12.3 Radiation Protection Design Features

12.3.1 Facility Design Features

The ABWR Standard Plant is designed to meet the intent of Regulatory Guide 8.8 (i.e., to keep radiation exposures to plant personnel as low as reasonably achievable (ALARA)). This section describes the component and system designs, in addition to the equipment layout, employed to maintain radiation exposures ALARA. Where possible, consideration of individual systems is provided to illustrate the application of these principles. To insure that the plant as designed meets all applicable radiation criteria, a two-step process is then applied where design details not included in this document are then subject to review and confirmation in accordance with radiation protection criteria. Therefore, the details in this section serve as input to the final design configuration and serve to determine the adequacy of the design with respect to radiation protection.

Material application for primary coolant piping, tubing, vessel internal surfaces, and other components in contact with the primary coolant is discussed in the following pages. Typical nickel and cobalt contents of the principal materials applied are given in Table 12.3-2.

Carbon steel is used in a large portion of the system piping and equipment outside of the Nuclear Steam Supply System. Carbon steel is typically low in nickel content and contains a very small amount of cobalt impurity.

Stainless steel is used in portions of the system such as the reactor internal components and heat exchanger tubes where high corrosion resistance is required. The nickel content of the stainless steel is in the 9 to 10.5% range and is controlled in accordance with applicable ASME material specifications. Cobalt content is controlled to less than 0.05% in the XM-19 alloy used in the control rod drives.

A previous review of materials certifications indicated an average cobalt content of only 0.15% in austenitic stainless steel.

Ni-Cr-Fe alloys such as Inconel 600 and Inconel X750, which have high nickel content, are used in some reactor vessel internal components. These materials are used in applications for which there are special requirements to be satisfied (such as possessing specific thermal expansion characteristics along with adequate corrosion resistance) and for which no suitable alternative low-nickel material is available. Cobalt content in the Inconel X750 used in the fuel assemblies is limited to 0.05%.

Stellite is used for hard facing of components which must be extremely wear resistant. Use of high cobalt alloys such as Stellite is restricted to those applications where no satisfactory alternative material is available. An alternative material (Colmonoy) has been used for some hard facings in the core area.

12.3.1.1 Equipment Design and Material Selection for Maintaining Exposure ALARA

12.3.1.1.1 Equipment Design

This subsection describes specific components, as well as system design features, that aid in maintaining the exposure of plant personnel during system operation and maintenance ALARA. Equipment layout to provide ALARA exposures of plant personnel is discussed in Subsection 12.3.1.2.

(1) Pumps

Pumps located in radiation areas are designed to minimize the time required for maintenance. Quick change cartridge-type seals on pumps, and pumps with back pullout features that permit removal of the pump impeller or mechanical seals without disassembly of attached piping, are employed to minimize exposure time during pump maintenance. The configuration of piping about pumps is designed to provide sufficient space for efficient pump maintenance. Provisions are made for flushing and in certain cases chemically cleaning pumps prior to maintenance. Pump casing drains provide a means for draining pumps to the sumps prior to disassembly, thus reducing the exposure of personnel and decreasing the potential for contamination. Where two or more pumps conveying highly radioactive fluids are required for operational reasons to be located adjacent to each other, shielding is provided between the pumps to maintain exposure levels ALARA. An example of this situation is the CUW circulation pumps. Pumps adjacent to other highly radioactive equipment are also shielded to reduce the maintenance exposure, for example, in the Radwaste System.

Pump control instrumentation is located outside high radiation areas, and motor or pneumatic-operated valves and valve extension stems are employed to allow operation from outside these areas.

(2) Instrumentation

Instruments are located in low radiation areas such as shielded valve galleries, corridors, or control rooms, whenever possible. Shielded valve galleries provided for this purpose include those for the CUW, FPC, and Radwaste (cleanup phase separator, spent resin tank, and waste evaporator) Systems. Instruments required to be located in high radiation areas due to operational requirements are designed such that removal of these instruments to low radiation areas for maintenance is possible. Sensing lines are routed from taps on the primary system in order to avoid placing the transmitters or readout devices in high radiation areas. For example, reactor water level and recirculation system pressure sensing instruments are located outside the drywell.

Liquid service equipment for systems containing radioactive fluids are provided with vent and backflush provisions. Instrument lines, except those for the reactor vessel, are designed with provisions for backflushing and maintaining a clean fill in the sensing lines. The reactor vessel sensing lines may be flushed with condensate following reactor blowdown.

(3) Heat Exchangers

Heat exchangers are constructed of stainless steel or Cu/Ni tubes to minimize the possibility of failure and reduce maintenance requirements. The heat exchanger design allows for the complete drainage of fluids from the exchanger, avoiding pooling effects that could lead to radioactive crud deposition. Connections are available for condensate or demineralized water flushing of the heat exchangers. For the Reactor Water Cleanup (CUW) System, separate connections are provided to chemically decontaminate both the heat exchangers (both regenerative and non-regenerative) and the pumps. The other main heat exchangers (RHR and RIP) are provided connections by which the exchangers can be flushed with clean water. The last main heat exchanger (the fuel pool heat exchanger) is downstream of the filter/demineralizer and is therefore not subjected to flows containing significant amounts of fission or activation products. In all cases, the pumps directly involved with the heat exchangers are also inline for decontamination with the exchangers. Instrumentation and valves are remotely operable to the maximum extent possible in the shielded heat exchanger cubicles, to reduce the need for entering these high radiation areas.

(4) Valves

Valve packing and gasket material are selected on a conservative basis, accounting for environmental conditions such as temperature, pressure, and radiation tolerance requirements to provide a long operating life. Valves have back seats to minimize the leakage through the packing. Straight-through valve configurations were selected where practical, over those which exhibit flow discontinuities or internal crevices to minimize crud trapping. Teflon gaskets are not used.

Wherever possible, valves in systems containing radioactive fluids are separated from those for “clean” services to reduce the radiation exposure from adjacent valves and piping during maintenance.

Pneumatically or mechanically-operated valves are employed in high radiation areas, whenever practical, to minimize the need for entering these areas. For certain situations, manually-operated valves are required and, in such cases, extension valve stems are provided which are operated from a shielded area. Flushing and drain provisions are employed in radioactive systems to reduce exposure to personnel during maintenance.

For areas in which especially high radiation levels are encountered, valving is reduced to the maximum extent possible with the bulk of the valve and piping located in an adjacent valve gallery where the radiation levels are lower.

(5) Piping

Piping was selected to provide a service life equivalent to the design life of the plant, with consideration given to corrosion allowances and environmental conditions. Piping for service in radioactive systems such as the CUW System have butt-welded connections, rather than socket welds, to reduce crud traps. Distinction is made between piping conveying radioactive and non-radioactive fluids, and separate routing is provided whenever possible. Piping conveying highly radioactive fluids is usually routed through shielded pipe chases and shielded cubicles. However, when these options are not feasible, the radioactive piping is embedded in concrete walls and floors.

(6) Lighting

Lighting is designed to provide sufficient illumination in radiation areas to allow quick and efficient surveillance and maintenance operations. To reduce the need for immediate replacement of defective bulbs, multiple lighting fixtures are provided in shielded cubicles. Consideration is also given to locating lighting fixtures in easily accessible locations, thus reducing the exposure time for bulb replacement.

(7) Floor Drains

Floor drains with appropriately sloped floors are provided in shielded cubicles where the potential for spills exist. Those drain lines having a potential for containing highly radioactive fluids are routed through pipe chases, shielded cubicles, or are embedded in concrete walls and floors. Smooth epoxy-type coatings are employed to facilitate decontamination when a spill does occur.

(8) SGTS Filters

The SGTS filter is located in a separate shielded cubicle and is separated by a shield wall from the exhaust fans to reduce the radiation exposure of personnel during maintenance. The dampers located in the cubicles are remotely-operated, thus requiring no access to the cubicle during operation. A pneumatic transfer system is employed to remove the radioactive charcoal from the filter, requiring entry into the shielded cubicle only during the connection of the hoses to the SGTS filter unit.

12.3.1.1.2 Material Selection

In the ABWR design maintaining radiation exposure ALARA has been considered in the material selection of systems and components exposed to reactor coolant. For example, radiation exposure potential has been reduced appreciably through the removal or reduction of cobalt from many components as compared to current BWR fleet. Much of the cobalt is removed from contact with reactor coolant by eliminating Stellite where practical and reducing cobalt in the core stainless steel components. The ABWR design has taken a graded approach to using various grades of low cobalt stainless steel by using the lowest cobalt bearing materials in the most radiologically significant areas with increasing cobalt content in less sensitive areas. The ABWR standards for cobalt are: 0.02 wt percent for those items in the core; 0.03 wt percent for those items in the vessel internals; and 0.05 wt percent for all other components. Also, with the current materials, there are no proven substitutes for Stellite for many hard surface applications shuch as MSIV seats. Current efforts by the nuclear and metallurgical industry indicate that in the future, practical alternatives to Stellite maybe feasible and are being researched.

These cobalt contents are target values for reduced occupational exposure per ALARA principles and are not specifications.

The estimation of occupational exposure for the ABWR, was generated by reviewing current plant work records and practices at operating BWRs, and taking into account distinct plant features in the ABWR. An estimate of the average annual occupational exposure was made during the US Standard ABWR certification work. It is noted that the reduced cobalt loadings (i.e. target values) were not considered in the estimation. Therefore, based upon the methods used and assumptions made in evaluating occupational exposure, the materials procured with 0.05 wt percent maximum cobalt have no adverse effect on the estimated occupational exposure.

12.3.1.2 Plant Design for Maintaining Exposure (ALARA)

This subsection describes features of equipment layout and design which are employed to maintain personnel exposures ALARA.

(1) Penetrations

Penetrations through shield walls are avoided whenever possible to reduce the number of streaming paths provided by these penetrations. Whenever penetrations are required through shield walls, however, they are located to minimize the impact on surrounding areas. Penetrations are located so that the radiation source cannot "see" through the penetration. When this is not possible, or to provide an added order of reduction, penetrations are located to exit far above floor level in open corridors or in other relatively inaccessible areas. Penetrations which are offset through a shield wall are frequently employed for electrical penetrations to reduce the streaming of radiation through these penetrations.

Where permitted, the annular region between pipe and penetration sleeves, as well as electrical penetrations, are filled with shielding material to reduce the streaming area presented by these penetrations. The shielding materials used in these applications include a lead-loaded silicone foam, with a density comparable to concrete, and a boron-loaded refractory-type material for applications requiring neutron as well as gamma shielding. There are certain penetrations where these two approaches are not feasible or are not sufficiently effective. In those cases, a shielded enclosure around the penetration as it exits in the shield wall, with a 90 degree bend of the process pipe as it exits the penetration, is employed.

(2) Sample Stations

Sample stations in the plant provide for the routine surveillance of reactor water quality. These sample stations are located in low radiation areas to reduce the exposure to operating personnel. Flushing provisions are included using demineralized water, and pipe drains to plant sumps are provided to minimize the possibility of spills. Fume hoods are employed for airborne contamination control. Both working areas and fume hoods are constructed of polished stainless steel to ease decontamination if a spill does occur. Grab spouts are located above the sink to reduce the possibility of contaminating surrounding areas during the sampling process.

(3) HVAC Systems

Major HVAC equipment (blowers, coolers, and the like) is located in dedicated low radiation areas to maintain exposures to personnel maintaining these equipment ALARA. HVAC ducting is routed outside pipe chases and does not penetrate pipe chase walls, which could compromise the shielding. HVAC ducting penetrations through walls of shielded cubicles are located to minimize the impact of the streaming radiation levels in adjoining areas. Additional HVAC design considerations are addressed in Subsection 12.3.3.

(4) Piping

Piping containing radioactive fluids is routed through shielded pipe chases, shielded equipment cubicles, or embedded in concrete walls and floors, whenever possible. “Clean” services such as compressed air and demineralized water are not routed through shielded pipe chases.

For situations in which radioactive piping must be routed through corridors or other low radiation areas, an analysis is conducted to ensure that this routing does not compromise the existing radiation zoning.

Radioactive services are routed separately from piping containing nonradioactive fluids, whenever possible, to minimize the exposure to personnel during maintenance. When such routing combinations are required, however, drain provisions are provided to remove the radioactive fluid contained in equipment and piping. In such situations, provisions are made for the valves required for process operation to be controlled remotely, without need for entering the cubicle.

Penetrations for piping through shield walls are designed to minimize the impact on surrounding areas. Approaches used to accomplish this objective are described in Subsection 12.3.1.2(1).

Piping configurations are designed to minimize the number of "dead legs" and low points in piping runs to avoid accumulation of radioactive crud and fluids in the line. Drains and flushing provisions are employed whenever feasible to reduce the impact of required "dead legs" and low points. Systems containing radioactive fluids are welded to the most practical extent to reduce leakage through flanged or screwed connections. For highly radioactive systems, butt welds are employed to minimize crud traps. Provisions are also made in radioactive systems for flushing with condensate or chemically cleaning the piping to reduce crud buildup.

(5) Equipment Layout

Equipment layout is designed to reduce the exposure of personnel required to inspect or maintain equipment. "Clean" pieces of equipment are located separately from those which are sources of radiation whenever possible. For systems that have components that are major sources of radiation, piping and pumps are located in separate cubicles to reduce exposure from these components during maintenance. These major radiation sources are also separately shielded from each other.

(6) Contamination Control

Contaminated piping systems are welded to the most practical extent to minimize leaks through screwed or flanged fittings. For systems containing highly radioactive fluids, drains are hard piped directly to equipment drain sumps, rather than to allow contaminated fluid to flow across the floor to a floor drain. Certain valves in the main steamline are also provided with leakage drains piped to equipment drain sumps to reduce contamination of the steam tunnel. Pump casing drains are employed on radioactive systems whenever possible to remove fluids from the pump prior to disassembly. In addition, provisions for flushing with condensate, and in especially contaminated systems, for chemically cleaning the equipment prior to maintenance, are provided.

The HVAC System is designed to limit the extent of airborne contamination by providing air flow patterns from areas of low contamination to more contaminated areas. Penetrations through outer walls of the building containing radiation sources are sealed to prevent miscellaneous leaks into the environment. The equipment drain sump vents are fitted with charcoal canisters or piped directly to the radwaste HVAC

System to remove airborne contaminants evolved from discharges to the sump. Wet transfer of both the steam dryer and separator also reduces the likelihood of contaminants on this equipment being released into the plant atmosphere. In areas where the reduction of airborne contaminants cannot be eliminated efficiently by HVAC Systems, breathing air provisions are provided (e.g., for CRD removal under the reactor pressure vessel and in the CRD maintenance room).

Appropriately sloped floor drains are provided in shielded cubicles and other areas where the potential for a spill exists to limit the extent of contamination. Curbs are also provided to limit contamination and simplify washdown operations. A cask decontamination vault is located in the Reactor Building where the spent fuel cask and other equipment may be cleaned. The CRD maintenance room is used for disassembling control rod drives to reduce the contamination potential.

Consideration is given in the design of the plant for reducing the effort required for decontamination. Epoxy-type wall and floor coverings have been selected which provide smooth surfaces to ease decontamination surfaces. Expanded metal-type floor gratings are minimized in favor of smooth surfaces in areas where radioactive spills could occur. Equipment and floor drain sumps are stainless steel lined to reduce crud buildup and to provide surfaces easily decontaminated.

12.3.1.3 Radiation Zoning

Radiation zones are established in all areas of the plant as a function of both the access requirements of that area and the radiation sources in that area. Operating activities, inspection requirements of equipment, maintenance activities, and abnormal operating conditions are considered in determining the appropriate zoning for a given area. The relationship between radiation zone designations and accessibility requirements is presented in the following tabulation:

Zone Designation	Dose Rate (μGy/h)	Access Description
A	≤6	Uncontrolled, unlimited access
B	< 10	Controlled, unlimited access
C	< 50	Controlled, limited access, 20 h/wk
D	< 250	Controlled, limited access, 4 h/wk

Zone Designation	Dose Rate (µGy/h)	Access Description
E	< 1.0E+03	Controlled, limited access, 1 h/wk
F	≥ 1.0E+03	Controlled infrequent access. Authorization required.

The dose rate applicable for a particular zone is based on operating experience and represents design dose rates in a particular zone, and should not be interpreted as the expected dose rates which would apply in all portions of that zone, or for all types of work within that zone, or at all periods of entry into the zone. Large BWR plants have been in operation for three decades, and operating experience with similar design basis numbers shows that only a small fraction of the 10CFR20 maximum permissible dose is received in such zones from radiation sources controlled by equipment layout or the structural shielding provided. Therefore, on a practical basis, a radiation zoning approach as described above accomplishes the as low as reasonably achievable objectives for doses as required by 10CFR20.1(c). The radiation zone maps for this plant with zone designations as described in the preceding tabulations are contained in Figures 12.3-1 through 12.3-3, 12.3-5 through 12.3-11, and 12.3-37 through 12.3-53.

Access to areas in the plant is controlled and regulated by the zoning of a given area. Areas with dose rates such that an individual would receive a dose in excess of 1 mGy in a period of one hour are locked and posted with “High Radiation Area” signs. Entry to these areas is on a controlled basis. Areas in which an individual would receive a dose in excess of 50 µGy up to 1 mGy within a period of one hour are posted with signs indicating that this is a radiation area and include, in certain cases, barriers such as ropes or doors.

12.3.1.4 Implementation of ALARA

In this subsection, the implementation of design considerations to radioactive systems for maintaining personnel radiation exposures ALARA is described for the following five systems:

(1) Reactor Water Cleanup System

(2) Residual Heat Removal System (shutdown cooling mode)

(3) Fuel Pool Cooling and Cleanup System

(4) Main Steam

(5) Standby Gas Treatment System

12.3.1.4.1 Reactor Water Cleanup (CUW) System

The CUW System is designed to operate continuously to reduce reactor water radioactive contamination. Components for this system are located outside the containment and include filter/demineralizers, a backwash receiving tank, regenerative and non-regenerative heat exchangers, pumps, and associated valves.

The highest radiation level components include the filter/demineralizers, heat exchangers, and backwash receiving tank. The filter/demineralizers are located in separate concrete-shielded cubicles which are accessible through shielded hatches. Valves and piping within the cubicles are reduced to the extent that entry into the cubicles is not required during any operational phase. Most of the valves and piping are located in a shielded valve gallery adjacent to the filter/demineralizer cubicles. The valves are remotely operable to the greatest practical extent to minimize entry requirements into this area. The CUW heat exchangers are also located in a shielded cubicle with valves operated remotely by use of extension valve stems, or from instrument panels located outside the cubicle. The backwash tank is shielded separately from the resin transfer pump, permitting maintenance of the pump without being exposed to the spent resins contained in the backwash tank. The pump valves are operated remotely from outside the cubicle.

The CUW System is provided with chemical cleaning connections which can utilize the condensate system to flush piping and equipment prior to maintenance. The CUW filter/demineralizers can be remotely backflushed to remove spent resins and filter aid material. If additional decontamination is required, chemical addition connections are provided in the piping to clean piping as well as equipment prior to maintenance. The backwash tank employs an arrangement to agitate resins prior to discharge. The tank vent is fitted with a charcoal filter canister to reduce emission of radioiodines into the plant atmosphere. The HVAC System is designed to limit the spread of contaminants from these shielded cubicles by maintaining a negative pressure in the cubicles relative to the surrounding areas.

Personnel access to the cubicles for maintenance of these components is on a controlled basis, whereby specific restrictions and controls are implemented to minimize personnel exposure.

12.3.1.4.2 Residual Heat Removal System (Shutdown Cooling Mode)

In the shutdown cooling (SC) mode, the RHR System is placed in operation to recirculate reactor coolant to remove reactor decay heat following the period of approximately 2 to 4 hours after shutdown. During power operation, the system is not in use except for flow testing to and from the suppression pool. Therefore, there is no reactor coolant flow through the RHR System and only traces of residual radioactive contamination may exist from prior operation.

System components are located in the Reactor Building and include three RHR pumps and three heat exchangers, which are actively used in the SC mode. The heat exchangers and associated pumps work independently of the other pump and heat exchangers and are located in separate concrete-shielded cubicles. The cubicles are accessible through labyrinths which reduce radiation levels outside the cubicle to acceptable levels. A knockout wall constructed of vertically and horizontally lapped concrete blocks is provided for pump removal. A concrete hatch is provided through the roof of the cubicle for heat exchanger removal. Highest radiation levels occur at the heat exchangers during the cooldown period (1/2 to 4 hours after shutdown). During all other operation and plant shutdown periods, the radiation level near these components is considerably decreased.

Access to the RHR pumps and heat exchangers for any inspection or maintenance is permitted on a controlled basis. System maintenance is performed during periods of system shutdown when no reactor coolant is being circulated through the system. Specific restrictions and controls for personnel entry into the shielded cubicles are implemented to minimize personnel exposures. Inspection of the equipment in these cubicles can be conducted from platforming about the heat exchangers to simplify inspection of this equipment and consequently reduce the exposure during inspection.

The Reactor Building is not used exclusively for radioactive equipment or systems. However, all components of the system, as described, are contained within shielded cubicles. This shielding is sufficient to reduce the radiation level during the shutdown mode of operation to less than 50 μGy/h in adjacent areas where clean components, materials, or equipment are located.

System control panels and instrumentation are located in the main control room. This precludes exposure to the control operator during operation of the system for plant cooldown.

12.3.1.4.3 Fuel Pool Cooling and Cleanup (FPC) System

The FPC System is designed to operate continuously to handle the spent fuel cooling load and to reduce pool water radioactive contamination.

The FPC System components are located in the Reactor Building. Included are two filter/demineralizer units which serve to remove radioactive contamination from the fuel pool and suppression water. These units are the highest radiation level components in the system. Each unit is located in a concrete-shielded cubicle which is accessible through a shielded hatch. Provisions are made for remotely backflushing the units when filter and resin material are spent. This removal of radioactively contaminated material reduces the component radiation level considerably and serves to minimize exposures during maintenance. All valves (inlet, outlet, recycle, vent, and drain) to the filter/demineralizers units are located outside the shielded cubicles in a separate shielded cubicle together with associated piping, headers, and instrumentation. The radiation level in this cubicle is sufficiently low to permit required maintenance to be performed. Piping potentially containing resin is continuously sloped downward to the backwash tank.

The backwash tank is shared with the CUW System (Section 12.3.1.4.1). The system also includes two low radiation level heat exchangers and two circulation pumps. The heat exchangers' design radiation levels are low enough to locate them in an open alcove area. The pumps are located in a low radiation area adjacent to the shielded backwash tank. System piping is routed so as not to compromise zoning requirements as established in the radiation zone maps.

All of the aforementioned shielded system components are consolidated in the same section of the Reactor Building. Personnel access to shielded system components is controlled to minimize personnel exposure. Shielding for the components is designed to reduce the radiation level to less than 10 μGy/h in adjacent areas where normal access is permitted. Controlled areas where the new resin tank, filter aid tank, and pumps are located, are shielded to less than 50 μGy/h.

Operation of the system is accomplished from the Main Control Room and local control panels located where designed radiation levels are less than 10 μGy/h and normal personnel access is permitted.

12.3.1.4.4 Main Steam System

All radioactive materials in the Main Steam System, located in the main steam-feedwater pipe tunnel of the Reactor Building, result from radioactive sources carried over from the reactor during plant operation, including high energy short-lived N-16. During plant shutdown, residual radioactivity from prior plant operation is the radiation source.

Access to the main steam pipe tunnel in the Reactor Building is controlled. Entry into the Reactor Building steam tunnel is through a controlled personnel access door shielded by a concrete labyrinth to attenuate radiation streaming from the steam lines to adjoining areas. During reactor operation, the steam tunnel is not accessible except in the hot standby conditions under regulated access.

Leakage from selected valves on to surrounding areas is minimized by providing valve drains piped to equipment drain sumps. Floor drains are provided to minimize the spread of contamination should a leakage occur.

Penetrations through the steam tunnel walls are minimized to reduce the streaming paths made available by these penetrations. Penetrations through the steam tunnel walls, when they are required, are located so as to exit in controlled access areas or in areas that are not aligned with the steamlines. A lead-loaded silicone foam or equivalent is employed whenever possible for these penetrations to reduce the available streaming area presented.

12.3.1.4.5 Standby Gas Treatment System

The Standby Gas Treatment System (SGTS) treats the Reactor Building ventilation air in the event of the release of radioactivity to this building. The system contains radioactivity only in the event of an emergency of abnormal condition. However, it is a potential source of concentrated radioactivity following such an occurrence.

The SGTS starts automatically on a high building ventilation radiation or LOCA signal and can also be manually started from the main control room. Operation of the system does not require entering the shielded filter cubicle.

The SGTS consists of two parallel treatment trains, each train being located in its own shielded room. In addition, the fans for each train are shielded from the filter, which is the dominant source of radiation for the system. Each train includes high efficiency particulate filters and charcoal filters for removal of radioactivity prior to exhausting air to the outside environment.

All components are located in the Reactor Building, and personnel access to the shielded rooms for inspection or maintenance is on a controlled basis. A remote charcoal filter removal capability is provided to minimize exposures, which requires entry into the filter area only during the initial connection of the unit to the charcoal removal system. Sufficient space is provided around the filter unit to allow easy removal and bagging of the high efficiency filters.

The SGTS filter shielding is adequate to reduce the radiation level in fuel areas of the Reactor Building to less than 10 μGy/h following an isolation scram event with containment purge.

12.3.2 Shielding

12.3.2.1 Design Objectives

The primary objective of the radiation shielding is to protect operating personnel and the general public from radiation emanating from the reactor, the power conversion systems, the radwaste process systems, and the auxiliary systems, while maintaining appropriate access for operation and maintenance. The radiation shielding is also designed to keep radiation doses to equipment below levels at which disabling radiation damage occurs. Specifically, the shielding requirements in the plant are designed to perform the following functions:

(1) Limit the exposure of the general public, plant personnel, contractors, and visitors to levels that are ALARA and within 10CFR20 requirements

(2) Limit the radiation exposure of personnel, in the unlikely event of an accident, to levels that are ALARA and which conform to the limits specified in 10CFR50 Appendix A, Criterion 19 to ensure that the plant is maintained in a safe condition during an accident

(3) Limit the radiation exposure of critical components within specified radiation tolerances, to assure that component performance and design life are not impaired

12.3.2.2 Design Description

12.3.2.2.1 General Design Guides

In order to meet the design objectives, the following design guides are used in the shielding design of the ABWR:

(1) All systems containing radioactivity are identified and shielded based on access and exposure level requirements of surrounding areas. The radiation zone maps described in Subsection 12.3.1.3 indicate design radiation levels for which shielding for equipment contributing to the dose rate in the area is designed.

(2) The source terms used in the shielding calculations are analyzed with a conservative approach. Transient conditions as well as shut down and normal operating conditions are considered to ensure that a conservative source is used in the analysis.

Shielding design is based on fission product quantities in the coolant corresponding to the design basis offgas release, in addition to activation products. This is considered an anticipated operational occurrence, and hence represents conservatism in design. For components where N-16 is the major radiation source, a concentration based upon operating plant data is used.

(3) Effort is made to locate processing equipment in a manner which minimizes the shielding requirements. Shielded labyrinths are used to eliminate radiation streaming through access ways from sources located in cubicles.

(4) Penetrations through shield walls are located so as to minimize the impact on surrounding areas due to radiation streaming through the penetrations. The approaches used to locate and shield penetrations, when required, are discussed in Subsection 12.3.1.2 (1).

(5) Wherever possible, radioactive piping is run in a manner which will minimize radiation exposure to plant personnel. This involves:

(a) Minimizing radioactive pipe routing in corridors

(b) Avoiding the routing of high-activity pipes through low-radiation zones

(c) Use of shielded pipe trenches and pipe chases, where routing of high-activity pipes in low-level areas cannot be avoided, or if these are not available and the pipe routing permits, embedding the pipes in concrete walls and floor

(d) Separating radioactive and nonradioactive pipes for maintenance purposes

(6) To maintain acceptable levels at the valve stations, motor-operated or diaphragm valves are used where practical. For valve maintenance, provision is made for draining and flushing associated equipment so that radiation exposure is minimized. If manual valves are used, provision is made for shielding the operator from the valve by use of shield walls and valve stem extensions, where practicable.

(7) Shielding is provided to permit access and occupancy of the control room to ensure that plant personnel exposure following an accident does not exceed the guideline values set forth in 10CFR50 Appendix A, Criterion 19. The analyses of the doses to control room personnel for the design basis accidents are included in Chapter 15.

(8) The dose at the site boundary as a result of direct and scattered radiation from the turbine and associated equipment is considered.

(9) In selected situations, provisions are made for shielding major radiation sources during inservice inspection to reduce exposure to inspection personnel. For example, steel platforms are provided for ISI of the RPV nozzle welds and associated piping.

(10) The primary material used for shielding is concrete at a density of 2.3 g/cm^3. Concrete used for shielding purposes is designed in accordance with Regulatory Guide 1.69. Where special circumstances dictate, steel, lead, water, lead-loaded silicone foam, or a boron-laced refractory material is used.

(11) There is no field-routed piping in the ABWR design. Large and small piping, as well as instrument tubing, are routed by designers as indicated in the preceding paragraph (5).

12.3.2.2.2 Method of Shielding Design

The radiation shield wall thicknesses are determined using basic shielding data and proven shielding codes. A list of the computer programs used is contained in Table 12.3-1. The shielding design methods used also rely on basic radiation transport equations contained in Reference 12.3-1. The sources for basic shielding data, such as cross sections, buildup factors, and radioisotope decay information, are listed in References 12.3-2 through 12.3-10.

The shielding design is based on the plant operating at maximum design power with the release of fission products resulting in a source of 3.7 GBq/s of noble gas after a 30-minute decay period, and the corresponding activation and corrosion product concentrations in the reactor water listed in Section 11.1. Radiation sources in various pieces of plant equipment are cited in Section 12.2. Shutdown conditions, such as fuel transfer operation, as well as accident conditions, such as a LOCA or an FHA, have also been considered in designing shielding for the plant.

The mathematical models used to represent a radiation source and associate equipment and shielding are established to ensure conservative calculational results. Depending on the versatility of the applicable computer program, various degrees of complexity of the actual physical situation are incorporated. In general, cylindrically-shaped equipment such as tanks, heat exchangers, and demineralizers are mathematically modelled as truncated cylinders. Equipment internals are sectionally homogenized to incorporate density variations where applicable. For example, the tube bundle section of a heat exchanger exhibits a higher density than the tube bundle clearance circle, due to the tube density, and this variation is accounted for in the model. Complex piping runs are conservatively modelled as a series of point sources spaced along the piping run. Equipment containing sources in a parallel-piped configuration, such as fuel assemblies, fuel racks, and the SGTS charcoal filters, are modelled as parallel-piped with a suitable homogenization of materials contained in the equipment. The shielding for these sources is also modelled on a conservative basis, with discontinuities in the shielding, such as penetrations, doors, and partial walls accounted for. The dimension of the floor decking is not considered in the shielding calculation as it is part of the effective shield thickness provided by the floor slab.

Pure gamma dose rate calculations, both scattered and direct, are conducted using point kernel codes (QADF/GGG). The source terms are divided into groups as a function of photon energy, and each group is treated independently of the others. Credit is taken for attenuation through all phases of material, and buildup is accounted for using a third-order polynomial buildup factor equation. The more conservative material buildup coefficients are selected for laminated shield configuration to ensure conservative results.

For combined gamma and neutron shielding situations, discrete ordinates (ANISN) techniques are applied.

The shielding thicknesses are selected to reduce the aggregate dose rate from significant radiation sources in surrounding areas to values below the upper limit of the radiation zone specified in the zone maps in Subsection 12.3.1.3. By maintaining dose rates in these areas at less than the upper limit values specified in the zone maps, sufficient access to the plant areas is allowed for maintenance and operational requirements.

Where shielded entries to high-radiation areas such as labyrinths are required, a gamma ray scattering code (GGG) is used to confirm the adequacy of the labyrinth design. The labyrinths are designed to reduce the scattered as well as the direct contribution to the aggregate dose rate outside the entry, such that the radiation zone designated for the area is not violated.

12.3.2.3 Plant Shielding Description

Figures 12.3-1 through 12.3-11 show the layout of equipment containing radioactive process materials. The general description of the shielding is described below:

(1) Drywell

The major shielding structures located in the drywell area consist of the reactor shield wall and the drywell wall. The reactor shield wall, in general, consists of 0.6m of concrete sandwiched between two 3.7 cm thick steel plates. The primary function served by the reactor shield wall is the reduction of radiation levels in the drywell due to the reactor, to valves that do not unduly limit the service life of the equipment located in the drywell. In addition, the reactor shield wall reduces gamma heating effects on the drywell wall, as well as providing for low radiation levels in the drywell during reactor shutdown. Penetrations through the reactor shield wall are shielded to the extent that radiation streaming through the penetrations does not exceed the total neutron and gamma dose rates at the core midplane just outside the reactor shield wall. The drywell is an F radiation zone during full power reactor operation and is not accessible during this period.

The upper drywell radiation shield design differs significantly from prior BWR designs in that the upper drywell shield extends to within 10.2 cm of the drywell ceiling, thereby presenting a collimated angle to the upper drywell for fuel bundles as they are raised from the core to the upper pools. The design is shown in Figure 12.3-74. This design also protects from the remote possibility of a fuel bundle being dropped onto the refueling bellows, in that a lip has been added to the upper drywell ceiling to shield and collimate radiation streaming into the upper drywell from a fuel bundle on the bellows. This lip which extends 36.6 cm toward the vessel from the drywell ceiling wall and is 51.8 cm in height, consists of concrete with the bottom 5.1 cm of the lip made of steel with the steel plate extending 61 cm into the upper drywell. The radiation fields generated by a dropped fuel bundle event are shown in Figure 12.3-74 and, though not low, are sufficiently low to permit egress of the area without significant operator exposure. The radiation field runs at a maximum 5.6 Gy/h in the far upper corner nearest the bundle, dropping to less than 3 Gy/h within 50 cm and below 1 Gy/h at 1.5m from the corner.

The drywell wall is a 2m thick reinforced concrete cylinder, which is topped by a 2.4m thick reinforced concrete cap. The drywell wall attenuates radiation from the reactor and other radiation sources in the drywell, such as the recirculation system and main steam piping, to allow occupancy of the Reactor Building during full power reactor operation.

(2) Reactor Building

In general, the shielding for the Reactor Building is designed to maintain open areas at dose rates less than 10 μGy/h.

Penetrations of the drywell wall are shielded to reduce radiation streaming through the penetrations. Localized dose rates outside these penetrations are limited to less than 50 μGy/h. The penetrations through interior shield walls of the Reactor Building are shielded using a lead-loaded silicone sleeve to reduce the radiation streaming. Penetrations are also located so as to minimize the impact of radiation streaming into surrounding areas.

The components of the Reactor Water Cleanup (CUW) System are located in the Reactor Building. Both the CUW regenerative and non-regenerative heat exchangers are located in shielded cubicles separated from the other components of the system. Neither cubicle needs to be entered for system operation.

Process piping between the heat exchangers and the filter/demineralizers is routed through shielded areas or embedded in concrete to reduce the dose rate in surrounding areas. The two CUW System filter/demineralizers are located in separate shielded cubicles, which allows maintenance of one unit while operating the other. The dose rate in the adjoining filter/demineralizer cubicle from the operating unit is less than 60 μGy/h. Entry into the filter/demineralizer cubicle, which is infrequently required, is via a stepped shield plug at the top of the cubicle. The bulk of the piping and valves for the filter/demineralizers is located in an adjacent shielded valve gallery. Backflushing and resin application of the filter/demineralizers are controlled from an area where dose rates are less than 10 μGy/h. The CUW System backwash receiving tank is also separately shielded from the other components of the CUW System, including the tank discharge pump, which allows maintenance of the pump without direct exposure to the spent resins contained in the backwash tank. The backwash tank cubicle is shielded to reduce the dose rate outside the entry to less than 10 μGy/h.

The traversing incore probe (TIP) consists of three sets of detectors, cables, and mechanical components which are periodically driven into the core via three guide tubes penetrating the primary containment at the 1700 level above the personnel airlock. A TIP indexer located in the access tunnel then permits the TIPs to be driven into any of 52 separate housing lines into the core for instrumentation calibration. Because the TIP system is subject to neutron activation during core operation, the TIP detector and approximately 3.66 m of cable are activated (Subsection 12.2.1.2.9.3). Therefore, the TIP has become a special point of protection both during use and when withdrawn from the core as is discussed below.

The TIP is utilized for a period of approximately three hours once a month during power operations when the reactor is above 50% power. For the 48-hour period (Table 12.2-24) following withdrawal of the TIP from the core, special precautions are necessary to protect workers from inadvertent exposure to the TIP. Shielding of the TIP, when completely withdrawn from the core and stored, is supervised by locating the higher radiation components in a separate shielded room with a locked entry at the 1500 level. The TIP itself is withdrawn into a lead shielded cask with activated cable covered by a lead shield to permit entry into the TIP room during the first 48 hours after withdrawal from the core. The TIP location is maintained by a set of position sensors which are alarmed to the control room. Area radiation monitors in both the TIP room and its associated spooler room maintain a secondary surveillance of both rooms causing alarms in both the control room and locally in the

TIP facility mandating immediate egress from the TIP area. In the unlikely event of a spooler failing to stop on TIP withdrawal, the TIP system incorporates an electromechanical switch which cuts power to the spoolers, thereby preventing damage to the system or pulling the TIP onto the spoolers. After a 48-hour cooldown period, radiation levels are sufficiently reduced (to less than 200 μGy/h) to permit maintenance activities.

While in use, the TIPs must transverse a limited but essentially open area from the TIP room to the drywell penetration. To protect workers in the access way to the personnel air lock from inadvertent exposure, three measures are taken. The first measure is primarily administrative requiring any work in the area to be done under a controlled radiation work permit (RWP). Such a permit is required prior to entry to this area, since the area is always key-locked into the access pathway. No TIP activity should be scheduled when RWPs indicate work in the area. The second measure is a series of two flashing alarms, one located in the access way and the second external to the access way by the locked door. Both alarms are activated upon power being supplied to the TIP spoolers. The alarm in the personnel air lock area requires evacuation of the area, while the alarm on the locked door warns against entry to the area when flashing. The third measure is designed to reduce potential exposure in the event prior measures fail. During use, the TIP system moves along the separate lines performing specific measurements in the core. Upon withdrawal from the core, the TIPs automatically switch to high mode motion, pulling the TIPs from the indexer to the TIP room at 27.4m per minute. This provides an estimated exposure time of four seconds for people in the access entrance and an exposure assuming one TIP in motion of less than 1000 μGy.

(3) ECCS Components

The ECCS are located in separately shielded cubicles. Shield labyrinths are provided to gain entry into the cubicles, and equipment removal doors are shielded with removable horizontally and vertically lapped concrete block. Piping to and from the ECCS is routed through shielded pipe chases. Access into the cubicles is not required to operate the systems. In general, the radiation levels in the open corridors of the Reactor Building are less than 10 μGy/h, except during RHR shutdown cooling mode operation, when radiation levels may temporarily range between 10 and 50 μGy/h in areas near the RHR cubicles.

The CUW System pumps are located in a shielded cubicle designed to reduce the radiation levels in the adjoining open corridor to less than 10 μGy/h. The pumps are separated by shield walls to allow operation of one of the pumps while performing maintenance on the other. Dose rates at this pump due to the operating pump and piping are less than 50 μGy/h. A shielded valve gallery is employed to permit manual operation of the valves associated with the CUW System pumps without entering the pump area. Piping for the pumps is directly routed from the steam tunnel to the CUW System pump area.

The CRD maintenance room walls are designed to reduce dose rates in the adjoining corridor to less than 10 µGy/h during all CRD maintenance operations except CRD transfer, when dose rates in the corridor temporarily range between 10 and 50 µGy/h.

The main steamlines are located in the shielded steam tunnel. The steam tunnel reduces the dose rates from the steamlines to less than 10 µGy/h in all adjoining areas except the roof of the steam tunnel, which is less that 50 µGy/h.

(4) Fuel Components

The fuel storage pool is designed to insure that the dose rate around the pool area is less than 10 µSv/h. In the event of an anticipated operational occurence where the fuel sustains significant damage, such as a fuel drop accident, airborne dose rates in the pool area may significantly exceed this dose rate. Egress from this area can be successfully accomplished well before dose rates exceed moderate levels (250 µSV/h) since the local area radiation monitors will alarm in the area.

(5) Control Room

The dose rate in the control room is much less than 10 µGy/h normal reactor operating conditions. The outer walls of the Control Building are designed to attenuate radiation from radioactive materials contained within the Reactor Building and from possible airborne radiation surrounding the Control Building following a LOCA. The walls provide sufficient shielding to limit the direct-shine exposure of control room personnel following a LOCA to a fraction of the 5 Rem limit as is required by 10CFR50 Appendix A, Criterion 19. Shielding for the outdoor air cleanup filters is also provided to allow temporary access to the mechanical equipment area of the Control Building following a LOCA, should it be required.

(6) The main steam tunnel extends from the primary containment boundary in the Reactor Building through the Control Building up to the turbine stop valves. The primary purpose of the steam tunnel is to shield the plant complex from N-16 gamma shine in the main steamlines. A minimum of 1.6 meters of concrete or its equivalent (other material or distance) is required on any ray pathway from the main steamlines to any point which may be inhabited during normal operations. The design of the steam tunnel is shown on Figures 1.2-14, 1.2-15, 1.2-20, 1.2-21, and 1.2-33. The tunnel is classified as Seismic Category I in the Reactor Building and in the Control Building and is designed to IBC Seismic Standards in the Turbine Building. The interface between the buildings provides for bayonet connection to permit

differential building motion during seismic events and shielding in the areas between buildings. The exact details on the bayonet design are not shown on the referenced arrangement drawings but requires complete shielding in the building interface area.

12.3.3 Ventilation

The HVAC systems for the various buildings in the plant are discussed in Section 9.4, including the design bases, system descriptions, and evaluations with regard to the heating, cooling, and ventilating capabilities of the systems. This section discusses the radiation control aspects of the HVAC systems.

12.3.3.1 Design Objectives

The following design objectives apply to all building ventilation systems:

(1) The systems shall be designed to make airborne radiation exposures to plant personnel and releases to the environment ALARA. To achieve this objective, the guidance provided in Regulatory Guide 8.8 shall be followed.

(2) The concentration of radionuclides in the air in areas accessible to personnel for normal plant surveillance and maintenance shall be kept below the limits of 10CFR20 during normal power operation. This is accomplished by establishing in each area a reasonable compromise between specifications on potential airborne leakages in the area and HVAC flow through the area. Appendix 12A to this chapter outlines the methodology by which such calculations are made. As part of plant inspections, tests, analyses and acceptance criteria, Table 3.2(b) of Tier 1 requires the COL licensee to perform calculations for the expected airborne radionuclide concentrations to verify the adequacy of the ventilation system prior to fuel load. See Subsection 12.3.7.1 for COL license information.

The applicable guidance provided in Regulatory Guide 1.52 has been implemented for the ESF filter systems for the Control Building outdoor air cleanup system and the Standby Gas Treatment System (SGTS) as described in Subsections 6.5.1 and 9.4.1.

12.3.3.2 Design Description

In the following sections, the design features of the various ventilation systems that achieve the radiation control design objectives are discussed. For all areas potentially having airborne radioactivity, the ventilation systems are designed such that during normal and maintenance operations, airflow between areas is always from an area of low potential contamination to an area of higher potential contamination.

12.3.3.2.1 Control Room Ventilation

The Control Building atmosphere is maintained at a slightly positive pressure (up to 6.4 mm wg) at all times, except if exhausting or isolation are required, in order to prevent infiltration of contaminants. Fresh air is taken in via a dual inlet system, which has both intake structures on the roof of the building. The inlets are arranged with respect to the SGTS exhaust stack such that at least one of the intakes is free of contamination after a LOCA. Both inlets, however, can be submerged in contaminated air from a LOCA, but the calculated dose in the control room from such an eventuality is still below the limit of Criterion 19 of 10CFR50 Appendix A.

Outside air coming into the intakes is normally filtered by a particulate filter. If a high radiation level in the air is detected by the Process Radiation Monitoring System, flow is automatically diverted to another filter train (an outdoor air cleanup unit) that has:

(1) A particulate filter

(2) A HEPA filter

(3) A charcoal filter

(4) Another HEPA filter

Two redundant, divisionally separated radiation monitors and filter trains are provided (see Subsection 9.4.1 for detailed description of the design). Conservative calculations show that the filters keep the dose in the control room from a LOCA below the limits of Criterion 19 of 10CFR50 Appendix A.

The outdoor cleanup units are located in individual, closed rooms that help prevent the spread of any radiation during maintenance. Adequate space is provided for maintenance activities. The particulate and HEPA filters can be bagged when being removed from the unit. Before removing the charcoal, any radioactivity is allowed to decay to minimal levels, and is then removed through a connection in the bottom of the filter by a pneumatic transfer system. Air used in the transfer system goes through a HEPA filter before being exhausted. Face masks can be worn during maintenance activities, if desired.

12.3.3.2.2 Drywell

Access into the drywell is not permitted during normal operation. The ventilation system inside merely circulates, without filtering, the air. The only airflow out of the drywell into accessible areas is minor leakage through the wall.

During maintenance, the drywell air is purged before access is allowed.

12.3.3.2.3 Reactor Building

The Reactor Building HVAC System is divided into three zones, which are separated by leaktight, physical barriers. The zones are:

(1) Secondary containment (this area contains equipment that is a potential source of radioactivity and, if a leak occurs, the other accessible areas of the building are not contaminated).

(2) Electrical equipment area, cable tunnels, cable spreading rooms, remote control panel area, diesel generator rooms, reactor internal pump panel rooms, and the heating and ventilating equipment rooms.

(3) Steam tunnel (this room also contains a potential source of radioactive material leakage).

Air pressure in the rooms in Zone 1 is maintained slightly below outside atmospheric pressure by a fresh air supply and exhaust system. The supply air is filtered by a particulate filter. The exhaust stream is monitored for radioactivity, and if a high activity level is detected, the exhaust stream is diverted to the SGTS.

Normally, exhaust air is drawn from the corridor and various rooms. The exhaust duct has two isolation valves in series and a radiation monitor. The valves isolate the system if high airborne radioactivity is detected by the radiation monitor.

Zone 2 of the Reactor Building is maintained at a positive pressure during normal operation.

Zone 3 is open to both the Turbine Building and the environment through a blow-out vent at the Turbine Building steam tunnel interface.

For a description of the Reactor Building HVAC System see Subsection 9.4.5.

12.3.3.2.4 Radwaste Building

The Radwaste Building is divided into two zones for ventilation purposes. The control room is one zone, and the remainder of the building is the other zone. The air pressure in the first zone is maintained slightly above atmospheric, while the air pressure in the second zone is maintained slightly below atmospheric. Air in the second zone is drawn from outside the building and distributed to various work areas within the building. Air flows from the work areas and is then discharged via the Reactor Building stack. An alarm sounds in the control room if the exhaust fan fails. The exhaust flow is monitored for radioactivity, and if a high activity level is detected, the potentially radioactive cells are automatically isolated, but airflow through the work areas continues.

If the exhaust flow high-radiation alarm continues to annunciate after the tank and pump rooms are isolated, the work area branch exhaust ducts are selectively manually isolated to locate the involved building area. Should this technique fail, because the airborne radiation has spread throughout the building, the control room air conditioning continues, but the air conditioning for the balance of the building is shut down.

The work area's exhaust air is drawn through a filter unit consisting of a particulate filter and a HEPA filter, before being discharged to the Reactor Building stack. The air is monitored for radioactivity and, if a high level is detected, supply and exhaust is terminated.

Maintenance provisions for the filters are similar to those for the Control Building HVAC System.

See Subsection 9.4.6 for a detailed discussion of the Radwaste Building HVAC System.

12.3.4 Area Radiation and Airborne Radioactivity Monitoring Instrumentation

The following systems are provided to monitor area radiation and airborne radioactivity within the plant:

(1) The Area Radiation Monitoring System (D21/ARM) continuously measure, indicate and record the gamma radiation levels at strategic locations throughout the plant except within the primary containment, and activate alarms locally as well as in the control room on high levels to warn operating personnel to avoid unnecessary or inadvertent exposure. This system is classified as non-essential.

(2) The Containment Atmospheric Monitoring System (D23/CAM) continuously measures, indicates, and records the gamma radiation levels within the primary containment (drywell and suppression chamber), and activates alarms in the main control room on high radiation levels. As described in Subsection 7.6.2, four gamma sensitive ion chamber channels are provided to monitor gamma radioactivity in the primary containment during normal, abnormal and accident conditions. Each of the four monitoring channels covers the range from 10^{-2} Sv/h to 10^{5} Sv/h. The CAM System is classified as safety-related.

(3) The airborne radioactivity in effluent releases and ventilation exhausts is continuously sampled and monitored by the Process Radiation Monitoring System (D11/PRM) for noble gases, air particulates and halogens. As described in Section 11.5, the presence of airborne contamination is sampled and monitored at the stack common discharge, in offgas releases, and in the ventilation exhaust from buildings. Samples are periodically collected and analyzed for radioactivity. In addition to this instrumentation, portable air samplers are used for compliance with 10CFR20 restrictions. This portable system is designed to meet the criteria of Table 3.2b of Tier 1 and monitors airborne radioactivity in work areas prior to entry where potential levels exist that may exceed the allowable concentration limits. The instrumentation

provided to monitor airborne radioactivity is classified as non-essential, and is the responsibility of the COL applicant. See Subsection 12.3.7.2 for COL license information.

12.3.4.1 ARM System Description

The Area Radiation Monitoring (ARM) System consists of gamma sensitive detectors, digital area radiation monitors, local auxiliary units with indicators and local audible warning alarms, and recording devices. The detector signals are transmitted to the radiation monitors in the main control room. Each ARM radiation channel has two independently adjustable trip alarm circuits, one is set to trip on high radiation and the other is set to trip on downscale indication (loss of sensor input). Also, each ARM monitor is equipped with self-test feature that monitors for gross failures and will activate an alarm on loss of power or when a failure is detected. Auxiliary units with local alarms are provided in selected local areas for radiation indication and for activating the local audible alarms on abnormal levels. Each area radiation channel is powered from the non-Class 1E vital 120 VAC source, which is continuously available during loss of offsite power. The recording devices are powered from the 120 VAC instrument bus. The ARMs are calibrated in accordance with procedures developed from calibration instructions provided by the manufacturer. Periodic calibration verification and channel functional tests are performed with procedures based on pre-operational acceptance testing to verify operability, including alarm functions.

12.3.4.2 ARM Detector Location and Sensitivity

The location of each area detector is shown on the plant layout drawings for each building (Figures 12.3-56 through 12.3-73). The specific area radiation channels for each building are listed in Tables 12.3-3 through 12.3-7, along with reference to map location of the detector, the channel sensitivity range, and the areas for the local alarms. The range and sensitivity of each area radiation channel is classified as follows:

(1) Range 0.10 μSv/h to 1 mSv/h-H (High Sensitivity)

(2) Range 1 μSv/h to 10 mSv/h-M (Medium Sensitivity)

(3) Range 10 μSv/h to 10^2 mSv/h-L (Low Sensitivity)

(4) Range 1 mSv/h to 10 Sv/h-LL (Low Low Sensitivity)

(5) Range 1 mSv/h to 10^2 Sv/h-VL (Very Low Sensitivity)

12.3.4.3 Pertinent Design Parameters and Requirements

Two high-range radiation channels are provided to monitor radiation from accidental fuel handling. One detector is positioned near the fuel pool and the other located in the fuel handling area. Criticality detection monitors are not needed to satisfy the criticality accident requirements of 10CFR70.24, when specialized high density fuel storage racks preclude the possibility of criticality accident under normal and abnormal conditions. The new and spent fuel bundles are stored in racks that are placed at the bottom of the fuel storage pool. A full array of loaded fuel storage racks are designed to be subcritical, as defined in Sections 9.1 and 9.2. The COL applicant must verify and certify that the design meets the criteria specified in Subsection 12.3.7.3.

The detectors and radiation monitors are responsive to gamma radiation over an energy range of 80 keV to 7 MeV. The energy dependence from 100 keV to 3 MeV is accurate within ±20%. The overall system design accuracy is within 9.5% of equivalent linear full-scale recorder output for any decade.

The alarm setpoints will be established in the field by the COL applicant, as specified in Subsection 12.3.7.2, following equipment installation at the site. The exact settings will be based on sensor location, background radiation levels, expected radiation levels, and low occupational radiation exposures. The high radiation alarm setpoint for each channel is set slightly above the background radiation level that is normal to the area.

The area radiation monitoring instrumentation is designed to provide early detection and warning for personnel protection to insure that occupational radiation exposures will be as low as is reasonably achieved (ALARA) in accordance with guidelines stipulated in Regulatory Guide 8.2 and 8.8.

The Area Radiation Monitoring System includes instrumentation provided to assess the radiation conditions in crucial areas in the Reactor Building (the RHR equipment areas) where access may be required to service the safety-related equipment during post-LOCA per Regulatory Guide 1.97.

12.3.5 Post-Accident Access Requirements

The locations requiring access to mitigate the consequences of an accident during the 100-day post-accident period are the control room, the technical support center, the remote shutdown panel, the primary containment sample station (Post-Accident Sample System), the health physics facility (counting room), the nitrogen gas supply bottles, and the firewater valve room (see special stipulations below). Each area has low post-LOCA radiation levels. The dose evaluations in Subsection 15.6.5 are within regulatory guidelines.

Access to vital areas throughout the Reactor Building/Control Building/Turbine Building complex is controlled via the Service Building. Entrance to the Service Building and access to the other areas are controlled via double-locked secured entry ways. Access to the Reactor Building is via two specific routes, one for clean access and the second for controlled access. During an event such as a design basis accident, the Service Building/Control Building are maintained under filtered HVAC at a positive pressure with respect to the environment. Air infiltration is minimized by positive flow via double entry ways. Therefore, radiation exposure is limited to gamma shine from the Reactor Building, Turbine Building, main steamline access corridor, and skyline. This shine is minimized by locating highly populated areas below ground.

During a DBA event, access to remote shutdown panel, nitrogen bottles, and the PASS and monitor systems is controlled from the Service Building via the controlled access way. These corridors are not maintained under filtered positive pressure so that personal protection equipment (radiation protection suits, breathing gear, etc.) will be required in the access corridor. Primary contamination would occur from leakage through the PASS system and air infiltration from the environment. Both pathways are considered minimal and minor contamination under even the most adverse conditions is expected.

The Reactor Building vital areas are all located off one of the two primary access ways except the nitrogen bottle areas, which are located on the refueling floor and are accessible from the clean access corridor at the 4800 level (B1F) and up three floors to the 23500 level (3F). There are two access corridors, clean and dirty, with contamination in those areas limited to air infiltration from the environment and penetration leakage from the PASS system. In addition the lines penetrating the PASS room are doubly valved permitting line isolation in the event of any potential rupture. Sources of radiation therefore are limited to minor leakage and gamma shine, including the stack monitor room which contains only instrumentation and associated penetrations for monitoring stack effluent.

The firewater valve room (designated Room 431) shall be considered a vital area for those cases when the RHR System fails or has not been used. Entry to this area is permitted and planned for those low probability events when no contaminated containment water has circulated through the components in Room 431.

12.3.6 Post-Accident Radiation Zone Maps

The post-accident radiation zone maps for the areas in the Reactor Building are presented in Figures 12.3-12 through 12.3-22. The zone maps represent the maximum gamma dose rates that exist in these areas during the post-accident period. These dose rates do not include the airborne contribution in the Reactor Building.

Post-accident zone maps of the Control Building and Turbine Building are presented in Figures 12.3-54 and 12.3-55 respectively. The zone maps are designed to reflect the criteria established in Subsection 3.1.2.2.10.

12.3.7 COL License Information

12.3.7.1 Airborne Radionuclide Concentration Calculation

The COL applicant will provide the calculations of the expected concentrations of the airborne radionuclide for the requisitioned ABWR plant design (Subsection 12.3.3.1).

12.3.7.2 Operational Considerations

Area radiation monitoring operational considerations, such as monitor alarm setpoints, listed in Regulation Guide 1.70 are the COL applicant’s responsibility. Airborne radiation monitoring operational considerations such as the procedures for operations and calibration of the monitors, as well as the placement of the portable monitors, are also the COL applicant’s responsibility (Subsection 12.3.4).

12.3.7.3 Requirements of 10CFR70.24

COL applicants will provide information showing that their plant meets the requirements of 10CFR70.24 or request an exemption from this 10CFR 70.24 requirement (Subsection 12.3.4.3).

12.3.7.4 Material Selection

The COL applicant shall address state-of-the-art developments in material selection options for maintaining exposure ALARA.

12.3.8 Minimization of Contamination

The ABWR incorporates many Radiation Protection design features to limit contamination and are summarized below:

- Pumps located in radiation areas are provided with flush lines and in certain cases chemical cleaning capabilities for use prior to maintenance. Pump casing drains provide a means for draining pumps to the sump prior to disassembly, thus reducing the exposure of personnel and decreasing the potential for contamination.
- Instrumentation lines in liquid service for systems containing radioactive fluids are provided with vent and backflush provisions. Reactor vessel sensing lines may be flushed with condensate following reactor blowdown.
- Heat exchangers are constructed of stainless steel or Cu/Ni tubes to minimize the possibility of failure. The heat exchanger design allows for complete draining of fluids from the exchanger, and connections are available for condensate or demineralized water flushing.
- Valves have back seats to minimize leakage through the packing. Teflon gaskets are not used.
- Piping was selected to provide a service life equivalent to the design life of the plant, with consideration given to corrosion allowances and environmental conditions. Piping for systems containing radioactive fluids is welded to the most practical extent to reduce leakage through flanged or screwed connections.

- Floor drains with appropriately sloped floors are provided in shielded cubicles where the potential for spills exist. Smooth, epoxy-type coatings are employed to facilitate decontamination when a spill does occur. Curbs are provided to limit contamination and simplify washdown operations, and expanded metal-type floor gratings are minimized in favor of smooth surfaces in areas where radioactive spills could occur. Equipment and floor drain sumps are stainless steel lined to preclude leakage.

- Material selection consideration is used for systems and components exposed to reactor coolant. Specifically, a graded approach to the use of cobalt lowers the potential for the spread of contamination. Much of the cobalt is removed from contact with reactor coolant by eliminating Stellite where practical and reducing cobalt in the core stainless steel components.

- Sample stations in the plant contain flushing provisions using demineralized water, and sample station piping drains to plant sumps minimize the possibility of spills. Fume hoods are employed for airborne contamination control. Working areas and fume hoods are stainless steel to ease decontamination should a spill occur, and sample spouts are located above the sink to reduce the possibility of contaminating surrounding areas during the sampling process.

- HVAC systems are designed to limit the extent of airborne contamination by providing air flow patterns from areas of low contamination to more contaminated areas. HVAC Equipment drain sump vents are fitted with charcoal canisters or are piped directly to the Radwaste HVAC System to remove airborne contaminants evolved from discharges to the sump. HVAC penetrations through outer walls of buildings containing radioactive sources are sealed to prevent miscellaneous leaks into the environment.

12.3.9 References

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12.3-7 Reactor Physics Constants, Second Edition, ANL-5800, U.S. Atomic Energy Commission, July 1963.

12.3-8 ENDF/B-III and ENDF/B-IV Cross Section Libraries, Brookhaven National Laboratory.

12.3-9 PDS-31 Cross Section Library, Oak Ridge National Laboratory.

12.3-10 DLC-7, ENDF/B Photo Interaction Library.

Table 12.3-1 Computer Codes Used in Shielding Design Calculations

Computer Code Description	
QADF	A multigroup, multiregion, point kernal, gamma ray code for calculating the flux and dose rate at discrete locations within a complex source-geometry configuration.
GGG	A multigroup, multiregion, point kernal code for calculating the contribution due to gamma ray scattering in a heterogeneous three-dimensional space.
DOT4.4	A discrete ordinate, two-dimensional transport code. Multigroup, multiregion neutron or gamma transport.

Table 12.3-2 Typical Nickel and Cobalt Content of Materials

Material	Nickel (%)	Cobalt (%)
Carbon Steel	0.25	1% of Ni
Stainless Steel	10	1% of Ni
Ni-Cr-Fe (Inconel 600, Inconel X750)	70	1% of Ni
Stellite 6	3	58

Table 12.3-3 Area Radiation Monitors Reactor Building

No.	Location & Description	Figure #	Sensitivity Range	Local Alarms
1	Reactor area (A)-4F	12.3-62	H	X
2	Reactor area (B)-4F	12.3-62	LL	X
3	Fuel storage pool area (A)-4F	12.3-62	LL	X
4	Fuel storage pool area (B)-4F	12.3-62	LL	X
5	R/B 4F south area	12.3-62	H	X
6	R/B 4F SE area	12.3-62	H	X
7	R/B 3F NW area	12.3-60	H	X
8	R/B 3F SE area	12.3-60	H	X
9	CUW control panel area-B3F	12.3-56	H	X
10	R/B equipment hatch-B2F	12.3-57	H	X
11	HCU area (A)-B3F	12.3-56	M	X
12	HCU area (B)-B3F	12.3-56	M	X
13	SRV/MSIV valve maintenance room-3F	12.3-63	M	X
14	R/B 1F SE hatch area	12.3-59	H	X
15	RPV instrument rack room (A)-B1F	12.3-58	H	X
16	PV instrument rack room (B)-B1F	12.3-58	H	X
17	R/B B1F SE hatch area	12.3-58	H	X
18	TIP drive machine room-EL 1500	12.3-57	M	X
19	TIP machine equipment room-EL 1500	12.3-57	L	X
20	Core cooling water sampling room-M4F	12.3-61	M	X
21	CRD maintenance room-B2F	12.3-57	M	X
22	R/B B2F SE hatch area	12.3-57	H	X
23	R/B B2F NW hatch area	12.3-57	H	X
24	R/B B3F NW area-RHR “A” equip area	12.3-56	VL	X
25	R/B B3F SE area-RHR “B” equip area	12.3-56	VL	X
26	R/B B3F SW area-RHR “C” equip area	12.3-56	VL	X
27	R/B Operating Deck C	12.3-62	H	X
28	R/B Corridor D	12.3-57	M	X
29	R/B Cask Pil	12.3-60	M	X
30	R/B Sampling Room	12.3-58	M	X

Table 12.3-4 Area Radiation Monitors Control Building

No.	Location & Description	Figure #	Sensitivity Range
1	Main Control Room	12.3-64	H
2	Passageway underneath steam tunnel	12.3-64	H
3	RBCW “A” area-El-1315	12.3-64	H
4	RBCW “B” area-El-1315	12.3-64	H
5	RBCW “C” area-El-1315	12.3-64	H

Table 12.3-5 Area Radiation Monitors Service Building

No.	Location & Description	Figure #	Sensitivity Range
1	Service Building Tech. Support Center	12.3-64	H

Table 12.3-6 Area Radiation Monitors Radwaste Building

No.	Location and Description	Figure #	Sensitivity Range	Local Alarms
1	Electrical Equipment Room El 12300	12.3-67	H	X
2	Control Room El 12300	12.3-67	H	X
3	High Activity Spent Resin Tank Room Tank A El 5300	12.3-66	H	X
4	High Activity Spent Resin Tank Room Tank B El 5300	12.3-66	H	X
5	Trailer Access Area El 12300	12.3-67	H	X
6	LRW Mobile Skid Area El 12300	12.3-67	H	X
7	DAW & Wet Solid Waste Accumulation Area El 12300	12.3-67	H	X
8	High Activity Waste Storage Area El 12300	12.3-67	H	X
9	Waste Sorting Area El 12300	12.3-67	H	X
10	Phase Separator Tank A El 5300	12.3-66	H	X
11	Phase Separator Tank B El 5300	12.3-66	H	X

Table 12.3-7 Area Radiation Monitors Turbine Building

No.	Location & Description	Figure #	Sensitivity Range	Local Alarms
1	Operation Area (Laydown Space)	12.3-72	M	X
2	Corridor Condensate Sampling & Control Area	12.3-69	M	X
3	Rack Room	12.3-68	M	X
4	MD-RFP Area	12.3-70	H	X
5	CF Maintenance Area	12.3-71	M	X
6	CD Resin Strainer Room	12.3-70	H	X
7	Steam Ejector Units Room	12.3-70	H	X
8	OG Recombiner (A) Room	12.3-70	H	X
9	OG Recombiner (B) Room	12.3-70	H	X
10	High Pressure Drain Room	12.3-70	H	X
11	Moisture Separator and Reheater (A) Room	12.3-72	H	X
12	Moisture Separator and Reheater (B) Room	12.3-72	H	X
13	Turbine Building Operating Floor	12.3-73	H	X
14	Corridor (Unloading Bay)	12.3-70	H	X

The following figures are located in Chapter 21:

Figure 12.3-18 Reactor Building Radiation Zone Map Post-LOCA at Elevation 23500 mm (3F)

Figure 12.3-19 Reactor Building Radiation Zone Map Post-LOCA at Elevation 27200 mm (3.5F)

Figure 12.3-20 Reactor Building Radiation Zone Map Post-LOCA at Elevation 31700/38200 mm (4FM)

Figure 12.3-21 Reactor Building Radiation Zone Map Post-LOCA at Section A–A

Figure 12.3-22 Reactor Building Radiation Zone Map Post-LOCA at Section B–B

Figures 12.3-23 thru 12.3-36 Not Used

Figure 12.3-37 Radwaste Building, Radiation Zone Map, Normal Operation at Elevation -1700 mm

Figure 12.3-38 Radwaste Building, Radiation Zone Map, Normal Operation at Elevation 5300 mm

Figure 12.3-39 Radwaste Building, Radiation Zone Map, Normal Operation at Elevation 12300 mm

Figure 12.3-40 Radwaste Building, Radiation Zone Map, Normal Operation at Elevation 19100 mm

Figure 12.3-41 Radwaste Building, Radiation Zone Map, Normal Operation at Section A–A (Sheets 1 - 2)

Figure 12.3-42 Control and Service Building, Radiation Zone Map, Normal Operation at Elevation -8200 mm

Figure 12.3-43 Control and Service Building, Radiation Zone Map, Normal Operation at Elevation -2150 mm

Figure 12.3-44 Control and Service Building, Radiation Zone Map, Normal Operation at Elevation 3500 mm

Figure 12.3-45 Control and Service Building, Radiation Zone Map, Normal Operation at Elevation 7900 mm

Figure 12.3-46 Control and Service Building, Radiation Zone Map, Normal Operation at Elevation 12300 mm

Figure 12.3-47 Control and Service Building, Radiation Zone Map, Normal Operation at Elevation 17150 mm

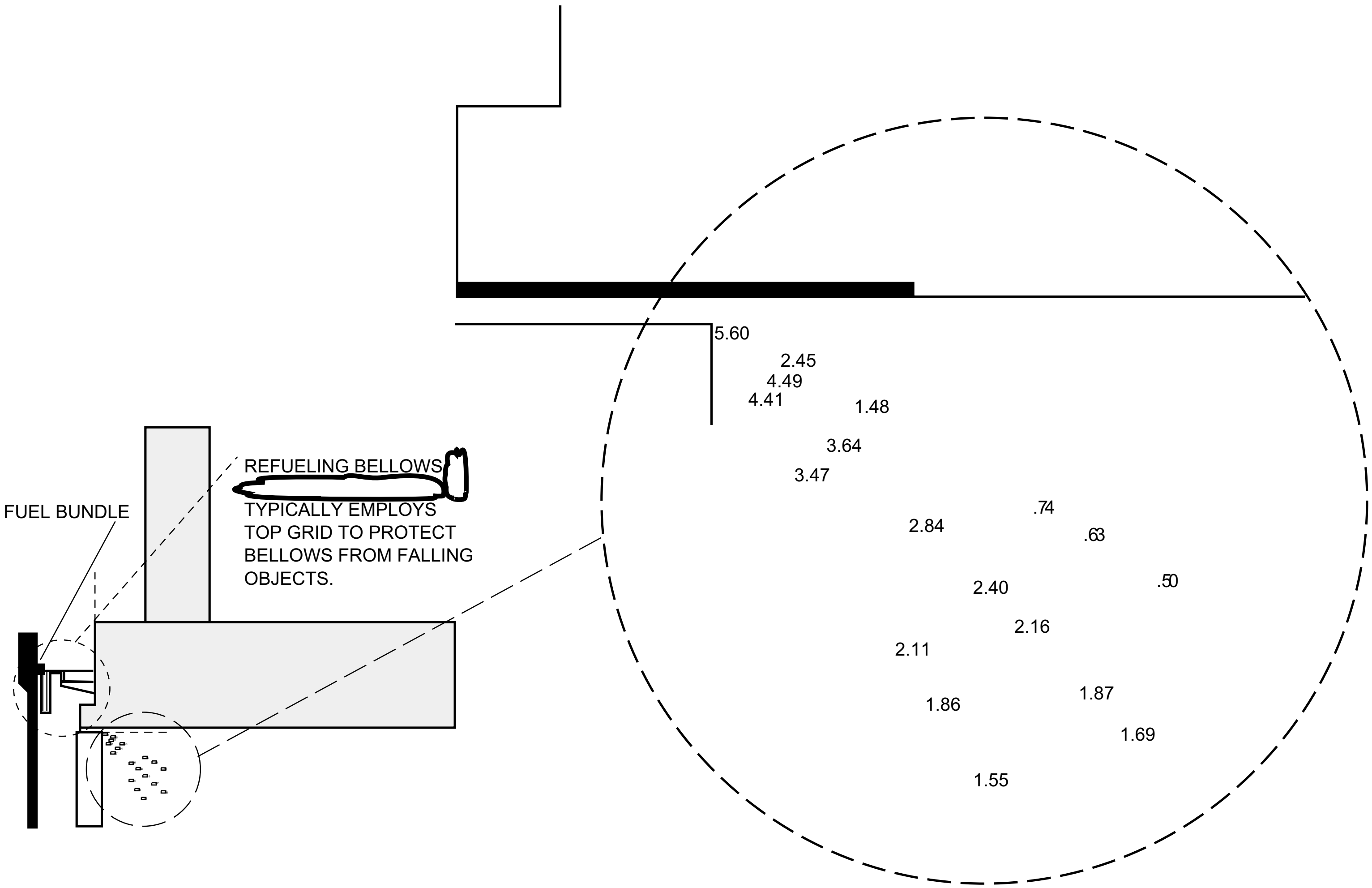

Figure 12.3-74 Upper Drywell Shielding Radiation Dose Rates with Fuel Bundle on Refueling Bellows (Gy/h)