12.4 Dose Assessment

Radiation exposures in the AP1000 are primarily due to direct radiation from components and equipment containing radioactive material. In addition, in some areas of the plant there can be radiation exposure to personnel due to the presence of airborne radionuclides. This section addresses the anticipated occupational radiation exposure (ORE) due to normal operation and anticipated inspection and maintenance.

12.4.1 Occupational Radiation Exposure

Radiation exposures to operating personnel are restricted to be within the limits of 10 CFR 20. The health physics program in Section 12.5 and the radiation protection features described in Section 12.3 together maintain occupational radiation exposures as low as reasonably achievable (ALARA).

In the analysis of occupational radiation exposure data from operating plants (domestic plants having Westinghouse designed nuclear steam supply systems), the best operating plant performance is 0.1 man-rem per MWe-year of electricity produced. Major factors contributing to this level of occupational radiation exposure include low plant radiation fields, good layout and access provisions, and operational practices and procedures that minimize time spent in radiation fields.

As discussed in Section 12.3, the AP1000 design incorporates features to reduce occupational radiation exposure that go beyond the designs provided for plants currently in operation.

The estimated annual occupational radiation exposures are developed within the following categories:

- Reactor operations and maintenance
- Routine maintenance
- Inservice inspection
- Special maintenance
- Waste processing
- Fuel handling operations

Exposure data obtained from operating plants have been reviewed to obtain a breakdown of the doses incurred within each category. For several routinely performed operations, this information has been used to develop detailed dose predictive models. These models identify the various steps that are included in the operation, the radiation zones, the required number of workers, and the time to perform each step. This information has been used to develop dose estimates for each of the preceding categories.

There is no separate determination of doses due to airborne activity. Past experience demonstrates that the dose from airborne activity is not a significant contributor to the total doses.

12.4.1.1 Reactor Operations and Surveillance

To support plant operations, the performance of various systems and components is monitored. Also, operation of some manual valves requires personnel to enter radiation fields. Examples of activities in this category are:

- Routine inspections of plant components and systems
- Unidentified leak checks
- Operation of manual valves
- Reading of instruments
- Routine health physics patrols and surveys
- Decontamination of equipment or plant work areas
- Calibration of electrical and mechanical equipment
- Chemistry sampling and analysis

When the plant is at power, the containment radiation fields are significantly higher than at plant shutdown. The frequency and duration of at-power containment entries is dependent on the plant operator. Based on review of current plant operations and on the AP1000 design changes and reliability improvements, it is assumed that 100 worker-hours per year spent in the containment during power operations.

Table 12.4-1 provides a breakdown of the collective doses for reactor operations and surveillance.

12.4.1.2 Routine Inspection and Maintenance

Routine inspection and maintenance are required for mechanical and electrical components. Table 12.4-2 provides a breakdown of the collective doses for routine inspection and maintenance. These estimates are based on having good access to equipment (a characteristic of the AP1000 layout).

Table 12.4-3 lists the doses associated with inspection of the sealless motor reactor coolant pumps (RCPs). Table 12.4-4 itemizes the doses estimated to be incurred from steam generator sludge lancing operations and Table 12.4-5 lists the doses resulting from the visual examination of the secondary side of the steam generators.

12.4.1.3 Inservice Inspection

ASME Code, Section XI requires periodic inservice inspection (ISI) on plant safety-related components. The Code defines the inservice inspection interval as a 10-year period and sets requirements for each one-third interval (each 40 months). In general, at least 25 percent (with credit for no more than 33-1/3 percent) of the specified inspections must be performed in each 40-month testing interval. The amount of inspection required for an area varies according to the category but is explicitly defined in the Code. Table 12.4-6 provides the doses for inservice inspection activities.

Detailed listings of the doses associated with certain major inservice inspection activities appear in Table 12.4-7 (eddy current inspection of 33 1/3 percent of the steam generator tubes and plugging of three tubes) and Table 12.4-8 (steam generator exterior). The dose estimates in Table 12.4-7 reflect the dose-reducing features of the AP1000 design, such as:

- Permanent work platforms
- Manway cover handling device
- Improved manway insert fasteners (tapered-end type)
- Trailer-mounted data collection station
- Use of robotics to perform eddy current inspection and tube plugging (no worker entry of the channel head required)

12.4.1.4 Special Maintenance

Maintenance that goes beyond the routine scheduled maintenance is considered to be special maintenance. This category includes both the modification of equipment to upgrade the plant and repairs to failed components. Dose estimates assume no significant equipment upgrade efforts. 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 the reduced number of components relative to currently operating plants.

In the past, special maintenance of the steam generators has resulted in significant personnel doses. The AP1000 benefits both from design changes and from improved primary and secondary water chemistry. The plugging of three tubes per steam generator each time eddy current examination is performed is included in the inservice inspection category.

No special maintenance activities are forecast for the sealless motor reactor coolant pumps.

Table 12.4-9 provides the estimated doses due to special maintenance operations.

12.4.1.5 Waste Processing

The AP1000 radwaste system designs incorporate an uncomplicated approach to waste processing. The AP1000 design does not include waste or boron recycle evaporators and it does not include a catalytic hydrogen recombiner in the gaseous radwaste system. Elimination of high maintenance components contributes significantly to lower anticipated doses due to waste processing activities.

Estimated annual doses from waste processing operations appear in Table 12.4-10.

12.4.1.6 Fuel Handling

Criticality monitoring of the new fuel handling and storage areas is performed in accordance with 10 CFR 70.24. Details of the fuel handling area monitoring are provided in subsections 11.5.6 and 11.5.6.4. A criticality excursion will produce an audible local alarm and an alarm in the plant MCR.

The refueling process is labor intensive. Detailed planning and coordination of effort are essential in order to maintain personnel doses as-low-as-reasonably achievable. Incorporation of advanced technology into the refueling process also reduces doses. Table 12.4-11 lists some of the AP1000 features that reduce doses during refueling operations.

Table 12.4-12 provides dose estimates for the various refueling activities.

12.4.1.7 Overall Plant Doses

The estimated annual personnel doses associated with the six activity categories discussed above are summarized below:

Category	Percent of Total	Estimated Annual (man-rem)
Reactor operations and surveillance	21.8	13.8
Routine inspection and maintenance	19.2	12.1
Inservice inspection	22.7	14.3
Special maintenance	23.7	15.0
Waste processing	8.2	5.2
Refueling	4.4	2.8
Total	100.0	63.2

These dose estimates are based on operation with an 18-month fuel cycle and are bounding for operation with a 24-month fuel cycle.

12.4.1.8 Post-Accident Actions

Requirements of 10 CFR 52.79(b) relative to plant area access and post-accident sampling (10 CFR 50.34 (f) (2)(viii) are included in Section 1.9.3. If procedures are followed, the design prevents radiation exposures to any individual from exceeding 5 rem to the whole body or 50 rem to the extremities. Figure 12.3-2 in Section 12.3 contains radiation zone maps for plant areas including those areas requiring post-accident access. This figure shows projected radiation zones in areas requiring access and access routes or ingress, egress and performance of actions at these locations. The radiation zone maps reflect maximum radiation fields over the course of an accident. The analyses that confirm that the individual personnel exposure limits following an accident are not exceeded reflect the time-dependency of the area dose rates and the required post-accident access times. The areas that require post-accident accessibility are:

- Main control room
- Class 1E regulating transformer areas
- Ventilation control area for MCR and I & C rooms with PAMS equipment
- Valve area to align spent fuel pool makeup
- Ancillary diesel room
- Passive containment water inventory makeup area

12.4.2 Radiation Exposure at the Site Boundary

12.4.2.1 Direct Radiation

The direct radiation from the containment and other plant buildings is negligible. The AP1000 design also provides storage of refueling water inside the containment instead of in an outside storage tank that eliminates it as a radiation source.

12.4.2.2 Doses due to Airborne Radioactivity

Subsection 11.3.3 discusses doses at the site boundary due to activity released as a result of normal operations.

12.4.3 Combined License Information

This section has no requirement for information to be provided in support of the Combined License application.

Table 12.4-1

DOSE ESTIMATE FOR REACTOR OPERATIONS AND SURVEILLANCE

Work Description	Annual Dose (man-rem)
Operation Supervision	
Routine patrols and inspections	5.4
Valve line-ups (manual)	0.2
System flushing and testing	0.4
Health Physics	
Job coverage	1.9
Routine surveys	1.6
Decontamination of Equipment and Work Areas	2.7
Calibration of Instrumentation	1.1
Chemistry Sampling and Analysis	0.5
Total Collective Dose:	13.8

Table 12.4-2

DOSE ESTIMATE FOR ROUTINE INSPECTION AND MAINTENANCE

Work Description	Annual Dose (man-rem)
Valve Adjustment/Repacking	1.8
Auxiliary Pump Overhaul	3.8
SG Sludge Lance	2.24
Demineralizer Resin Change-out	1.1
Filter Replacement	0.8
Calibrate/Repair Electrical Components	1.2
Miscellaneous Work	0.8
SG Secondary Side Inspection	0.34
Total Collective Dose:	12.1

Table 12.4-3

DOSE ESTIMATE FOR REACTOR COOLANT PUMP INSPECTION

Activity	Average Dose Rate (millirem/hr)	Crew Size (no. workers)	Time (hours)	Occupational Radiation Exposure (man-rem)
A. Electrical[a]				
Measure insulation resistance to ground	0	1	0.2	0
Measure winding resistance	0	1	0.2	0
B. Mechanical Specification				
Measure rotor breakaway torque	5	2	0.5	0.005
Measure rotor axial end play	5	2	0.5	0.005
Total RCP intermediate routine maintenance ORE = 0.010 man-rem/18 months Total intermediate routine maintenance ORE for 4 RCPs = 0.04 man-rem/18 months Annual total ORE for 4 RCPs = 0.027 man-rem/year[b]				

Notes:

a. Electrical measurements may be made from RCP switchgear, which is located outside containment.

b. The dose calculated based on an 18-month fuel cycle bounds plant operation with a 24-month fuel cycle.

Table 12.4-4

DOSE ESTIMATE FOR SLUDGE LANCING OF STEAM GENERATORS

Activity	Average Dose Rate (millirem/hr)	Crew Size (no. workers)	Time (hours)	Occupational Radiation Exposure (man-rem)
Move Equipment into Containment	10	6	4	0.24
Remove Insulation and Handhole Cover	40	1	0.5	0.02
Complete Pre-lance Water Balance	40	2	1	0.08
Install Lance on Handhole	40	2	0.5	0.04
Operate Water Lance	40	2	12	0.96
Complete Post-Lance Water Balance	40	2	1	0.08
Remove Equipment	10	6	4	0.24
Install Handhole Cover and Insulation	40	1	0.5	0.02
Total ORE per SG = 1.68 man-rem/18 months Total ORE for both SG = 3.36 man-rem/18 months Annual total ORE for two SGs = 2.24 man-rem/year[a]				

Note:

a. The dose calculated based on an 18-month fuel cycle bounds plant operation with a 24-month fuel cycle.

Table 12.4-5

DOSE ESTIMATE FOR VISUAL EXAMINATION OF STEAM GENERATOR SECONDARY SIDE

Activity	Average Dose Rate (millirem/hr)	Crew Size (no. workers)	Time (hours)	Occupational Radiation Exposure (man-rem)
Remove Insulation and 2 Manway Covers[(a)]	1	2	2.5	0.005
Inspect Separators Orifices and Feedwater Ring[(a)]	10	1	0.5	0.005
Install Two Manway Covers and Insulation and Lower Water Level below Handholes[(a)]	1	2	2.5	0.005
Remove Insulation and Secondary Handhole Cover	40	2	0.5	0.04
Photograph Support Plates	40	2	2	0.16
Install Handhole Covers and Insulation	40	2	0.5	0.04
Total ORE per SG = 0.255 man-rem/18 months Total ORE for two SGs = 0.51 man-rem/18 months Annual ORE for two SGs = 0.34 man-rem/year[(b)]				

Notes:

a. Secondary side water level at the lower deck plate.

b. The dose calculated based on an 18-month fuel cycle bounds plant operation with a 24-month fuel cycle.

Table 12.4-6

DOSE ESTIMATE FOR INSERVICE INSPECTION

Component	**Annual Dose (man-rem)**
Valve Bodies and Boltings	6.10
SG Primary Side Inspections	1.25
Reactor Vessel and Head	0.31
Reactor Coolant Loop Piping and Supports	1.45
SG Shell	0.12
Other Piping	2.83
Heat Exchanger Shells	0.73
Pressurizer Shell	1.20
Pumps	0.11
Tank Shells and Supports	0.15
Filter Housings and Supports	0.06
Total Dose:	14.3

Table 12.4-7 (Sheet 1 of 2)

DOSE ESTIMATE FOR STEAM GENERATOR EDDY CURRENT TUBE INSPECTION AND TUBE PLUGGING

Activity	Average Dose Rate (millirem/hr)	Crew Size (no. workers)	Time (hours)	Occupational Radiation Exposure (man-rem)
Move Equipment into Containment	2	4	4	0.032
Install Ventilation Equipment	50	1	1	0.050
Remove Insulation on both Manway Covers	50	2	0.2	0.020
Remove both Manway Covers with Handling Fixture	50	2	1	0.100
Remove both Manway Inserts	300	2	0.1	0.060
Install Fixture on Manway	300	2	0.1	0.060
Install Universal/Robotic Arm on Manway	50	2	0.25	0.025
Insert Nozzle Hot and Cold Leg Dams with Robotic Arm	50	2	0.5	0.050
Replace Dam Fixture Tool with EC End Effector on Robotic Arm (Hot Leg Channel)	50	1	0.25	0.013
Perform EC Exam of 33-1/3% of Tubes	1	1	111	0.111
Remove EC End Effector and Replace with Mechanical Plugging Tool	50	1	0.2	0.010
Insert Plugs in 3 Tubes	50	1	0.75	0.0375
Transfer Robotic Arm to Cold Leg Channel	50	2	0.25	0.025

Table 12.4-7 (Sheet 2 of 2)

DOSE ESTIMATE FOR STEAM GENERATOR EDDY CURRENT TUBE INSPECTION AND TUBE PLUGGING

Activity	Average Dose Rate (millirem/hr)	Crew Size (no. workers)	Time (hours)	Occupational Radiation Exposure (man-rem)
Insert Plugs in 3 Tubes	50	1	0.75	0.0375
Remove Robotic Arm	50	2	0.25	0.025
Remove Hinged Fixture	300	2	0.1	0.060
Install Manway Inserts	300	2	0.1	0.060
Install Both Manway Covers with Handling Fixture	50	2	1	0.100
Replace Insulation Both Manway Covers	50	2	0.2	0.020
Remove Ventilation Equipment	50	1	0.5	0.025
Move Equipment out of Containment	2	4	2	0.016

Total SG special maintenance ORE = 0.94 man-rem/18 months
Total SG special maintenance ORE for 2 SGs = 1.88 man-rem/18 months
Annual total ORE for 2 SGs = 1.25 man-rem/year[a]

Note:
a. The dose calculated based on an 18-month fuel cycle bounds plant operation with a 24-month fuel cycle.

Table 12.4-8 (Sheet 1 of 2)

DOSE ESTIMATE FOR STEAM GENERATOR INSERVICE INSPECTION (10-YEAR INTERVAL)

Activity	Average Dose Rate (millirem/hr)	Crew Size (no. workers)	Time (hours)	Occupational Radiation Exposure (man-rem)
Move Equipment into Containment	2	4	4	0.032
Remove/Install Insulation				
Steam nozzle	1	2	0.1	0.0002[a]
Secondary manways	1	2	0.1	0.0002[a]
Feedwater nozzle	10	1	0.1	0.001[a]
Upper shell girth welds	5	2	1.0	0.010[a]
Secondary hand hole	40	1	0.1	0.004[b]
Lower shell girth welds	40	2	1.0	0.080[a]
Channel head to tubesheet weld	100	2	0.3	0.060[b]
Pump to channel head welds	100	2	0.2	0.040[b]
Passive core cooling system (PXS) pipe to channel head weld	100	1	0.1	0.010[b]
Hot leg to channel head weld	100	2	0.2	0.040[b]
Install Ultrasonic Inspection Rig				
Upper shell girth welds	5	2	0.3	0.003[a]
Lower shell girth welds	40	2	0.3	0.024[a]
Channel head to tube sheet weld	100	2	0.1	0.020[b]
Pump to channel head welds	100	2	0.2	0.040[b]
PXS pipe to channel head weld	100	1	0.1	0.010[b]
Hot leg to channel weld	100	1	0.3	0.030[b]
Ultrasonic Inspection[c]				
Upper shell girth welds	0.1	2	7.5	0.0015[a]
Lower shell girth welds	0.1	2	7.5	0.0015[a]
Channel head to tube sheet	0.1	2	3.0	0.0006[b]
Pump to channel head welds	0.1	2	2.0	0.0004[b]
PXS to channel head weld	0.1	2	0.5	0.0001[b]
Hot leg to channel head weld	0.1	2	1.0	0.0002[b]

Notes:

a. ISI requires inspection of only 1 SG during each inspection interval.
b. ISI requires inspection on both SG during each inspection interval.
c. Operations performed from a low radiation area.

Table 12.4-8 (Sheet 2 of 2)

DOSE ESTIMATE FOR STEAM GENERATOR INSERVICE INSPECTION (10-YEAR INTERVAL)

Activity	Average Dose Rate (millirem/hr)	Crew Size (no. workers)	Time (hours)	Occupational Radiation Exposure (man-rem)
Dye Penetrant Inspection				
Steam nozzle	1	2	0.2	0.0004[a]
Feedwater nozzle	10	1	0.1	0.001[a]
Pump to channel head	100	2	0.5	0.100[b]
PXS to channel head	100	1	0.1	0.010[b]
Hot leg to channel head	100	2	0.2	0.040[b]
Visual Inspection[b]				
Secondary manway bolts	1	2	0.1	0.0002
Secondary handhole bolts	40	1	0.1	0.004
Primary handhole bolts	100	2	0.2	0.040
Primary manway bolts	100	2	0.1	0.020
SG support	100	1	0.1	0.010
Remove Equipment from Containment	2	4	4	0.032
Total in-service inspection ORE for one SG = 0.67 man-rem/10 years Total in-service inspection ORE for two SGs = 1.15 man-rem/10 years Annual total ISI ORE for two SGs = 0.12 man-rem/year				

Notes:

a. ISI requires inspection of only 1 SG during each inspection interval.
b. ISI requires inspection on both SG during each inspection interval.
c. Operations performed from a low radiation area.

Table 12.4-9

DOSE ESTIMATE FOR SPECIAL MAINTENANCE OPERATIONS

Work Description	Annual Dose (man-rem)
Valve Repairs	3.8
Auxiliary Pump Repairs	4.1
Electrical Repairs	3.2
Repairs to Tanks, Heat Exchangers, Piping, etc.	1.3
SG Secondary Side Repairs	1.1
Pressurizer Repairs	1.0
CRDM Repairs	0.5
Total Collective Dose:	15.0

Table 12.4-10

DOSE ESTIMATE FOR WASTE PROCESSING

Work Description	Annual Dose (man-rem)
Radioactive Waste Handling	3.0
System Adjustments/Repairs	1.8
System Operation (Sampling, Valve Adjustments, Monitoring, etc.)	0.4
Total Collective Dose:	5.2

Table 12.4-11

DESIGN IMPROVEMENTS THAT REDUCE REFUELING DOSES

Improved Design/Method	Reference Design/Method
Integrated RV Head Package	Conventional RV head package
RV Head Insulation with Suitcase-Type Fasteners and Permanent ID Markings	Insulation fastened with screws (no markings)
Combination Thermocouples and Flux Detectors	Top-mounted thermocouples and bottom-mounted flux detectors
Quick-Opening Fuel Transfer Tube Closure System	Bolted cover
Quick-Acting Stud Tensioner	Threaded-on stud tensioner
Pass and One-Half Stud Tensioning Procedure	Three-pass stud tensioning procedure
Electrical-Driven Stud Spin-Out Tool	Air-driven, spin-out tool
Permanent Reactor Cavity Seal Ring	Bolted or inflatable seal ring
Expandable Stud Hole Plugs	Threaded stud hole plugs
Shielded RV Head Storage Stand	Nonshielded stand
Smooth-Finish Reactor Cavity Liner (#1 Finish)	Rough-finish reactor cavity liner

Table 12.4-12

DOSE ESTIMATE FOR REFUELING ACTIVITIES

Refueling Operations Work Description	Dose (man-rem)
Preparation	0.1
Reactor Disassembly	1.4
Fuel Shuffle	0.5
Reactor Reassembly	2.2
Clean-Up	<0.1
Total Refueling Dose:	4.2
Average Annual Dose:	2.8[a]

Note:
a. Based on an 18-month fuel cycle. The stated dose bounds operation with a 24-month fuel cycle.