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Non-Proprietary Information

BWRX-300 Darlington New Nuclear Project (DNNP) Occupational Dose Assessment Report

INFORMATION NOTICE

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1	All	Initial Issue as Non-Proprietary Version

1.0 INTRODUCTION

1.1 Purpose

The purpose of this report is to establish a projected BWRX-300 annual collective occupational dose estimate for the normal operation of a GE-Hitachi Nuclear Energy Americas, LLC (GEH) BWRX-300. The report supports the Licence to Construct (LTC) application submitted by Ontario Power Generation (OPG) for the BWRX-300 Darlington New Nuclear Project (DNNP). The collective effective worker doses reported here represent the sum of individual effective doses received by plant workers while maintaining the facility in normal conditions.

1.2 Scope

This collective worker dose tabulation is based on task specific person-hour estimates of previous studies using BWR operating data, plant maintenance records, exposure measurements, and prior dose estimates supporting other GEH Boiling Water Reactor (BWR) designs.

The collective worker dose reported here is a high confidence upper boundary estimate of the worker doses expected based on the current conceptual design and future design iterations are expected to establish a basis to reduce the estimate. This report is preliminary and can be updated as the final design is developed, and numeric values presented are developmental and unconfirmed.

Doses from postulated Anticipated Operational Occurrences (AOO), Design Basis Accidents (DBA), and potential releases into the environment for Design Extension Conditions (DEC) are determined for members of the public and are not within the scope of this analysis.

Additionally, the scope of this analysis does not include individual effective and individual equivalent doses because the necessary staffing levels for various work activities have not been established during this conceptual stage of the BWRX-300 design development. An estimate of the effective and equivalent doses to individuals can be made using these results when staffing levels are established.

1.3 Regulatory Compliance

This analysis is developed to support the BWRX-300 standard plant design which is subject to regulatory review in multiple countries and regions. However, this analysis addresses Canadian Nuclear Safety Commission (CNSC) regulations to support the LTC application submitted by OPG for the BWRX-300 DNNP.

SOR/2000-203, Radiation Protection Regulations establishes effective dose limits for nuclear energy workers in Canada but does not specify requirements for collective worker doses (Reference 5-1). Methods for demonstrating compliance with the SOR/2000-203 are described in CNSC REGDOC-2.7.1 and REGDOC-2.7.2 (References 5-2 and 5-3) which include direct monitoring, indirect monitoring, and dose modelling. Since there are no workers to monitor in the design phase of the project, and information needed for rigorous predictions is still in development, the collective dose estimate provided in this analysis does not demonstrate compliance with SOR/2000-203.

CNSC Guide G-129 (superseded by REGDOC-2.7.1) does cite the following dose criteria that if exceeded would require ALARA assessment beyond an initial analysis (Reference 5-4):

1. Individual occupational doses are unlikely to exceed 1 mSv per year.
2. Dose to individual member of the public is unlikely to exceed 50 μSv per year.
3. The annual collective dose (both occupational and public) is unlikely to exceed 1 person-Sv per year.

As noted earlier, individual worker doses can only be determined when staffing levels are established, so this analysis does not demonstrate the first criterion is met. Additionally, this analysis provides no indication of doses to members of the public due to normal operation of the facility, so this analysis also does not provide any indication that the second criterion is met. However, with regard to the third dose criterion, this analysis does demonstrate that annual collective occupational dose at an operating BWRX-300 ([[ ]] person-Sv/year per Table 3-1) is less than 1 person-Sv/year so the results of this analysis do indicate further ALARA assessments for annual collective worker doses are not needed. The results of this analysis provide no indication with regard to annual collective doses to the public which is an evaluation that is part of the site environmental impact assessment.

Additionally, CNSC REGDOC-2.5.2 Section 6.4 does establish additional analysis requirements for meeting Canadian radiation protection acceptance criteria, and one of those requirements is to provide an estimated annual collective dose to site personnel (Reference 5-5).

REGDOC-2.5.2 Section 6.4 also indicates worker dose assessments should include major facility functions, including radioactive waste handling, normal maintenance, special maintenance, refueling and in-service inspection. Those categories of worker tasks are included in the results reported in Section 3.0.

However, it is noted that the other assessments required by REGDOC-2.5.2 Section 6.4 are well beyond the scope of this analysis because they include doses to the public for AOOs and DBAs, potential releases into the environment for DECs, and individual effective and equivalent radiation doses to site personnel.

2.0 DOSE ASSESSMENT

The estimated annual occupational radiation exposures are categorized into six collective occupational dose assessment categories:

1. Radioactive Waste Handling
2. Normal Maintenance
3. Special Maintenance
4. Refueling
5. In-Service Inspection (ISI)
6. Operation and Surveillances

The occupational dose assessment is a significant element in supporting the facility design and methods of operation to ensure occupational radiation 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 radioactive waste handling, normal maintenance, special (unscheduled) maintenance, refueling, ISI, and operation and surveillances.

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 license applicant or licensee will make that determination 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 radiation dose to personnel, dose rate estimates (in units of μSv/h) for the performance of duties in the assessment categories are developed using a variety of available methods including BWRX-300 radiation zoning levels, available technical reports and experiential data based on previous and current BWR plant designs and operational information. Person-hours expended annually in performance of the various tasks are estimated in a similar manner. The person-hours per year defined within this assessment are the estimated person-hours spent in a significant (≥ 1 μSv/hour) radiation zone annually and should not be compared with overall person-hours required for the normal operational activities of a nuclear power plant which include work activities performed in non-radiation areas.

In this occupational dose assessment, there is no separate determination of doses due to airborne activity. Airborne radiation in the BWRX-300 is controlled to negligible levels during normal operation of the facility [[ ]], so the dose from airborne activity is not a significant contributor to the total collective dose. As such, the estimated collective doses in this evaluation represent the result of Deep Dose Equivalent exposures only; no inhalation or airborne dose contributions are assumed.

The BWRX-300 Reactor Building (RB) and containment vessel are constructed using an advanced steel-plate/concrete composite system [[ ]]. For this analysis, the RB and containment are treated as traditional BWRs constructed with nuclear grade concrete, and it is [[ ]]. This assumption reflects current expectations but will require further validation.

2.1 Methods and Assumptions

This analysis calculates task specific doses for workers performing activities in areas of the facility with significant radiation fields or sources (Table 3-2 through Table 3-7) and sums those task specific doses to determine the total annual collective occupational dose estimate for normal operation of the plant (Table 3-1). The task specific collective doses are calculated as the product of (a) the estimated effective dose rates where the activities are performed multiplied by (b) the collective person-hours/year estimates required to complete them.

The task specific collective occupational dose estimates in this analysis are based on BWR operating/technical data [[ ]], occupational exposure estimates established for prior GEH BWR designs [[ ]], and the median dose rate in the radiation zones currently established for the BWRX-300 [[ ]]. The technical bases employed for this estimate represent insights gained over several evolutions of BWR technology.

The major differences between the BWRX-300 design and the BWR designs supplying the information that comprises the technical bases for this assessment are the size of the reactor, the plant system configuration, and the plant arrangement. Therefore, the estimate provided at this stage of design development only credits reductions from prior occupational dose estimates based on the differing BWRX-300 size, systems, and plant arrangement. Credit for reduced staffing, classification of components, surveillance/inspection requirements, and other design features can be applied when they are established in the design which is expected to further reduce the collective occupational dose estimate reported in Table 3-1.

2.1.1 Task Dose Rates

In general, the dose rates applied in this analysis are unchanged from the established operating data or prior reactor design estimate bases since BWRX-300 specific dose rate calculations have not been performed at this stage of design development. This is an adequately conservative approach for this stage of design development since the established dose rates are based on operational data from large operating BWRs that aren't equipped with the safety features integrated into the BWRX-300 design [[ ]]. As the BWRX-300 design progresses, the dose rates are reevaluated with additional considerations for safety features and design differences from Economic Simplified Boiling Water Reactor (ESBWR).

In cases where dose rates were increased or decreased from their prior estimates the adjustment is made to account for the differing BWRX-300 plant arrangement. [[

]]

2.1.2 Task Person-Hour Estimates

Task specific person-hour/year estimates used in this analysis are also made by extrapolating data [[ ]] to account for the differing BWRX-300 size, systems, and plant arrangement.

[[

]]. Another example is the prior person-hours/year estimates for surveillance of the Fine Motion Control Rod Drive (FMCRD) Hydraulic Control Units (HCUs) [[

]]. Therefore, those person-hours/year estimates are [[ ]]. These adjustments are validated [[

]].

2.2 Collective Worker Doses by Category

2.2.1 Radioactive Waste Handling

Radioactive waste is processed by the BWRX-300 Liquid Waste Management System (LWM) and the Solid Waste Management System (SWM) which are located in the RWB. The LWM is designed to segregate, collect, store, and process radioactive liquids generated during operation. The SWM 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 skid mounted process systems that are remotely operated from a central RWB control panel. The radioactivity removed from the liquid waste is concentrated in filter media, ion exchange resins, and in other forms. The LWM and SWM process equipment that accumulate radiation sources from filtering process streams are remotely operated, including the backwashing operations. These concentrated waste forms are sent to the SWM for further processing. The output of the radwaste processing systems generally consists of Dry Active Waste (DAW), wet solid waste in High Integrity Containers (HICs), and mixed wastes, which are both radiologically and chemically contaminated.

[[

]].

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

The estimated annual collective doses associated with radioactive waste handling operations appear in Table 3-2.

2.2.2 Normal Maintenance

Normal (routine) inspection and maintenance activities are required for mechanical and electrical components throughout the operation of a power plant. In the BWRX-300, [[

]]. The BWRX-300 RB has been designed for ease of maintenance with [[
]] and adequate space to maintain equipment in-place.

Shutdown Cooling System (SDC) [[
]]. The Fuel Pool Cooling and Cleanup System (FPC) uses a similar design philosophy for its components. The FPC will require normal maintenance of the filter/demineralizers, pumps and motors, and system valves. The Reactor Water Cleanup System (CUW) consists of one train fed by two inlet nozzles located in the Reactor Pressure Vessel (RPV). Although it is assumed that some maintenance may be conducted during normal operation, certain portions of the SDC, FPC, and CUW may require additional maintenance during refueling outages. Piping in these systems have butt-welded connections, rather than socket welds, to reduce crud traps. Features to

prevent flow discontinuities that can lead to retention of corrosion products (crud traps) in equipment and components are incorporated into the design. Bends, branches, corners, dead legs, and low points are avoided in piping and piping layout. Mitigating engineering features are added where avoidance is not possible. These piping and valve design features reflect implementation of ALARA guidance, and simplification of these systems results in a significant reduction in the total number of valves and instrumentation with an accompanying decrease in maintenance time.

The TB houses the steam turbine generator, standby diesel generators, main condenser, condensate and feedwater systems, turbine-generator support systems, and parts of the Offgas System (OGS) excluding the offgas charcoal adsorbers. Due to the high radiation from N-16 in reactor steam, the major steam containing equipment in the TB is segregated into a shielded area and maintenance on those systems is performed when the plant is in shutdown. Maintenance on supporting systems can be performed if there exists a sufficient decay period for the N-16 (> 2 minutes). Miscellaneous routine maintenance tasks in the TB includes surveillance, testing, process sampling, health physics surveys, patrols and inspections, routine shift tours, and work assignments in radiation fields.

For normal maintenance in the RWB, the BWRX-300 design implements the use of skid-mounted process systems for radwaste processing, thereby reducing the maintenance requirements to the permanently installed systems. The RWB normal maintenance activities in Table 3-1 accounts for the radwaste processing systems and the offgas charcoal adsorbers.

Table 3-1 provides a breakdown of the collective doses associated with overall normal maintenance activities.

2.2.3 Special Maintenance

Maintenance that goes beyond routine scheduled maintenance or cannot be performed without significant expenditure of resources in non-negligible radiation fields is considered special maintenance. In addition to maintenance, this category includes both the modification of equipment to replace and/or repair components. The special maintenance activities are a large contributor to the collective dose due to the work being large-scale efforts to fix components during this phase. The primary special maintenance areas are described below.

2.2.3.1 Primary Containment

The Nuclear Boiler System (NBS) generates and delivers steam to the turbine for safe power generation. The system is comprised of three primary subsystems, the RPV, MS, and NBS instrumentation.

The BWRX-300 design has two MS lines that run from the RPV to the TB through the steam tunnel, [[ ]]. Each MS line includes two inline MS Isolation Valves (MSIVs) attached directly to the RPV (four valves total) and a valve outboard of the primary containment isolation wall in the RB steam tunnel (two valves total). [[ ]]. There are no recirculation pumps and associated piping in the BWRX-300 design, [[ ]], and the NBS system does not utilize safety or relief valves.

The primary containment systems considered in this category include:

- MSIVs;
- FMCRDs;
- Local Power Range Monitors (LPRMs)/Gamma Thermometers (GTs);
- Miscellaneous pumps and valves;

- Miscellaneous instrumentation; and
- Other containment systems including passive systems.

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

The BWRX-300 design incorporates three specific features to reduce occupational exposures in the MSIV maintenance areas in the containment and RB:

- Improved MSIV leakage rate test procedures;
- Improved maintenance procedures with some procedures automated;
- Improved reliability of the MSIVs attached to the RPV; and
- Reduced radiation fields, due to state-of-the-art water chemistry control and the absence of recirculation piping.

Maintenance is reduced by [[ ]]. Use of these [[ ]] results in an additional overall reduction in maintenance times compared to conventional BWRs. This, along with improved containment access, significantly reduces the maintenance time necessary for [[ ]]. The BWRX-300 does not have recirculation lines, [[

]].

Control rod drive maintenance is significantly reduced in the BWRX-300, as compared to hydraulic systems used in most BWRs, with the utilization of FMCRDs. [[

]].

In containment, BWRX-300 nuclear instrumentation consists of the Power Range Neutron Monitoring System (PRNM), LPRMs, and GTs. GTs are in-core devices that convert local gamma flux to an electrical signal that supplies information required to calibrate the LPRMs in the PRNM. Maintenance requirements for the LPRMs and GTs have not been established at this stage of design. Therefore, this analysis conservatively applies the dose rate and annual person-hour per year task estimates from Reference 5-12 which is for a large BWR with more neutron monitoring system components that would require inspection. [[ ]]. Further reductions in these assumptions can be applied when supporting design information related to special maintenance is established for the LPRMs and GTs in containment.

The elimination of active systems such as High-Pressure Coolant Injection (HPCI), Low Pressure Coolant Injection (LPCI), Reactor Core Isolation Cooling (RCIC), and Residual Heat Removal (RHR) currently employed in operating BWRs, and replacement of those systems with passive systems that use relatively few valves and no pumps, [[

]].

The remaining containment maintenance activities such as passive safety system maintenance, scaffolding erection and dismantling, and snubber inspection/replacement [[ ]].

2.2.3.2 Reactor Building

The RB surrounding containment houses containment support systems and is arranged to take advantage of the reduced quantity of equipment associated with the BWRX-300 systems. The building arrangement features numerous dose-reducing benefits and improved equipment maintenance durations to assist in keeping doses to workers ALARA. Equipment is more accessible which facilitates improved access control and maintenance. Equipment access is provided for all surveillance, maintenance and replacement activities with local service areas and laydown space for periodic inspections. Lifting points, cranes 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 RB include:

- MSIV rework;
- SDC Pumps and Motors;
- FMCRD rebuild;
- FMCRD HCU work;
- Instrumentation maintenance;
- Condensate Filters and Demineralizers System (CFD) maintenance; and
- Miscellaneous RB outage maintenance (including passive systems).

As in containment, MSIV related exposure in the RB comes from maintenance, rework, and testing of the MSIVs during the plant refueling shutdown. [[ ]].

In addition to maintenance during normal operation, some of the FMCRD HCUs or the associated piping may require service or rebuilding during an outage. [[ ]].

In the BWRX-300, there is a single CFD train [[ ]].

Additional RB outage maintenance items such as passive system maintenance, minor valve, pump, or other equipment maintenance [[ ]].

2.2.3.3 Turbine Building

The TB houses the steam turbine generator, main condenser, CUW, turbine-generator support systems, and the OGS excluding the offgas charcoal adsorbers which are in the RWB. 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 shut down for refueling. The major activities involving maintenance on TB components associated with non-negligible radiation fields are:

- Turbine Overhaul; and
- Valves/Pumps Maintenance.

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 a redesigned OGS as compared to a conventional BWR, [[

]].

The valve and pump maintenance requirements for the BWRX-300 do not vary significantly from current plants, although the smaller turbine and generator systems may require slightly less work. As such, the total hours for this type of work are 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. [[

]].

Table 3-4 provides the estimated doses due to special maintenance operations.

2.2.4 Refueling

In the BWRX-300, refueling operations are conducted from the fuel handling area operating deck in the RB [[ ]]. The RB houses the equipment pool, fuel pool, reactor cavity pool, and the Refueling and Servicing Equipment System (RES).

The RES provides the necessary equipment and facilities for receipt, storage, and installation of new fuel assemblies, as well as removal and storage of spent fuel assemblies. The RES system also provides equipment and facilities for disassembly and re-assembly of the reactor, as it pertains to refueling and servicing outage activities. Replacement of control rods, control rod drives, nuclear instrumentation, and other reactor internals is facilitated by the RES. The RES includes a refueling platform, fuel preparation machines, and various additional equipment used for the receipt of new fuel assemblies.

The refueling platform is a rigid structure built to ensure accurate and repeatable positioning during the refueling process. The telescoping mast and grapple are suspended from a trolley system and are used to lift and orient fuel bundles for placement in the core or storage in the fuel pool storage racks. Storage racks are provided in the RB fuel pool for the temporary and long-term storage of new and spent fuel assemblies and associated equipment. The fuel pool is equipped with new and spent fuel pool racks designed to maintain a subcriticality of at least 5% $\Delta k/k$, and the rack arrangement prevents accidental insertion of fuel assemblies between racks.

Space is provided for new 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 refueling platform. New fuel is channeled and stored wet in in the RB fuel pool in the new fuel racks.

During the refueling outage, new fuel assemblies are placed in the reactor core using the refueling machine, the core is shuffled, and spent fuel removed to the RB fuel pool where it is stored. Transfer of channeled new fuel and spent fuel assemblies is conducted underwater which provides adequate radiation shielding for workers on or adjacent to the fuel handling area operating deck. The fuel handling equipment has provisions to limit maximum fuel assembly lift height to maintain sufficient water inventory above the top of the fuel assemblies.

At this time, control rods or other in-core components may be replaced. Spent fuel assemblies removed from the core are transferred through the spent fuel racks. The RES also facilitates the transfer of spent fuel assemblies into casks for possible storage at an independent spent fuel storage installation.

Prior to commencing refueling operations, the containment closure and reactor vessel heads are disassembled and removed. Reactor vessel access and reassembly exposure times are reduced [[ ]]. Underwater transfer of the [[ ]] decreases exposures during refueling operations. The improved fuel inspection equipment and increased use of remote operations significantly reduce the refueling floor exposure. [[ ]]

Fuel handling in the refueling and maintenance outage is divided into two phases. Phase I removes the fuel from the core for in-vessel maintenance and inspections. The Phase II fuel handling reloads the in-vessel maintenance fuel offload, loads new fuel assemblies, and shuffling of fuel assemblies in the core to complete the refueling and maintenance outage fuel transfer. BWRX-300 fuel transfers are accomplished by workers on the refueling platform. [[ ]].

The annual collective doses associated with refueling operations are reported in Table 3-5.

2.2.5 In-Service Inspection

ISI requirements for the BWRX-300 facility are still being established at this stage of design, and are dependent, in part, on how plant systems and components are classified. Therefore, this category of worker doses is estimated based on the assumption that, similar to operating BWRs, extensive inspections of the RPV, reactor coolant pressure boundary, containment penetrations, pressure-retaining components, core support components, and internal components will require ISI. Additionally, all welds associated with the reactor coolant pressure boundary and valves are also assumed to be subject to ISI.

In addition to the RPV, portions of the MS, feedwater, Boron Injection System (BIS), CUW, SDC, ICS, and other passive systems are inspected. The inspections, generally performed during refueling outages, usually consist of pressure tests (leakage or hydrotest), visual inspections, and non-destructive examinations. The methods used in the tests and inspections include ultrasonic, visual, surface, eddy current or radiographic testing, and other nondestructive examination methods.

The containment design includes personnel airlocks, equipment hatches, and other design features to facilitate ISI. Additional improvements include the use of [[ ]] remote-operated mechanical devices for inspection of the RPV body and nozzle welds, [[ ]], and provisions for additional ISI laydown space. The use of natural circulation simplifies the design within the containment by eliminating the recirculating loops, pumps, pipe supports, hangers, and shock suppressors. Due to the elimination of active safety systems such as HPCI, LPCI, RCIC, and RHR, the required inspection of attached piping and valve systems [[ ]]. Due to the smaller vessel used in the BWRX-300, the total vessel weld length inspection [[ ]]. Modern robotic methods used for vessel ISI such as automated inspection equipment for inspection should result in lowered effective dose rates for the inspection activities.

[[ ]].

Based on an extrapolation of estimates performed for conventional BWRs, the ISI collective occupational dose estimates associated with the BWRX-300 are shown in Table 3-6.

2.2.6 Operation and Surveillances

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 and 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 are considered in this category. Because the containment is inaccessible during full power operations, testing and surveillance activities in containment are performed after a shutdown or during a refueling outage. Some non-routine tasks such as fuel sipping or cleanup of spills are not generally planned but require performance for continued optimal plant operations and maintenance of an effective ALARA program. Sipping techniques are widely used to identify failed fuel assemblies by detection of radioactive fission gases released through cladding breaches.

Some examples of routine operation and surveillance activities include:

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

These activities may be conducted in the RB, RWB or TB. 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 the CFD, SDC, and ICS, and elimination of systems such as [[ ]] result 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 BWRX-300 is expected to have reduced general radiation levels during operation compared to the typical BWR due to more stringent water chemistry controls, state-of-the-art reactor water cleanup capacity, titanium or stainless-steel condenser tubing, and the use of low-cobalt materials.

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 BWRX-300. Person-hour estimates of activities performed in this category, the associated dose rates, and the collective dose from these activities are shown in Table 3-7.

3.0 RESULTS

3.1 Projected BWRX-300 Annual Collective Occupational Dose Estimates

[[

]]. The projected BWRX-300 annual collective occupational dose estimates for the six dose assessment work categories at this preliminary stage of conceptual design are reported in the following tables:

- Table 3-2: Collective Occupational Dose Estimate from Radioactive Waste Handling
- Table 3-3: Collective Occupational Dose Estimate from Normal Maintenance
- Table 3-4: Collective Occupational Dose Estimate from Special Maintenance
- Table 3-5: Collective Occupational Dose Estimate from Refueling
- Table 3-6: Collective Occupational Dose Estimate from In-Service Inspection
- Table 3-7: Collective Occupational Dose Estimate from Operation and Surveillances

Table 3-1: BWRX-300 Total Collective Occupational Dose Estimate

Activity	Estimated Collective Hours Annually (person-hours/year)	Projected Annual Collective Dose (person-mSv/year)	Percent of Total Collective Dose (%)
Radioactive Waste Handling	[[		
Normal Maintenance			
Special Maintenance			
Refueling			
In-Service Inspection			
Operation and Surveillances			
Totals			]]

Table 3-2: Collective Occupational Dose Estimate from Radioactive Waste Handling

Facility Area/Activity	Estimated Average Dose Rate (μSv/hour)	Estimated Time (person-hours/year)	Collective Dose (person-mSv/year)
Radwaste Building			
LWM/SWM, and Lab Operation	[[		
DAW Sorting/Processing			
HIC Processing/Shipments			
DAW Shipments			
Miscellaneous Activities[1]			
Totals			]]

(1) [[

]].

Table 3-1: Collective Occupational Dose Estimate from Normal Maintenance

Facility Area/Activity	Estimated Average Dose Rate (µSv/hour)	Estimated Time (person-hours/year)	Collective Dose (person-mSv/year)
Reactor Building -General Maintenance			
SDC Pipes/Valves	[[		
SDC Pumps/Motors			
FMCRD HCUs			
Passive System Valves (ICS)			
Passive System Pools (ICS)			
Instrumentation			
FPC Filters/Demineralizers			
FPC Pumps/Motors			
FPC Valves			
Fuel Pool, Fuel Racks, Fuel Casks			]]
Radwaste Building General Maintenance			
Reverse Osmosis	[[		
Demineralizers			
Tanks			
Pumps			
Valves			
Instrumentation			]]
Turbine Building - General Maintenance			
CUW Heat Exchanger/Pipes/Valves	[[		
Miscellaneous TB Work in Accessible Areas			
Totals			]]

Table 3-4: Collective Occupational Dose Estimate from Special Maintenance

Facility Area/Activity	Estimated Average Dose Rate (μSv/hour)	Estimated Time (person-hours/year)	Collective Dose (person-mSv/year)
Primary Containment			
MSIV Rework	[[		
FMCRD Under Vessel			
LPRMs/GTs			
Miscellaneous Valves & Pumps			
Miscellaneous Instrumentation			
Other Outage Maintenance Including Passive Systems			]]
Reactor Building			
MSIV Rework	[[		
SDC Pumps/Motors			
FMCRD HCU			
FMCRD Rebuild			
Instrumentation			
Condensate Treatment			
Other Outage Maintenance Including Passive Systems			]]
Turbine Building			
Major Turbine Overhaul	[[		
Turbine Valves/Pumps			
Totals			]]

Table 3-5: Collective Occupational Dose Estimate from Refueling

Facility Area/Activity	Estimated Average Dose Rate (µSv/hour)	Estimated Time (person-hours/year)	Collective Dose (person-mSv/year)
Reactor Building			
Containment and RPV Disassembly/Reassembly	[[		
Phase I Refueling[1]			
Phase II Refueling[2]			
Fuel transfer to Independent Fuel Storage Facility (if utilized)			
Totals			]]

(1) [[

(2)

]].

Table 3-6: Collective Occupational Dose Estimate from In-Service Inspection

Facility Area/Activity	Estimated Average Dose Rate (µSv/hour)	Estimated Time (person-hours/year)	Collective Dose (person-mSv/year)
Primary Containment			
General Activities	[[		
RPV Welds/Nozzles			
Main Steam piping/valves			
Feedwater piping/valves			
CUW piping/valves			
SDC piping/valves			
Other Equipment (Passive systems)			]]
Reactor Building			
General Activities	[[		
SDC			
BIS piping and valves			
FMCRD			
Other Equipment (Passive systems)			
Totals			]]

Table 3-7: Collective Occupational Dose Estimate from Operation and Surveillances

Facility Area/Activity	Estimated Average Dose Rate (µSv/hour)	Estimated Time (person-hours/year)	Collective Dose (person-mSv/year)
Reactor Building			
Routine Operation, Chemistry, Health Physics and Security Surveillance	[[		
FMCRD HCU Surveillance			
CUW Piping Surveillance			
SDC Surveillance			
Passive Systems Surveillance			
Instrumentation and Control Surveillance and Testing			
Outside Steam Tunnel			
Nonroutine Clean-up and Decontamination			
Routine Operating Deck/Pool Surveillances			
Fuel Receipt, Processing, and Channeling			
FPC System Surveillances			
Nonroutine Fuel Sipping			]]
Radwaste Building			
Included in Table 3-2 estimate	[[		]]
Turbine Building			
Routine Operation, Chemistry, Health Physics and Security Surveillance	[[		
Totals			]]

3.2 Conclusions

As noted earlier, some of the information necessary to perform a rigorous prediction of individual and collective worker doses for the BWRX-300 design is currently in development. That information includes not only the safety classification of plant systems and components, maintenance requirements, characterization of the field strengths, and inspection requirements for many plant systems, but also staffing levels. Without such information, it is not possible at this stage in the design process to establish predictions of individual effective or individual equivalent doses for the work activities included in any collective occupational dose estimate.

The annual collective occupational dose estimate does give an indication of the radiological conditions at a plant and are, therefore, often used by plant operators and regulators to assess the overall performance of the plant operation in relation to radiation protection. Given that, comparison of these results to reported industry data provides insights that can be used to inform future design decisions impacting individual worker doses.

To that end, industry occupational exposure data is extracted from the Nuclear Energy Agency Information System on Occupational Exposure (ISOE) (Reference 5-14) and compared to the projected BWRX-300 annual collective occupational dose estimate in Figure 3-1. Based on that comparison, the projected BWRX-300 annual collective occupational dose estimate of [[ ]], albeit conservative, is significantly lower than the average collective occupational doses reported at operating CANDU and BWR reactors over the most recent reporting period (2009 to 2019) and is slightly lower than the average collective occupational doses reported for PWRs over that period.

This is an indication that when relaxations such as credit for remote operation of process equipment or lower dose rates based on calculations are applied, the projected BWRX-300 annual collective occupational dose estimate is likely be lower than the average annual collective occupational doses observed at operating BWR, PWR, and CANDU reactors.

The comparison also indicates that there should be no expectation that worker doses at BWRs are proportional to power. However, certain critical worker exposure contributors related to reactor power such as the amount of fuel, and the quantity of radioactive waste do significantly decrease worker doses.

[[ ]]

Figure 3-1: Comparison of BWRX-300 Results to ISOE Industry Operating Data

4.0 ACRONYMS, DEFINITIONS

4.1 Acronyms

Acronym	Explanation
ABWR	Advanced Boiling Water Reactor
ALARA	As Low As Reasonably Achievable
AOO	Anticipated Operational Occurrences
BIS	Boron Injection System
BWR	Boiling Water Reactor
CFD	Condensate Filters and Demineralizers System
CNSC	Canadian Nuclear Safety Commission
CUW	Reactor Water Cleanup System
DAW	Dry Active Waste
DBA	Design Basis Accidents
DEC	Design Extension Conditions
DNNP	Darlington New Nuclear Project
ESBWR	Economic Simplified Boiling Water Reactor
FMCRD	Fine Motion Control Rod Drive
FPC	Fuel Pool Cooling and Cleanup System
GEH	GE-Hitachi Nuclear Energy Americas LLC
GT	Gamma Thermometer
HCU	Hydraulic Control Unit
HIC	High Integrity Container
HPCI	High-Pressure Coolant Injection
ICS	Isolation Condenser System
ISI	In-Service-Inspection
ISOE	Information System on Occupational Exposure
LPCI	Low Pressure Coolant Injection
LPRM	Local Power Range Monitor
LTC	Licence to Construct
LWM	Liquid Waste Management System
MS	Main Steam
MSIV	Main Steam Reactor Isolation Valve
NBS	Nuclear Boiler System
OPG	Ontario Power Generation
PRNM	Power Range Neutron Monitoring System
RB	Reactor Building

Acronym	Explanation
RCIC	Reactor Core Isolation Cooling
RES	Refueling and Servicing Equipment System
RHR	Residual Heat Removal
RPV	Reactor Pressure Vessel
RWB	Radwaste Building
SDC	Shutdown Cooling System
SWM	Solid Waste Management System
TB	Turbine Building

4.2 Definitions

None.

4.3 Symbols

None.

5.0 REFERENCES

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5-2 REGDOC-2.7.1, Radiation Protection, Canadian Nuclear Safety Commission, July 2021.

5-3 REGDOC-2.7.2, Dosimetry, Volume I: Ascertaining Occupational Dose, Canadian Nuclear Safety Commission, July 2021.

5-4 G-129, "Keeping Radiation Exposures and Doses 'As Low As Reasonably Achievable (ALARA)'," Regulatory Guide, Canadian Nuclear Safety Commission, 2004.

5-5 REGDOC-2.5.2, Version 1, Design of Reactor Facilities: Nuclear Power Plants, Canadian Nuclear Safety Commission, May 2014.

5-6 [[ ]].

5-7 [[ ]].

5-8 [[ ]].

5-9 [[ ]].

5-10 [[ ]].

5-11 [[ ]].

5-12 ESBWR Design Control Document Section 12.4, Dose Assessment, Revision 10, April 2014. (Available in NRC ADAMS, Accession Number ML14100A539)

5-13 ABWR Design Control Document Section 12.4, Radiation Protection Dose Assessment, Revision 10, April 2014. (Available in NRC ADAMS, Accession Number ML11126A113)

5-14 Occupational Exposures at Nuclear Power Plants, Annual Report of the Information System on Occupational Exposure (ISOE) Programme, Nuclear Energy Agency, 2009 through 2019. (Publicly Available Document Series)