12. RADIATION PROTECTION

12.1 Introduction

The AP1000 Design Control Document (DCD) Tier 2, Chapter 12, “Radiation Protection,” describes the radiation protection measures of the AP1000 reactor design and operating policies. The U.S. Nuclear Regulatory Commission (the NRC or staff) evaluated this information against the criteria in Chapter 12, NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants—LWR Edition” (SRP).

The AP1000 reactor design incorporates radiation protection measures intended to ensure that internal and external radiation exposures to station personnel, contractors, and the general population, resulting from plant conditions, including anticipated operational occurrences (AOOs), will be within regulatory criteria and will be as low as is reasonably achievable (ALARA). Doses to the public under these conditions are discussed in Chapter 11, “Radioactive Waste Management,” of this report. As set forth in Chapter 11 of this report, normal operational doses to members of the public meet the requirements of 10 CFR Part 20 that set limits on doses for persons in unrestricted areas. With respect to occupational doses, the applicant’s radiation protection design and program features should also be consistent with the guidelines of Regulatory Guide (RG) 8.8, “Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations Will Be As Low As Is Reasonably Achievable,” Revision 3, dated June 1978, or an acceptable alternative.

Compliance with these criteria provides assurance that doses to workers will be maintained within the limits of Title 10 of the Code of Federal Regulations (CFR) Part 20, “Standards for Protection Against Radiation.” The requirements of 10 CFR Part 20 applicable to workers at an NRC-licensed facility limit the sum of the external whole-body dose (deep dose equivalent) and the committed effective equivalent doses resulting from radioactive material deposited inside the body (deposited through injection, absorption, ingestion, or inhalation) to 50 millisievert (mSv) (5 rem) per year with a provision (i.e., by planned special exposure) to extend it to 100 mSv (10 rem) per year with a lifetime dose limit of 250 mSv (25 rem) due to planned special exposures.

The SRP acceptance criteria provide assurance that the radiation doses resulting from exposure to radioactive sources both outside and inside the body can each be maintained ALARA and well within the limits of 10 CFR Part 20. The balancing of internal and external exposure necessary to ensure that their sum is ALARA is an operational concern. An applicant seeking a combined license (COL) must address these operational concerns, as well as programmatic radiation protection concerns.

The staff has received sufficient information from the applicant to conclude that the radiation protection measures incorporated in the AP1000 reactor design offer reasonable assurance that occupational doses during all plant operations will be maintained ALARA and within the limits of 10 CFR Part 20. The following sections present the bases for the staff’s conclusions.

12.2 Ensuring That Occupational Radiation Doses Are As Low As Is Reasonably Achievable

The staff reviewed the information in DCD Tier 2, Section 12.1, “Assuring That Occupational Radiation Exposures Are As Low As Reasonably Achievable,” to assess adherence to the guidelines in RG 1.70, “Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants,” Revision 3, as well as the criteria in Section 12.1 of the SRP regarding the radiation protection aspects of the AP1000 reactor design. Specifically, the staff reviewed DCD Tier 2, Section 12.1 to ensure that the applicant had either committed to adhere to the criteria of the RGs and staff positions referenced in Section 12.1 of the SRP, or had provided acceptable alternatives. The staff finds that DCD Tier 2, Section 12.1 is consistent with the guidance contained in these RGs and applicable staff positions. Therefore, the staff concludes that the relevant requirements of 10 CFR Part 20 have been met.

12.2.1 Policy Considerations

In DCD Tier 2, Section 12.1.1, “Policy Considerations,” the applicant described the design, construction, and operational policies that have been implemented to ensure that ALARA considerations are factored into each stage of the AP1000 design process. The applicant has committed to ensure that the AP1000 plant will be designed and constructed in a manner consistent with the guidelines of RG 8.8. In particular, DCD Tier 2, Section 12.1.1.1, “Design and Construction Policies,” states that the applicant has met this commitment by reviewing the plant design during the design phase for ALARA considerations. This ALARA policy is consistent with the guidelines of RG 8.8 and is therefore acceptable.

The requirements of 10 CFR Part 20 specify that all licensees must develop, document, and implement a radiation protection program. Specifically, this program shall encompass the ALARA concept and include provisions for maintaining radiation doses and intakes of radioactive materials ALARA. The detailed policy considerations regarding overall plant operations and implementation of such a radiation protection program are outside the scope of this design certification review. The operational ALARA policy forms the basis for the operating station's ALARA manual. In order to maintain doses to plant personnel ALARA, the applicant stated, in DCD Tier 2, Section 12.1.3, “Combined Licensee Information,” that the COL applicant will review all plant procedures and modification plans that involve personnel radiation exposure to ensure that the ALARA policy is applied. In addition, a COL applicant referencing the AP1000 certified design will address operational ALARA concerns and will submit an operational ALARA policy which conforms to the requirements of 10 CFR Part 20 and the recommendations of Revision 2 to RG 1.8, “Qualification and Training of Personnel for Nuclear Power Plants," RG 8.8, and Revision 1-R to RG 8.10, “Operating Philosophy for Maintaining Occupational Radiation Exposure As Low As Is Reasonably Achievable.” The staff identified this issue as COL Action Item 12.2.1-1.

12.2.2 Design Considerations

The plant radiation protection design should ensure that individual doses and total person roentgen equivalent man (rem) doses to plant workers and to members of the public are ALARA, and individual doses are maintained within the limits of 10 CFR Part 20. DCD Tier 2, Section 12.1.2, "Design Considerations," describes the objectives for the general design and shielding to minimize the time employees spend in radiation areas and to minimize radiation levels in areas routinely occupied and housing equipment requiring attention by plant personnel. DCD Tier 2, Section 12.1.2 also states that these design considerations are consistent with the guidelines in RGs 8.8 and 8.10. Specifically, DCD Tier 2, Section 12.1.2 states that the basic management philosophy guiding the AP1000 design is to ensure that exposures are ALARA by designing structures, systems, and components to achieve the following objectives:

- Attain optimal reliability and maintainability, thereby reducing maintenance requirements for radioactive components.

- Reduce radiation fields, thereby allowing operations, maintenance, and inspection activities to be performed in reduced radiation fields.

- Reduce access, repair, and equipment removal times, thereby reducing the time spent in radiation fields.

- Accommodate remote and semi-remote operation, maintenance, and inspection, thereby reducing the time spent in radiation fields.

In addition, DCD Tier 2, Section 12.1.2 describes several design features which satisfy the objectives of the plant's radiation protection program:

- The use of highly reliable equipment reduces the frequency of maintenance and associated personnel exposure.

- Except in limited applications where it is necessary for reliability considerations, materials in contact with the reactor coolant system (RCS) have low concentrations of cobalt and nickel. This reduces the amounts of cobalt-60 and cobalt-58 introduced in the RCS. (Cobalt-60 and cobalt-58 are the major sources of radiation exposure during shutdown, maintenance, and inspection activities at light water reactors (LWRs).)

- Adequate spacing and laydown areas facilitate access for maintenance and inspection.

- The amount of time spent in radiation areas is minimized with enhanced servicing convenience for anticipated maintenance or potential repairs, including ease of disassembly and modularization of components for replacement or removal to a lower radiation area for repair.

- Radioactive systems are separated from non-radioactive systems, and high radiation sources are located in separate shielded cubicles.

- Equipment requiring periodic servicing or maintenance (e.g., pumps, valves, and control panels) are separated from sources with higher radioactivity such as tanks and piping.

- Valves located in high radiation areas are equipped with reach rods or motor operators to minimize operator exposure.

- Equipment and piping are designed to minimize the accumulation of radioactive materials.

- Drains are located at low points.

- Piping is seamless, and the number of fittings is minimized, thereby reducing the radiation accumulation at seams and welds.

- Use of flushing connections minimizes the buildup of crud in system components.

- Systems that produce radioactive waste are located close to radwaste processing systems to minimize the length of piping runs carrying highly radioactive material.

- Pipes that carry resin slurries are run vertically as much as possible and large-radius bends are used instead of elbows, thereby minimizing the potential for pipe plugging.

These design considerations incorporate the basic management philosophy guiding the AP1000 design effort and are consistent with the guidelines in RG 8.8. Therefore, the staff finds them to be acceptable.

In addition to the features described above, the AP1000 reactor design incorporates several features that represent improvements over many currently operating plants:

- The AP1000 design accommodates the use of robotic technology to perform maintenance and surveillance in high radiation areas.

- The design reduces the number of components containing radioactive fluids and clearly and deliberately separates clean areas from potentially contaminated areas.

- The design eliminates the need for waste and recycle evaporators and the boron recycle system, which have historically required frequent operational and maintenance attention, exposing plant personnel to substantial levels of radiation.

The design features described in DCD Tier 2, Section 12.1.2 are intended to minimize personnel exposures and comply with the guidelines of RG 8.8. As such, these design features should maintain individual doses and total person-rem doses to plant workers and to members of the public ALARA, while maintaining individual doses within the limits of 10 CFR Part 20. The staff therefore finds these design features to be acceptable.

12.2.3 Operational Considerations

Operational considerations regarding the implementation of a radiation protection program are outside the scope of this design certification review. The applicant has stated that a COL applicant who references the AP1000 certified design will address operational considerations consistent with the level of detail provided in Revision 3 of RG 1.70. Section 12 of the SRP lists the following RGs that the COL applicant must address:

- RG 8.2, "Guide for Administrative Practices in Radiation Monitoring," February 1973
- RG 8.20, "Applications of Bioassay for I-125 and I-131," Revision 1, September 1979
- RG 8.26, "Applications of Bioassay for Fission and Activation Products," September 1980
- RG 8.27, "Radiation Protection Training for Personnel at Light-Water Cooled Nuclear Power Plants," March 1981
- RG 8.28, "Audible-Alarm Dosimeters," August 1981

Since the issuance of Chapter 12 of the SRP in 1981, the staff has revised some existing RGs and has developed additional RGs to address new issues that have resulted from the major revision of 10 CFR Part 20 in 1991. Some of the new or revised RGs that pertain to DCD Tier 2, Chapter 12 are listed below:

- RG 8.7, "Instructions for Record Keeping and Recording Occupational Radiation Exposure Data," Revision 1, June 1992
- RG 8.9, "Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program," Revision 1, July 1993
- RG 8.13, "Instruction Concerning Prenatal Radiation Exposure," Revision 3, June 1999
- RG 8.15, "Acceptable Programs for Respiratory Protection," Revision 1, October 1999
- RG 8.25, "Air Sampling in the Work Place," Revision 1, June 1992
- RG 8.29, "Instructions Concerning Risks from Occupational Radiation Exposure," Revision 1, February 1996
- RG 8.34, "Monitoring Criteria and Methods to Calculate Occupational Radiation Doses," July 1992
- RG 8.35, "Planned Special Exposures," June 1992
- RG 8.36, "Radiation Dose to the Embryo/Fetus," July 1992

- RG 8.38, “Control of Access to High and Very High Radiation Areas in Nuclear Power Plants,” June 1993

Addressing the above RGs is outside the scope of this design certification review. In DCD Tier 2, Section 12.1.3, the applicant stated that the COL applicant will address operational considerations of the SRP consistent with the level of detail provided in RG 1.70. The applicant also listed the following RGs that the COL applicant will need to address in its application—8.2, 8.7, 8.9, 8.13, 8.15, 8.20, 8.25, 8.26, 8.27, 8.28, 8.29, 8.34, 8.35, 8.36, and 8.38. The staff identified this issue as COL Action Item 12.2.3-1.

12.2.4 Conclusion

Based on the information supplied by the applicant, as described above, the staff concludes that the AP1000 design features meet the criteria of Section 12.1 of the SRP. These design features are intended to maintain individual doses and total person-rem doses to plant workers and to members of the public ALARA, while maintaining individual doses within the limits of 10 CFR Part 20. Therefore, the staff finds the AP1000 design features to be acceptable. The COL applicant will address the policy and operational considerations for the AP1000. The staff finds it acceptable for the applicant to defer discussion of the material addressed by COL Action Items 12.2.1-1 and 12.2.3-1. The staff will determine compliance with the requirements of 10 CFR Part 20 in these areas during the COL review.

12.3 Radiation Sources

The staff reviewed the descriptions of the radiation sources given in DCD Tier 2, Chapter 11, “Radioactive Waste Management,” and DCD Tier 2, Section 12.2, “Radiation Sources,” to assess completeness against the guidelines in RG 1.70 and the criteria in Section 12.2 of the SRP. The applicant will use the contained source terms described in the DCD as the basis for the radiation design calculations (shielding and equipment qualification) and personnel dose assessment. The applicant will use the airborne radioactive source terms in the DCD in the design of ventilation systems and for assessing personnel dose. The staff reviewed the source terms in the DCD to ensure that the applicant had either committed to follow the guidelines of the RGs and staff positions set forth in Section 12.2 of the SRP, or provided acceptable alternatives. Where the DCD adheres to these RGs and staff positions, the staff can conclude that the relevant requirements of 10 CFR Part 20 and 10 CFR Part 50, Appendix A (General Design Criterion (GDC) 61, “Fuel Storage and Handling and Radioactivity Control”) have been met.

12.3.1 Contained Sources

In DCD Tier 2, Section 12.2.1, “Contained Sources,” the applicant describes the shielding design source terms during normal full-power operation, shutdown, and design basis accident events. To calculate these shielding design source terms, the applicant assumed 0.25-percent fuel cladding defects at full-power operation. Other than the reactor core, the RCS is the principal contributor to radiation levels in the containment. Sources of radiation in the RCS include the following:

- fission products (which are released from defective fuel cladding)
- activation products
- corrosion products

Of these radiation sources, the activation product nitrogen-16 (N-16) is the predominant radionuclide in the RCS piping, reactor coolant pumps (RCPs), and steam generators (SGs) (all of which are located in containment) during plant operations. Containment access, however, is not normally required during power operation of the AP1000, and the applicant does not anticipate access to the loop compartments. The nitrogen-16 activity is not a factor in the radiation sources for systems and components located outside containment during normal power operations because of the short half-life (7.11 seconds) of N-16. In addition, the normal letdown flow path is entirely inside containment.

The applicant used the design basis source term values for the various radionuclides in determining the shielding design necessary to obtain the desired plant area radiation levels for the AP1000. In arriving at the design basis corrosion product activity levels for the AP1000, the applicant used a set of values that are reasonably conservative relative to current operating plant experience. The AP1000 design basis source term values (values used to determine the shielding thickness) for the major corrosion product nuclides exceed the average operating four-loop plant measured values by factors in the range of 2 to 7.

In accordance with the criteria set forth in Section 12.2 of the SRP, DCD Tier 2, Section 12.2.1 describes all large contained sources of radiation which are used as the basis for designing the radiation protection program and completing shield design calculations. These sources include the reactor core; the RCS; the chemical and volume control system; spent fuel and the spent fuel pool cooling system; the liquid, gaseous, and solid radwaste systems; and other miscellaneous sources. For each of these contained sources, the applicant provided either the source strength by energy group or the associated maximum activity levels listed by isotope. The DCD provides system layouts within rooms or cubicles, as well as information about the type and size of components in these systems. In its response to staff request for additional information (RAI) 471.007, the applicant provided additional clarifying information on dimensions, volumes, material, and equipment self-shielding for dominant radiation sources within the plant.

Section 12.2 of the SRP also states that this section should include descriptions of any required radiation sources containing byproduct, source, and special nuclear materials. In DCD Tier 2, Section 12.2.3, “Combined License Information,” the applicant stated that the COL applicant will address any contained radiation sources not identified in DCD Tier 2, Section 12.2.1, including radiation sources used for instrument calibration or radiography. The staff identified this issue as COL Action Item 12.3.1-1.

The AP1000 core activity release model for a core melt accident is based on the source term model from NUREG-1465, “Accident Source Terms for Light-Water Nuclear Power Plants.”

The applicant used the resulting source strengths to calculate post-accident dose rates, as well as worker doses incurred during vital area access/activities following an accident. In the event of core degradation, core cooling would be provided by the passive core cooling system, which is totally inside the containment such that no high activity sump solution would be recirculated outside the AP1000 containment. The use of the NUREG-1465 source term model complies with the requirements of 10 CFR 50.34(f)(2)(vii). Therefore, the staff finds the use of this accident source term acceptable.

The DCD also includes the assumptions that the applicant used in arriving at quantitative values for contained and airborne source terms, based on the relevant requirements of GDC 61 and 10 CFR Part 20.

12.3.2 Airborne Radioactive Material Sources

In DCD Tier 2, Section 12.2.2, “Airborne Radioactive Material Sources,” the applicant described the sources of airborne radioactivity for the AP1000 reactor design. These include leakage of primary coolant and activation of naturally occurring argon in the atmosphere in containment; leakage from stored spent fuel assemblies and evaporative losses from the spent fuel pool in the fuel-handling area; and primary equipment leakage in the auxiliary building.

The applicant uses airborne radioactive source terms in the design of ventilation systems and for personnel dose assessment. RG 1.70 states that DCD Tier 2, Section 12.2 should include a tabulation of the calculated concentrations of airborne radioactive material, by nuclide, for areas normally occupied by operating personnel. DCD Tier 2, Section 12.2 describes the assumptions and parameters used to determine the maximum expected airborne radioactivity concentration levels during normal operations in the containment, fuel-handling area, and auxiliary building.

12.3.3 Conclusion

On the basis of its review of the information on radiation sources supplied by the applicant for the AP1000, as described above, the staff concludes that the applicant has committed to follow the guidelines of the RGs and staff positions set forth in Section 12.2 of the SRP. The staff finds that DCD Tier 2, Section 12.2 is consistent with the guidance contained in these RGs and staff positions. Therefore, the staff concludes that the relevant requirements of 10 CFR Part 20 and GDC 61 have been met. The staff finds it acceptable for the applicant to defer discussion of the material addressed by COL Action Item 12.3.1-1. Thus, the staff finds the material contained in DCD Tier 2, Section 12.2 acceptable.

12.4 <u>Radiation Protection Design</u>

The staff reviewed the facility design features, shielding, ventilation, and area and airborne radiation monitoring instrumentation contained in DCD Tier 2, Section 12.3, “Radiation Protection Design Features,” for adherence to the guidelines in RG 1.70 and the criteria in Section 12.3-12.4 of the SRP. The purpose of this review was to ensure that the applicant had either committed to follow the guidelines of the RGs and applicable staff positions, or offered acceptable alternatives. Where the DCD adheres to these RGs and staff positions, the staff can conclude that the relevant requirements of 10 CFR Parts 20, 50, and 70 have been met. The following sections present the staff's findings.

12.4.1 Facility Design Features

The AP1000 reactor design incorporates several features to help maintain occupational radiation exposures ALARA in accordance with the guidance in RG 8.8. These design features are founded on the ALARA design considerations described in DCD Tier 2, Section 12.1 and discussed in Section 12.2.2 of this report.

The AP1000 reactor vessel design includes an integrated head package which combines the head lifting rig, control rod drive mechanisms and gray rod drive mechanisms (CRDM/GRDM), lift columns, missile shield, CRDM cooling system, and power and instrumentation cabling into a one-package reactor vessel head design. The use of this integrated head package design helps to minimize the time, manpower, and radiation exposure associated with head removal and replacement during refueling operations. The AP1000 design replaces conventional top-mounted thermocouple and movable incore flux detectors with a combination thermocouple/incore detector system. This system eliminates the need to disassemble and reassemble the instrument port conoseals at each refueling. This task has historically resulted in relatively high radiation exposures. Permanently installed shielding is integral to the head package for reducing work area dose rates from the CRDM drive shafts and the thermocouple/incore detector system.

Insulation in the area of the reactor vessel nozzle welds is fabricated in sections with quick-disconnect clasps to facilitate insulation removal for weld inspection. Permanent identification markings of the insulation sections will accommodate rapid reinstallation, thereby reducing the personnel exposure associated with this task.

The AP1000 RCPs are hermetically sealed, canned motor pumps. The shaft for the impeller and rotor is contained within the reactor coolant pressure boundary. Hence, seals are not required to restrict RCS leakage out of the pump. The RCPs are designed to require infrequent maintenance and inspection. When maintenance or replacement is required, the pump can be unbolted from a flange connection for quick removal to a low radiation background work area using a specially designed pump removal cart. This will also reduce personnel exposure.

The AP1000 SGs are designed to be compatible with the use of robotic equipment for inspection and maintenance activities. The lower portion of the primary channel head is hemispherical and merges into a cylindrical portion, which mates with the tube sheet. This arrangement provides enhanced robotic access to all tubes, including those at the periphery of the tube bundle, without the need for a manned entry into the channel head. The area surrounding the SGs has adequate pull and laydown areas and permanent platforms. In addition, the SGs are provided with handholes and removable insulation. The SG manways are sized for easy entrance and exit of workers with protective clothing and to facilitate the installation and removal of tooling. These features enhance accessibility and reduce overall exposure during SG inspection and maintenance activities. To minimize the deposit of radioactive corrosion products on the channel head surfaces, and enhance the decontamination of these surfaces, the SG channel head cladding is machined or electro-polished to a smooth surface. The tube ends are designed to be flush with the tube sheet in the SG channel head to eliminate a potential crud trap. The SG design includes a sludge control system/mud drum which reduces the need for sludge lancing and minimizes tube and tube support degradation. These features enhance the ability to inspect and repair the AP1000 SGs while resulting in lower personnel exposures.

The DCD states that motor-operated, air-operated, or other remotely actuated valves will be employed where justified by the activity levels and frequency of use, to minimize personnel exposures resulting from valve operations. The piping in pipe chases is designed for a 60-year life with consideration given to corrosion and the operating environment. Pumps and associated piping are arranged to provide adequate space for access to the pumps for servicing. Pumps in radioactive waste systems will be provided with flanged connections for ease of removal. Cartridges and filter bags that accumulate radioactivity, as well as filters in radioactive liquid systems, will be provided with remote or semi-remote filter handling systems to minimize personnel exposure and radioactive release to the environment. Instrument devices are located in low radiation zones away from radiation sources, whenever practicable, and primary instrument devices located in high radiation zones are designed for easy removal to a lower radiation zone for calibration. The heating, ventilation, and air conditioning (HVAC) systems will maintain the airflow direction from areas of lower potential airborne contamination to areas of higher potential airborne contamination.

In addition to designing equipment to comply with ALARA guidelines, the AP1000 plant layout is designed to reduce personnel exposures. The design provides adequate work and laydown space at each inspection and maintenance station. In addition, it provides for rigging and lifting equipment to facilitate the removal, transport, or replacement of equipment and the use of portable shielding during maintenance activities. Adequate illumination and support services (e.g., power, compressed air, water, ventilation, and communications) will be available at work stations. Tube pull areas for components that handle radioactive fluids will be designed with curbs, drains, and coated floors to prevent the spread of contamination in the event of spills. Valves associated with highly radioactive components will be separated from other components, and will be located in shielded valve galleries. Radioactive piping will be routed through pipe chases to minimize personnel exposures. Major components in radioactive systems will be located in shielded compartments where practicable. To minimize radiation streaming through wall penetrations, the AP1000 design calls for as many wall penetrations as practicable to be located with offsets between the radioactive source and the normally accessible areas. The equipment and layout design features described above conform with the guidelines of RG 8.8 for maintaining occupational radiation exposures ALARA. Therefore, the staff finds these features acceptable.

The AP1000 design also incorporates several features to minimize the build up, transport, and deposition of activated corrosion products in the RCS and auxiliary systems. The DCD states that the AP1000 design will reduce or eliminate the use of materials containing cobalt and nickel that are in contact with reactor coolant, except in cases in which the use of these materials is necessary for reliability purposes. The DCD further states that the majority of materials exposed to high temperature reactor coolant will have cobalt impurities of no more than 0.05-weight percent cobalt. The major use of nickel-based alloys in the RCS is in the inconel SG tubes. Inconel SG tubing will be limited to 0.015-weight percent cobalt, while the surfaces on the inside of the SGs, other than the tubing, will have a cobalt limit of 0.10-weight percent cobalt. Materials used for rod cluster control assemblies, gray rod cluster control assemblies, and secondary source rod cladding will be Type 304 stainless steel, with an assumed maximum cobalt limit of 0.12-weight percent cobalt. Bolting materials in reactor internals and other small components in regions of high neutron flux will be limited to 0.20-weight percent cobalt. Auxiliary components, such as valves, piping, instrumentation, and welding materials, will not be limited in cobalt content, but will have average cobalt concentrations of approximately 0.20-weight percent.

The presence of antimony in RCP journal bearings in some current generation plants has increased the number of hot particles at these plants. The AP1000 design will restrict the presence of antimony to less than 1 percent in all materials that contact the RCS, and will prohibit antimony completely from the RCP and its bearings. Crud traps created in weld areas will be minimized by using butt welds. Tanks containing radioactive liquid will have drain pipes connected at the lowest part of the tank, and will have convex or sloped-bottom designs to minimize radioactivity deposition. Piping systems used to transport process resins will be designed to minimize pipe plugging by running the piping vertically as much as practicable and sloping horizontal piping runs towards the spent resin tanks. Smooth curves will replace elbows in piping runs, where practicable, to reduce potential crud traps. Welds will be made smooth to prevent crud traps from forming. Equipment and piping containing radioactive materials will have provisions for draining and flushing. These design features, which are intended to minimize the buildup, transport, and deposition of activated corrosion products in the RCS and auxiliary systems, are based on the guidelines in RG 8.8 and are, therefore, acceptable.

The applicant provided the staff with detailed drawings of the AP1000 plant layout which indicate the nine radiation zones used in the plant design. These radiation zones serve as a basis for classifying occupancy and access restrictions for various areas within the plant during normal operations and accident conditions. On this basis, the applicant establishes the maximum design dose rates for each zone, and uses these as input for shielding of the respective zones. On the basis of its review of the detailed zoning drawings, the staff concludes that the applicant’s method of plant zoning, for normal operations, is consistent with the guidance in RG 1.70 and the SRP. Therefore, the staff finds this method acceptable.

As required by 10 CFR 50.34 (f)(2)(vii), an applicant must fulfill the following requirements:

- Perform radiation and shielding design reviews of spaces around systems that may, as a result of an accident, contain radioactive materials.

- Design, as necessary, adequate access to important areas and protection of safety equipment from the radiation environment.

Item II.B.2 of NUREG-0737, “Clarification of TMI Action Plan Requirements,” dated November 1980, provides additional guidance on how these requirements can be met. Item II.B.2 describes source term information that should be used to calculate post-accident radiation levels. Item II.B.2 states that the post-accident plant dose rates should be such that the dose to plant personnel should not exceed 5E-2 sieverts (5 rem) whole body, or its equivalent to any part of the body, for the duration of the accident (per 10 CFR Part 50 and GDC 19—Control Room). The dose rate in areas requiring continuous occupancy should be less than 15E-5 sieverts per hour (15 millirem per hour) averaged over 30 days.

Item II.B.2 of NUREG-0737 describes a “vital area” as any area that will, or may, require occupancy to permit an operator to aid in the mitigation of, or recovery from, an accident. Item II.B.2 also recommends listing all vital areas in the plant, and providing a summary of the integrated doses to personnel for each of the plant areas requiring either continuous occupancy or infrequent access for the duration of the accident. (These doses should include exposure received while in transit between vital areas.) DCD Tier 2, Section 12.4.1.8, “Post-Accident Actions,” lists all of the AP1000 vital plant areas requiring postaccident accessibility and states that all vital areas can be accessed following an accident for less than 5E-2 sieverts (5 rem) to the whole body or 5E-1 sieverts (50 rem) to the extremities. DCD Tier 2, Figure 12.3-2 contains plant radiation zone maps which reflect maximum radiation fields over the course of an accident. The applicant performed analyses that confirmed that the individual exposure limits following an accident did not exceed the applicable requirements of GDC 19. In response to staff RAI 471.009, the applicant provided verification of these analyses. The staff finds that the listing of the plant vital areas, along with these analyses, satisfies the requirements of 10 CFR 50.34(f)(2)(vii) as they apply to plant shielding of vital areas.

The information contained in DCD Tier 2, Section 12.3.1 adequately addresses the relevant requirements of 10 CFR Part 20 and 10 CFR 50.34(f)(2)(vii). Therefore, the staff finds the information contained in this section to be acceptable.

12.4.2 Shielding

The objective of the plant's radiation shielding is to minimize plant personnel and population exposures to radiation during normal operation (including AOOs and maintenance) and during accident conditions while maintaining a program of controlled personnel access to and occupancy of radiation areas. The AP1000 design also includes shielding, where required, to mitigate the possibility of radiation damage to materials.

The DCD states that radioactive components and piping will be separated from nonradioactive components and piping to minimize personnel exposure during maintenance and inspection activities. When radioactive piping must be routed through corridors or other low radiation zones, shielded pipe chases are provided. Where applicable, pumps and other support equipment for components that contain radioactive material are separated from the more highly radioactive components by locating them outside the component cubicle in separate shielded cubicles. Shielded compartments have labyrinth entrances to minimize radiation streaming directly through access openings. Penetrations are located to preclude a direct line from the radioactive source to adjacent occupied areas. Space is allocated, where needed, for the erection of temporary shielding. These shielding techniques comply with the guidelines contained in RG 8.8 for protecting plant personnel and the public against exposure from various sources of ionizing radiation in the plant. Therefore, the staff finds these techniques acceptable.

Several recent instances of overexposures, or near overexposures, have occurred at current generation pressurized-water reactors (PWRs). Potentially lethal exposures have occurred in the reactor cavity. Personnel can also be exposed to potentially lethal doses of radiation in the vicinity of the fuel transfer tube when a spent fuel assembly passes through this tube during refueling operations. Access to the fuel transfer tube for the AP1000 is through a removable concrete or steel hatch that allows access for periodic inspection of the fuel transfer tube welds. The staff has stated that the opening of this hatch should be administratively controlled (i.e., the spent fuel transfer tube should be treated as a very high radiation area under 10 CFR Part 20), and that this hatch should be locked during all spent fuel transfer operations. The applicant has stated, in DCD Tier 2, Section 12.3.5, “Combined Licensee Information,” that the COL applicant will address the administrative controls for use of the design features provided to control access to radiologically restricted areas, including potentially very high radiation areas, such as the reactor cavity and the fuel transfer canal during refueling operations. The hatch to the spent fuel transfer canal will be treated as an entrance to a very high radiation area under 10 CFR Part 20 and will be locked during spent fuel transfer operations. The staff identified this issue is identified as COL Action Item 12.4.2-1.

Section 12.3.2 of the SRP states that the applicant must describe how the shielding parameters were determined, including pertinent codes, assumptions, and techniques used in the shielding calculations. The AP1000 DCD describes the shielding codes used to determine the adequacy of the station shielding design. Specifically, the applicant stated that it used the point kernel shielding code MicroShield 4 to calculate most gamma dose rates throughout the AP1000 plant. MicroShield 4 is a personal computer version of the mainframe code QAD, which is listed as an acceptable shielding code in the SRP. For complex geometries, where doses cannot be calculated using methods based on line-of-sight attenuation, such as the point kernel method, the applicant used the MCNP code. This code, which is a Monte Carlo neutron and photon transport code, is contained in the code description file of the Radiation Shielding Information Center at the Oak Ridge National Laboratory. Monte Carlo shielding codes such as this one are commonly used to calculate doses for complex geometries, such as labyrinth structures and penetrations. Therefore, the staff finds the use of this shielding code to be acceptable to evaluate the adequacy of the AP1000 station shielding design.

The information contained in DCD Tier 2, Section 12.3.2 adequately addresses the relevant requirements of 10 CFR Part 20, 10 CFR 50.34(f)(2)(vii), and GDC 61. Therefore, the staff finds the information contained in this section to be acceptable.

12.4.3 Ventilation

RG 8.8 contains guidance on acceptable ventilation design features to control airborne radioactivity levels and maintain personnel doses ALARA. The AP1000 ventilation systems are designed to protect personnel and equipment from extreme environmental conditions, and to ensure that personnel exposure to airborne radioactivity levels is minimized and maintained ALARA and within the applicable limits of 10 CFR Part 20. Further, the design ensures that the dose to control room personnel during accident conditions will not exceed the limits specified in GDC 19—Control Room.

The source of airborne radioactivity for a room or area is primarily from equipment leakage within the specified area. The AP1000 design incorporates the following features to minimize this leakage and thereby reduce the sources of airborne radioactivity.

- Ventilation air is supplied directly to the clean areas of the plant and exhausted from the potentially contaminated areas, thereby creating a positive flow of air from clean areas to potentially contaminated areas.

- Negative or positive pressure is used appropriately in plant areas to prevent exfiltration or infiltration of possible airborne radioactive contamination, respectively.

- Equipment vents and drains are piped directly to a collection system, preventing contaminated fluid from flowing across the floor to a drain and creating a potential airborne contamination problem.

- Valves under 5.08 cm (2 in.) in diameter located in the piping carrying radioactive fluids in containment, or carrying highly radioactive fluids outside containment, are hermetically sealed to preclude radioactive releases to the environment.

The AP1000 ventilation systems incorporate the following design features to minimize personnel exposures and maintain doses ALARA in accordance with the guidelines of RG 8.8.

- Ventilation fans and filters are provided with adequate access space to permit servicing and filter changeout with minimum personnel radiation exposure.

- Ventilation ducts are designed to minimize the build up of radioactive contamination within the ducts.

The requirements of 10 CFR Part 50, Appendix A (GDC 19—Control Room) state that adequate radiation protection shall be provided to permit access and occupancy of the control room under accident conditions without personnel receiving radiation exposure in excess of 5 E-2 sieverts (5 rem) whole body, or its equivalent to any part of the body, for the duration of the accident. The applicant has included the main control room in its list of vital areas. As discussed in Section 12.4.1 of this report, the applicant has performed analyses to ensure that individual exposure limits following an accident in vital areas will not exceed the applicable requirements of GDC 19.

The staff concludes that the AP1000 ventilation systems are designed to protect personnel and equipment from extreme environmental conditions, and to ensure that personnel exposure to airborne radioactivity levels is minimized and maintained ALARA and within the applicable limits of 10 CFR Part 20. Further, the design ensures that the dose to control room personnel during accident conditions will not exceed the limits specified in GDC 19. On this basis, the staff finds the AP1000 ventilation systems design acceptable.

12.4.4 Area Radiation and Airborne Radioactivity Monitoring Instrumentation

The area radiation and airborne radioactivity monitors are discussed in DCD Tier 2, Section 11.5, "Radiation Monitoring."

The plant area radiation monitoring equipment alerts operators and other station personnel to changing or abnormally high radiation conditions in the plant to prevent possible personnel overexposures and aid health physics personnel in keeping worker doses ALARA. The area radiation monitors supplement the personnel and area radiation survey provisions of the AP1000 health physics program, which is described in DCD Tier 2, Section 12.5, "Health Physics Facilities Design." The area radiation monitors should comply with the applicable requirements of 10 CFR Part 20, 10 CFR Part 50, and 10 CFR Part 70, as well as the personnel radiation protection guidelines of RGs 1.97, 8.2, and 8.8.

Control room displays provide information on monitor readings, alarm set points, and operating status. The area radiation monitors are located according to the potential for significant radiation levels in an area and the expected occupancy of the area. Specifically, area monitors will be installed in the following locations:

- areas that are normally accessible and where changes in normal plant operating conditions can cause significant increases in exposure rates above those normally designated for the areas

- areas that are normally or occasionally accessible where significant increases in exposure rates might occur because of operational transients or maintenance activities

In order to inform personnel of local dose rates in the area, area radiation monitors include a local readout and audible alarm in addition to readouts and alarms in the main control room. In addition, visible alarms are located outside each monitored area so that operating personnel can see them before entering the monitored area. Section 12.3-12.4 of the SRP reference American National Standards Institute/American Nuclear Society (ANSI/ANS) Standard HPSSC-6.8.1-1981, "Location and Design Criteria for Area Radiation Monitoring Systems for Light-Water Nuclear Reactors," dated May 1981, which provides acceptable guidance on the location and design criteria of area radiation monitoring systems. The location of the area and airborne radioactivity monitors for AP1000, as described in the DCD, meets the criteria of ANSI/ANS Standard HPSSC-6.8.1-1981. Therefore, the staff finds it acceptable.

The requirements of 10 CFR 70.24 specify the use of a monitoring system capable of detecting a criticality in designated areas where specified quantities of special nuclear material are handled, used, or stored. DCD Tier 2, Section 11.5.6.4, "Fuel Handling Area Criticality Monitors," states that two fixed radiation monitors (which meet the radiation sensitivity requirements of 10 CFR 70.24 for criticality monitors) will be located to provide coverage on the operating deck level of the Annex Building where new and spent fuel will be handled. In addition, a portable radiation monitor will be used on the crane handling fuel to detect potential criticalities during fuel handling operations. The staff finds that the use and location of these radiation monitors satisfies the criticality accident requirements of 10 CFR 70.24 and therefore finds the use of these radiation monitors to be acceptable.

The requirements of 10 CFR 50.34(f)(2)(xvii) (corresponding to Item II.F.1(3) of NUREG-0737) specify, in part, that the control room must include instrumentation to measure, record, and read out containment radiation intensity (high level). Further guidance is provided in Item II.F.1(3) of NUREG-0737, which states that the reactor containment must be equipped with two physically separate radiation monitoring systems that are capable of measuring up to 10^5 Gray per hour (10^7 roentgen per hour) in the containment following an accident. In DCD Tier 2, Section 11.5.6.2, “Post Accident Area Monitors,” the applicant stated that the AP1000 design incorporates four electrically independent ion chambers located inside the containment to measure high range gamma radiation. These detectors will be mounted on the inner containment wall in widely separated locations, and will have an unobstructed “view” of a representative volume of the containment atmosphere. The design and qualification of these monitors complies with the guidelines of RG 1.97, "Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident," Revision 3, dated May 1983, and NUREG-0737, Item II.F.1(3), with respect to detector range, response, redundancy, separation, onsite calibration, and environmental design qualification. The staff, therefore, finds these monitors to be acceptable.

The airborne radiation monitoring equipment will be placed in selected areas and ventilation systems to give plant operating personnel continuous information about the airborne radioactivity levels throughout the plant. The airborne radioactivity monitors are located upstream of the filter trains to monitor representative radioactivity concentrations from the areas being sampled. The airborne radiation monitoring system, as described in the DCD, meets the scope of the post-accident monitoring requirements set forth in 10 CFR Part 50, GDC 64, “Monitoring Radioactivity Releases,” and the guidance of RG 1.97. Therefore, the staff finds the system acceptable.

Section 12.3 of the SRP states that airborne radioactivity monitors shall be able to detect the time integrated change of the most limiting particulate and iodine species equivalent to those concentrations specified in Appendix B of 10 CFR Part 20 (one derived air concentration (DAC)) in each monitored plant area within 10 hours (i.e., monitors should be sensitive enough to measure 10 DAC-hours). DCD Tier 2, Section 11.5.2.3, “Monitor Descriptions,” states that those airborne radioactivity monitors which monitor plant areas which may be occupied by plant personnel will be capable of detecting 10 DAC-hours.

Section 12.3 of the SRP states that the DCD must provide the criteria and methods for obtaining representative in-plant airborne radioactivity concentrations in all work areas. Further, Item III.D.3.3 of NUREG-0737 (corresponding to 10 CFR 50.34(f)(2)(xxvii)) states that each applicant should provide equipment and associated training and procedures for accurately determining the airborne iodine concentrations in areas within the facility where personnel may be present during an accident. The applicant has stated, in DCD Tier 2, Section 12.3.5, “Combined Licensee Information,” that the COL applicant will address the criteria and methods for obtaining representative measurements of radiological conditions, including airborne radioactivity concentrations in work areas (Item III.D.3.3 of NUREG-0737). The COL applicant will also address the use of portable instruments, and the associated training and procedures, to accurately determine the airborne concentrations in areas within the facility where plant personnel may be present during an accident. The staff has identified this issue as COL Action Item 12.4.4-1.

The staff concludes that the area radiation and airborne radioactivity monitors described in the AP1000 DCD comply with the applicable requirements of 10 CFR Parts 20, 50, and 70, as well as the personnel radiation protection guidelines of RGs 1.97, 8.2, and 8.8. These monitors are designed to monitor both area and airborne radioactivity levels in the plant to ensure that doses to plant personnel are maintained ALARA. Therefore, the staff finds that these monitoring systems are acceptable.

12.4.5 Conclusion

On the basis of its review of the information on radiation protection design (including facility design features, shielding, ventilation, and area radiation and airborne radioactivity monitoring instrumentation) supplied by the applicant for the AP1000, as described above, the staff concludes that the applicant has committed to follow the guidelines of the RGs and staff positions set forth in Section 12.3-12.4 of the SRP. Because the DCD adheres to these RGs and staff positions, the staff concludes that the relevant requirements of 10 CFR Parts 20, 50, and 70 have been met. The staff finds it acceptable for the applicant to defer discussion of the material addressed by COL Action Items 12.4.2-1 and 12.4.4-1. The staff, therefore, finds the material contained in DCD Tier 2, Section 12.3 acceptable.

12.5 Dose Assessment

The staff reviewed the applicant’s dose assessment contained in DCD Tier 2, Section 12.4, “Dose Assessment,” for completeness against the guidelines in RG 1.70 and the criteria set forth in Section 12.3-12.4 of the SRP. The staff ensured that the applicant had either committed to follow the criteria of the applicable RGs and staff positions set forth in Section 12.3-12.4 of NUREG-0800, or provided acceptable alternatives. Where the DCD adheres to these RGs and staff positions, the staff can conclude that the relevant requirements of 10 CFR Part 20 have been met. In addition, the staff selectively compared the applicant's dose assessment, for specific functions and activities, against the experience of operating PWRs. (Radiation exposures to operating personnel shall not exceed the occupational dose limits specified in 10 CFR 20.1201.)

In DCD Tier 2, Section 12.4, “Dose Assessment,” the applicant provided an assessment of the annual occupational radiation dose that would be received by the operating staff of an AP1000 facility. DCD Tier 2, Tables 12.4-1 through 12.4-12 provide estimated doses for various jobs and inspections that would be performed in the plant during maintenance and refueling periods, as well as for power operations. These activities result in an estimated total annual dose of 0.671 person-sievert (67.1 person-rem). DCD Tier 2, Section 12.4 does not contain a separate determination of doses attributable to airborne activity; however, experience at operating LWRs demonstrates that the dose from airborne radioactivity is not a significant contribution to the total dose.

In performing the dose assessment, the applicant reviewed exposure data from operating plants to obtain a breakdown of the doses incurred within each dose assessment category referenced in RG 8.19, “Occupational Radiation Dose Assessment in Light-Water Reactor Power Plants—Design Stage Man-Rem Estimates,” Revision 1, dated June 1979. The applicant then adjusted these values to account for AP1000 design features. Based on its calculations, the applicant obtained an estimated annual dose of 0.671 person-sievert (67.1 person-rem).

The cumulative annual dose of 0.671 person-sievert (67.1 person-rem) for operating an AP1000 plant is consistent with the Electric Power Research Institute design guideline of 1.0 person-sievert (100 person-rem) per year and compares favorably with the average current PWR experience (the 2002 average collective dose for U.S. PWRs was 0.87 person-sievert (87 person-rem)). Although the applicant’s dose assessment for the AP1000 is not in the format specified in RG 8.19, it is a detailed dose assessment that meets the intent of RG 8.19, and, therefore, the staff finds it acceptable.

As discussed above, the AP1000 design incorporates several improvements over current operating PWR designs. These improvements are intended to significantly reduce the personnel exposure associated with operational and maintenance activities. The occupational radiation exposure resulting from unscheduled repairs on valves, pumps, and other components will be lower for the AP1000 than for current plant designs because of the reduced radiation fields, increased equipment reliability, and reduced number of components relative to currently operating plants. Historically, special maintenance performed on SGs has resulted in significant personnel doses. The applicant estimates that the annual dose incurred for special maintenance of the AP1000 SGs will be slightly more than 0.01 person-sievert (1 person-rem). These low estimated SG doses result from improved SG design and improved primary and secondary water chemistry controls. The applicant does not predict that any special maintenance activities will be required for the canned motor RCPs used in the AP1000 design.

The AP1000 radwaste system design incorporates a less complicated approach to waste processing than do current generation PWRs. The AP1000 does not use waste or boron recycle evaporators and does not have a catalytic hydrogen recombiner in the gaseous radwaste system. Elimination of these high maintenance components should contribute significantly to lower anticipated doses associated with waste processing activities for the AP1000 design.

Since the refueling process is labor intensive, detailed planning and coordination are essential in order to maintain personnel doses ALARA. The AP1000 design incorporates advanced technology (e.g., integrated reactor vessel head package, combination thermocouple and flux detectors, permanent reactor cavity seal ring, and “pass and one-half” stud tensioning procedures) into the refueling process, thereby reducing personnel doses during refueling operations.

The direct radiation at the site boundary from the containment and other plant buildings is negligible. The containment shield building walls are a minimum of 0.91 m (3 ft) thick, reducing radiation levels outside the containment to less than 2.5 microsieverts per hour (0.25 millirem per hour) from sources inside containment. The AP1000 design also provides storage for refueling water inside the containment, instead of in an outside storage tank, thereby eliminating the refueling water storage tank as an offsite radiation source.

The staff finds that the dose assessment for the AP1000 complies with the guidelines in RG 1.70 and the criteria set forth in Section 12.3-12.4 of the SRP. This dose assessment also meets the intent of RG 8.19. By addressing the anticipated occupational radiation exposures due to normal and anticipated inspection and maintenance, and by incorporating design features to reduce occupational radiation exposures, the applicant has shown that the AP1000 is designed to operate within the occupational dose limits specified in 10 CFR 20.1201. The staff, therefore, finds the material contained in DCD Tier 2, Section 12.4 acceptable.

12.6 Health Physics Facilities Design

The requirements in 10 CFR 20.1101 state that each licensee shall develop, document, and implement a radiation protection program commensurate with the scope and extent of licensed activities and sufficient to ensure compliance with the provisions of 10 CFR Part 20. Section 12.5 of RG 1.70 and the SRP state that the operational aspects of an acceptable radiation protection program should address the following three areas:

- organization
- equipment, instrumentation, and facilities
- procedures

DCD Tier 2, Section 12.5, “Health Physics Facilities Design,” addresses the objectives and design of the AP1000 health physics facilities. The applicant stated that the COL applicant will address the organizational and procedural aspects of the AP1000 radiation protection program.

The health physics facilities are designed with the objectives of:

- Providing capability for administrative control of the activities of plant personnel to maintain personnel exposure to radiation and radioactive materials ALARA and within the requirements of 10 CFR Part 20.

- Providing capability for administrative control of effluent releases from the plant to maintain the releases ALARA and within the limits of 10 CFR Part 20 and plant Technical Specifications.

- Providing capability for administrative control of waste shipments from the plant to meet applicable requirements for the shipment and receipt of the material at the storage or burial site.

DCD Tier 2, Section 12.5 describes the equipment and facilities contained in the AP1000 design, including a discussion of whole body and portable survey instrumentation. The DCD also discusses the facilities that are displayed on the plant layout drawings, and describes the traffic flow patterns that personnel would take through the health physics access control area for access to and from the radiation control area. The plant will be designed so that significant radiation sources are minimized, locally shielded, and/or located in shielded cubicles in order to maintain doses to plant personnel ALARA. Area radiation monitoring equipment with local alarms will provide plant personnel with an indication of plant radiation levels. The ventilation system is designed to minimize the spread of airborne radioactivity. For radiation protection purposes, areas in the plant are classified as nonradiation areas and restricted radiologically controlled areas. Restricted areas are further categorized as radiation areas, high radiation areas, very high radiation areas, airborne radioactivity areas, and radioactive materials areas. These categorizations comply with 10 CFR Part 20. The AP1000 health physics facilities comply with the guidance contained in RG 8.8 and are designed to ensure that personnel radiation exposures will be maintained ALARA and within the dose limits of 10 CFR Part 20.

DCD Tier 2, Section 12.5 contains a description of how the health physics facilities have been designed to maintain personnel exposure to radiation and radioactive materials ALARA and within the requirements of 10 CFR Part 20. The staff, therefore, finds the description of the health physics facilities described in DCD Tier 2, Section 12.5 acceptable. However, the applicant makes no reference in this section of the DCD to the organization or procedures that will be used to ensure that personnel radiation exposures will be maintained ALARA. The applicant stated, in DCD Tier 2, Section 12.5.5, “Combined Licensee Information,” that the COL applicant will address the organization and procedures used for adequate radiological protection and will provide methods to maintain personnel radiation exposures ALARA. The staff has identified this issue as COL Action Item 12.6-1.