12.0 Radiation Protection

This chapter provides information on radiation protection measures employed in the design and operation of the U.S. EPR nuclear power plant, as well as estimated radiation exposures of personnel during normal operation and anticipated operational occurrences (AOOs). In accordance with 10 CFR Part 50, Appendix A, AOOs are those conditions of normal operation which are expected to occur one or more times during the life of the nuclear power unit and include, but are not limited to, loss of power to all recirculation pumps, tripping of the turbine generator set, isolation of the main condenser, and loss of all offsite power. This chapter also provides information on facility and equipment design, planning and procedures programs, and techniques and practices used to meet the radiation protection standards of 10 CFR Part 20 to achieve occupational and public radiation exposures that are as low as reasonably achievable (ALARA).

12.1 Ensuring that Occupational Radiation Exposures are as Low as Reasonably Achievable (ALARA)

12.1.1 Policy Considerations

12.1.1.1 Management ALARA Policy

The management ALARA policy and organizational structure are described in Section 12.1.3.

12.1.1.2 ALARA Design and Construction Policies

Operating experience with reactor plants in the U.S., France, and Germany shows that the majority of occupational worker radiation exposure is because of maintenance on certain highly radioactive systems, radioactive waste handling, inservice inspection, refueling, abnormal operations, and decommissioning activities. These activities are specifically addressed and factored into the design of the U.S. EPR through the plant physical layout, selection of materials, shielding, reduction of activated corrosion product traps, and improved chemistry control. The U.S. EPR design results in a lower occupational annual dose compared to previous plant designs (see Section 12.3.5.1). The U.S. EPR design process complies with 10 CFR 20.1101(b) and is in accordance with the guidance provided in RG 8.8 Section C.2 to achieve occupational doses and doses to members of the public that are ALARA.

12.1.1.3 Implementation of ALARA Policy

Implementation of the ALARA policy is described in Section 12.1.3.

12.1.2 Design Considerations

U.S. EPR designers and engineers receive guidance on incorporating ALARA into the design evolution process, which includes information on lessons learned from the nuclear power industry, federal guidance, and review responsibilities. Design changes undergo review by the U.S. design review board; the board members may include representatives from the German design team, the French design team, and operators of existing U.S. nuclear plants. These design reviews include an ALARA review if radiation exposure is affected.

10 CFR 20.1406 design considerations to minimize the contamination of the facility and the environment, to facilitate eventual decommissioning, and to minimize the generation of radioactive waste are described in Section 12.3.6. ALARA operational considerations for plant modifications are described in Section 12.1.3.

12.1.2.1 Accessibility

12.1.2.1.1 Facility Layout

Experience from past reactor plant designs shows that the facility layout, particularly the proximity of components to each other, is a factor in the cumulative annual facility dose. The U.S. EPR includes layout considerations in the plant design that reduce personnel radiation exposure. For instance, the design of plant buildings includes anterooms that serve as entries to higher dose rate rooms to further protect workers from radiation within the room. In one example of this configuration, anterooms are provided for the engineered safety features (ESF) filter rooms in the Fuel Building on elevations +24 feet and +36 feet. The facility layout also provides sufficient space for tools and equipment staging in low dose rate areas, space for supervisors to monitor work in progress, space to easily disassemble and reassemble components while in protective clothing, and space for temporary shielding, if needed. Services such as compressed dry air, demineralized water, and communications equipment are provided in local compartments where experience has shown the need for them.

Past reactor plant designs were examined for places in which workers have typically installed scaffolding to perform maintenance. Where possible and appropriate, the U.S. EPR components are moved to the floor level for ease of maintenance. Where the component must be placed higher in the room than can be reached from the floor level, platforms are installed to eliminate the need for scaffolding. An example of the use of platforms is in the main steam valve rooms in the Safeguard Building, located at elevation +69 feet.

The U.S. EPR components are segregated into compartments. This arrangement allows workers to perform maintenance on a given component, while being shielded from the dose of adjacent components. The design also segregates multiple systems into operating trains. The layout by trains is most evident for the safeguard systems located in the Safeguard Building. This building consists of four separate and well-shielded divisions. This physical separation and shielding allows an entire train of safeguard equipment to be taken out of service, flushed, and maintained while remaining shielded from the other three trains.

Additional examples of compartmental configurations include the following:

- Reactor Building (RB). Compartmentalization of the reactor coolant system (RCS) major components, the steam generators (SGs), and reactor coolant pumps (RCPs), as shown on Figure 12.3-13—Reactor Building Cross-Section Radiation Zones.

- Safeguard Building (SB). Compartmentalization of components in the chemical and volume control system, primary coolant purification system, and primary coolant degasification system, such as shown in Figure 12.3-21.

- Fuel Building. Compartmentalization of components in the fuel pool cooling and purification system (FPCPS), such as shown in Figure 12.3-30.

- Nuclear Auxiliary Building. Compartmentalization of components in the liquid waste management system and gaseous waste processing system, such as shown in Figure 12.3-42. The design of this building also includes additional shielding walls within some compartments, such as those for the sealing liquid tanks and waste compressors room.

- Radioactive Waste Processing Building. Compartmentalization of components in the solid waste management system, as shown in Figure 12.3-52.

The ventilation system is also compartmentalized into cells in the buildings in the Nuclear Island (NI), as described in Section 9.4.

12.1.2.1.2 Equipment Layout

The U.S. EPR equipment layout design generally segregates nonradioactive systems from radioactive systems. For nonradioactive systems, equipment that requires maintenance and inspection is located outside of radiation areas.

The general design principle used for locating radioactive components is to minimize the area in which the component is contained, yet allow sufficient space for maintenance. Additionally, higher radioactive sources are confined to the lower floors of the building in which they are located and are placed on one side of the building. Examples of this configuration include the following:

- Reactor Building. The RCS is centered low in the building.

- Safeguard Building. The controlled area is limited to the bottom two levels and to that portion of the building that is adjacent to the Reactor Building.

- Fuel Building. The major sources are confined to the side of the building adjacent to the Reactor Building.

- Nuclear Auxiliary Building. Sources are confined to the west wall adjacent to the Fuel Building and to the south wall. The radioactive components are located on the lower floors of the building. The exception to this configuration is the location of the delay beds. The delay beds are located in the upper floors of the building because these units rely on gravity to drain the moisture-sensitive charcoal that they contain.

The design of the systems within the NI avoids field-run piping to reduce potential deviations from ALARA design standards. The systems that contain radioactive materials are modeled in a 3-D computer model from which structural drawings, piping and instrumentation drawings, and isometric drawings are developed. This model permits designers and engineers to perform the following as part of the design process:

- Develop detailed isometric piping layouts.
- Check the piping runs relative to the structure design to avoid arrangements that could cause streaming.
- Check interference with components and verify the smooth run of piping to maintain laminar flow.
- Verify piping slope for proper drainage (i.e., avoid horizontal piping runs).
- Minimize portions of piping that could trap corrosion products.
- Verify that high-point vents are properly located, verify that low-point drains are properly located, and verify the segregation of nonradioactive piping from radioactive piping.

Each facility is divided into radiation zones, as described in Section 12.3.2.3. Section 12.3.2.3 also includes examples of design considerations provided above.

12.1.2.2 Reduction of Maintenance

Components are chosen for high reliability, ease of maintenance, ease of replacement, accessibility, and ease of decontamination. When possible, components located in higher dose rate areas are maintenance free.

During maintenance activities, worker doses are reduced through the use of:

- Individually separated trains of equipment in systems, which minimize exposure to workers from the other operating trains containing recirculating reactor coolant.
- Special tools and remotely controlled equipment for operations that result in significant radiation exposures to station personnel. Examples of these operations are changeout of purification filters, tensioning and detensioning of the reactor pressure vessel closure head, and handling of the core internals and fuel assemblies under water.
- Installed isolation, drain, and vent valves in systems and components to allow draining, flushing, or decontamination. This configuration minimizes the amount of contamination in the component to be repaired.
- Components and piping that are designed to keep deposits of radioactive materials at a minimum.
- Design of exposed surfaces of components to allow decontamination.
- Flanged connections for large vessels in which higher dose rates are expected because of radioactive deposits. If necessary, these connections are used to

perform decontamination to reduce the dose rate prior to major maintenance activities. Flanged connections are located outside the room in which the vessel is located in order to shield the maintenance worker and minimize the exposure to radiation.

Site-specific information describing how the plant implements the design consideration guidance provided in Section C.1 of RG 8.8 is provided in Section 12.1.3.

12.1.2.3 Activated Corrosion Product Production, Distribution, and Retention

Experience from past reactor plant designs shows that proper material selection and chemistry control are the two most important factors for reducing the production of activated corrosion products present in the reactor coolant and auxiliary systems. These factors have a direct bearing on the overall facility annual dose.

12.1.2.3.1 Material Selection

The cobalt content and the corrosion resistance of a given material influence the production of corrosion products that become activated. The U.S. EPR design eliminates, to the maximum extent possible, cobalt-containing alloys for the material selected for each part, which minimizes the production, distribution, and retention of activated corrosion products through the primary system. This material selection results in significantly less cobalt entrained in the reactor coolant available for activation and thus minimizes production of activated corrosion products.

The U.S. EPR uses low-cobalt-content alloys, such as Alloy 690, for SG tubes. Alloy 690 has superior corrosion resistance and less cobalt content than the Alloy 600 that has typically been used in past designs in the U.S. Because of the relatively large surface area of the tubes inside the four SGs, the use of this material results in significantly smaller quantities of corrosion products available to become activated. Similarly, low-cobalt-content and corrosion-resistant materials are specified for other components in auxiliary systems, including pumps and valves, which further reduce corrosion products available for activation.

Wherever it is compatible with the process, stainless steel is used for parts of components that contact reactor coolant or processed reactor coolant. For example, the coolant storage tanks are made of stainless steel.

12.1.2.3.2 Water Chemistry

The reactor coolant chemistry for the U.S. EPR is designed to minimize the production of activated corrosion products by creating an environment that is less corrosive to the selected materials. Chemistry, which is coordinated with the boron content of the reactor coolant, is used to provide a constant pH in a target range that is optimized to minimize the production of corrosion products at the operating temperature. Enriched boron is used to limit the required boric acid concentration for reactivity control, limiting the addition of a pH buffer to the reactor coolant. A slightly basic solution is used to minimize corrosion of metals exposed to reactor coolant at operating conditions. Lithium hydroxide is used as the pH buffer and is enriched in lithium-7 to limit the production of tritium via the $^{6}Li(n,)^{3}H$ reaction. Suspended solids in the reactor coolant can be activated when they pass through the core, and contribute to activation of plant systems and increase dose rates when they are deposited at different places through the RCS. The coordinated boron–lithium chemistry is designed to minimize the amount of suspended solids.

Hydrogen is added to the RCS to maintain a reducing environment in the primary coolant, thereby minimizing oxidation and corrosion of the primary system materials of construction. Dissolved hydrogen accomplishes this efficiently at power operation by scavenging oxidizing molecular products formed by the radiolysis of water. By its action on the stability and solubility of corrosion products, hydrogen also has a significant influence on the radiation fields in and around SGs, in and around reactor coolant piping, and on crud buildup on the fuel rods.

The chemistry control scheme for cold shutdown increases corrosion product concentration, which may be removed through the CVCS. The changes in reactor coolant physics and chemistry causing these conditions are because of boration, decrease in temperature, change from a reducing environment to an oxidizing environment, changes in pump operation, and residual heat removal system operations. During shutdown and normal operation, the chemical and volume control system can purify approximately 10 percent of the RCS liquid volume per hour.

The reactor coolant chemistry is optimized prior to plant start-up. In order to minimize the corrosion potential, the oxygen level in the RCS is minimized during startup by vacuum venting and filling. To avoid deposition of corrosion products, lithium is not added until the reactor coolant is purified and the temperature is at an acceptable level. The lithium addition establishes conditions for maximum nickel solubility and subsequent removal by the coolant purification system. When the chemical characteristics of the reactor coolant are consistent with chemistry requirements, the hydrogenation station is placed in operation to provide the required hydrogen concentration in the reactor coolant to control dissolved oxygen during power operations.

12.1.3 Operational Considerations

A COL applicant that references the U.S. EPR design certification will fully describe, at the functional level, elements of the ALARA program for ensuring that occupational radiation exposures are ALARA. This program will comply with the provisions of 10 CFR Part 20 and be consistent with the guidance in RGs 1.8, 8.2, 8.7, 8.8, 8.9, 8.10, 8.13, 8.15, 8.27, 8.28, 8.29, 8.34, 8.35, 8.36, 8.38, and the applicable portions of NUREG-1736 (Reference 1).

12.1.4 References

1. NUREG-1736, "Consolidated Guidance: 10 CFR Part 20 - Standards for Protection Against Radiation," NRC, October 2001.