The six principles are:

1. Eliminate or reduce the source of radiation,

2. Contain the source,

3. Minimize time in a radiation field,

4. Maximize distance from a radioactive source,

5. Use radiation shielding, and

6. Optimize manpower since using more workers to cut the time will increase the collective dose.

C. Hierarchy of Controls.

Emphasis should be placed on engineered controls instead of procedures, administration, or personal practices. The objective is to design an inherently safe facility.

(Insert facility-specific applications for the six fundamental ALARA principles, as appropriate.)

2. ELIMINATE OR REDUCE THE RADIOACTIVE SOURCE

The first ALARA design principle is to eliminate or reduce the source of radiation exposure.

A. Source Elimination.

Eliminate the use of the source by substitution of other appropriate technologies or materials. A good example of this is the use of an ultrasound exam (sonogram) in prenatal examinations rather than an X-ray exam or flushing a pipe to remove radioactive material.

B. Source Reduction.

A reduction in source means a reduction in dose rate. In planning a job or operation involving radiation exposure, consideration should be given to reduction of as much of the radioactive source(s) as possible. This may include:

1. Installing filtration and processing equipment to clean liquids;

2. Removal of nonessential radioactive material or equipment from the vicinity;

3. Selection of appropriate materials to minimize activation and deposition;

4. Draining and/or flushing of radioactive liquids from fluid systems; or

5. Ventilation of airborne radioactivity areas (with appropriate filtering of the air to reduce the concentration of airbornes and minimize deposition).

6. If practical, allow the radionuclide source(s) to decay for several half-lives to decrease the radiation field.

3. CONTAINMENT AND CONFINEMENT

The second ALARA design principle (which some view as a subset of the first principle) is to control and contain radioactivity by the use of containment, ventilation, and processing systems.

A. Methods to Control and Contain.

The methods one can use to control and contain radioactive sources are:

1. Containment: Leak-tight or controlled-opening enclosure to keep radioactive materials confined within (e.g., fuel cladding, piping, hot cells, and curbing around tanks that contain radioactive materials).

    a. Examples of temporary containments are tents and glove bags.

    b. Examples of structural containments for the control of radioactive materials are walls, windows, doors, floors, transfer ports, and ceilings, with appropriate gaskets, caulking, etc.

2. Ventilation: Provision of air and other gas flow direction and rate such that airborne material and radioactive gases are captured and directed to filters and an appropriate release point. Note that negative pressure is an important aspect of control for some contaminants.

3. Filtration: The capture of airborne material on a medium, thus confining them to a small and disposable volume.

B. Protective Designs.

Protective designs include such items as:

1. Ventilated fume hoods,
2. Gloveboxes for handling radioactive material,
3. Exhaust systems,
4. Water filtration and processing systems,
5. Conservatively sized ventilation cleanup systems, and
6. Double-walled pipes and tanks, canned pumps, and leak-tight valves.

4. MINIMIZING TIME

The third ALARA design principle is to eliminate or reduce the time a worker must spend in the vicinity of a radioactive source.

The amount of dose received is directly proportional to the amount of time spent in a given radiation field; therefore, dose is minimized if time is minimized.

A. Design Factors.
Appendix A discusses the application of ALARA in facility system design in greater detail.

Design factors to reduce time spent in radiation fields include:

1. Installing reliable equipment to reduce maintenance,

2. Choosing equipment that requires less frequent calibration,

3. Providing adequate clearance for maintenance and inspection around components,

4. Utilizing special tools to speed maintenance and access,

5. Using robots or remote equipment,

6. Removing components from the radiological area for repair or calibration, and

7. Installing permanent lighting and platforms.

8. Use mock-ups to allow practicing of tasks in nonradiological areas.

5. MAXIMIZING DISTANCE

The fourth ALARA design principle is to maximize the distance from the source.

A. Dose Rate Versus Source Size.

1. Point Source: For a point source (in which the size of the source is very small compared to the distance from it), radiation intensity varies inversely with the square of the distance from the source. This is called the inverse square law.

2. Large Source: Reduction in dose rates with distance from large sources such as pipes, tanks, floors, and walls is somewhat less dramatic, but the dose rate will still decrease with the distance from the source.

B. Design Factors.
Design factors to maximize the distance from radioactive sources include:

1. Remote operation (process, maintenance, surveillance, decontamination, sampling, remote tools and controls).

2. Locating all nonradioactivity-bearing instruments and readouts in low-dose areas;

3. Provision for removal of components to low-dose areas for maintenance;

4. Use of cameras, microphones, and other transmitters to perform remote surveillance and inspections; and

5. Layout of equipment so as to maximize the distance between workers and the radioactive source.

6. USE OF RADIATION SHIELDING

The fifth ALARA design principle is to provide shielding between the worker and the radiation source by providing permanent or temporary shielding between sources and the workers.

In general, any material through which ionizing radiation passes absorbs some or all of the radiation. This attenuation depends on the type and energy of the radiation, as well as the thickness and composition of the shielding material.

A. Design Factors.

Considerable thought should be given to incorporating adequate shielding structures during the design phase of a nuclear facility. This shielding can be quite elaborate in some cases and may even consist of several layers of different materials best suited for different types of radiation.

Considerations for shielding design include:

1. Anticipation of crud buildup and hot spots;

2. Use of labyrinths for shielding penetrations and cubicle entrances;

3. Installation of special shields such as hot spot covers, leaded windows, and shielded carts and forklifts;

4. Allow for adequate space and access for installing temporary shielding for anticipated hot spots or in frequent jobs; and

5. Use of appropriate shielding materials based on the type and level of radiation.

B. Shielding Materials.

The choice of shielding material depends on the type(s) of radiation to be shielded.

1. Alpha (can be stopped by a single sheet of paper): Due to the extremely low penetrating ability of alpha particles, shielding is not considered necessary.

2. Beta (can be stopped by 1/2-inch Plexiglas; 1/4-inch aluminum, wood, rubber): Due to the potential creation of bremsstrahlung when the beta particles are slowed or stopped, consideration must be given to shielding these X-rays whenever beta radiation is present.

This phenomenon is strongest when beta particles are stopped by materials with a high atomic number (such as steel or lead), making these materials inappropriate for shielding beta particles unless they are sufficiently thick to stop the bremsstrahlung also.

3. Gamma (lead, concrete, steel): The denser the material, the better it is suited for attenuation of gamma and X-rays.

4. Neutron (water, polyethylene, concrete, boron): Neutron-absorbing radionuclides (such as boron-10) and materials that contain large amounts of hydrogen make efficient neutron shields. The production of “capture gammas” in some materials must also be considered.

C. Fortuitous Shielding.

Fortuitous shielding should be used when possible. Fortuitous shielding is material placed in an area for reasons other than shielding but acting as a shield because of its location, composition and thickness. Steel cabinets, steel security doors, concrete columns, and similar objects can serve as fortuitous shielding. These objects should be permanently mounted if relied on as shielding, however.

D. Sequence of Shielding.

Shielding should be correctly layered for structural integrity and attenuation of different types of radiation. For example, with gammas and strong betas, a layer of plastic might precede a layer of lead, so that betas would be captured in the plastic and not produce bremsstrahlung in the lead.

E. Concrete.

The use of concrete can be considered for stopping any type of radiation when space, weight, and cost are not limiting, because it is the best all-purpose shield.

7. OPTIMIZATION

The sixth ALARA design principle is optimization.

ALARA design uses methods such as cost-benefit analysis to balance competing factors in dose reduction. It is important to maintain a separation between those concepts related to keeping radiation exposures below limits and those aimed at optimization or ALARA.

The purpose of an optimization analysis is to show that the expense (in terms of money, person hours, dose, etc.) of a project or feature of a project is justified in terms of the benefit received. This is in accordance with the idea of balancing ALARA considerations against technical, social, operational, and economic considerations.

Optimization is further addressed in Module 110. Both formal and informal methods of optimization analyses are addressed. In Appendix F, examples of analyses are performed.

8. SUMMARY

Following self-study and/or classroom review, participants will be able to:

A. Module 101 Objectives.

1. Define the acronym ALARA,
2. List the ALARA recommendations of the RadCon Standard, and
3. Identify which groups should participate in ALARA design reviews.

B. Module 102 Objectives.

1. Identify the penetrating abilities in tissue:
   a. alpha,
   b. beta,
   c. gamma and X-ray, and
   d. neutron radiation.

C. Module 103 Objectives.

1. List four ways radioactive material enters the body.
2. Define the terms “crud” and activation products.
3. Discuss controls for airborne radioactive material.
4. Discuss methods to process radwaste.
5. Define the terms “Controlled Area” and “Radiological Area.” Discuss types of radiological areas.
6. Identify types of contamination control measures, and
7. Define scattering and streaming.

D. Module 104 Objectives.

1. Identify the six fundamental principles used to reduce radiation doses and the spread of radioactive materials,

2. Identify applications of the fundamental principles, and

3. Identify appropriate shielding material used to reduce radiation exposures.

V. MODULE 105

1. APPLICATIONS OF ALARA

A. Objectives.

During the presentation of Module 105, participants should demonstrate the application of ALARA principles of source term reduction and control by actively participating in the group exercises.

2. CRUD PRODUCTION AND RADIOACTIVE MATERIAL DEPOSITION REDUCTION IN LIQUID SYSTEMS

A. Reduce Crud Production.

Reduce crud production by avoiding the use of nickel, cobalt, and other readily activated materials in areas of high neutron radiation, such as:

1. On wetted surfaces that may come into contact with reactor coolant.

2. Near spontaneous or man-made neutron emitters.

3. In accelerators that produce neutrons as a result of beam interactions (including component cooling systems).

Where wear-resistant facings are essential, the use of stellite, inconel, and some stainless steels are undesirable from this standpoint.

Note that other radioactivity in liquid systems (i.e., not produced by neutron activation of loose particles) may stick to loose, eroded, or corroded particles and thus collect in places where such particles are deposited.

(Insert facility-specific information concerning crud buildup, including dose rates and locations.)

B. Reduce Erosion.

Reduce the loss of material by erosion:

1. Use good flow geometry.

2. Avoid sharp bends, reducers, and rough internal surfaces.

C. Reduce Corrosion Loss.

Reduce the loss of material by corrosion:

1. Use corrosion resistant material.

2. Pretreat or precoat surfaces.

3. Use pH and other chemistry controls.

4. Provide for wet layup during maintenance and shutdown periods.

D. Reduce Deposition.

Reduce the deposition of crud and/or other radioactive material circulating in a system:

1. Select a flow velocity appropriate for the stream to keep solids in suspension and to ensure representative sampling.

2. Provide strainers, if practical, upstream of a neutron source (in reactors, before the coolant reaches the core).

3. Ensure that all equipment and piping runs are drainable and flushable.

4. Minimize crevices, elbows, low points, sharp bends, and dead legs (low flow areas in which deposition may occur).

5. Generally use butt welds, consumable inserts, and freeze fits that usually produce smoother welds than socket welds and backing rings.

6. Generally use full-ported valves (plug, gate, or ball valves instead of globe valves).

7. Choose straight-tube, vertical heat exchangers rather than U-tube, horizontal ones.

8. Consider temperature or chemistry controls that can inhibit deposition (e.g., control of pH to inhibit a particular chemical deposition reaction).

3. CONTAMINATION CONTROL AND DECONTAMINATION

A. Contamination Control Measures.

Provide for proper contamination control measures.

Within radiological areas, contamination should be controlled as follows:

1. Contamination in one area should not result from minor or moderate incidents that occur in other radiological areas.

2. Outside radiological areas, radioactive surface contamination should not exceed the release values specified in 10 CFR 835 for Controlled Areas or DOE 5400.5 for uncontrolled areas.

3. Select equipment that can be readily, easily, and completely dismantled and allow sufficient space for dismantling the equipment and allow sufficient space for dismantling the equipment.

B. Equipment Decontamination.

Provide for equipment decontamination. There are many methods that can be used for decontamination, but not all methods will be suitable for a particular radionuclide or surface. Keep in mind that it is ALARA to select a method that reduces the dose to the worker (including both the external and the internal dose) while reducing the volume of radwaste produced and the cost of the decontamination, but there may be some tradeoffs that must be weighed.

VI. MODULE 106

1. APPLICATION OF ALARA TO FACILITY AND SYSTEM DESIGN

A. Objectives.

During presentation of Module 106, participants should demonstrate the application of
ALARA principles to system design by participating in group exercises.

A designer or operations planner must consider which systems or components are likely to produce worker doses and select types that minimize dose. He/she must also consider which components may require a great deal of maintenance or may prove unreliable. He/she must select types that are highly reliable, easy to maintain, and consistent with the necessary functions. Finally, he/she must keep in mind the types of jobs that are associated with the operation and maintenance of each system or component and consider which ones may account for the most individual and collective dose over the operation or the life of the equipment. This is important when there are tradeoffs between, for example, cost and maintenance time.

2. RELIABILITY AND EQUIPMENT QUALIFICATION

A. Choose Reliable Equipment.

1. Select equipment for ease and low frequency of maintenance.

2. Select equipment for length of service life under the expected conditions.

B. Choose Qualified Equipment.

1. Select materials that are qualified for the expected use (i.e., that will not degrade unduly under the expected combination of conditions of temperature, humidity, pressure, and especially radiation level).

2. Avoid using aluminum in High or Very High Radiation Areas where it may be in contact with fluids or concrete due to the potential for adverse chemical reactions to occur over time.

3. Avoid locating microelectronics, rubber, cork, and other radiation-sensitive items in radiation areas. If necessary, place them in low-field areas only.

3. AIRBORNE RADIOACTIVITY AND HVAC

Airborne sources should be reduced or eliminated as much as possible. Where airborne levels may still be significant, well- designed ventilation systems should be provided to limit the possibility of intake of airborne radioactive material.

Such systems should be designed considering both normal and abnormal conditions. Routinely requiring workers to wear respiratory protection generally is not an acceptable solution to reducing intakes of radioactive material.

A. Essential Features.

As noted before, ventilation systems are provided to direct airborne contamination away from personnel and over to filters or other collection points; to reduce airborne concentrations; and to prevent or limit the release of airborne materials through necessary openings.

To attain these objectives, ventilation systems usually incorporate the following features:

1. Airflow:
   a. A system of differential pressure should be used to direct flow. The flow rate should be sufficient to ensure that airborne particles or gases are adequately captured or diluted.

   b. Airflow should go from areas with no or less potential contamination to areas with greater potential for contamination.

   c. Air should be exhausted from areas with greatest potential for contamination.

   d. Room air may be recirculated if adequate filtration and monitoring are provided.

   e. When transporting potentially contaminated air, the exhaust duct should be routed away from frequently occupied areas.

2. Filtration:
   a. Filters should be selected to match the chemical and physical form of the radionuclide(s). For example, High Efficiency Particulate Filters (HEPAs) should generally be used for particulate forms and charcoal filters for iodines.

b. Prefilters, moisture removal devices, and the like should be provided as necessary to prevent overloading the filter with dust, degrading it with moisture, etc. These provisions can increase the life and effectiveness of the radionuclide filter.

c. Local filtration (e.g., for hoods) should be provided where appropriate to maximize capture of particles near where they are produced.

d. Filters should be located upstream of fans and most of the ductwork to minimize contamination of ventilation system internal surfaces.

B. Area-Specific Requirements.

Even apparently similar areas do not always require identical ventilation characteristics, especially differential pressure and filtration. Ventilation design criteria need to accommodate a measure of flexibility because conditions may change as work changes and local or portable ventilation may be effective in reducing local airborne levels sufficiently.

(Insert facility-specific information.)

C. Maintenance.

Design ventilation systems for ease of maintenance, inspections, testing, and operations.

D. Monitoring and Sampling.

Design of ventilation systems should address monitoring and sampling requirements, such as inclusion of sampling ports.

4. CONTAINMENT

A. Containment.

A containment is an area enclosed by a set of barriers. These can be passive barriers, like walls, or active barriers, like valves and ventilation flow.

1. Primary Containment: is the barrier or set of barriers most intimately in contact with the radioactivity.

2. Secondary Containment: encloses the primary and receives and handles any leakage from it. The room(s) or vault enclosing the tank and piping are the secondary

containment and should be so designed; the outer wall of a double-walled tank may be the secondary.

3. Tertiary Containment (may also need to be provided): The building, itself, may be the tertiary containment.

   One constraint on defining these is that it usually must not be possible for a single failure to compromise two containments at once (e.g., a primary and its secondary).

B. Gloveboxes/Glovebags.

Gloveboxes and other handling enclosures are primary containments when radioactivity in them is not completely enclosed or is enclosed in containers that cannot be assumed to be well-sealed. Gloveboxes are secondary containments when the radioactivity is actually contained in a piping system, vessel, instrument, etc., inside the box. In the latter case, the room may be designed as the tertiary containment.

C. Primary Containment Penetrations.

Primary containment penetrations must be carefully laid out and minimized in number and size. They should be carefully sealed with regard to radiation streaming, air-flow control, fire protection, and flooding as applicable. Permeation of radioactivity through these seals should be considered. Transfer ports for passing items in and out should, in general, be airlocks or mini-airlocks, with purging capabilities.

D. Isolation Systems.

A principle of good confinement is good isolation: systems with widely differing levels of actual or potential radioactivity content should be isolated from one another by check valves or other reverse-flow control devices. Pressure-relief devices should be required, and leak detection devices should be provided as appropriate to the process.

5. MECHANICAL AND ELECTRICAL SYSTEMS

This section will discuss six areas: piping, valves, pumps, filters, tanks, and heat exchangers.

A. Piping

Piping is used for fluid flow, pressure boundaries, and heat transfer. Piping can trap radioactive crud which can result in dose to personnel and potential for spread of contamination.

B. Valves.
Since operation and maintenance of valves can be two of the major contributors to workers' dose, the design engineer should carefully select and locate valves. It is generally recommended to use full-ported valves such as plug, gate, or ball valves.

C. Pumps.
Many pumps circulate radioactive water and other types of fluids and can trap radioactive crud. Maintenance and operation can thus present problems in minimizing dose and the spread of contamination. For example, crud can be trapped in piping elbows. Consider whether flooding due to leakage or backup may cause contamination of equipment.

D. Filters, Strainers, Evaporators, and Ion Exchangers
Filters, strainers, evaporators, and ion exchangers provide cleanup of radioactive fluid systems. Since these systems concentrate radioactivity, it is important that maintenance be reduced. Also, remote handling and shielding should be considered.

E. Tanks, Sumps, and Drains
Tanks, sumps, and drains prevent plugging in transfer systems. This equipment must be chosen carefully, considering decontamination and eventual decommissioning.

F. Heat Exchangers.
Heat exchangers may cause radiation dose during their cleaning, repair, inspection, and replacement. Design, modification, or replacement of heat exchangers carrying radioactive fluids should address shielding and placement.

6. ELECTRICAL POWER SYSTEMS.
Even something as seemingly simple as the type of light bulbs used to illuminate areas can be an ALARA and waste consideration. The use of long-life bulbs can decrease maintenance time in elevated dose rate areas by requiring less frequent replacement; the number used up over the life of the facility will be fewer than for shorter-lived bulbs.

VII. MODULE 107

1. APPLICATION OF ALARA FOR VARIOUS ENGINEERING DISCIPLINES

A. Objective.

Participants should demonstrate the application of ALARA principles in design by actively participating in group exercise(s).

B. Introduction.

This module addresses radiation dose assessment and radiological design considerations of new facilities and the modification of existing facilities.

Once a facility is built, changes in shielding or facility layout are difficult to accomplish and often cannot bring about the desired dose rates without considerable added cost and loss of usable work space.

Thus, it is more cost effective to design for anticipated and possible future radiological conditions rather than designing for near-term limited functions.

In many cases, existing facilities must be modified. The resultant need to avoid impact on existing operations and activities may present a major challenge to the engineer.

C. Civil/Structural Design Considerations.

The support structures within a facility can act as shielding devices and reduce doses. On the other hand, support structures may make maintenance difficult because of inaccessibility and may consequently result in increased doses. Therefore, facility design and layout can make a big difference in occupational doses.

2. ASSESSING RADIOLOGICAL DOSES

Radiation designs should provide for anticipated dose by including analysis of the tasks and processes that occur in these areas, the anticipated dose rates for the area, and the proposed inventories of radioactive materials.

A. Worker and Time.

The numbers of workers and the amount of time they are expected to spend in the area should be taken into consideration.

1. For example, general (low-level) operations areas consist of those areas with small or moderate inventories of radioactive materials or low dose rates. Examples are general

radionuclide research labs, rooms containing shielded X-ray diffraction and spectroscopy units, and operation areas with low contamination and low dose-rate potential.

2. Work in higher-level operation areas, however, typically involves more radioactive material or higher dose rates than does work in general operation areas. Examples of higher-level operation areas are glovebox and hot cell operating areas, control areas for high-dose rooms, and selected areas of accelerator facilities where experiments with moderate dose or contamination potential cannot be remote-controlled.

B. Multiple Sources.

It is important in building layout to minimize simultaneous dose from multiple sources at locations where maintenance personnel may be required to work. Similarly, individual work stations should be shielded from one another if work by one individual may expose others in the same area to unnecessary dose. Multiple sources must be taken into account when assessing possible doses.

C. Isolation of Areas.

Areas with high dose rates or airborne contamination levels should be isolated. Unauthorized and unmonitored entry in these areas is forbidden, and design features shall prevent the unauthorized entry of personnel. All personnel are prohibited from entering when conditions in the area present an immediate hazard to human life. Physical controls are required to limit doses when these areas are occupied. The ability to isolate areas with high dose rates should be taken into account when assessing possible doses.

3. ACCESS CONTROL

Access to radiological areas can be prevented by active (personnel) or passive (e.g.locks) controls. Interlocks are recommended because the source is moved or shielded when the interlock is tripped.

Building layout is an important factor in controlling personnel dose by regulating the flow of personnel and material. Proper layout reduces casual or transient exposures to radiation fields by segregating heavily used corridors and the work areas of nonradiological workers from the areas of elevated dose rate and potential contamination. The layout should effectively limit occupational dose to areas where the performance of an assigned task requires some receipt of radiation dose.

Radiological areas should be made as small as possible to aid in access and contamination control. Eventual decontamination and decommissioning (D&D) activities should be considered.

Controlled areas defined in 10 CFR 835 or the RadCon Standard are addressed in Module 103.

A general discussion follows.

A. Sequential Areas.

An acceptable technique for achieving proper building layout is to establish a system of sequential areas. This means that Radiological Areas have been laid out in a way that will minimize dose and reduce the spread of contamination. This concept is frequently used because it is adaptable to the physical control of external and internal dose equivalents.

B. General Access and Controlled Areas.

Two major types of areas are included in any nuclear facility: general access areas and controlled areas.

1. General access: General access areas are normally places to which public access is restricted but where radiation exposure is not necessary for job performance, such as the work areas of administrative and nonradiological support personnel. These areas include conference rooms, file rooms, clerical and other support offices, lunch rooms, and rest rooms.

2. Controlled areas: Controlled areas are areas to which access is managed to protect individuals from exposure to radiation and/or radioactive material. Individuals who enter only the controlled areas without entering radiological areas are not expected to receive a total effective dose of more than 100 mrem (0.001 Sv) in a year. Note that this is the same limit as that for a member of the public outside the facility.

   Controlled areas may include corridors that are adjacent to, or connected with, areas that contain radioactive materials, change rooms, or special offices for radiation workers.

C. Traffic and Access.

1. Traffic: Locate frequently used pathways in low-dose rate and noncontaminated areas, but use common sense and logic; if the pathway is through “clean areas” but in a long and illogical route, people will not use it and may take “short cuts” through hot areas. Place inspection, control and readout instrumentation in low dose areas.

2. Access: Ensure that doorways are wide enough and large enough and access areas are provided for readily removing and servicing equipment.

4. CONTAMINATION CONTROL DESIGN

Contamination control measures may consist of curbs, gutters, drains, catch tanks and other liquid controls. Special attention needs to be given to drains not only for collection of radioactive liquids but also as potential inadvertent release points. Glove boxes and use of proper ventilation are examples of contamination control devices/practices for non-liquids. Contamination control designs should address eventual decontamination/ decommissioning with focus on a specific endpoint (e.g., completely clean or elevated contamination to be re-used as contaminated).

5. RADIOACTIVE WASTE

Locations for the temporary storage of radioactive wastes must be designed into both the building plan and the plan for each area where radioactive materials are handled. To prevent accumulations of waste in operating areas if normal disposal methods are temporarily interrupted, the waste storage area should be large enough to accommodate more than the expected volume of waste.

Additional considerations include transportation, drainage of liquid systems, monitoring, and fire suppression.

6. SHIELDING, PENETRATIONS, AND ROUTING

A. Shielding.

Obtain information on shielding types, thicknesses, and layout from a radiological specialist (a radiological engineer, ALARA specialist, or health physicist, as appropriate for your project or operation).

B. Penetrations.

Have experts from all affected disciplines review a planned penetration before the hole is made.

C. Routing of Ducts, Pipes, Cables, and Conduit (DPCs).

Don't route DPCs containing radioactive materials through general access areas, and don’t route clean DPCs through potentially contaminated or high-dose-rate areas. Do not regard the X-Y-Z grid as sacred. Minimize runs of piping by routing diagonally, using bends other than 90 degrees, and sloping lines, where appropriate.

7. SEPARATION, SEGREGATION, PLACEMENT, AND ISOLATION OF EQUIPMENT

A. Separation.

Put shield walls between components sharing the same cubicle to reduce the dose to a worker maintaining one of them (the equipment should be placed so that the worker does not have to pass close to one to get to the other).

B. Segregation.

Segregate highly radioactive equipment from moderately radioactive equipment, and both from clean equipment. Similarly, segregate equipment with high airborne potential from equipment with less airborne potential, and both from clean equipment.

C. Placement.

Even with shielding, lay out equipment in an area or equipment cubicle so that from the point that the worker enters, he progresses from low-dose rate areas to moderate to high-dose-rate areas, and from active to passive equipment.

D. Isolation.

The interconnections between systems of different radioactivity potential must be carefully considered.

1. Properly place isolation valves so as to minimize dead legs.

2. Minimize pipe runs in valve aisles (consider reach rods and valve operators).

E. Redundancy.

Provide adequate redundancy and backup capability, especially in systems of high radioactivity content and safety systems. Provide appropriate cross-connections to achieve this.

8. ACCESSIBILITY, LAYDOWN, AND STORAGE

Allow adequate working space around major components, usually at least 3 feet. Do not allow this space to be filled by reach rods, shields, pipes, scaffolds, etc.

Provide laydown space in a low-dose-rate area (besides equipment, consider such items as tool boxes, carts, and hoses).

(Insert facility-specific information.)

9. SNUBBERS, STRUTS, HANGERS, AND ANCHORS

Holding devices should be designed and located to facilitate removal and not interfere with inspections and maintenance.

10. HUMAN FACTORS

Design should address human factors such as vision, hearing, and physical limitations. These factors should be considered when the use of protective equipment is evaluated. For instance, heat stress, restricted vision, impaired hearing and speech are all associated with full-face respirators.

Working in elevated dose rate areas requires special considerations for lifting devices and access to equipment.

See Appendix B for supplemental information concerning ALARA civil/structural design principles.

VIII. MODULE 108

1. ALARA DESIGN REVIEW

This lesson provides guidance to the design engineer to determine through a dose assessment if an ALARA design review should be performed, and to incorporate radiation and contamination reduction considerations into a design or modification.

A. Objective.

Participants should demonstrate the application of ALARA principles in design reviews.

B. Definitions.

An ALARA design review is a systematic review of the design, modification, or construction of equipment and facilities to ensure that ALARA considerations are evaluated, incorporated if reasonable, and documented.

C. Requirements for ALARA Designs.

Part 835.1001 requires that engineered features and administrative controls be used for facilities and equipment to keep radiation exposures in controlled areas ALARA.

D. Phases.

The ALARA design review is conducted in five discrete phases:

1. Dose assessment.
2. Determination of need to conduct or not to conduct.
3. Selection of reviewers or review team.
4. Selection of criteria and conduct of review.
5. Documentation of the ALARA process.

2. DOSE ASSESSMENT

A. Initial Dose Assessment.

The first step in the ALARA Design Review is to perform an initial dose assessment, if this has not already been done in the course of design.

B. Information for Determining Dose.

The information should be supplied to the radiological engineer (or another qualified person on the project) as early as possible in each design stage even though some of this information will be tentative or sketchy in the early stages of the project. Include such details as:

1. Layouts and location diagrams;

2. Number and types of workers in each known or possible radiological area associated with the facility or system;

3. Nature of each task workers are to do;

4. Time spent by each worker on each task;

5. Paths to and from the radiological area(s) and the transit time;

6. Physical features such as ladders, manholes, hoods, etc.; and

7. Any dose rates, radioactive source strengths, and shield thicknesses, and the like that are known or recommended by a vendor.

The above information will allow the radiological engineer (or other qualified person), with the help of other radiation protection personnel, to estimate doses and dose rates associated with the project.

C. Detailed Dose Assessment.
During later stages of the project, when the details of the design are known, a more detailed dose estimate may be performed.

1. At this point, it may prove to be of value to perform a walkdown of the installation with construction and radiological personnel. This will aid in the estimation of the installation dose, as well as scoping and planning installation.

2. Detailed dose information is needed for selection of design alternatives or to determine if the cost to incorporate an ALARA consideration is cost-beneficial.

3. The detailed dose assessment involves identification and estimation of the dose for the work tasks that involve radiation exposure for operation, maintenance, inspection, and installation of the equipment, similar to the initial dose assessment.

3. IS AN ALARA DESIGN REVIEW REQUIRED?

Following the initial dose assessment, the cognizant engineer should determine if an ALARA design review should be conducted. This is a two-step process.

First, the engineer or planner must determine if the facility design or design change involves work on a radioactive or potentially radioactive system. If not, an ALARA Design Review need not be performed.

Then the engineer or planner should use the information from the dose assessment to answer questions such as these:

1. Will this design change create a new radiological area or increase the exposure from an existing source?

2. Will this design change create or increase routine maintenance, operations, or inspection requirements in an area?

3. Will this design change cause workers to receive a total of 1 rem per year or greater?

If any of these criteria are met, additional occupational dose will result from the design change, and a review of design features that can reduce dose and the spread of contamination should be initiated.

If the answer to all three questions is "no," an ALARA design review need not be performed. However, this determination should be documented.

For those design changes where there is one-for-one replacement of equipment or if the design change does not present the practical opportunity to incorporate dose reduction improvements or ALARA considerations, the ALARA design review need not be performed.

4. ALARA DESIGN REVIEW TEAM

The material below is included as an example of the Team Member process and conduct of an ALARA Design Review. Site-specific information should be substituted where applicable.

A. Key Personnel.

For a review of a simple facility or process, a radiation protection or ALARA representative may provide the review. The radiation protection and/or ALARA representative(s) should be qualified to provide an overall review of the facility design and should evaluate and approve the completeness of the designed safeguards, including redundancy, fail-safe features, interlocks, and alarms. However, for an extensive and complex review, other disciplines must be involved. The scope of the review should be determined either by procedure or by the project manager in consultation with radiation protection personnel. Others who may participate include:

1. Design Team: the group of people providing input into the project. It is composed of members from all appropriate engineering and other technical disciplines and should include a radiological member with safety expertise such as a radiological engineer or ALARA engineer.

2. Contributor Group: other groups who may not provide formal design input to the project but whose comments and suggestions are considered relevant to the project, such as:

   X Maintenance,
   X Production, and
   X Research groups.

   Both the members of the design team and representative members of the contributor group should participate in the ALARA Design Review, even if some of the latter may not be trained in the ALARA design review process.

3. ALARA Review Coordinator: ALARA engineer, radiological engineer, or even a qualified operations representative who with other project and safety personnel will provide radiological input to the project. The ALARA Review Coordinator, together with the project engineer, is responsible for seeing that the ALARA Review is performed, completed, and documented.

5. SELECTION OF CRITERIA AND CONDUCT OF ALARA DESIGN REVIEW

The following methods are suggested as a practical way of accomplishing and documenting the review. A simplification of this process is appropriate for small, uncomplicated projects and system modifications.

A. Stages Recommended for Review.

An ALARA Design Review should be performed at each important stage of design or modification of a facility, building, or system, unless there is no radiologically significant change between stages (see PNNL-6577).

B. Radiological Design Criteria.

In conjunction with production of the Functional Design Criteria, the radiological engineer may produce, at her/his discretion and depending on the size of the project, either a set of Radiological Design Criteria or a memorandum containing radiological design

considerations. This will be used by the design team beginning at the Conceptual Design Stage, and it should be updated in subsequent stages.

C. Minimum Criteria.

During the review, the review team should assess the features of the design against the Radiological Design Criteria and other applicable criteria to determine whether provision of an ALARA working environment is ensured. The review team should review the facility operation plan and determine if the radiological engineer has done a complete assessment of potential dose.

In the following review processes, different alternatives should be identified, differential costs and dose should be estimated, and cost-benefit analyses conducted to evaluate the alternatives.

1. Show that the public and facility personnel are protected from hazards associated with the use of radioactive and other hazardous materials as a result of:

   – Normal operations,
   – Anticipated operational occurrences, and
   – Design basis accidents.

2. Protection should be provided for normal operation and for those accidents that can be anticipated as occurring during the facility lifetime, such as radioactive material spills and small fires involving radioactive materials.

3. Review the general facility layout, considering traffic patterns, radiation zoning, change room location and size, adequacy of personnel decontamination facilities, location of fixed survey equipment, and provision of adequate space for anticipated maintenance needs.

4. Verify that the ventilation system design provides the required level of protection from airborne contamination, with particular attention to air flow patterns and locations of air inlets and exhausts.

5. Evaluate and confirm the adequacy of specific radiological control devices for reducing occupational exposures, including hoods, gloveboxes, shielded cells, decontamination areas, and remote operations.

6. Verify that shielding is adequate to support ALARA operation of the facility, system, or component.

7. Assess the adequacy of planned radiation monitoring and nuclear criticality safety instrumentation, including whether the proposed instrumentation is appropriate for the radiation types and intensities, and whether it has suitable redundancy and capability for operation both under normal operating conditions and in emergency situations.

8. Radiological requirements and ALARA considerations should be balanced against the total risk, including industrial safety and industrial hygiene requirements. The requirements must also be balanced with operational productivity.

D. Design Basis.

Occupational exposure to radiation should be limited according to 10 CFR 835. This primarily addresses the way people operate and use existing facilities and sites. Designs for new facilities and major modifications to existing facilities should be based on the following additional radiological control design criteria:

1. Individual worker dose in frequently occupied areas should be ALARA and less than 500 mrem per year;

2. Discharges of radioactive liquid to the environment are covered by provisions in DOE Order 5400.5, and other regulatory documents, and should not degrade the ground water;

3. Control of contamination should be achieved by containment of radioactive material;

4. Efficiency of maintenance, operations, decontamination and decommissioning should be maximized;

5. Components should be selected to minimize the buildup of radioactivity; and

6. Support facilities should be provided for donning and removal of protective clothing and for personnel monitoring, where appropriate.

E. ALARA Design Review Checklist.

(Insert facility-specific checklist.)

To serve as an aid in performing the ALARA Design Review, a checklist such as the one in Appendix D may be used.

The first part is a list of preliminary questions called “First Level Screening Questions” which identify appropriate questions from the main checklist.

The second part is the main checklist, a series of questions grouped by subject.

The last part is a disposition sheet on which individual answers may be discussed and resolutions may be recorded.

F. Performing the Review.

(Substitute facility-specific information as applicable.)

Near the end of each stage, the ALARA Design Review for that stage will take place.

Each ALARA reviewer may obtain a copy of the ALARA Design Checklist and fill it out according to her/his knowledge of the project. If the reviewer recognizes any issues of

potential radiological impact not covered by the checklist, these issues should be noted on an attached sheet.

G. Existing Features and Non-radiological Additions.
The review is to consider not only new or newly added features, but also existing features which might be affected. The impact of non-radiological additions on radiological items must be considered.

H. Optimization Analysis.
As part of the design or modification, an optimization analysis may have been performed. This should also be examined in case anything has changed in the course of the design. However, the ALARA Design Review may show the need for an optimization analysis as well, and this analysis may be done as part of the review. Optimization is covered in Module 110.

I. Completed Review.
(Substitute facility-specific information, as applicable.)

When each reviewer has filled out the checklist, it is sent to the ALARA Review Coordinator.

6. DOCUMENTATION AND APPROVAL

A. Review Documentation.
(Substitute facility-specific information, as applicable.)

When all comments are returned, the ALARA Review Coordinator makes a final resolution of all comments and issues a memorandum report.

The report lists all reviewers, describes the areas covered, summarizes the conclusions of the Design Review, highlights any conflicts, and gives any recommendations the ALARA
Review Coordinator may have.

B. Review Approval.
(Insert facility-specific information.)

The report (with associated documentation) may then be reviewed and approved by the site Radiological Control Manager (RCM) or Radiological Engineering Manager (REM), if she/he elects to do so.

The written waiver of review and approval by the RCM/REM constitutes approval of the project ALARA design.

C. Copies of the Report.
(Insert facility-specific information.)

Copies of the report (with associated documentation) should also be sent by the ALARA Review Coordinator to relevant management and technical review committees, and to appropriate health and safety groups. The ALARA Committee(s), who may also need to review the design, should be sent copies.

IX. MODULE 109

1. ALARA OPERATIONAL REVIEWS

A. Objective.

Participants should demonstrate the application of ALARA principles in operations.

B. Definitions and Purpose of Review.

An ALARA operational review (sometimes referred to as an ALARA job/experiment review) is a systematic pre- and post-job review of activities within the potential for significant dose, contamination, or airborne concentrations to ensure that ALARA controls are planned, evaluated, implemented where reasonable, and documented. An ALARA operational review serves to document the use of ALARA and to show any compromises or adjustments made in balancing ALARA against operational, practical, and other considerations.

C. Requirements.

10 CFR 835.1003 requires that during operations, the combination of engineered controls and administrative controls shall ensure that the total effective dose equivalent does not exceed 5 rem in a year and that the ALARA process is used.

2. WHEN TO PERFORM A REVIEW

A. Operational Review.

An Operational Review can be done when required by procedure or requested by the operational group, facility manager, ALARA Committee, or other groups such as the Facility Review Committees. Reviews should also be performed if the site-specific trigger levels (as identified in articles 312.3 and 312.6 of the RadCon Standard) are exceeded.

In addition, an ALARA review should be performed for the following cases:

1. Non-routine jobs, operations, or campaigns in which any individual might receive a dose of 100 mrem or more, or where there is any uncertainty in the predicted dose;

2. Routine jobs, operations, or campaigns in which any individual might receive as much as 300 mrem;

3. Any job or operation in which the collective dose is expected to exceed the site-specific trigger level;

4. Any job, operation, or campaign in which any individual might exceed an administrative dose level (e.g., 2,000 mrem /yr);

5. Any job, operation, or campaign in which the dose to an individual might cause the ALARA goal of the facility, the division, or the work group to be exceeded; and

6. Any job, operation, or campaign in which airborne levels may potentially exceed 10 percent of the DAC.

7. Any job, operation, or campaign in which there is a potential for significant levels of contamination to be present.

B. Operational Review Versus Radiological Work Permit (RWP) and Prejob Briefing

The operational review is conducted in addition to the Radiological Work Permit (RWP) preparation (which may be required by procedure), or it can be part of it. A simplification of this process would be appropriate for small, uncomplicated operations; for example, the RWP preparation could satisfy this review if all areas required to be considered in both are covered, and appropriate operational reviewers are consulted.

Also, the operational review could support RWP preparation or the reviews to be done by operating division personnel, as required by procedure.

An operational review is not the same as the prejob briefing, since in the review, the planners are collecting and evaluating information on the final, agreed-upon plan for the work. At the end of the review, changes may remain to be made, while at the end of the briefing, everybody should understand what to do. However, for smaller jobs, the two could be combined provided that any concerns are fully evaluated and resolved before work begins.

3. PERFORMING AN OPERATIONAL REVIEW

A. Conduct of the Review.

The following method is suggested as a practical way of accomplishing and documenting the review. A simplification of this process is appropriate for small, uncomplicated projects. Usually representatives of the group managing the operation or job, worker groups, and the radiological control organization should participate.

To serve as an aid in performing an ALARA Operational Review, an ALARA Operational Review Checklist is provided in Appendix E.

B. Documentation of the Review.

The review should be documented appropriately, usually by a written statement that a review was performed and by incorporation of the selected controls into the RWP and work documents. The documentation should be kept in either the appropriate job or operation file or in the radiological control organization's ALARA files, consistent with the requirement that records of ALARA decisions be retained (10 CFR 835).

X. MODULE 110

1. OPTIMIZATION ANALYSIS

A. Objective.

During the presentation of Module 110, participants will demonstrate the application of optimization techniques by actively participating in the group exercises.

B. Definition.

"Optimization" may be defined as arriving at an optimal solution to a problem or selecting the best from among the available alternatives, in accordance with a given analytical method.

C. Purpose of Optimization Analysis.

The purpose of an optimization analysis is to show that the expense (in terms of money, person-hours, dose to install and maintain, etc.) of a project or feature of a project is justified in terms of the benefit received. This is in accordance with the idea of balancing ALARA considerations against technological, social, operational, and economic considerations.

D. Regulations and Guidance for Optimization.

1. 10 CFR 835.1002(a), Occupational Radiation Protection.

   "Optimization shall be used to assure that occupational exposure is maintained ALARA in developing and justifying facility design and physical controls."

2. DOE Order 5400.5, "Radiation Protection of the Public and the Environment."

   DOE 5400.5 requires that "...contractors develop a program to implement the ALARA process for all activities that cause dose to the general public." Furthermore, DOE 5400.5 states that "...Factors to be considered, at the minimum, shall include:

   a. The maximum dose to the public;

   b. The collective dose to the population;

   c. Alternative methods of processing, treating, controlling, and operating radioactive effluent systems;

d. The dose associated with each alternative;

e. The cost for each technological alternative;

f. Examination of the changes in costs associated with the various alternatives; and

g. Examinations of the changes in societal impact associated with the various alternatives.

3. ICRP 55, "Optimization and Decision-Making in Radiological Protection."

   ICRP 55 states that "...optimization provides a basic framework of thinking wherein it is proper to carry out some kind of balancing of the resources put into production, and the level of protection obtained against a background of other factors and constraints, so as to obtain the best that can be achieved in the circumstances."

4. The RCS, Article 312, addresses major and minor activities.

5. PNL-6577, "Department of Energy, Health Physics Manual of Good Practices for Reducing Radiation Exposure to As Low As Reasonably Achievable (ALARA)."

   PNL-6577 gives guidance on how to perform cost-benefit analyses.

2. OPTIMIZATION METHODS

A. Informal Analysis.

There are various ways to determine whether a design or operation is optimized. One is a consensus recognition by the ALARA engineer and others on the design or operation team that a particular project or feature of a project justifies the cost in terms of dose, money, work-hours, and operational adjustments required to produce the project. Such a project or feature can be termed "patently advantageous" as regards ALARA. This conclusion should be documented.

B. Other Considerations.

Often, however, the justification for the design, design feature, or operation is not so clear-cut. Then a more rigorous optimization must be done to demonstrate that the project is

optimized by the design, the inclusion of the design feature, or the plan of the operation. This is particularly true if there are alternatives to the design, feature, or operation, and if "doing nothing" (status *quo*) is one of the alternatives.

C. Formal (Analytical) Optimization Analysis.

In formal (analytical) optimization analyses, one must express the value of all resources, including dose, in commensurate units, or rank them in some consistent way, or both. Usually the value expression is done by assuming a dollar value for each parameter, including dose.

A formal optimization typically consists of a Cost-Benefit Analysis (CBA). In the CBA, all of the items to be considered must be expressed in the same units, usually dollars. Because of that reason, a dollar value must be given to the dose saved. DOE has specified that this value be determined on a site-by-site basis. The NRC uses a value of $2000 per person-rem.

The net benefit of a feature, system, or method is then determined by subtracting the costs of production, radiation protection, and dose from the gross benefit. Using this methodology, the net benefit can be determined for several alternatives and compared to determine the optimal choice.

See Appendix F for further details regarding the CBA, including examples.