HITACHI

**GE Hitachi Nuclear Energy**

James C. Kinsey
Vice President, ESBWR Licensing

PO Box 780 M/C A-55
Wilmington, NC 28402-0780
USA

T 910 675 5057
F 910 362 5057
jim.kinsey@ge.com

MFN 08-208

Docket No. 52-010

March 28, 2008

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, D.C. 20555-0001

Subject: **Response to RAI Letter 60 Related to the ESBWR Design Certification – Radiation Protection – RAI Numbers 12.5-1 and 12.5-6**

The purpose of this letter is to submit the GE Hitachi Nuclear Energy (GEH) response to the U.S. Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) sent by NRC letter dated September 18, 2006. GEH response to RAI Numbers 12.5-1 and 12.5-6 are addressed in Enclosure 1. DCD Markups related to these responses are provided in Enclosure 2.

If you have any questions or require additional information, please contact me.

Sincerely,

James C. Kinsey

James C. Kinsey
Vice President, ESBWR Licensing

D068
NRO

Reference:

1. MFN 06-342, Letter from U.S. Nuclear Regulatory Commission to David H. Hinds, GEH, *Request For Additional Information Letter No. 60 Related To ESBWR Design Certification Application*, dated September 18, 2006.

Enclosures:

1. Response to Portion of NRC Request for Additional Information Letter No. 60 Related to ESBWR Design Certification Application – Radiation Protection – RAI Numbers 12.5-1 and 12.5-6
2. DCD Markups

| | | |
|---|---|---|
| cc: | AE Cubbage | USNRC (with enclosure) |
| | GB Stramback | GEH/San Jose (with enclosure) |
| | RE Brown | GEH/Wilmington (with enclosure) |
| | eDRF | 0000-0081-5942 |

Enclosure 1

MFN 08-208

Response to Portion of NRC Request for Additional Information Letter No. 60 Related to ESBWR Design Certification Application

Radiation Protection

RAI Numbers 12.5-1 and 12.5-6

**NRC RAI 12.5-1:**

*Provide a complete tabulated dose assessment with a scope and detail consistent with the guidance in RG 8.19. Data should be presented in the format provided in RG 8.19 or an acceptable alternative. The analysis should clearly indicate the basis (i.e., based on recent BWR experience or calculated based on similar tasks in other industries) for the staff-hour and dose rate estimates assumed and show how each was adjusted to account ESBWR specific design features. Estimates on work activities similar to the Advanced Boiling Water Reactor (ABWR) design (i.e., control rod drive removal and maintenance) should be based on experience from operating ABWRs.*

**GEH Response:**

DCD Tier 2, Section 12.4 has been rewritten in its entirety to address the requirements of this RAI. The rewritten Section 12.4 is provided in the attachment.

**DCD Impact:**

DCD Tier 2, Section 12.4 will be revised as noted on the attached markup.

**NRC RAI 12.5-6:**

*DCD Tier 2, Rev 1, Section 12.4.5 indicates that the Radwaste Building work activities considered in the dose assessment include movement of casks and liner, activated filter handling, resin moving and the removal of mobile radwaste processing skids. However, DCD Tier 2, Rev 1, Table 12.4-1 indicates that the average dose rate of 2.5 mrem/hr was assumed for these radwaste activities. Justify this low dose rate for what are typically high dose jobs. Several of the entries in Table 12.4-1 are substantially lower in DCD Rev. 1 than DCD Rev. 0 (i.e., refueling hours decreased from 1000 person-hours annually to 250 person hours, the dose rate assumed for main steam isolation valve (MSIV) work decreased from an already low 9 mrem/hr to 4 mrem/hr, etc.). Provide the basis for each of the assumptions and parameters used in the dose assessment (see question 12.5-1 above).*

**GEH Response:**

DCD Tier 2 Section 12.4, including Table 12.4-1, has been rewritten in its entirety to address Regulatory Guide 8.19 guidance described in RAI 12.5-1 and to address RAI 12.5-6 comments. The Radwaste Building work activity occupational dose estimates have been revised and are discussed in DCD Chapter 12.4.3 Waste Processing. The quantitative dose estimate is shown in Table 12.4-4 of the revised Section 12.4. Refueling work activities are now described in DCD Chapter 12.4.4 Refueling Operations, and the quantitative dose estimate is shown in Table 12.4-5.

**DCD Impact:**

DCD Tier 2, Section 12.4 will be revised in its entirety as noted on the attached markup.

Enclosure 2

MFN 08-208

DCD Markups

## 12.4 DOSE ASSESSMENT

This section discusses the occupational radiation dose assessment for the ESBWR facility. An occupational dose assessment is required by Regulatory Guide 1.70 (Reference 12.4-1) following the format requirements of Regulatory Guide 8.19 (Reference 12.4-2). Subsections 12.4.1 through 12.4.6 discuss the dose assessment categories following the format guidance in Reference 12.4-2. Tables 12.4-2 through 12.4-7 provide tabulated numerical collective dose estimates for the individual assessment categories discussed in the subsections. Table 12.4-1 provides a summary and overall occupational collective dose assessment in units of person-Sievert per year and man-rem per year.

The estimated annual occupational radiation exposures are developed within the following collective occupational dose assessment categories described in Reference 12.4-2:

(1) Reactor Operations and Surveillance

(2) Routine Maintenance

(3) Waste Processing

(4) Refueling Operations

(5) Inservice Inspection

(6) Special Maintenance

The occupational dose assessment is a significant element in supporting the facility design and methods of operation to ensure occupational radiological exposures are as low as reasonably achievable (ALARA). The dose assessment performed herein depends on estimates of occupancy, dose rates in various occupied areas, frequency of operations, and the number of personnel participating in reactor operations and surveillance, routine maintenance, waste processing, refueling, inservice inspection and special (unscheduled) maintenance. Facility personnel include station and utility employees, as well as contract workers. In this assessment, no differentiation is made between numbers of station, utility or contract workers used to perform specific tasks since the COL holder is responsible for the overall plant staffing makeup. The occupations for these personnel may include maintenance, operations, health physics, supervision and engineering, although no differentiation is made in this assessment due to the above reason.

To estimate the total annual radiological dose to personnel, dose rate estimates (in units of μSv/hr) for the performance of duties in the assessment categories are developed using a variety of available methods including ESBWR radiation zoning levels, available technical reports and experiential data based on previous and current BWR plant designs and operational information. Person-hours expended in performance of the various tasks are estimated in a similar manner. The person-hours defined within this assessment are the estimated person-hours spent in a significant ($\geq$ 1 μSv/hr) radiation zone, and should not be compared with overall person-hours required for the normal operational activities of a nuclear power plant. Estimates of the dose rates and person-hours applied to ESBWR activities are made by extrapolating results of previous studies/information for the BWR and ABWR product lines and adjusting to the lowered equipment and component utilization of the simplified systems of the ESBWR.

For example, the dose rates and maintenance person-hours due to elimination of the recirculation loop systems in ESBWR is considered both from a reduced drywell radiation signature as well as decreased maintenance requirements from the absent recirculation loop components. In other cases, data is extrapolated factoring the maintenance impact of the elimination of active safety systems such as HPCI, RCIC, and RHR systems in favor of the passive safety design of the ESBWR. Where ESBWR radiation zone map values are employed to estimate dose rates, a representative "effective" dose rate for a given area or activity was employed. In some cases, experiential and/or operational dose rates and person-hour data are employed to estimate the collective occupational dose after correction for ESBWR design parameters.

The analytical method used for the person-Sievert assessment is based on the product of the estimated occupancy time (i.e., person-hours per year) and the estimated effective dose rate (μSv/hr) determined using the methods described above. The collective doses in each of the assessment categories are added and shown in the associated tables, and the total for all categories summed in Table 12.4-1.

The occupational dose assessment collective doses are based on a 24 month refueling cycle.

In this occupational dose assessment, 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 collective dose when compared to the overall results direct radiation doses evaluated in this assessment. As such, the estimated collective doses in this evaluation represent the result of Deep Dose Equivalent (DDE) exposures only; no inhalation or airborne dose contributions are assumed.

The assessment for each of the collective dose categories is given below.

### 12.4.1 Reactor Operations and Surveillance

During plant operation, the performance of various systems and components is routinely monitored by operator tours through the plant during each shift. These inspections include monitoring rotating machinery for leaks, proper operation, and ensuring instrumentation readings lie within acceptable limits. Also, operation of some manual valves may require personnel to briefly enter radiation fields. In some cases, minor repairs or equipment adjustments may also be required to be performed. Health physics surveys and work party monitoring are considered in this category. Because the drywell is inaccessible during full power operations, testing, and surveillance activities in the drywell are performed after a shutdown or during a refueling outage. Some non-routine tasks such as clean up of radioactive spills or conducting fuel sipping are not generally planned, but require performance for continued optimal plant operations and maintenance of an effective ALARA program.

Some examples of routine operation and surveillance activities 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

These activities may be conducted in the Reactor, Fuel, Radwaste and/or Turbine Buildings. The significant reductions in component and instrumentation requirements due to the emphasis on passive safety systems in lieu of the active systems used in current BWRs, combination of systems such as reactor water cleanup and shutdown cooling, and elimination of systems such as the TIP system, results in a significant reduction in surveillance, monitoring and testing work.

Exposure from these miscellaneous surveillance, testing, and monitoring activities during normal operation is due to N-16, as well as reactor coolant corrosion and fission products. Additional shielding is provided to reduce radiation levels in routinely occupied areas during power operation from N-16 sources. The ESBWR is expected to have reduced general radiation levels during operation compared to the typical BWR due to more stringent water chemistry controls, two percent reactor water clean up capacity, titanium or stainless steel condenser tubes, and low cobalt usage.

Estimates of the collective doses to operations and surveillance personnel have been made by extrapolating results of previous studies for BWRs to the reduced equipment and component utilization of the simplified systems of the ESBWR. Person-hour estimates of activities performed in this category, the associated dose rates, and the collective dose from these activities are shown in Table 12.4-2

### 12.4.2 Routine Maintenance

Routine inspection and maintenance are required for mechanical and electrical components throughout the operation of a power plant. This category summarizes collective dose incurred during routine scheduled maintenance and inspection activities, which in some cases, can be performed while the plant is in normal operation. The special maintenance category reviewed in Section 12.4.6 sums collective dose associated with specialized procedures that can be performed only during refueling outages.

In the ESBWR, simplifying systems in the reactor building result in a significant reduction in the total number of valves and an attendant decrease in maintenance time. This work includes all valve work, minor maintenance, and CRD hydraulic line work. Use of live-load valve packing to control stem leakage reduces maintenance and worker radiation exposure for valve repair. The ESBWR reactor building has been designed to provide for ease of maintenance with overhead lifts, coordinated hatchways and ample space to maintain in-place equipment. In addition, most of the equipment in the reactor building is removable. The combined RWCU/SDC system purifies reactor coolant during normal operation and shutdown. Two 100% redundant RWCU/SDC trains are provided in the ESBWR design that uses state-of-the-art water treatment technology to significantly reduce the concentration of radionuclide material in the coolant. The system is constructed of stainless steel for those portions in contact with the reactor coolant. For system piping, smooth bends are used instead of welds and the nuclear grade pipes are electro-polished to reduce corrosion product buildup.

RWCU/SDC maintenance work consists of inspection of two pumps per year in each train. The FAPCS system uses a similar design philosophy for its components. Although it is assumed that some maintenance may be conducted during normal operation, certain portions of the RWCU/SDC and FAPCS systems in the fuel building may require additional maintenance during refueling outages. Maintenance activities for other systems in the reactor and fuel buildings are shown in Table 12.4-3.

For routine maintenance in the radwaste building, the ESBWR design implements the use of skid-mounted process systems for radwaste processing, thereby reducing the maintenance requirements to the permanently installed systems.

Due to the high radiation from N-16 in the turbine building, maintenance on major systems must be performed when the plant is shutdown. Maintenance on supporting systems can be performed if there exists a sufficient decay period for the N-16.

Table 12.4-3 provides a breakdown of the collective doses associated with overall routine inspection and maintenance activities.

### 12.4.3 Waste Processing

Radioactive waste is processed in systems housed in the radwaste building, which consists of the Liquid Waste Management System (LWMS) and the Solid Waste Management System (SWMS). The LWMS is designed to segregate, collect, store, and process radioactive liquids generated during operation. The SWMS is designed to control, collect, handle, process, package and temporarily store wet and dry solid radioactive waste prior to shipment offsite. The processing systems consist of pumps, valves, tanks and process systems (skid-mounted) that are remotely operated from a central Radwaste Building Control Room. In the LWMS, radioactive contaminants are removed and the bulk of the liquid is purified and either returned to the condensate storage tank or discharged to the environment, minimizing overall liquid waste. The radioactivity removed from the liquid waste is concentrated in filter media, ion exchange resins, and concentrated waste. The filter sludge, ion exchange resins, and concentrated waste are sent to the Solid Waste Management System (SWMS) for further processing. The output of the radwaste processing systems generally consists of dry active waste (DAW), wet solid waste in high integrity containers (HIC), and mixed wastes, which are both radiologically and chemically contaminated.

The dose projections below are based on representative systems currently used in the industry. Dose from surveillance and maintenance activities in the radwaste building are captured in the other respective categories of this analysis.

General radwaste building work consists of pump and valve maintenance, shipment handling, radwaste management and general clean up activity. Maintenance collective dose estimates are captured in Section 12.4.2. The LWMS collects liquid wastes from equipment drains, floor drains, filter backwashes and other sources within the facility. Some examples of SWMS activities include movement of casks and liners, filter handling, resin transport, and movement or reconfiguration of radwaste processing skids. Generally, much of the activity is remotely performed and controlled by operators in the Radwaste Building Control Room. Dose estimates for the collection, packaging and shipment of radwaste quantities are based on the assumptions below.

Operation of the Radwaste Building Control Room is assumed to occur approximately once per day for one shift in a maximum dose rate of 10 μSv/hr. Processing and packaging of DAW is assumed to occur once a day for two hours using two workers in a dose field of 50 μSv/hr. This activity is assumed to occur three times per week. Shipments of concentrated wet solid waste in HICs are assumed to occur once per week in a dose field of 50 μSv/hr using four workers. DAW shipments are assumed to occur once per month in a dose field of 50 μSv/hr using three workers. Finally, miscellaneous activities in high dose rate areas such as valve line-ups or filter changes are assumed to be required approximately 4 person-hours per week in an average dose rate field of 150 μSv/hr.

The estimated annual collective doses associated with waste processing operations appear in Table 12.4-4.

### 12.4.4 Refueling Operations

In the ESBWR design, refueling operations are conducted in two general areas. The fuel building houses the spent fuel pool and various equipment used for the receipt of new fuel assemblies. Space is also provided for fuel assembly receipt inspection and the installation of fuel channels on the new fuel assemblies. When new fuel assemblies are readied for transfer to the reactor, the assemblies are transferred using the Inclined Fuel Transfer System (IFTS), which is located in the upper portion of the reactor building. Here the new fuel assemblies are kept in the buffer pool until the refueling outage. This dual pool system is similar to that implemented in the BWR/6 product line. During the refueling outage, new fuel assemblies are placed in the reactor core using the robotic control refueling machine, the core shuffled, and spent fuel removed to the reactor building buffer pool. At this time, control rods or other incore components may be replaced. Spent fuel assemblies, which were removed from the core, are then transferred through the IFTS to the fuel building spent fuel pool. The fuel building also contains facilities for the transfer of spent fuel assemblies into casks for possible storage at an onsite Independent Spent Fuel Storage Installation (ISFSI).

Prior to commencing refueling operations, the drywell and reactor vessel heads must be disassembled and removed. Reactor vessel access and reassembly exposure times are reduced by use of a special stud tensioner for the 80 RPV head bolts. Underwater transfer of the dryer, chimney/partitions, and chimney head/separator decreases exposures during refueling operations. Refueling exposures are also decreased by the use of the robotically controlled automated refueling platform. The improved fuel, inspection equipment, and increased use of remote operations significantly reduce the refueling floor exposure. Drywell access and RPV disassembly and reassembly in conventional BWRs typically require 4500 person-hours of work at an effective dose rate of 30 μSv/hr. The ESBWR work will involve the use of an automated stud tensioner for the RPV top head. This equipment coupled with other automatic equipment available is estimated to reduce the drywell and RPV vessel disassembly/reassembly time to 1200 person-hours.

ESBWR refueling is accomplished via the robotically controlled refueling bridge in which the operator works in an enclosed automation center off the refueling floor. This reduces the operator effective dose rate to 8 μSv/hr, and time for a complete core offload and/or shuffle is reduced to approximately 500 person-hours. Time for refueling operations including control rod replacement is reduced from a typical BWR value of 4,400 person-hours to approximately 1,500 person-hours and from an effective dose rate of 25 μSv/hr to approximately 8 μSv/hr. This is accomplished using the automated refueling machine and it is estimated that approximately 500 person-hours are spent in transfer of the spent fuel and other replaced components to the buffer pool in the reactor building, and 1000 person-hours is spent transferring the spent fuel and removed components through the IFTS to the spent fuel pool in the fuel building. General area reactor building refueling floor and fuel building radiation zone effective values of 8 μSv/hr are used for the dose projections. An additional 4000 person-hours is estimated for an optional spent fuel transfer campaign into storage casks for possible onsite storage in an ISFSI, if utilized. Because cask loading operations are conducted entirely underwater, an effective dose rate value of 5 μSv/hr is used for the cask loading and transfer process. The total Person-Sv associated with the above refueling operations is shown in Table 12.4-5.

## 12.4.5 Inservice Inspection

The ASME Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components", requires extensive inspections of the reactor pressure vessel, reactor coolant pressure boundary, containment penetrations, pressure retaining components, core support components, and internal components. All welds associated with the reactor coolant pressure boundary are inspected. In addition, safety related valves are also subject to inservice inspection. Because the ESBWR design does not utilize safety related pumps, no pumps are included in the inservice inspection program. In addition to the reactor pressure vessel, portions of the main steam, feedwater, standby liquid control, RWCU/SDC, isolation condenser and gravity driven cooling systems are also inspected. The inspections, generally performed during refueling outages, usually consist of pressure tests (leakage or hydrotest), visual inspections, and/or non-destructive examinations. The methods used in the tests and inspections include ultrasonic, visual, surface, eddy current and/or radiographic testing, and other non-destructive testing (NDE) methods. 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 ASME Code, Section XI.

The drywell design includes many features to facilitate inservice inspections (ISI). Some of these include the use of stand-off mirror type insulation around the reactor vessel, use of remote-operated mechanical devices for inspection of the RPV body and nozzle welds, removable pipe insulation, and provisions for additional ISI operations laydown space. The use of natural circulation simplifies the design within the drywell by eliminating the recirculating loops, pumps, pipe supports, hangers, and shock suppressors. Due to the elimination of active safety systems such as HPCI, LPCI, RHR and RCIC, the required inspection of attached piping and valve systems result in significantly reduced expenditure of person-hours compared to conventional BWRs. Due to the larger vessel used in the ESBWR, the total vessel weld length inspection may increase by up to 40% as compared to a conventional BWR. Modern robotic methods used for vessel ISI such as automated turtles for inspection should result in lowered effective dose rates for the inspection activities.

Overall, it is estimated that by elimination of the recirculation system and active safety systems inspection requirements and the use of facilitated automated inspection, person-hours expended in ISI is reduced by almost a factor of two from conventional BWRs. The person-hours reduction is approximately 1,500 person-hours during a refueling outage (750 person-hours per year) at approximately half the conventional effective drywell dose rate or

60 μSv/hr, and is estimated at 30 μSv/hr for inspections in the reactor building.

Based on an extrapolation of estimates performed for conventional BWRs, the ISI collective dose estimates associated with the ESBWR are shown in Table 12.4-6.

### 12.4.6 Special Maintenance

Maintenance that goes beyond routine scheduled maintenance and/or cannot be performed without significant expenditure of resources in non-negligible radiation fields is considered to be special maintenance. In addition to maintenance, this category includes both the modification of equipment to upgrade the plant and repairs to failed components. A review of the primary special maintenance areas is provided below.

Drywell

Because the drywell is inaccessible during normal operation, special maintenance activities are primarily conducted in the drywell during refueling outages. In the ESBWR design, deletion of the recirculation pumps and associated piping has a major effect on the in-drywell dose rates experienced during maintenance procedures. This effect has already been demonstrated in the ABWR fleet currently in operation.

The primary drywell systems that are considered to be in this category are:

- Main Steam Isolation Valve (MSIV);
- Safety and Safety Relief Valve (SV/SRV);
- Fine Motion Control Rod Drive (FMCRD)
- Local Power Range Monitor (LPRM) /Automated Fixed In-Core Probe (AFIP)
- Miscellaneous Pumps and Valves
- Drywell Instrumentation
- Other In-Drywell Systems Including Passive Systems

The overall maintenance scope and radiation environment associated with work on these major components is described below.

The ESBWR design incorporates three specific features to reduce occupational exposures in the MSIV maintenance areas both in the drywell and reactor building:

- Improved MSIV leakage rate test procedures;
- Improved maintenance procedures with some procedures automated; and
- Reduced radiation fields, primarily due to the absence of the recirculation piping.

Maintenance operations incorporate an improved seat grinding system and other special tools. Overall maintenance is reduced by use of the MSIV overhauling devices, use of main steam line plugs and the improved MSIV grinding system. Use of these automatic systems results in an additional overall reduction in maintenance times of approximately 50% compared to conventional BWRs. This, along with improved drywell access, significantly reduces the maintenance time necessary for MSIV repair. Additionally, the ESBWR is designed to limit the use of cobalt bearing materials on moving components that have historically been identified as major sources of reactor coolant contamination. As stated above, the primary source of radiation exposure, the recirculation lines, have been removed. In addition, deposited activity in the feedwater lines is expected to be lower than typical BWRs owing to an enhanced condensate system with full cleanup of all condensate water, enhanced water quality and chemistry procedures, and titaniumor stainless steel condenser tubes which limit the transfer of metallic ion contamination to feedwater and lessen activation product radioactivity. Maintenance in the drywell/steam tunnel is expected to be approximately 1,600 person hours at an effective dose rate of 18 μSv/hr and maintenance in the reactor building 2,600 person hours at an effective dose rate of 13 μSv/hr.

The ESBWR safety (SV) and safety relief valve (SRV) design does not vary significantly from past designs. However the natural recirculation core flow and consequent elimination of the recirculation piping will reduce maintenance exposure doses accordingly. Maintaining the SV and SRVs, for the most part consists of minor maintenance and/or removal of valves to a maintenance facility. Overhead tracks and in-place removal equipment is provided in the ESBWR for removal/replacement of the 18 SV/SRVs to an external maintenance facility. This work is estimated to require 200 person-hours per outage in an effective radiation field of 60 μSv/hr.

Control rod drive maintenance is significantly reduced in the ESBWR as compared to hydraulic systems used in most BWRs with the utilization of fine motion control rod drives (FMCRDs). These drives vary most significantly in that they eliminate scram discharge lines and the associated radiation in and around areas where the lines are routed. Due to the significantly modified design of the FMCRD, only two to four drives and 20 motors are assumed required to be maintained per outage. For maintenance on four FMCRDs, estimated work will consist of 64 person-hours undervessel preparation, 80 person-hours for FMCRD removal and re installation, and 200 person-hours motor removal and installation, and 64 person-hours cleanup. Due to the removal of the recirculation pumps and lines, the overall undervessel effective dose rate is estimated to be approximately 65 μSv/hr.

In the ESBWR, a design improvement for the Neutron Monitoring System (NMS) involves replacing the conventional BWR Traversing In-core Probe (TIP) system with fixed in-core detectors (AFIP) for calibrating the Local Power Range Monitors (LPRMs). Eliminating the complex drive and indexer mechanism with associated controls, which are required to insert and withdraw the TIPs from the core region, substantially improves operability, maintainability, and reduces occupational radiological exposures. The AFIP system is located within the LPRM "string" assembly and both systems are replaced concurrently. LPRM design has been improved and currently each monitor lasts up to seven years. LPRM/AFIP assemblies are removed remotely from beneath the reactor vessel, cut up, and placed in a shielded cask for disposal. The ESBWR uses 64 LPRM/AFIP string assemblies, and it is assumed that 8 assemblies are replaced in an outage. To perform this work, it is assumed 3 hrs/per assembly to remove and replace with a crew of two for 48 person hours at an effective dose rate of 100 μSv/hr.

In addition to the MSIV and SRV major valve components, simplified systems result in a significant reduction in the total number of supporting system valves and instrumentation located in the drywell with an accompanying decrease in maintenance time. The elimination of HPCI, RCIC and RHR type active systems and replacement with passive systems that use relatively few valves and no pumps result in a markedly shorter time for drywell maintenance activities. The estimated time to perform maintenance on miscellaneous drywell valves is 1,500 person-hours at 40 μSv/hr. The estimated time to perform maintenance on miscellaneous drywell instrumentation is 1,000 person-hours at 50 μSv/hr.

Other remaining drywell maintenance activities such as passive safety system maintenance, scaffolding erection and dismantling, and snubber inspection/replacement are conservatively estimated to require an additional 1300 person-hours in an effective dose rate field of 50 μSv/hr.

Reactor Building

The reactor building surrounds the drywell (primary containment) and houses the support systems for the drywell components. The reactor building has been arranged to take advantage of the reduced quantity of equipment associated with the simpler ESBWR systems. The building arrangement features numerous dose-reducing benefits and improved equipment maintenance durations. Equipment is more accessible which facilitates improved access control and maintenance. The building features enhanced accessibility on all floors. Equipment access is provided for all surveillance, maintenance and replacement activities with local service areas and laydown space for periodic inspections. Lifting points, monorails and other installed devices are provided to facilitate equipment handling and minimize the need for re-rigging individual equipment movements. Valve galleries are provided to minimize personnel exposure during system operation or preparation for maintenance.

The major special maintenance activities that occur in the reactor building are:

- MSIV Rework
- Fine Motion Control Rod Drive (FMCRD) Rebuild Work
- Control Rod Drive Hydraulic Control Unit (CRD HCU) Work
- Reactor Water Cleanup/Shutdown Cooling (RWCU/SDC) System Maintenance
- Instrumentation Maintenance Testing and Repair
- Additional Miscellaneous Work to Valves and Systems

As in the drywell, MSIV related exposure in the reactor building comes from maintenance, rework and testing of the MSIVs during the plant refueling shutdown. As indicated above in relation to MSIV work in the drywell, reductions in maintenance are expected from the use of improved procedures. Maintenance in the Reactor Building is expected to require 2,600 person-hours per cycle at an effective dose rate of 13 μSv/hr.

While the FMCRD are removed from the undervessel area of the drywell, the drives themselves are rebuilt in a special area in the reactor building. Assuming the same four drives/cycle are rebuilt as removed from the drywell, rebuilding estimates are 60 hours per drive. It is assumed the four drives will be rebuilt in the control rod drive maintenance equipment room at an effective dose rate of 30μSv/hr.

In addition to maintenance during normal operation, some of the CRD hydraulic control units (HCU) and/or the associated piping may be required to be serviced or rebuilt during an outage. The major task is servicing the hydraulic control units in which 50 units are assumed to require service at 3hrs/unit using a crew of four for approximately 600 person-hours at an effective dose rate of 30 μSv/hr in the HCU areas or maintenance room.

RWCU/SDC maintenance work, which cannot be performed during normal operation, consists of inspection for two pumps and associated heat exchangers in each train. In the RWCU/SDC the ESBWR uses canned pumps in both trains with an estimated maintenance of 100 person-hours per pump for a total of 400 person-hours/cycle. This work is assumed to be performed in the RWCU/SDC pump rooms at an effective dose rate of 150μSv/hr.

Reactor building instrumentation, maintenance, and repair work that cannot be performed during normal operation is assumed to require 600 person-hours/year at an effective dose rate of 30μSv/hr

Additional reactor building outage maintenance items such as passive system maintenance, minor valve, pump or other equipment maintenance is assumed to involve 3400 person-hours/year at an average dose rate of 8μSv/hr.

Turbine Building

Although some turbine maintenance may be conducted during plant operation, the N-16 radiation produced during normal operation prohibits significant maintenance work until the plant is shutdown or in an outage. The major activities involving maintenance on turbine building components associated with non-negligible radiation fields are:

- Turbine Overhaul
- Valves/Pumps Maintenance
- Condensate Treatment
- Other Miscellaneous Turbine Work

With the use of improvements in the automation of turbine maintenance and overhaul procedures, a simpler overall system design, titanium or stainless steel condenser tubes, and redesigned offgas system as compared to a conventional BWR, turbine overhaul work is estimated to require approximately 24,000 person-hours during an outage. An effective dose rate value of 3 μSv/hr is assumed for turbine overhaul work.

The valve and pump maintenance requirements for the ESBWR do not vary significantly over current plants; although the larger turbine and generator systems may require slightly more work. As such, the total hours for this type of work is assumed to be approximately the same as conventional turbine systems when including the benefits of titanium or stainless steel condenser tubes, improved valves, maintenance jigs, and automated devices. The man-hour estimates for turbine valve and pump estimated maintenance time is 2,000 person-hours per outage. In the ESBWR, assuming maintenance of high operating water quality standards and a significant reduction in cobalt bearing materials, the overall effective dose rate is estimated at 39 μSv/hr for this work.

Work on the turbine condenser and associated condensate system is assumed to require 2,000 person-hours per outage using conventional high efficiency filter systems. Again, assuming maintenance of high operating water quality standards, and a significant reduction in cobalt bearing materials, the overall effective dose rate is estimated at 35 μSv/hr for this work

Other work in the turbine building is assumed to expend approximately 12000 hours in a cycle conducted in both outage and non-outage conditions and is accounted for in the routine maintenance section. This work is assumed to take place in shielded locations at an effective dose rate of 1 μSv/hr.

Table 12.4-7 provides the estimated doses due to special maintenance operations.

## 12.4.7 Overall Plant Doses

The estimated annual personnel doses associated with the six activity categories discussed above are summarized in Table 12.4-1.

## 12.4.8 COL Information

None.

## 12.4.9 References

12.4-1 USNRC Regulatory Guide 1.70 Revision 3, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants (LWR Edition)," November 1978.

12.4-2 USNRC Regulatory Guide 8.19 Revision 1, "Occupational Radiation Dose Assessment in Light-Water Reactor Power Plants Design Stage Man-Rem Estimates," June 1979.

## ~~12.4 DOSE ASSESSMENT~~

~~This section discusses the radiological dose assessment (person-Sievert) for the ESBWR facility. Subsections 12.4.1 through 12.4.5 discuss the various factors involved with dose assessment within the different plant radiation areas. The resulting annual radiation dose estimate is summarized in Table 12.4-1.~~

~~Dose assessment is a significant element in determining that the facility design and methods of operation ensure occupational radiological exposures are as low as reasonably achievable (ALARA). Dose assessment depends on estimates of occupancy, dose rates in various occupied areas, frequency of operations, and number of personnel participating in reactor operations and surveillance, routine maintenance, waste processing, refueling, in-service inspection and special (unscheduled) maintenance. Facility personnel include station and utility employees, as well as contract workers. The occupations for these personnel include maintenance, operations, health physics, supervision and engineering.~~

~~These dose estimates are based on operation with a 24-month fuel cycle.~~

~~To estimate the total annual radiological dose to personnel, five facility areas are specified, and the annual person-Sievert dose for each area/task is evaluated separately. These designations are listed in Table 12.4-1. Where job functions and expected radiation levels are predictable or clearly defined, analytical methods were employed for the person-Sievert estimates. The~~

~~resulting dose estimates for the ESBWR are contained in Table 12.4-1. Subsections 12.4.1 through 12.4.6 discuss the various factors involved in the evaluations and their related elements.~~

~~The analytical method used for the person-Sievert assessment is based on the product of the estimated occupancy time (i.e., person-hours per year) and the estimated average dose rate. Estimates of the occupancy time required for operations associated with equipment in facility radiation areas (e.g., maintenance, testing or surveillance time) are first determined. An applicable frequency of occurrence is also incorporated in the resulting annual occupancy time for each operation. Areas with insignificant radiation sources or occupancy are not included in the exposure estimate. Where radiation sources are present, a design maximum dose rate of 10 μSv/hr (1 mrem/hr) is assumed for Radiation Zone B areas and 50 μSv/hr (5 mrem/hr) for Radiation Zone C areas. Other estimated dose rates are based on either calculations or extrapolated from radiation levels reported at operating plants.~~

~~The primary purpose for dose assessment is to aid in reducing the radiological exposure associated with all phases of plant operation consistent with practical considerations for performing each task. To achieve this ALARA objective, the ESBWR design includes numerous significant design improvements to reduce occupational exposures from past BWR experience. For example, facility design improvements include the elimination of recirculation piping and valves, improved water chemistry and low cobalt alloys for the reactor cooling water boundary, a simplified Control Rod Drive (CRD) system, reduced equipment maintenance and improved access, increased use of live-load valve packing to mitigate stem leakage, overhaul handling and refueling devices, multiple main steam line plugs, improved MSIV seat grinding system and a reactor vessel stud tensioner. In assessing the collective occupational radiological dose, each potentially significant dose-causing activity was evaluated. The major activities are provided in Table 12.4-1. Examples of significant design improvements that affect dose assessment in different plant areas are discussed below.~~

### ~~12.4.1 Drywell Dose~~

~~For the ESBWR drywell, design simplicity is the key to reduced occupational doses. Reactor systems are simpler with more passive safety features. The recirculation piping and pumps have been eliminated and a steel cylindrical shield has been provided around the reactor vessel to reduce drywell radiation fields.~~

~~Significant dose-causing activities identified for the drywell primarily involve maintenance tasks. The drywell is inaccessible during full power operations. Testing, maintenance, and surveillance activities will be performed after shutdown.~~

~~Projected ESBWR annual radiation exposures are shown in Table 12.4-1.~~

~~The major drywell activities identified in Table 12.4-1 are:~~

- ~~Main Steam Isolation Valve (MSIV) Repair;~~
- ~~Safety Relief Valve (SRV) Work;~~
- ~~Fine Motion Control Rod Drive (FMCRD)/Automated Fixed In-Core Probe (AFIP) Work;~~
- ~~Local Power Range Monitor (LPRM) Work;~~
- ~~In-Service Inspection (ISI);~~

- ~~Misc. Valves; and~~
- ~~Misc. Instrumentation.~~

~~The Nuclear Boiler System (NBS) supplies steam to the main turbine. The MSIVs are located in the upper drywell area (4 valves) and in the reactor building outboard of the primary containment isolation wall (4 valves).~~

~~The ESBWR design incorporates three specific features to reduce occupational exposures in the MSIV maintenance areas:~~

- ~~Improved MSIV leakage rate test procedures;~~
- ~~Improved maintenance procedures with some procedures automated; and~~
- ~~Reduced radiation fields, primarily due to the absence of the recirculation piping.~~

~~The MSIVs require periodic testing and maintenance to ensure proper action and leak tightness. Maintenance operations incorporate an improved seat grinding system and other special tools. Overall maintenance is reduced by use of the MSIV overhauling devices, use of main steamline plugs and the improved MSIV grinding system. Use of these automatic systems results in an additional overall reduction in maintenance times of approximately 50%. This, along with improved drywell access, significantly reduces the maintenance time necessary for MSIV repair.~~

~~Beginning in the early 1980's, the BWR Owner's Group began an extensive study of the causes for failure of MSIVs to meet the leakage rate limits and the extensive person-hours required to maintain these valves. As a result of these studies, the ESBWR uses the improved leakage rate test procedures and latest technology for valve maintenance to reduce the personal exposures. As a result of these aids, there is an estimated overall maintenance person-hour reduction to the value shown in Table 12.4-1.~~

~~Early studies on dose rates during MSIV maintenance showed increases in dose rate directly proportional to recirculation line activity. The ESBWR does not have these recirculation lines, thus removing the most significant shutdown source of radiation in the drywell. Additionally, the ESBWR is designed to limit the use of cobalt bearing materials on moving components that have historically been identified as major sources of in-water contamination. Overall, the feedwater line radiation is expected to be a factor of two lower than current BWRs.~~

~~The estimated dose rate for SRV work is shown in Table 12.4-1. In the ESBWR, the primary source of radiation exposure, the recirculation lines, has been removed. Overall, the reduction in drywell dose level for these types of maintenance is shown in Table 12.4-1. Overhead tracks and in-place removal equipment is provided in the ESBWR to reduce dose rates for maintenance.~~

~~A design improvement for the Neutron Monitoring System (NMS) involves replacing the conventional Traversing In-core Probe (TIP) system with fixed in-core detectors (AFIP) for calibrating the Local Power Range Monitors (LPRMs). Eliminating the complex drive and indexer mechanism with associated controls, which are required to insert and withdraw the TIPs from the core region, substantially improves operability, maintainability and reduces occupational radiological exposures.~~

~~LPRM design has been improved and currently each monitor lasts up to seven years. The estimated annual time and dose rates are shown in Table 12.4-1.~~

~~The drywell design includes many features to accommodate in-service inspection (ISI). Some of these include the use of stand-off mirror type insulation around the reactor vessel, use of remote-operated mechanical devices for inspection of the RPV body and nozzle welds, removable pipe insulation, and provisions for additional ISI operations laydown space. The use of natural circulation simplifies the design within the drywell by eliminating the recirculating loops, pumps, pipe supports, hangers, and shock suppressors. This also results in reduced ISI maintenance and personnel exposures.~~

~~ISI primarily consists of NDE examination of vessel and piping systems and welds. Dose resulting from ESBWR ISI is estimated based on the following:~~

- ~~Elimination of recirculation lines and pumps with savings of annual time and dose.~~
  - ~~Elimination of 14 nozzle inspections at 2 per year;~~
  - ~~Elimination of shield penetration and shield plug removal; and~~
  - ~~Reduction in drywell dose by 50% with the provision that the feedwater line dose is more than half the recirculation line dose and general drywell dose level and therefore, removal of recirculation line inspection may reduce the general drywell dose rate by 50%.~~
- ~~Overall, it is estimated that by use of automated inspection, person-hour expended in ISI is reduced by a factor of two.~~
- ~~The total vessel weld length inspection is reduced and the total weld inspection is reduced from the inspection required for conventional BWRs; and~~
- ~~The ESBWR design incorporates specific access into inspection areas past insulation areas with additional reductions in annual time.~~

~~The overall person-hours and typical effective dose rate for the ESBWR are shown in Table 12.4-1.~~

~~Simplified systems result in a significant reduction in the total number of valves and instrumentation located in the drywell with an accompanying decrease in maintenance time. Valve design is also enhanced. For example, operation of the Gravity-Driven Cooling System (GDCS) requires reactor depressurization. This depressurization utilizes eight depressurization valves (DPVs) with four located on the steam pipes and four located on stub tubes off the RPV shared with the IC lines in the upper drywell. Squib valves were selected for the DPV function because they are simple, reliable, eliminate all leakage concerns and have low maintenance requirements. The DPVs are a non-leak, non-simmer, and non-maintenance design. They also simplify the Automatic Depressurization System (ADS) by reducing the total number of relief valve discharge lines and steam quenchers mounted in the suppression pool. The estimated annual time to perform maintenance on miscellaneous drywell valves is shown in Table 12.4-1. The estimated annual time to perform maintenance on miscellaneous drywell instrumentation is also shown in Table 12.4-1.~~

~~Improved materials of construction and design for the reactor core fuel reduces the probability of fuel failure, thus, fuel leakage is significantly limited. This results in a reduced source term throughout the facility's radiation areas. Dose reduction improvements also include improved water chemistry and the use of special materials for the reactor cooling water boundary. The~~

~~design employs materials and processes that prevent intergranular stress corrosion and corrosion cracking by adopting resistant materials, limiting sensitizing operations, incorporating heat treatment techniques and eliminating crevice conditions. In addition, a significant reduction in the drywell radiation levels result by restricting the cobalt content of selected vessel internals, using materials or cladding with corrosion resistance, and designing for erosive conditions.~~

~~Other drywell work includes items such as minor valve maintenance and instrumentation work. Overall reduction, in this effort, to the values shown in Table 12.4-1 is estimated due to the following ESBWR design improvements:~~

- ~~Significant savings in total hours are estimated due to removal of the recirculation lines with miscellaneous recirculation line work such as line snubbers, fewer drywell cooling units, and less assembly/disassembly work on insulation.~~
- ~~Overall reduction in the drywell radiation due to removal of the recirculation system results in the reduction of the overall upper drywell dose rate to the values shown in Table 12.4-1 because the components involved, such as drywell coolers, typically do not carry radioactive inventory.~~

### ~~12.4.2 Reactor Building Dose~~

~~The reactor building surrounds the Reinforced Concrete Containment Vessel (RCCV) and provides holdup and decay of radionuclides during an accident. It has been arranged to take advantage of the reduced quantity of equipment associated with the simpler reactor systems. The building arrangement features numerous dose-reducing benefits and improved equipment maintenance times. Equipment is more accessible which facilitates improved access control and maintenance. The building features enhanced accessibility on all floors. Equipment access is provided for all surveillance, maintenance and replacement activities with local service areas and laydown space for periodic inspections. Lifting points, monorails and other installed devices are provided to facilitate equipment handling and minimize the need for re-rigging individual equipment movements. Valve galleries are provided to minimize personnel exposure during system operation or preparation for maintenance.~~

~~Projected ESBWR annual radiation exposures are shown in Table 12.4-1.~~

~~The major reactor building activities identified in Table 12.4-1 are:~~

- ~~Reactor Pressure Vessel (RPV) Access/Reassembly~~
- ~~Refueling~~
- ~~Fine Motion Control Rod Drive (FMCRD) Work~~
- ~~Control Rod Drive Hydraulic Control Unit (CRD HCU) Work~~
- ~~Reactor Water Cleanup/Shutdown Cooling (RWCU/SDC) System~~
- ~~Instrumentation~~
- ~~Other~~

~~Refueling operations involves all work with fuel and reactor components performed above the reactor and in pool area. Reactor vessel access and reassembly exposure times are reduced by use of a special stud tensioner for the RPV head bolts. The projected time to remove the RPV~~

~~bolts with this equipment and reassemble, and average estimated exposures are shown in Table 12.4-1. Underwater transfer for the dryer and separator decreases exposures during refueling operations.~~

~~Refueling exposures are also decreased by use of an automated refueling platform. The improved fuel, inspection equipment and increased remote operations significantly reduce the refueling floor exposure. Also, fuel sipping is not required based upon the improved fuel design.~~

~~The RWCU/SDC purifies reactor coolant during normal operation and shutdown. Two 100% redundant trains are provided in the ESBWR design that uses state-of-the-art water treatment technology to significantly reduce the concentration of radionuclide material in the coolant. In addition, the material of construction for the system is stainless steel for those portions in contact with the reactor coolant. For system piping, smooth bends are used instead of welds and the nuclear grade pipes are electro-polished to reduce corrosion product buildup.~~

~~RWCU/SDC maintenance work consists of inspection for two pumps per year in each train. The ESBWR uses canned pumps in both trains with an estimated reduction in maintenance time to the values shown in Table 12.4-1. With improved water chemistry and overall reductions in reactor water concentrations due to the two percent cleanup system, the effective dose rate is estimated at the value shown in Table 12.4-1.~~

~~With significant reductions in instrumentation due to reduced emphasis on active safety systems in lieu of passive systems, and combining systems such as the FAPCS, or deleting systems such as the TIP system, instrumentation work is reduced. With these changes, combined with improvements in water chemistry systems, the anticipated ESBWR effective dose rate is as shown in Table 12.4-1.~~

~~Simplifying systems in the reactor building result in a significant reduction in the total number of valves and an accompanying decrease in maintenance time. This work includes all valve work, minor maintenance, and CRD hydraulic line work. Use of live-load valve packing to control stem leakage reduces maintenance and worker radiation exposure for valve repair. The major task in this area involves the Hydraulic Control Units. With the use of the FMCRD units, an additional reduction of maintenance is anticipated. In addition, the ESBWR reactor building has been designed to provide for ease of maintenance with overhead lifts, coordinated hatchways and ample space to maintain in-place equipment. In addition, most of the equipment in the reactor building is removable. Because of these factors, an additional reduction in work is anticipated, resulting in the final value shown in Table 12.4-1. Because of the improved water chemistry, the overall effective dose rate is anticipated at the reduced value shown in Table 12.4-1.~~

### ~~12.4.3 Fuel Building Dose~~

~~The Fuel building houses the Spent Fuel Pool and the FAPCS that purifies spent fuel pool water during normal operation and shutdown. Simplified systems result in a significant reduction in the total number of valves with an accompanying decrease in maintenance time.~~

~~ESBWR refueling is performed as described above and expected doses in the Fuel building during refueling are shown in Table 12.4-1.~~

### ~~12.4.4 Turbine Building Dose~~

~~The steam and power conversion system includes the turbine main steam system, the main turbine generator, main condenser, main condenser air removal system, turbine gland seal system, turbine bypass system, extraction steam system, condensate purification system, and the condensate and feedwater pumping and heating system. The heat rejected to the main condenser is removed by a circulating water system and discharged to the normal power heat sink.~~

~~Steam, generated in the reactor, is supplied to the high pressure turbine and the second stage reheater of the steam moisture separators/reheaters. Steam leaving the high pressure turbine passes through a combined moisture separator/reheater prior to entering the low pressure turbines. The moisture separator drains, steam reheater drains, and the drains from the two high pressure feedwater heaters are drained to the open feedwater heater which is combined with a feedwater storage tank. The reactor feedwater pumps take suction from the open feedwater heater storage tank. The low pressure feedwater heater drains are cascaded to the condenser.~~

~~Steam exhausted from the low pressure turbines is condensed and deaerated in the condenser. The condensate pumps take suction from the condenser hotwell and deliver the condensate through filters and demineralizers, gland steam condenser, steam jet air ejector condenser, off-gas recombiner condensers, and through the low pressure feedwater heaters to the open feedwater heater storage tank. The reactor feed pumps discharge through the high pressure feedwater heaters to the reactor.~~

~~Projected ESBWR annual radiation exposures are shown in Table 12.4-1.~~

~~The major turbine building activities identified in Table 12.4-1 are:~~

- ~~Turbine Overhaul~~
- ~~Valves/Pumps~~
- ~~Condensate Treatment~~
- ~~Other~~

~~With additional operational improvements in automating and a simpler overall system design, the expected overall turbine maintenance (overhaul) work is reduced to the value shown in Table 12.4-1.~~

~~The condensate system in the ESBWR uses hollow fiber filled filters that require approximately half the maintenance of typical systems, resulting in an estimated annual maintenance time shown in Table 12.4-1. The condenser tube material (with compatible tubesheet material) is corrosion resistant (titanium or stainless steel) which reduces leakage of corrosion products into the Condensate and Feedwater System. Low pressure feedwater drains from the feedwater heaters are cascaded back to the condenser; thus, all corrosion products from these drains are filtered via condensate filter/demineralizers before returning to the RPV. The overall effective dose rate is estimated at the value shown in Table 12.4-1.~~

### ~~12.4.5 Radwaste Building Dose~~

~~Radwaste Building work consists of pump and valve maintenance, shipment handling, radwaste management and general clean up activity. Radwaste building doses result from routine~~

~~surveillance, testing, and maintenance of the solid and liquid waste treatment equipment. The liquid treatment system collects liquid wastes from equipment drains, floor drains, filter backwashes and other sources within the facility. The solid treatment system processes resins, backwash slurries and sludge from the phase separator. It also processes dry active waste from the plant. Some examples of radwaste activities include movement of casks and liners, filter handling, resin moving and installation and removal of mobile radwaste processing skids. Both waste treatment systems are based on current mobile radwaste processing technology and avoid complex permanently installed components. All radwaste tankage and support systems are permanently installed. More of the radwaste operations involve remote handling than in a typical BWR. This, as well as improved maintenance procedures and a more flexible radwaste system and building design, leads to the estimated value shown in Table 12.4-1 for maintenance tasks in the Radwaste Building. The average dose rate shown in Table 12.4-1 is estimated for all operations.~~

### ~~12.4.6 Work at Power Doses~~

~~Routine work at power represents various tours of operators through the plant each shift, inspections and miscellaneous maintenance in radiation zones, as necessary. It covers all aspects of plant maintenance performed during normal operations from health physics coverage to surveillance, to minor equipment adjustment and repair. Overall, the ESBWR is designed using more automated and remote handling equipment. It is estimated there is a reduction in the total hours for work at power to the value shown in Table 12.4-1.~~

~~Exposure from these miscellaneous surveillance, testing and maintenance activities at power is due to N-16 as well as reactor coolant corrosion and fission products. Additional shielding is provided to reduce radiation levels in routinely occupied areas during power operation from N-16 sources. The ESBWR is expected to have lower general radiation levels as compared to the typical BWR due to more stringent water chemistry controls, a full cleanup condensate flow system, a 1% reactor water clean-up program, titanium condenser tubes, and low cobalt usage. The overall estimated effective dose for work at power is shown in Table 12.4-1.~~

### ~~12.4.7 COL Information~~

~~None.~~

### ~~12.4.8 References~~

~~None.~~

## Table 12.4-1

## Projected ESBWR Total Occupational Radiation Exposure Estimates Based on 24 Month Refueling Cycle

| Activity | Estimated Annual Time (person-hours) | Projected Annual Collective Dose person-Sv/year (man-rem/year) | Percent of Total |
|---|---|---|---|
| Reactor Operations and Surveillance (See Table 12.4-2) | 4923 | 0.101 (10.14) | 12.75 |
| Routine Inspection and Maintenance (See Table 12.4-3) | 8010 | 0.158 (15.81) | 19.89 |
| Waste Processing (See Table 12.4-4) | 4024 | 0.134 (13.40) | 16.84 |
| Refueling (See Table 12.4-5) | 3350 | 0.034 (3.40) | 4.28 |
| Inservice Inspection (See Table 12.4-6) | 766 | 0.033 (3.29) | 4.13 |
| Special Maintenance (See Table 12.4-7) | 22858 | 0.335 (33.48) | 42.11 |
| Total | 43931 | 0.795 (79.49) | 100% |

~~Table 12.4-1~~

~~Projected ESBWR Annual Radiation Exposure~~

| ~~Facility Area/Task~~ | ~~Estimated Annual Time, person-hour~~ | ~~Estimated Average Dose Rate, µSv/hr (mrem/hr)~~ | ~~Projected Annual Collective Dose, person-Sv (person-rem)~~ |
|---|---|---|---|
| ~~Drywell~~ | | | |
| ~~MSIV Repair~~ | ~~720~~ | ~~40 (4.0)~~ | ~~0.029 (2.9)~~ |
| ~~SRV Work~~ | ~~240~~ | ~~75 (7.5)~~ | ~~0.018 (1.8)~~ |
| ~~FMCRD/AFIP~~ | ~~405~~ | ~~80 (8.0)~~ | ~~0.032 (3.2)~~ |
| ~~LPRM Work~~ | ~~78~~ | ~~500 (50.0)~~ | ~~0.039 (3.9)~~ |

| ~~Facility Area/Task~~ | ~~Estimated Annual Time, person-hour~~ | ~~Estimated Average Dose Rate, μSv/hr (mrem/hr)~~ | ~~Projected Annual Collective Dose, person-Sv (person-rem)~~ |
|---|---|---|---|
| ~~ISI~~ | ~~720~~ | ~~55 (5.5)~~ | ~~0.040 (4.0)~~ |
| ~~Misc. Valves~~ | ~~600~~ | ~~40 (4.0)~~ | ~~0.024 (2.4)~~ |
| ~~Misc. Instrumentation~~ | ~~500~~ | ~~50 (5.0)~~ | ~~0.025 (2.5)~~ |
| ~~Reactor Building~~ | | | |
| ~~RPV Access/Reassembly~~ | ~~1,200~~ | ~~30 (3.0)~~ | ~~0.036 (3.6)~~ |
| ~~Refueling~~ | ~~250~~ | ~~5 (0.5)~~ | ~~0.001 (0.1)~~ |
| ~~CRD HCU~~ | ~~284~~ | ~~45 (4.5)~~ | ~~0.013 (1.3)~~ |
| ~~FMCRD~~ | ~~324~~ | ~~100 (10.0)~~ | ~~0.032 (3.2)~~ |
| ~~RWCU/SDC~~ | ~~200~~ | ~~40 (4.0)~~ | ~~0.008 (0.8)~~ |
| ~~Instrumentation~~ | ~~600~~ | ~~30 (3.0)~~ | ~~0.018 (1.8)~~ |
| ~~Other~~ | ~~3,400~~ | ~~18 (1.8)~~ | ~~0.061 (6.1)~~ |
| ~~Fuel Building~~ | | | |
| ~~Refueling~~ | ~~500~~ | ~~5 (0.5)~~ | ~~0.003 (0.3)~~ |
| ~~FAPCS~~ | ~~200~~ | ~~40 (4.0)~~ | ~~0.008 (0.8)~~ |
| ~~Turbine Building~~ | | | |
| ~~Turbine Overhaul~~ | ~~12,000~~ | ~~3 (0.3)~~ | ~~0.036 (3.6)~~ |
| ~~Valves/Pumps~~ | ~~910~~ | ~~39 (3.9)~~ | ~~0.035 (3.5)~~ |
| ~~Condensate Treatment~~ | ~~1,000~~ | ~~35 (3.5)~~ | ~~0.035 (3.5)~~ |
| ~~Other~~ | ~~6,000~~ | ~~1 (0.1)~~ | ~~0.006 (0.6)~~ |
| ~~Radwaste Building~~ | ~~1,000~~ | ~~25 (2.5)~~ | ~~0.025 (2.5)~~ |
| ~~Miscellaneous Work at Power~~ | ~~2,000~~ | ~~40 (4.0)~~ | ~~0.080 (8.0)~~ |
| | | | |
| ~~Total~~ | ~~33,131~~ | | ~~0.604 (60.4 person-rem)~~ |

## Table 12.4-2

## Occupational Dose Estimates During Operation and Surveillances

| Facility Area/Task/Activity | Estimated Average Dose Rate, (µSv/hr) | Estimated Annual Time (person-hours) | Projected Annual Collective Dose, person-Sv (man-rem) |
|---|---|---|---|
| **Primary Containment** | | | |
| None | - | - | - |
| **Reactor Building** | - | - | - |
| Routine Operator, Chem and HP Surveillances | 8 | 2190 | 0.0175 (1.75) |
| CRD/HCU Surveillance | 150 | 73 | 0.011 (1.1) |
| RWCU/SDC Surveillance | 150 | 73 | 0.011 (1.1) |
| Passive Systems Surveillance | 30 | 183 | 0.0055 (.0.55) |
| I&C Surveillance/Testing | 8 | 183 | 0.0015 (0.15) |
| Outside Steam Tunnel | 30 | 183 | 0.0055 (0.55) |
| Nonroutine Spill Clean-up | 30 | 96 | 0.0029 (0.29) |
| **Fuel Building** | - | - | - |
| Routine Surveillances | 8 | 365 | 0.0029 (0.29) |
| General Fuel Related Activities - Fuel Receipt/Processing/ Channeling | 8 | 365 | 0.0029 (0.29) |
| FAPCS Surveillances | 150 | 37 | 0.0056 (0.56) |
| Nonroutine Fuel Sipping | 30 | 80 | 0.0024 (0.24) |
| **Radwaste Building** | - | - | - |
| See Table 12.4-4 Waste Processing | - | - | - |
| **Turbine Building** | - | - | - |
| Routine Operator and HP Surveillances Through Accessible Areas. | 30 | 1095 | 0.0329 (3.29) |
| | | | |
| **Total** | | 4923 | 0.1014 (10.14) |

**Table 12.4-3**

**Occupational Dose Estimates During Routine Maintenance**

| Facility Area/Task/Activity | Estimated Average Dose Rate, (µSv/hr) | Estimated Annual Time (person-hours) | Projected Annual Collective Dose, person-Sv (man-rem) |
|---|---|---|---|
| **Primary Containment** | - | - | - |
| None | - | - | - |
| **Reactor Building** | - | - | - |
| RWCU/SDC Pumps/Motors | 150 | 150 | 0.0225 (2.25) |
| RWCU/SDC Valves | 150 | 100 | 0.015 (1.5) |
| CRD HCU | 30 | 100 | 0.003 (0.3) |
| Passive Systems (IC, GDCS, PCCS) Valves | 30 | 100 | 0.003 (0.3) |
| Passive System Pools | 30 | 100 | 0.003 (0.3) |
| Instrumentation | 30 | 300 | 0.009 (0.9) |
| **Fuel Building** | - | - | - |
| FAPCS Filter/Demin | 150 | 60 | 0.009 (0.90) |
| FAPCS Pumps/Motors | 30 | 60 | 0.0024 (0.24) |
| FAPCS Valves | 30 | 80 | 0.0024 (0.24) |
| Fuel Pools, Racks, Casks | 30 | 250 | 0.0075 (0.75) |
| **Radwaste Building** | - | - | - |
| RW Reverse Osmosis | 150 | 150 | 0.0225 (2.25) |
| RW Demins | 150 | 80 | 0.0120 (1.20) |
| RW Tanks | 150 | 225 | 0.0338 (3.38) |
| RW Pumps | 30 | 40 | 0.0012 (0.12) |
| RW Valves | 30 | 70 | 0.0021 (0.21) |
| RW Instrumentation | 30 | 125 | 0.0038 (0.38) |
| **Turbine Building** | - | - | - |
| Miscellaneous Turbine Building Work in Accessible Areas at Power | 1 | 6000 | 0.006 (0.60) |
| | | | |
| **Total** | | 8010 | 0.1581 (15.81) |

**Table 12.4-4**

**Occupational Dose Estimates During Waste Processing**

| Facility Area/Task/Activity | Estimated Average Dose Rate, (µSv/hr) | Estimated Annual Time (person-hours) | Projected Annual Collective Dose, person-Sv (man-rem) |
|---|---|---|---|
| **Radwaste Building** | | | |
| Control Room Operation of LWMS/SWMS | 8 | 2080 | 0.0166 (1.66) |
| DAW Processing/Packaging | 50 | 624 | 0.0312 (3.12) |
| Radwaste (HIC) Processing/ Shipments | 50 | 832 | 0.0416 (4.16) |
| DAW Shipments | 50 | 288 | 0.0144 (1.44) |
| Miscellaneous High Dose Rate Activities | 150 | 200 | 0.03 (3.00) |
| | | | |
| **Total** | | 4024 | 0.134 (13.4) |

**Table 12.4-5**

**Occupational Dose Estimates During Refueling**

| Facility Area/Task/Activity | Estimated Average Dose Rate, (µSv/hr) | Estimated Annual Time (person-hours) | Projected Annual Collective Dose, person-Sv (man-rem) |
|---|---|---|---|
| **Reactor Building** | | | |
| Drywell access RPV Disassembly/ Reassembly | 30 | 600 | 0.018 (1.8) |
| Refueling (Fuel assembly /component transfer to buffer pool/core shuffle) | 8 | 250 | 0.002 (0.2) |
| **Fuel Building** | | | |
| Refueling (Fuel assembly transfer to spent fuel pool) | 8 | 500 | 0.004 (0.4) |
| Fuel transfer to Independent Fuel Storage Facility(if utilized) | 5 | 2000 | 0.01 (1.0) |
| | | | |
| Total | | 3350 | 0.034 (3.4) |

## Table 12.4-6

## Occupational Dose Estimates During Inservice Inspection

| Facility Area/Task/Activity | Estimated Average Dose Rate, (μSv/hr) | Estimated Annual Time (person-hours) | Projected Annual Collective Dose, person-Sv (man-rem) |
|---|---|---|---|
| **Primary Containment** | | | |
| General Activities | 60 | 100 | 0.006 (0.60) |
| RPV Welds/Nozzles | 60 | 100 | 0.006 (0.60) |
| Main Steam piping/valves | 60 | 25 | 0.0015 (0.15) |
| Feedwater piping/valves | 60 | 30 | 0.0018 (0.18) |
| RWCU/SDC piping/valves | 60 | 12 | 0.0007 (0.07) |
| SLC piping/valves | 60 | 12 | 0.0007 (0.07) |
| Other Equipment | 60 | 50 | 0.0030 (0.30) |
| **Reactor Building** | | | |
| General Activities | 30 | 300 | 0.0090 (0.90) |
| RWCU/SDC | 30 | 75 | 0.0023 (0.23) |
| CRD | 30 | 12 | 0.0004 (0.04) |
| Other Equipment (Passive Systems) | 30 | 50 | 0.0015 (0.15) |
| | | | |
| **Total** | | 766 | 0.0329 (3.29) |

**Table 12.4-7**

**Occupational Dose Estimates During Special Maintenance**

| Facility Area/Task/Activity | Estimated Average Dose Rate, (µSv/hr) | Estimated Annual Time (person-hours) | Projected Annual Collective Dose, person-Sv (man-rem) |
|---|---|---|---|
| **Primary Containment** | - | - | - |
| MSIV Rework | 18 | 800 | 0.0144 (1.44) |
| SV and SRV Maint | 60 | 100 | 0.0060 (0.60) |
| FMCRD Undervessel | 65 | 204 | 0.0133 (1.33) |
| LPRM/AFIP | 100 | 24 | 0.0024 (0.24) |
| Miscellaneous Valves | 40 | 750 | 0.0300 (3.00) |
| Miscellaneous Instrumentation | 50 | 500 | 0.025 (2.50) |
| Other Drywell Outage Maintenance Including Passive Systems | 50 | 650 | 0.0325 (3.25) |
| **Reactor Building** | - | - | - - |
| MSIV Rework | 13 | 1300 | 0.0169 (1.69) |
| RWCU/SDC Pumps/Motors | 150 | 200 | 0.03 (3.00) |
| CRD HCU | 30 | 300 | 0.0090 (0.90) |
| FMCRD Rebuild | 30 | 120 | 0.0036 (0.36) |
| Instrumentation | 30 | 600 | 0.018 (1.80) |
| Other RB Outage Maintenance Including Passive Systems | 8 | 3400 | 0.0272 (2.72) |
| **Turbine Building** | | | |
| Major Turbine Overhaul | 3 | 12000 | 0.036 (3.60) |
| Condensate Treatment | 35 | 1000 | 0.0350 (3.50) |
| Turbine Valves/Pumps | 39 | 910 | 0.0355 (3.55) |
| | | | |
| **Total** | | 22858 | 0.3348 (33.475) |