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Application of the DG-1199 Methodology to the ESBWR and ABWR

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Abstract

Appendix A-5 of Draft Regulatory Guide DG-1199 “Alternative Radiological Source Term for Evaluating Design Basis Accidents at Nuclear Power Reactors” provides guidance – applicable to RADTRAD MSIV leakage models – for scaling containment aerosol concentration to the expected steam dome concentration in order to preserve the simplified use of the Accident Source Term (AST) in assessing containment performance under assumed design basis accident (DBA) conditions. In this study Economic and Safe Boiling Water Reactor (ESBWR) and Advanced Boiling Water Reactor (ABWR) RADTRAD models are developed using the DG-1199, Appendix A-5 guidance. The models were run using RADTRAD v3.03. Low Population Zone (LPZ), control room (CR), and worst-case 2-hr Exclusion Area Boundary (EAB) doses were calculated and compared to the relevant accident dose criteria in 10 CFR 50.67. For the ESBWR, the dose results were all lower than the MSIV leakage doses calculated by General Electric/Hitachi (GEH) in their licensing technical report. There are no comparable ABWR MSIV leakage doses, however, it should be noted that the ABWR doses are lower than the ESBWR doses. In addition, sensitivity cases were evaluated to ascertain the influence/importance of key input parameters/features of the models.

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1 INTRODUCTION

Current practices and the proposed revisions for the technical basis and regulatory requirements concerning main steam isolation valve (MSIV) performance for boiling water reactors (BWRs) under accident conditions were evaluated in “Analysis of Main Steam Isolation Valve Leakage in Design Basis Accidents Using MELCOR 1.8.6 and RADTRAD” [6]. The proposed methodology developed from that work was subsequently incorporated into Appendix A-5 of Draft Regulatory Guide DG-1199 “Alternative Radiological Source Term for Evaluating Design Basis Accidents at Nuclear Power Reactors” [3].

Conclusions from “Analysis of Main Steam Isolation Valve Leakage in Design Basis Accidents Using MELCOR 1.8.6 and RADTRAD” [6] and Appendix A-5 of Draft Regulatory Guide DG-1199 “Alternative Radiological Source Term for Evaluating Design Basis Accidents at Nuclear Power Reactors”[3] resulted in three fundamental changes to RADTRAD dose calculations for the CR, LPZ, and Worse-Case 2-hr EAB. These three changes are:

- MSIV leakage is evaluated using a source term to the reactor vessel steam dome (which feeds the main steam lines) and not a source term to the containment.

- Source term scaling factors are applied in the reactor vessel steam dome via the “source term fraction” parameter. The source term scaling factor is the steam dome-to-drywell ratio. The source term fractions for each steam dome is calculated by using the bounding steam dome-to-drywell concentration ratios from Table 5-1 of Reference 6 multiplied by the source term scaling factor.

- Based on the MSIV leakage test conditions specified in the technical specifications, MSIV leak area, is determined assuming 1-D, adiabatic, compressible, ideal gas flow. MSIV mass flow rate (and associated volumetric flow rate) under accident conditions are then evaluated using the MSIV leak area and the local thermodynamic conditions.

This study applies the guidance in the DG-1199, Appendix A-5 to the ESBWR and ABWR reactors. To that end RADTRAD MSIV leakage models for the ESBWR and ABWR were developed.

The RADTRAD code [2, 1] was developed for the U.S. Nuclear Regulatory Commission (USNRC) Office of Nuclear Reactor Regulation (NRR) to estimate the transport and removal of radionuclides through a reactor’s containment and the subsequent dose at various locations outside of the containment.

Background information on MSIV leakage analyses and the reasons for this and previous work [6] is provided in Section 2. Descriptions of the ESBWR and ABWR DG-1199 RADTRAD models, including model input values are located in Section 3. The analyses (base case and sensitivity cases) performed with the ESBWR and ABWR DB-1199 RADTRAD models are presented in Section 4 . The results of the analyses are discussed in Section 5 Conclusions drawn from the results are contained in Section 6

2 BACKGROUND

BWRs operate by boiling water in direct contact with the Zircaloy-clad reactor fuel rods and passing the steam produced directly through the power turbines by means of large main steam lines (MSLs) as shown in Figure 1 to the turbines. Because of this potential direct pathway from the core region to the environment, two main steam line isolation valves, one inboard of the containment boundary and one outboard, are included on each of the four steam lines in order to isolate the containment boundary from the environment in the event of a core damage accident. Anticipating some leakage from these MSIVs, a leakage control system (LCS) is often included to pull off leakage through the valves and route this effluent to the stacks to reduce on-site dose consequences in the control room and dilute releases from the site. Due to regulatory relief on MSIV leakage requirements some licensees have removed previously installed leakage control systems. The MSIVs are quite large and have a documented history of leaking beyond their design specifications and requiring costly maintenance and overhaul to maintain design specification leak rates [13].

As seen in Figure 1, the fission products release pathway from a damaged core to the containment must be either by safety relief valve venting to the wetwell, by venting to the drywell through a break in one of the four MSLs, or more circuitously through a recirculation line or bottom vessel drain line break, depending on the type of design basis accident under consideration. In any event, the source of fission products to the MSIVs is principally from the reactor vessel. Admittedly, if the DBA under consideration is a MSL break of one steam line between the vessel and the inboard MSIV, then this particular pathway would draw from the drywell volume, while the remaining three intact steam lines would continue to draw from the reactor vessel.

Historically, the radioactivity released through leaking MSIVs has been based on an assumed airborne concentration (Ci/ft^3) of radioactive particles or gas that are available to flow through the valves, and a characterized leak rate (ft^3/hr) for the valves. The leak rate of the valves (Ci/hr) is estimated based on a standard test wherein the space between the inboard and outboard valves (see Figure 1) is pressurized to a design specified pressure with air or nitrogen, and a leak rate inferred by the observed gradual depressurization of this intermediate space. The valve design-specified leak rate characterized at standard conditions can then be appropriately scaled to accident conditions to infer a leakage of radioactivity to the environment, providing an appropriate airborne concentration can be determined.

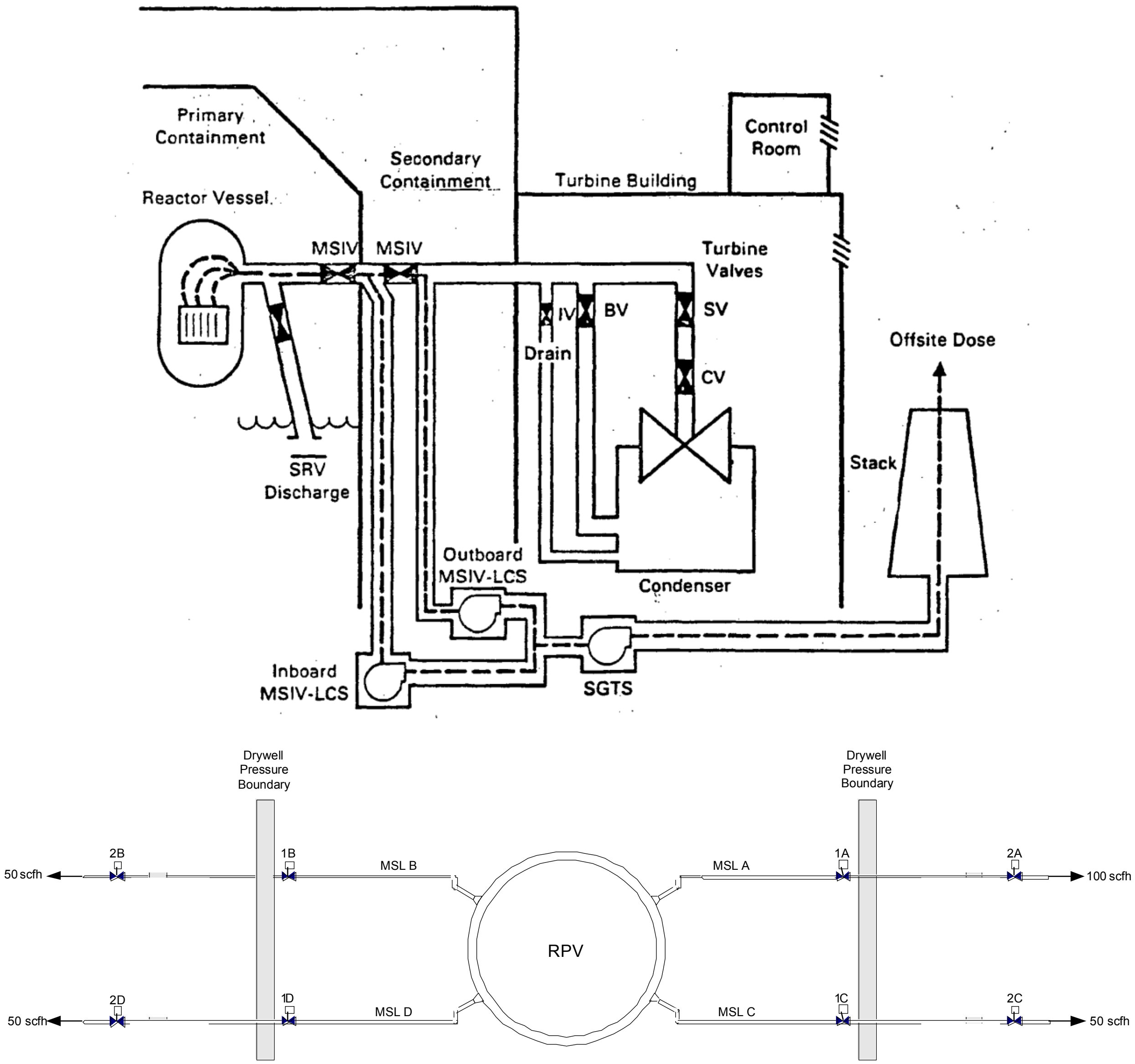

Figure 1. Schematic of BWR vessel, steam line and turbine, including location of MSIV's and Leakage Control System (LCS) (the LCS is designed to control leakage from MSIV and vent to stacks).

The July 2000 version of Regulatory Guide 1.183 [15] follows previously adopted convention by assuming that the concentration of airborne radioactivity is roughly approximated by the radioactivity released to the containment divided by the containment volume. (Item 6.1 in Appendix A of Regulatory Guide 1.183) [15]. This idealized view presumes that the radioactivity is released from the fuel, transported out of the vessel, and equilibrated with the drywell volume (and possibly the wetwell volume as well) and that this equilibrated atmosphere subsequently flows through the leaking MSIVs. Additionally, the Regulatory Guide generally permits that natural deposition and aerosol settling processes may be considered in the containment and by implication in regions upstream of outboard MSIVs to reduce the airborne activity reaching the environment.

The concept in the current Regulatory Guidelines of the radioactivity in the drywell space being the source to the MSIVs can be partially understood in terms of the historical usage of the now-retired U.S. Atomic Energy Commission Technical Information Document (TID) 14844 source term [4], where the release was presumed to be instantaneous. Instantaneously released fission products would be swept by steam advection from the vessel to the drywell where mixing and equilibration with the drywell volume could be expected; however, the major advance introduced by the NUREG-1465 [14] revised source term relative to the TID source term was that the release from fuel was not instantaneous, but instead protracted over time in distinct phases. The AST, which is based on NUREG-1465, in fact described the time phased release of fission products to the containment from the vessel, accounting for the facts that release from the fuel is gradual and occurring over a period of hours, that not all fission products released from the fuel find their way to the containment, some being deposited within the reactor primary system, and that some of these fission products that are retained within the vessel structures can subsequently become re-suspended by revaporization driven by continued decay heating of structures in the vessel.

The NUREG-1465 source term characterizes the radioactivity that escapes the fuel and vessel and enters the containment, but does not inform us on the distribution of fission products that have not yet escaped the vessel. In reality, as determined by best estimate analyses, the vessel becomes an ongoing source of airborne radioactivity to the drywell or wetwell (via steam line breaks or SRV venting) as well as the MSIVs on unbroken steam lines as long as release from overheated fuel is taking place and until vessel reflooding and accident recovery takes place. Figure 2 illustrates the two conceptual views. After accident recovery and vessel reflooding, the release from the fuel is terminated and the airborne radioactivity in the vessel will be swept into the drywell by the steam generated in the reflooding process, producing vessel airborne concentrations that can be lower than in the drywell region, as illustrated in Figure 3.

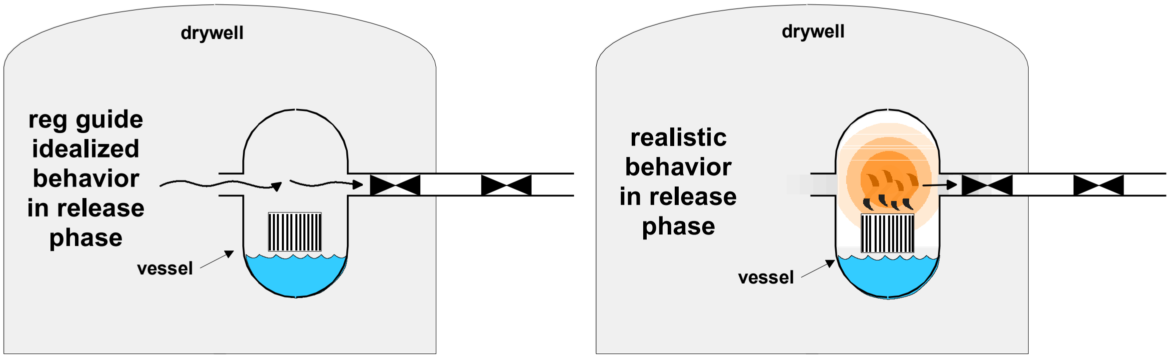

Figure 2. Idealized regulatory model of airborne fission products (left) compared to realistic prediction of airborne radioactivity (right) during release phase of a DBA with core damage. Note, source of airborne activity emanates from core (right) more so than the drywell (left).

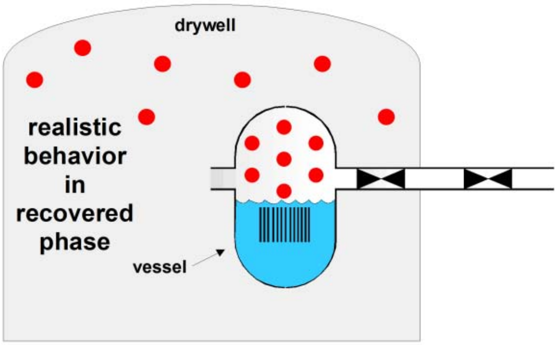

Figure 3. Qualitative distribution of airborne activity in post-recovery (reflood) phase of DBA core damage accident.

This misconception or oversimplification in viewing fission product transport from overheated fuel has led to subsequent important conceptual errors in analysis such as proposed use of drywell sprays to reduce airborne radioactivity (as illustrated in Figure 4) or equilibrating drywell and wetwell airspace volumes to achieve the same effect, when neither of these processes can directly affect the airborne concentration within the reactor vessel where a continuous source of fission products issues from the overheated fuel. In short, what is needed to evaluate MSIV leakage is a source term to the reactor vessel steam dome (which feeds the steam lines) and not a source term to the containment. SAND2008-6601 established a MELCOR best-estimate analyses of two DBAs for Mark-I and Mark-III BWR reactors, with significant core melting and fission product release. Results from the analysis show that the current regulatory guidelines permitting the use of the fission product concentration in the drywell atmosphere during the first two hours prior to assumed vessel reflood is non-conservative for the purposes of evaluating the dose resulting from MSIV leakage. SAND2008-6601 [6] investigated the means of adapting the current regulatory *containment* source term for application to MSIV leakage analysis by means of scaling factors, accounting for differences in vessel fission product concentration and containment concentrations, and for differences in the NUREG-1465 derived containment concentrations compared to current best estimate derived containment concentrations. As a result, the proposed methodology developed from that work was subsequently incorporated into Appendix A-5 of Draft Regulatory Guide DG-1199 "Alternative Radiological Source Term for Evaluating Design Basis Accidents at Nuclear Power Reactors"[3].

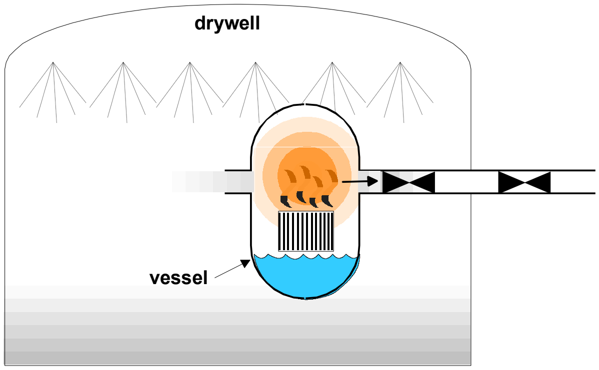

Figure 4. Illustration of drywell spray effect on airborne radioactivity in drywell and reactor vessel.

3 RADTRAD DG-1199 MODEL DESCRIPTIONS

Descriptions of the ESBWR and ABWR DG-1199 RADTRAD models are provided in this section. The models have the following general features.

- Three compartments are used to model the steam dome at various times during the simulation. Only one of the three compartments is "active" (i.e., providing source term to the balance of the model) at any given time. This is accomplished by setting the flow rates in transfer pathways connected to the "inactive" compartments equal to 0.0 cfm. The AST is released into these three compartments as specified by the reactor inventory in the .nif file and the release factions in the .rft file. The source term scaling factors (as specified by Section A-5.1 of Reference 3 and as defined in Sections 1.1 and 5.2 of Reference 6) are applied in these volumes via the "source term fraction" parameter.

- A single MSL is modeled by three compartments representing
    - the MSL volume between the steam dome and inboard MSIV,
    - the MSL volume between the MSIVs
    - the MSL volume between the outboard MSIV and the condenser

- A compartment is used to model the condenser.

- A compartment is used to model the environment. Total effective dose equivalent (TEDE) doses are calculated at the LPZ and EAB.

- A compartment is used to model the control room. Separate transfer pathways are used to model the filtered and unfiltered control room inleakage and the control room discharge. TEDE dose is calculated in the control room.

- Leakages other than that through the MSIVs (e.g., containment leakage) is modeled by a transfer pathways connected to a "sink" compartment. This avoids double-counting source term released via other leakage pathways in the MSIV leakage to the environment.

- The volumetric flow rate through the steam dome compartments, MSL compartments, and the condenser are determined from the MSIV technical specification limit and thermodynamic conditions in the system. The details of the volumetric flow rate calculations are contained in Appendix A.

- The Powers Aerosol Deposition model (BWR-DBA, 10th percentile) is credited in the steam dome volumes consistent with the analysis in Reference 6.

- Elemental iodine deposition is only credited in the SD-3 compartment, as this compartment characterizes a post-reflood well-mixed steam dome and drywell volume. As credit is taken in the GEH ESBWR RADTRAD model for elemental iodine removal in the drywell [10], credit for elemental iodine removal is also taken under similar circumstances in the models herein[1].

- Aerosol deposition is credited in the MSL volume between the MSIVs, the MSL volume between the outboard MSIV, and in the condenser. No credit is taken for aerosol deposition in the MSL volume between the steam dome and inboard MSIV per Section A.5-8 of Reference 3 (see Footnote 4) and Section 6.3 of Reference 6.

- No credit is taken for elemental iodine deposition in the MSL or condenser compartments.

- Supplemental time steps of 1 hr are used to ensure that the worst-case 2-hr EAB dose is determined correctly.

RADTRAD modeling details specific to the ESBWR and ABWR are provided in Sections 3.1 and 3.2 , respectively.

The ESBWR and ABWR RADTRAD model inputs are given Sections 4.1 and 4.2 , respectively.

3.1 ESBWR Model Description

The ESBWR DG-1199 RADTRAD model has the general features described in Section 3 (see Figure 5). In particular to the ESBWR:

- Three other leakage pathways to the environment are included (see Section 5.1 of Reference 10)
  - containment leakage released to the reactor building
  - PCCS leakage released from the containment
  - leakage from feedwater isolation valves released to the environment

- All of the ESBWR MSIV leakage occurs through a single MSIV and is released through a single MSL.

- Aerosol deposition coefficients for the MSL-M, MSL-O, and condenser compartments are taken from a previous ESBWR MSL/condenser aerosol deposition analysis [12]. This is consistent with the DG-1199 guidance (Section A-5.8 of Reference 3).

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[1] The elemental iodine removal mechanism was used "as is" for comparison purposes. Addressing the technical adequacy of this mechanism was not within the scope of this project. As such, no endorsement of this mechanism should be made or implied.

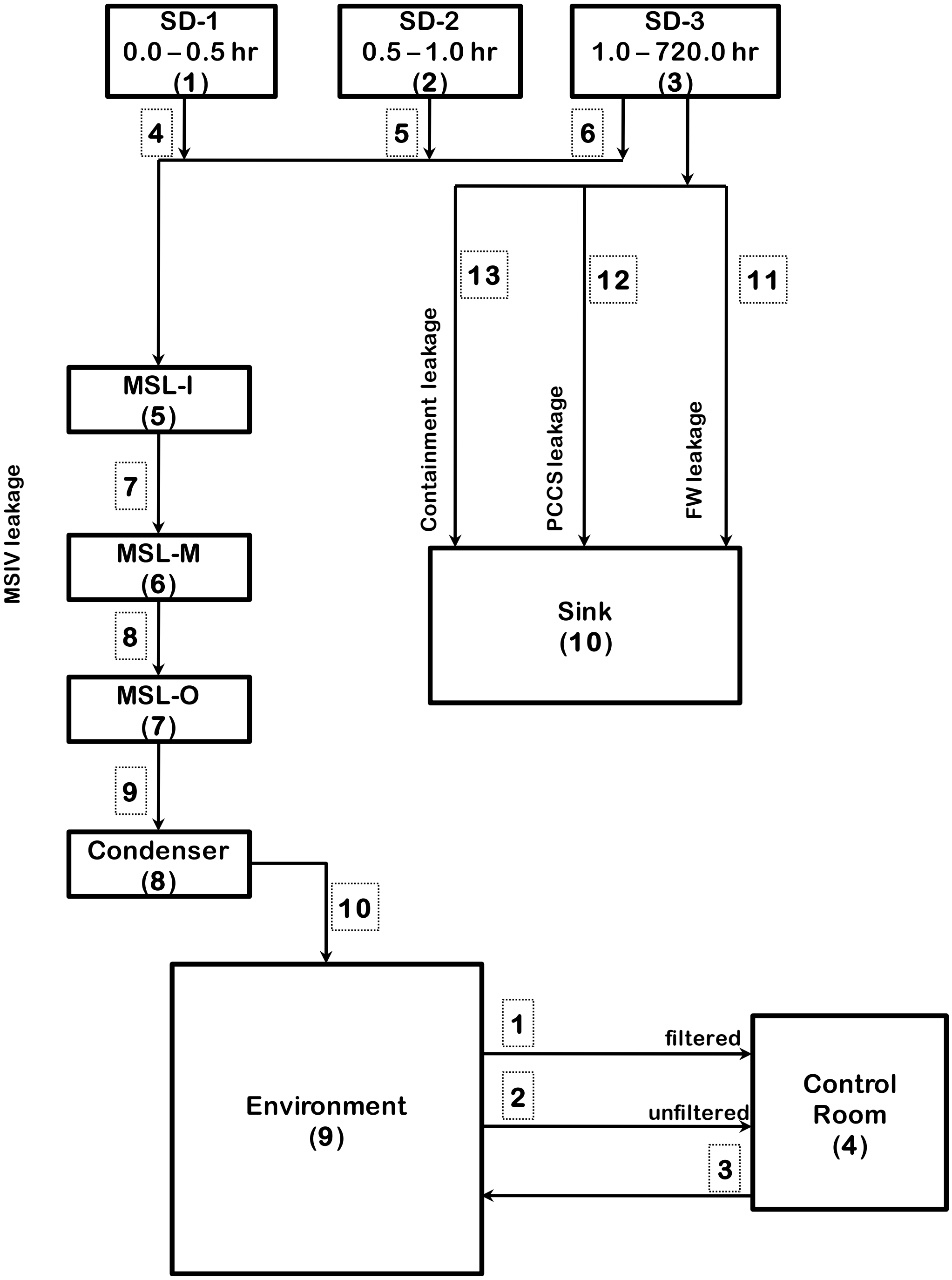

Figure 5. ESBWR DG-1199 RADTRAD Model.

3.1.1 RADTRAD ESBWR Compartment Input

The input values for the compartments in ESBWR DG-1199 RADTRAD model are documented in this section. The compartment input has been subdivided by

- steam dome compartments
- control room compartment
- main steam line compartments
- condenser compartment
- environment compartment
- sink compartment

A description of the inputs is provided along with one or more tables that provide the compartment input in a format that is easily compared with the associated RADTRAD input screens.

3.1.1.1 Steam Dome Compartments

The RADTRAD input for the compartments SD-1, SD-2, and SD-3 is given in Table 2, Table 3, and Table 4.

The steam dome volume is the VTT ESBWR MELCOR model steam dome volume (control volume 106) [16]. The ESBWR drywell volume is the "Containment, Free Air Volume" in Table A-1 of Reference 10.

The source term fractions from Table 5-1 of Reference 6 are calculated using the bounding steam dome-to-drywell concentration ratios for the 0.0-to-0.5 hr and 0.5-to-1.0 hr periods. For the 1.0-to-720.0 hr period a value of 1.0 is used in order to set the calculated source term fraction equal to the steam dome-to-drywell volume ratio (see Section 5.2 of Reference 6).

The concentration ratio values are multiplied by the ratio of the ESBWR steam dome (1.0232E+04 ft^3) to drywell volumes (4.447E+05 ft^3). These values are used as the source term fraction for their respective compartments (see Table 1).

Table 1. Source Term Fraction Input (ESBWR)

compartment	time period	bounding steam dome-to-drywell concentration (from Table 5-1 of Reference 6)	steam dome-to-drywell volume ratio [-]	source term fraction to be used in RADTRAD [-]
SD-1	0.0-to-0.5 hr	15.24	2.301E-02	3.506E-01
SD-2	0.5-to-1.0 hr	6.64	2.301E-02	1.528E-01
SD-3	1.0-to-720.0 hr[2]	1.0[3]	2.301E-02	2.301E-02

The Powers aerosol model is used with 10th percentile, BWR DBA settings, consistent with the analysis documented in Reference 6.

No natural deposition of iodine is credited in the steam dome compartments SD-1 or SD-2. Elemental iodine removal (0.86/hr; value used in Reference 10) is credited in steam dome compartment SD-3, with the deposition coefficient being non-zero after "reflood" (i.e., when the steam dome and drywell become well-mixed). A value of 2 hr is used for the time of "reflood”.

Table 2. SD-1 Compartment Input (ESBWR)

Compartment:	(1) SD-1
Type	3-other
Volume [ft^3]	1.0232E+04
Source Term Fraction [-]	3.506E-01
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES Powers Aerosol Model: 10%, BWR DBA Elemental Iodine: none

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[2] While 3rd time period in Table 5-1 [6] is 1.0-2.0 hr, Table 5-3 [6] shows the source term fraction calculated for this period as used for > 1 hr.

[3] Per the text, a value of 1.0 is used for this period rather than the bounding value from Table 5-1.

Table 3. SD-2 Compartment Input (ESBWR)

Compartment:	(2) SD-2
Type	3-other
Volume [ft^3]	1.0232E+04
Source Term Fraction [-]	1.528E-01
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES Powers Aerosol Model: 10%, BWR DBA Elemental Iodine: none

Table 4. SD-3 Compartment Input (ESBWR)

Compartment:	(3) SD-3
Type	3-other
Volume [ft^3]	1.0232E+04
Source Term Fraction [-]	2.301E-02
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES Powers Aerosol Model: 10%, BWR DBA Elemental Iodine: see below

Time [hr]	Elemental I [1/hr]
0	0.0
2	0.86
720.0	0.0

3.1.1.2 Control Room Compartment

The control room volume of 7.800E+04 ft^3 is taken from the “Control Room Parameters, Control Room Volume Credited” from Table A-1 of Reference 10.

Table 5. Control Room Compartment Input (ESBWR)

Compartment:	(4) Control Room
Type	1-Control Room
Volume [ft^3]	7.800E+04
Source Term Fraction [-]	0.0
Sprays	NO
Recirculating Filters	NO
Natural Deposition	NO

3.1.1.3 Main Steam Line Compartments

The MSL volumes are calculated from the MSL control volumes in the VTT ESBWR MELCOR model (file AS-1-melcor.txt) [16].

Table 6. ESBWR MSL Compartment Volume Calculation

MSL-I MELCOR CV	**volume [m3]**	**volume [ft3]**
120	0.99906	35.28
121	5.39331	190.46
	total	**225.7**
MSL-M MELCOR CV	**volume [m3]**	**volume [ft3]**
122	2.075	73.28
	total	**73.28**
MSL-O MELCOR CV	**volume [m3]**	**volume [ft3]**
123	3.37555	119.21
124	2.9293	103.45
125	2.88816	101.99
126	0.0044	0.1554
127	0.01641	0.5795
	total	**325.4**

The aerosol deposition coefficients are from Tables 6.6 and 6.7 of Reference 12. No natural deposition of iodine is credited in the MSL compartments. Note that no aerosol deposition is credited in the MSL-I compartment (see Section A-5.8, Footnote 4 of Reference 3 and Section 6.3 of Reference 6).

Table 7. Inboard Main Steam Line Compartment Input (ESBWR)

Compartment:	(5) MSL-I
Type	3-other
Volume [ft^3]	2.2570E+02
Source Term Fraction [-]	0.0
Sprays	NO
Recirculating Filters	NO
Natural Deposition	NO

Table 8. Middle Main Steam Line Compartment Input (ESBWR)

Compartment:	(6) MSL-M	
Type	3-other	
Volume [ft^3]	7.3280E+01	
Source Term Fraction [-]	0.0	
Sprays	NO	
Recirculating Filters	NO	
Natural Deposition	YES User-defined coefficients	
Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	2.7	0.0
0.67	2.2	0.0
1.67	3.0	0.0
2.67	1.7	0.0
3.67	2.2	0.0
5.67	0.68	0.0
7.67	0.61	0.0
11.67	0.57	0.0
15.67	0.57	0.0
19.67	0.57	0.0

Table 9. Outboard Main Steam Line Compartment Input (ESBWR)

Compartment:	(7) MSL-O	
Type	3-other	
Volume [ft^3]	3.254E+02	
Source Term Fraction [-]	0.0	
Sprays	NO	
Recirculating Filters	NO	
Natural Deposition	YES User-defined coefficients	
Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	3.0	0.0
0.67	1.4	0.0
1.67	0.33	0.0
2.67	0.51	0.0
3.67	0.48	0.0
5.67	0.87	0.0
7.67	1.5	0.0
11.67	0.43	0.0
15.67	0.44	0.0
19.67	0.44	0.0

3.1.1.4 Condenser Compartment

The volume for the condenser is the "Condenser Data, Free Air Volume" from Table A-1 in Reference 10.

The aerosol deposition coefficients are taken from Tables 6.8 of Reference 6. No natural deposition of iodine is credited in the condenser compartment.

Table 10. Outboard Main Steam Line Compartment Input (ESBWR)

Compartment:	(8) MSL-O	
Type	3-other	
Volume [ft^3]	4.18E+04	
Source Term Fraction [-]	0.0	
Sprays	NO	
Recirculating Filters	NO	
Natural Deposition	YES User-defined coefficients	
Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	0.73	0.0
0.67	0.57	0.0
1.67	0.45	0.0
2.67	0.35	0.0
3.67	0.30	0.0
5.67	0.26	0.0
7.67	0.18	0.0
11.67	0.13	0.0
15.67	0.20	0.0
19.67	0.28	0.0

3.1.1.5 Environment Compartment

The only user input for an "environment" compartment is defining the compartment type as "2-Environment".

Table 11. Environment Compartment Input (ESBWR)

Compartment:	(9) Environment
Type	2-Environment
Volume [ft^3]	0.0000
Source Term Fraction [-]	0.0
Sprays	NO
Recirculating Filters	NO
Natural Deposition	NO

3.1.1.6 Sink Compartment

The sink compartment is included in the RADTRAD model so that the other releases (e.g., containment, PCCS, FW) can be removed from the SD-3 compartment.

Table 12. Sink Compartment Input (ESBWR)

Compartment:	(10) Sink
Type	3-other
Volume [ft^3]	1.0E+06
Source Term Fraction [-]	0.0
Sprays	NO
Recirculating Filters	NO
Natural Deposition	NO

3.1.2 RADTRAD ESBWR Transfer Pathway Input

The input values for the transfer pathways in ESBWR DG-1199 RADTRAD model are documented in this section. The transfer pathway input has been subdivided by

- control room transfer pathways
- main steam line and condenser transfer pathways
- sink transfer pathways

A description of the inputs is provided along with one or more tables that provide the transfer pathway input in a format that is easily compared with the associated RADTRAD input screens.

3.1.2.1 Control Room Transfer Pathways

The control room filtered intake and unfiltered leakage are the “Control Room Emergency Filter Unit Intake Flow” and “Unfiltered Inleakage” – respectively – from Table A-1 of Reference 10. The discharge flow rate is the sum of the filtered and unfiltered flow rates. The filter efficiencies for the filtered intake are the “EFU Filter Efficiency” from Table A-1 in Reference 10.

Table 13. Control Room Filtered Intake Transfer Pathway Input (ESBWR)

Transfer pathway:		(1) Control Room Filtered Intake		
From compartment		Environment (9)		
To compartment		Control Room (4)		
Transfer mechanism		filter; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol Filter Efficiency [%]	Elem I Filter Efficiency [%]	Organic I Filter Efficiency [%]
0	4.66E+02	9.900E+01	9.900E+01	9.900E+01
720.000	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Table 14. Control Room Unfiltered Leakage Transfer Pathway Input (ESBWR)

Transfer pathway:		(2) Control Room Unfiltered Leakage		
From compartment		Environment (9)		
To compartment		Control Room (4)		
Transfer mechanism		filter; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol Filter Efficiency [%]	Elem I Filter Efficiency [%]	Organic I Filter Efficiency [%]
0	1.200E+01	0.000E+00	0.000E+00	0.000E+00
720.000	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Table 15. Control Room Discharge Transfer Pathway Input (ESBWR)

Transfer pathway:		(3) Control Room Discharge		
From compartment		Control Room (4)		
To compartment		Environment (9)		
Transfer mechanism		filter; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol Filter Efficiency [%]	Elem I Filter Efficiency [%]	Organic I Filter Efficiency [%]
0	4.78E+02	0.000E+00	0.000E+00	0.000E+00
720.000	0.000E+00	0.000E+00	0.000E+00	0.000E+00

3.1.2.2 Main Steam Line and Condenser Transfer Pathways

The flow rates from the steam dome compartments to the MSL-I compartment, as well as those through the MSL and the condenser, are set equal to the total volumetric flow rates calculated in Appendix A.

Note that no credit is taken for any radionuclide removal mechanisms in the transfer pathways (i.e, decontamination factors (DFs) are set equal to 1.0). Any deposition mechanisms credited are accounted for in the model compartments.

Table 16. SD-1 to MSL-I Transfer Pathway Input (ESBWR)

Transfer pathway:		(4) SD-1 to MSL-I		
From compartment		SD-1 (1)		
To compartment		MSL-I (5)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0.0	1.01	1.000E+00	1.000E+00	1.000E+00
0.5	0.000E+00	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 17. SD-2 to MSL-I Transfer Pathway Input (ESBWR)

Transfer pathway:		(5) SD-1 to MSL-I		
From compartment		SD-2 (2)		
To compartment		MSL-I (5)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0.0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
0.5	1.01	1.000E+00	1.000E+00	1.000E+00
1.0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 18. SD-3 to MSL-I Transfer Pathway Input (ESBWR)

Transfer pathway:		(6) SD-3 to MSL-I		
From compartment		SD-3 (3)		
To compartment		MSL-I (5)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
1.0	1.01	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 19. MSL-I to MSL-M Transfer Pathway Input (ESBWR)

Transfer pathway:		(7) MSL-I to MSL-M		
From compartment		MSL-I (5)		
To compartment		MSL-M (6)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	1.40	1.000E+00	1.000E+00	1.000E+00
24	1.40	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 20. MSL-M to MSL-O Transfer Pathway Input (ESBWR)

Transfer pathway:		(8) MSL-M to MSL-O		
From compartment		MSL-M (6)		
To compartment		MSL-O (7)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	1.40	1.000E+00	1.000E+00	1.000E+00
24	1.40	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 21. MSL-O to Condenser Transfer Pathway Input (ESBWR)

Transfer pathway:		(9) MSL-O to Condenser		
From compartment		MSL-O (7)		
To compartment		Condenser (8)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	4.22	1.000E+00	1.000E+00	1.000E+00
24	4.22	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 22. Condenser Leakage Transfer Pathway Input (ESBWR)

Transfer pathway:		(10) Condenser Leakage		
From compartment		Condenser (8)		
To compartment		Environment (9)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	2.77	1.000E+00	1.000E+00	1.000E+00
24	2.77	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

3.1.2.3 Sink Transfer Pathways

The feed water leakage rate is from “Containment Leakage Rate through Feedwater lines” in Table A-1 in Reference 10. The feed water leakage rate (0.0247 scfm) scaled by the steam dome-to-drywell volume ratio is equal to 5.68E-04 cfm.

The PCCS leakage rate of 0.01% is from “Containment Leakage Rate through PCCS” in Table A-1 in Reference 10. The total containment leakage rate of 0.35%/day is from “Total Containment Leak Rate” in Table A-1 in Reference 10. The containment leakage rate to the reactor building (0.34%/day) is the difference between the total containment leakage rate and the PCCS leakage rate. These leakage rates are converted to volumetric flow rates by multiplying them by the containment volume and converting from days to minutes. The containment volume of 4.447E+05 ft^3 is from “Containment, Free Air Volume” in Table A-1 in Reference 10.

Using the steam dome volume to convert the leakage rates to volumetric flow rates yields a containment leakage rate of 0.02416 cfm and a PCCS leakage rate of 7.1056E-04 cfm.

Table 23. FW Leakage 3 Transfer Pathway Input (ESBWR)

Transfer pathway:	(11) FW leakage 3			
From compartment	SD-3 (3)			
To compartment	Sink (10)			
Transfer mechanism	piping; user-specified removal coefficients			
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
2	5.68E-04	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 24. PCCS Leakage 3 Transfer Pathway Input (ESBWR)

Transfer pathway:	(12) PCCS leakage 3			
From compartment	SD-3 (3)			
To compartment	Sink (10)			
Transfer mechanism	piping; user-specified removal coefficients			
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
2	7.1056E-04	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 25. Containment Leakage 3 Transfer Pathway Input (ESBWR)

Transfer pathway:	(13) Containment leakage 3			
From compartment	SD-3 (3)			
To compartment	Sink (10)			
Transfer mechanism	piping; user-specified removal coefficients			
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
2	2.416E-02	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

3.1.3 RADTRAD ESBWR Dose Locations Input

The EAB and LPZ X/Q values are from Table 5.3 in Reference 10. The Control Room X/Q values are from Table 5.1 in NEDE Reference 10.

The breathing rate and control room occupation rate values are taken from the Table 15.4-5 of Reference 8.

Table 26. EAB Dose Location Input (ESBWR)

In compartment:	9 Environment
BR Defaults	EAB or LPZ
time [hr]	X/Q [s/m^3]
0.0	2.000E-03
720.0	0.0
time [hr]	breathing rate [m^3/s]
0.0	3.500E-04
8.0	1.800E-04
24.0	2.300E-04
720.0	0.000E+00

Table 27. LPZ Dose Location Input (ESBWR)

In compartment:	9 Environment
BR Defaults	EAB or LPZ
time [hr]	X/Q [s/m^3]
0.0	1.900E-04
2.000	1.900E-04
8.000	1.400E-04
24.000	7.500E-05
96.000	3.000E-05
720.0	0.0
time [hr]	breathing rate [m^3/s]
0.0	3.500E-04
8.0	1.800E-04
24.0	2.300E-04
720.0	0.000E+00

Table 28. Control Room Dose Location Input (ESBWR)

In compartment:	4 Control Room
BR Defaults	Control Room
time [hr]	X/Q [s/m^3]
0.0	1.200E-03
2.000	9.800E-04
8.000	3.900E-04
24.000	3.800E-04
96.000	3.200E-04
720.0	0.0
time [hr]	breathing rate [m^3/s]
0.0	3.500E-04
720.0	0.000E+00
time [hr]	occupancy factor – CR [-]
0.000	1.000E+00
8.000	6.000E-01
24.000	6.000E-01
96.000	4.000E-01
720.000	0.000

3.1.4 RADTRAD ESBWR Source Term and DCF Input

The nuclide inventory used (ESBWR LOCA.nif) is the same nuclide inventory used in the GE ESBWR RADTRAD analyses [10]. The plant power level is the "Power Level" in Table A-1 of Reference 10. The iodine chemical fractions are as specified in NUREG-1465 [14]. They are also documented as "Iodine Chemical Species" in Table A-1 of Reference 10. The BWR-DBA release fraction and timing file is used as it is consistent with a NUREG-1465 source term release [14]. The dose conversion factors (DCFs) used are the MACCS 60 isotope inventory, Federal Regulatory Guide (FGR) 11 & 12 dose conversion factors, consistent with Section 4 of Reference 15.

Table 29. Source Term and DCF Input (ESBWR)

Nuclide Inventory	User Inventory
Plant Power [MWt]	4590.00
NIF File	C:\Program Files\radtrad303\Defaults\ESBWR LOCA.nif
Decay and Daughter Products	Decay and Daughter Products
Iodine Chemical Fractions:	1465 Aerosol: 0.9500 Elemental: 0.0485 Organic: 0.0015
Release Fraction and Timing	BWR-DBA
Delay [hr]	0.0
RTF File	c:\program files\radtrad303\Defaults\bwr_dba.rft
DCFs	MACCS 60 isotope inventory, FRG 11 & 12 DCFs
DCF File	c:\program files\radtrad303\Defaults\fgr11&12.inp

3.1.5 RADTRAD ESBWR Control Options

A supplemental time step of 1 hr is implemented (see Table 30).

Table 30. Supplemental Time Steps (ESBWR)

time [hr]	time step [hr]
0.0	1.0
720.0	0.0

3.2 ABWR Model Description

The ABWR DG-1199 RADTRAD model has the general features described in Section 3 (see Figure 6). In particular to the ABWR:

- MSIV leakage is specified on a per valve basis. Because the number of compartments is limited to 10 in RADTRAD v3.03, all four MSLs in RADTRAD could not be modeled. Therefore, only a single MSL is modeled, with the flow through the other three MSLs combined and directed to the Sink compartment. Flow directed to the Sink does not contribute to dose; therefore the total dose for MSIV leakage from all four MSLs is calculated by multiplying the RADTRAD dose results for one MSL by four.

- Containment leakage to the environment is included.

- Due to a lack of information regarding the ABWR MSL geometry and aerosol deposition therein, the ESBWR MSL geometry (e.g., MSL compartment volumes) [16] and its aerosol deposition coefficients [12] were used as surrogates.

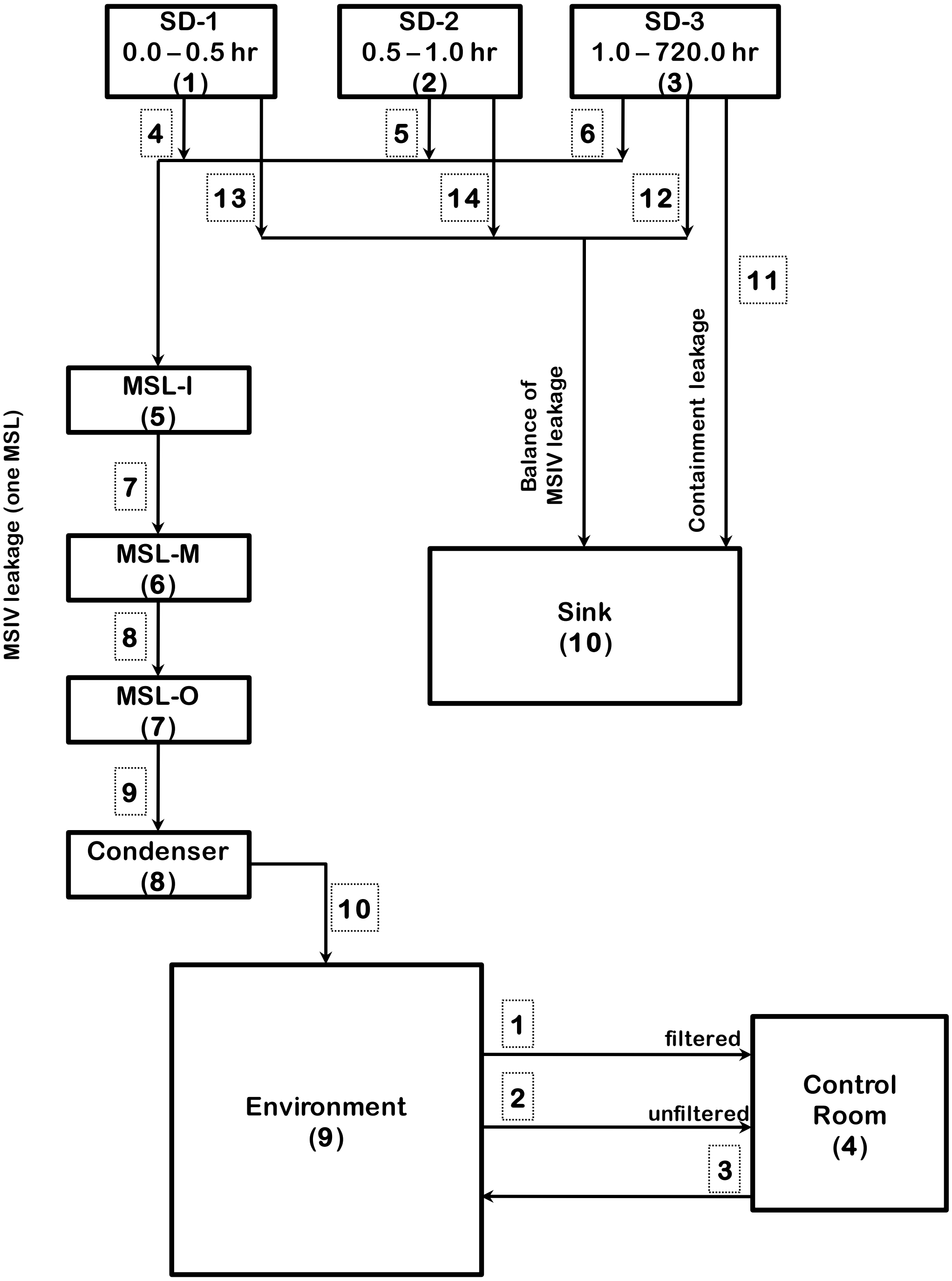

Figure 6. ABWR DG-1199 RADTRAD Model.

3.2.1 ABWR RADTRAD Compartment Input

The input values for the compartments in the ABWR DG-1199 RADTRAD model are documented in this section. The compartment input has been subdivided by

- steam dome compartments
- control room compartment
- main steam line compartments
- condenser compartment
- environment compartment
- sink compartment

A description of the inputs is provided along with tables that provide the compartment input in a format that is easily compared with the associated RADTRAD input screens.

3.2.1.1 Steam Dome (SD) Compartments

The RADTRAD input for compartments SD-1, SD-2, and SD-3 are given in Table 33, Table 34, and Table 35. SD-1 equates to the steam dome volume during time period one (0-0.5 hr). SD-2 is the steam dome during time period two (05-1.0 hr), and SD-3 is the steam dome during time period three (1.0-720 hr).

The steam dome volume (8.330E+03 ft^3) is the volume of the steam dome control volume (CV190) in the MELCOR ABWR model [5]. The drywell volume is calculated from the volumes of the containment compartments in the MELCOR ABWR model [5] (see Table 31).

Table 31. ABWR Drywell Volume Input

MELCOR CV	volume [m^3]	volume [ft^3]
201 (upper drywell)	6,056.0	213,862.0
202 (lower drywell)	1,294.0	45,696.0
203 (drywell connecting vents)	314.6	11,110.0
	total	2.71E+05

The source term fractions are calculated using the bounding steam dome-to-drywell concentration ratios for the 0.0-to-0.5 hr and 0.5-to-1.0 hr periods from Table 5-1 of Reference 6. For the 1.0-to-720.0 hr period a value of 1.0 is used in order to set the calculated source term fraction equal to the steam dome-to-drywell volume ratio (see Section 5.2 of Reference 6).

The concentration ratio values are multiplied by the ratio of the ABWR steam dome (8.330E+03 ft^3) to drywell volumes (2.71E+05 ft^3).

Table 32. Source Term Fraction Input (ABWR)

Compartment	Time Period	Bounding Value from Table 5-1 of Reference 6	Steam Dome-to-Drywell Volume Ratio [-]	Source Term Fraction to be Used in RADTRAD
SD-1	0.0-to-0.5 hr	15.24	3.0778E-02	4.6905E-01
SD-2	0.5-to-1.0 hr	6.64	3.0778E-02	2.0436E-01
SD-3	1.0-to-720.0 hr[4]	1.0[5]	3.0778E-02	3.0778E-02

The Powers aerosol deposition model is used with 10th percentile, BWR DBA settings, consistent with the analysis documented in Reference 6.

No natural deposition of iodine is credited in the steam dome compartments SD-1 or SD-2. Elemental iodine removal (0.86/hr; value used in Reference 10) is credited in steam dome compartment SD-3, with the deposition coefficient being non-zero after "reflood" (i.e., when the steam dome and drywell become well-mixed). A value of 2 hr is used for the time of "reflood”.

---

[4] While 3rd time period in Table 5-1 [6] is 1.0-2.0 hr, Table 5-3 [6] shows the source term fraction calculated for this period as used for > 1 hr.

[5] Per the text, a value of 1.0 is used for this period rather than the bounding value from Table 5-1.

Table 33. SD-1 Compartment Input (ABWR)

Compartment:	(1) SD-1
Type	3-other
Volume [ft^3]	8.330E+03
Source term fraction [-]	4.6905E-01
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES Powers Aerosol Model: 10%, BWR DBA Elemental Iodine: none

Table 34. SD-2 Compartment Input (ABWR)

Compartment:	(2) SD-2
Type	3-other
Volume [ft^3]	8.330E+03
Source term fraction [-]	2.0436E-01
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES Powers Aerosol Model: 10%, BWR DBA Elemental Iodine: none

Table 35. SD-3 Compartment Input (ABWR)

Compartment:	(3) SD-3
Type	3-other
Volume [ft^3]	8.330E+03
Source term fraction [-]	3.0778E-02
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES Powers Aerosol Model: 10%, BWR DBA Elemental Iodine: see below

Time [hr]	Elemental I [1/hr]
0	0.0
2	0.86
720.0	0.0

3.2.1.2 Control Room Compartment

The control room volume is 1.95E+05 ft^3 [7].

Table 36. Control Room Compartment Input (ABWR)

Compartment:	(4) Control Room
Type	1-Control Room
Volume [ft^3]	1.95E+05
Source term fraction [-]	0.0
Sprays	NO
Recirculating Filters	NO
Natural Deposition	NO

3.2.1.3 Main Steam Line Compartments

Due to ABWR MSL volumes not being available, MSL compartment volumes are calculated from the VTT ESBWR MELCOR model file (AS-1-melcor.txt) [16].

Table 37. ABWR MSL Compartment Volume Calculation

MSL-I MELCOR CV	Volume [m^3]	Volume [ft^3]
120	0.99906	35.28
121	5.39331	190.46
	total	**225.7**
MSL-M MELCOR CV	**Volume [m^3]**	**Volume [ft^3]**
122	2.075	73.28
	total	**73.28**
MSL-O MELCOR CV	**Volume [m^3]**	**Volume [ft^3]**
123	3.37555	119.21
124	2.9293	103.45
125	2.88816	101.99
126	0.0044	0.1554
127	0.01641	0.5795
	total	**325.4**

The aerosol deposition coefficients are from Tables 6.6 and 6.7 in Reference 12. No natural deposition of iodine is credited in the MSL compartments. Note that no aerosol deposition is credited in the MSL-I compartment (see Section A-5.8, Footnote 4 of Reference 3 and Section 6.3 of Reference 6).

Table 38. Inboard Main Steam Line Compartment Input (ABWR)

Compartment:	(5) MSL-I
Type	3-other
Volume [ft^3]	2.2570E+02
Source term fraction [-]	0.0
Sprays	NO
Recirculating Filters	NO
Natural Deposition	NO

Table 39. Middle Main Steam Line Compartment Input (ABWR)

Compartment:		(6) MSL-M
Type		3-other
Volume [ft^3]		7.3280E+01
Source term fraction [-]		0.0
Sprays		NO
Recirculating Filters		NO
Natural Deposition		YES
Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	2.7	0.0
0.67	2.2	0.0
1.67	3.0	0.0
2.67	1.7	0.0
3.67	2.2	0.0
5.67	0.68	0.0
7.67	0.61	0.0
11.67	0.57	0.0
15.67	0.57	0.0
19.67	0.57	0.0

Table 40. Outboard Main Steam Line Compartment Input (ABWR)

Compartment:	(7) MSL-O
Type	3-other
Volume [ft^3]	3.254E+02
Source term fraction [-]	0.0
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES User-defined coefficients

Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	3.0	0.0
0.67	1.4	0.0
1.67	0.33	0.0
2.67	0.51	0.0
3.67	0.48	0.0
5.67	0.87	0.0
7.67	1.5	0.0
11.67	0.43	0.0
15.67	0.44	0.0
19.67	0.44	0.0

3.2.1.4 Condenser Compartment

The volume for the condenser is 4.40E+04 ft^3 [7].

The aerosol deposition coefficients are taken from Tables 6.8 of Reference 12. No natural deposition of iodine is credited in the condenser compartment.

Table 41. Condenser Compartment Input (ABWR)

<table>
<tr><td colspan="2">Compartment:</td><td colspan="2">(8) Condenser</td></tr>
<tr><td colspan="2">Type</td><td colspan="2">3-other</td></tr>
<tr><td colspan="2">Volume [ft^3]</td><td colspan="2">4.40E+04</td></tr>
<tr><td colspan="2">Source term fraction [-]</td><td colspan="2">0.0</td></tr>
<tr><td colspan="2">Sprays</td><td colspan="2">NO</td></tr>
<tr><td colspan="2">Recirculating Filters</td><td colspan="2">NO</td></tr>
<tr><td colspan="2">Natural Deposition</td><td colspan="2">YES
User-defined coefficients</td></tr>
<tr><td>Time [hr]</td><td colspan="2">Aerosol [1/hr]</td><td>Elemental I [1/hr]</td></tr>
<tr><td>0</td><td colspan="2">0.73</td><td>0.0</td></tr>
<tr><td>0.67</td><td colspan="2">0.57</td><td>0.0</td></tr>
<tr><td>1.67</td><td colspan="2">0.45</td><td>0.0</td></tr>
<tr><td>2.67</td><td colspan="2">0.35</td><td>0.0</td></tr>
<tr><td>3.67</td><td colspan="2">0.30</td><td>0.0</td></tr>
<tr><td>5.67</td><td colspan="2">0.26</td><td>0.0</td></tr>
<tr><td>7.67</td><td colspan="2">0.18</td><td>0.0</td></tr>
<tr><td>11.67</td><td colspan="2">0.13</td><td>0.0</td></tr>
<tr><td>15.67</td><td colspan="2">0.20</td><td>0.0</td></tr>
<tr><td>19.67</td><td colspan="2">0.28</td><td>0.0</td></tr>
</table>

3.2.1.5 Environment Compartment

The only user input for an "environment" compartment is defining the compartment type as "2-Environment".

Table 42. Environment Compartment Input (ABWR)

Compartment:	(9) Environment
Type	2-Environment
Volume [ft^3]	0.0000
Source term fraction [-]	0.0
Sprays	NO
Recirculating Filters	NO
Natural Deposition	NO

3.2.1.6 Sink Compartment

The sink compartment is included in the RADTRAD model so that the other releases (e.g., containment leakage) can be removed from the SD-3 compartment.

Table 43. Sink Compartment Input (ABWR)

Compartment:	(10) Sink
Type	3-other
Volume [ft^3]	1.0E+06
Source term fraction [-]	0.0
Sprays	NO
Recirculating Filters	NO
Natural Deposition	NO

3.2.2 RADTRAD ABWR Transfer Pathway Input

The input values for the transfer pathways in the ABWR DG-1199 RADTRAD base case model are documented in this section. The transfer pathway input has been subdivided by

- control room transfer pathways
- main steam line and condenser transfer pathways
- sink transfer pathways

A description of the inputs is provided along with one or more tables that provide the transfer pathway input in a format that is easily compared with the associated RADTRAD input screens.

3.2.2.1 Control Room Transfer Pathways

The control room filtered intake is 2.106E+03 cfm and the unfiltered leakage is 9.960E+00 cfm. The discharge flow rate from the Control Room back to the Environment is the sum of the filtered and unfiltered flow rates. The filter efficiencies are 99% for the filtered intake [7].

Table 44. Control Room Filtered Intake Transfer Pathway Input (ABWR)

Transfer pathway:		(1) Control Room Filtered Intake		
From compartment		Environment (9)		
To compartment		Control Room (4)		
Transfer mechanism		filter; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol Filter Efficiency [%]	Elem I Filter Efficiency [%]	Organic I Filter Efficiency [%]
0	2.106E+03	9.900E+01	9.900E+01	9.900E+01
720.000	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Table 45. Control Room Unfiltered Leakage Transfer Pathway Input (ABWR)

Transfer pathway:		(2) Control Room Unfiltered Leakage		
From compartment		Environment (9)		
To compartment		Control Room (4)		
Transfer mechanism		filter; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol Filter Efficiency [%]	Elem I Filter Efficiency [%]	Organic I Filter Efficiency [%]
0	9.960E+00	0.000E+00	0.000E+00	0.000E+00
720.000	0.000E+00	0.000E+00	0.000E+00	0.000E+00

Table 46. Control Room Discharge Transfer Pathway Input (ABWR)

Transfer pathway:		(3) Control Room Discharge		
From compartment		Control Room (4)		
To compartment		Environment (9)		
Transfer mechanism		filter; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol Filter Efficiency [%]	Elem I Filter Efficiency [%]	Organic I Filter Efficiency [%]
0	2.116E+03	0.000E+00	0.000E+00	0.000E+00
720.000	0.000E+00	0.000E+00	0.000E+00	0.000E+00

3.2.2.2 Main Steam Line and Condenser Transfer Pathways

The flow rates from the steam dome compartments through the MSLs and the condenser are set equal to the values calculated in Appendix A.

Note that no credit is taken for any radionuclide removal mechanisms in the transfer pathways (i.e, decontamination factors are set equal to 1.0).

Table 47. SD-1 to MSL-I Transfer Pathway Input (ABWR)

Transfer pathway:		(4) SD-1 to MSL-I		
From compartment		SD-1 (1)		
To compartment		MSL-I (5)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0.0	0.27	1.000E+00	1.000E+00	1.000E+00
0.5	0.000E+00	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 48. SD-2 to MSL-I Transfer Pathway Input (ABWR)

Transfer pathway:		(5) SD-1 to MSL-I		
From compartment		SD-2 (2)		
To compartment		MSL-I (5)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0.0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
0.5	0.27	1.000E+00	1.000E+00	1.000E+00
1.0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 49. SD-3 to MSL-I Transfer Pathway Input (ABWR)

Transfer pathway:		(6) SD-3 to MSL-I		
From compartment		SD-3 (3)		
To compartment		MSL-I (5)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
1.0	0.27	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 50. MSL-I to MSL-M Transfer Pathway Input (ABWR)

Transfer pathway:		(7) MSL-I to MSL-M		
From compartment		MSL-I (5)		
To compartment		MSL-M (6)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	0.37	1.000E+00	1.000E+00	1.000E+00
24	0.37	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 51. MSL-M to MSL-O Transfer Pathway Input (ABWR)

Transfer pathway:		(8) MSL-M to MSL-O		
From compartment		MSL-M (6)		
To compartment		MSL-O (7)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	0.37	1.000E+00	1.000E+00	1.000E+00
24	0.37	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 52. MSL-O to Condenser Transfer Pathway Input (ABWR)

Transfer pathway:			(9) MSL-O to Condenser	
From compartment			MSL-O (7)	
To compartment			Condenser (8)	
Transfer mechanism			piping; user-specified removal coefficients	
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	1.13	1.000E+00	1.000E+00	1.000E+00
24	1.13	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 53. Condenser Leakage Transfer Pathway Input (ABWR)

Transfer pathway:			(10) Condenser Leakage	
From compartment			Condenser (8)	
To compartment			Environment (9)	
Transfer mechanism			piping; user-specified removal coefficients	
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	2.96	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

3.2.2.3 Sink Transfer Pathways

The containment leakage rate is 0.5% per day for the first 24.0 hr. Beyond 24.0 hr the containment leakage rate is reduced by 50% to a value of 0.25%/day [ABWR DCD Section 15.6.5.5.1 in page 15.6-10 and its Table 15.6-8 in page 15.6-30].

The balance of the MSIV leakage (i.e., the leakage through the three MSLs that are not explicitly modeled in the RADTRAD model) is equal to three times the 0.27 cfm leakage rate from the steam dome to the MSL-I compartment (0.81 cfm).

Table 54. Containment Leakage Transfer Pathway Input (ABWR)

Transfer pathway:			(11) RB Leakage	
From compartment			SD-3 (3)	
To compartment			Sink (10)	
Transfer mechanism			Air Leakage	
Time [hr]	Leakage Rate (Percent/Day)	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	5.0E-01	1.000E+00	1.000E+00	1.000E+00
24.0	2.5E-01	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 55. Balance of MSIV Leakage 1 Transfer Pathway Input (ABWR)

Transfer pathway:		(13) Balance of MSIV Leakage 1		
From compartment		SD-1 (1)		
To compartment		Sink (10)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	0.81	1.000E+00	1.000E+00	1.000E+00
0.5	0.000E+00	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 56. Balance of MSIV Leakage 2 Transfer Pathway Input (ABWR)

Transfer pathway:		(14) Balance of MSIV Leakage 2		
From compartment		SD-2 (2)		
To compartment		Sink (10)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
0.5	0.81	1.000E+00	1.000E+00	1.000E+00
1.0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 57. Balance of MSIV Leakage 3 Transfer Pathway Input (ABWR)

Transfer pathway:		(12) Balance of MSIV Leakage 2		
From compartment		SD-3 (3)		
To compartment		Sink (10)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
1.0	0.81	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

3.2.3 RADTRAD ABWR Dose Locations Input

The EAB, LPZ X/Q values, breathing rate values and control room occupation rate values are taken from the ABWR DCD [7].

Table 58. EAB Dose Location Input (ABWR)

In compartment:	(9) Environment
BR Defaults	EAB or LPZ
time [hr]	X/Q [s/m^3]
0.0	2.000E-03
720.0	0.0
time [hr]	breathing rate [m^3/s]
0.0	3.470E-04
8.0	3.470E-04
24.0	3.470E-04
720.0	3.470E-04

Table 59. LPZ Dose Location Input (ABWR)

In compartment:	(9) Environment
BR Defaults	EAB or LPZ
time [hr]	X/Q [s/m^3]
0.0	9.61E-04
2.000	9.61E-04
8.000	1.56E-04
24.000	3.36E-05
96.000	7.420E-06
720.0	0.0
time [hr]	breathing rate [m^3/s]
0.0	3.470E-04
8.0	3.470E-04
24.0	3.470E-04
720.0	3.470E-04

Table 60. Control Room Dose Location Input (ABWR)

In compartment:	(4) Control Room
BR Defaults	Control Room
time [hr]	X/Q [s/m^3]
0.0	3.10E-3
2.000	3.10E-3
8.000	1.83E-3
24.000	1.16E-3
96.000	5.12E-4
720.0	0.0
time [hr]	breathing rate [m^3/s]
0.0	3.470E-04
720.0	0.000E+00
time [hr]	occupancy factor – CR [-]
0.000	1.000E+00
8.000	6.000E-01
24.000	6.000E-01
96.000	4.000E-01
720.000	0.000

3.2.4 RADTRAD ABWR Source Term and DCF Input

The default RADTRAD BWR DBA nuclide inventory is used (BWR-DBA.nif). The plant power level was taken from Reference 11. The BWR-DBA release fraction and timing file is used as it is consistent with a NUREG-1465 source term release. The iodine chemical fractions are as specified in NUREG-1465. The DCFs used are the MACCS 60 isotope inventory, FGR 11 & 12 dose conversion factors, consistent with US NRC Reg Guide 1.183, Section 4.

Table 61. Source Term and DCF Input (ABWR)

Nuclide Inventory	User Inventory
Plant Power [MWt]	4004.52
NIF File	C:\Program Files\radtrad303\Defaults\BWR-DBA.nif
Decay and Daughter Products	Decay and Daughter Products
Iodine Chemical Fractions:	1465 Aerosol: 0.9500 Elemental: 0.0485 Organic: 0.0015
Release Fraction and Timing	BWR-DBA
Delay [hr]	0.0
RTF File	c:\program files\radtrad303\Defaults\bwr_dba.rft
DCFs	MACCS 60 isotope inventory, FRG 11 & 12 DCFs
DCF File	c:\program files\radtrad303\Defaults\fgr11&12.inp

3.2.5 RADTRAD ABWR Control Options

A supplemental time step of 1 hr is implemented (see Table 62).

Table 62. Supplemental Time Steps (ABWR)

time [hr]	time step [hr]
0.0	1.0
720.0	0.0

4 ANALYSIS

The ESBWR and ABWR models as described in Section 3 were run using the RADTRAD v3.03 code. Additional cases were also run in which various parameters/features of the models were changed to provide insight into their influence/importance.

- Sensitivity to the elemental iodine deposition coefficient: As noted in Section 3 the technical adequacy of the elemental iodine deposition coefficient was not evaluated. A set of sensitivity cases were run in which the value of the elemental iodine deposition coefficient was varied from the base case. The results of these cases, compared to the base case, will show the importance of elemental iodine deposition.

- Sensitivity to aerosol deposition coefficient -- Powers aerosol model: The Powers aerosol model is used in three steam dome compartments, consistent with Reference 6. However, that model is only valid for aerosol deposition in containment (i.e., drywell), hence its use in the SD-1 and SD-2 compartments could be invalid. A sensitivity case was run in which the Powers aerosol model is deactivated in the SD-1 and SD-2 compartments in order to ascertain its influence on the dose results.

- Sensitivity to aerosol deposition coefficient -- Deposition Coefficients: Deposition coefficients from a previous ESBWR analysis [12] are used in the ESBWR and ABWR models for the MSL-M, MSL-O, and Condenser compartments. Also, unlike the GEH analysis [10], in the base case model credit is taken for aerosol deposition over the entire 720 hr. A set of sensitivity cases were run to evaluate the impact on dose of lower aerosol deposition coefficients and taking no credit for aerosol deposition beyond 24 hr.

- Sensitivity to the Condenser: A case was run with the Condenser compartment removed from the model (i.e., source term is released from the MSL-O compartment to the Environment compartment). The results of this case will show the importance of aerosol deposition and hold-up in the condenser.

- Sensitivity to Volumetric Flow: A case was run using the technical specification MSIV leakage volumetric flow rate through the MSL and Condenser. Comparing this case with the base case will show the influence of using the DG-1199 volumetric flow methodology on the dose results.

Sections 4.1 and 4.2 contain descriptions of the additional ESBWR and ABWR cases, respectively. The results from the analyses are given in Section 5 .

4.1 ESBWR DG-1199 RADTRAD Analyses

4.1.1 Base Case

The ESBWR DG-1199 base case model (as described in Section 3.1) was run. The RADTRAD case number for the ESBWR base case model is e09.

4.1.2 No Elemental Iodine Removal in Compartment SD-3

No credit is taken for elemental iodine removal in the SD-3 compartment. Table 63 shows the changes to the SD-3 compartment input.

The RADTRAD case number for this ESBWR sensitivity model is e10.

Table 63. SD-3 Compartment Input (ESBWR) -- No Elemental Iodine Removal

Compartment:	(1) SD-3
Type	3-other
Volume [ft^3]	1.0232E+04
Source term fraction [-]	2.301E-02
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES Powers Aerosol Model: 10%, BWR DBA Elemental Iodine: none
Time [hr]	Elemental I [1/hr]
0	0.0
2	**0.0**
720.0	0.0

4.1.3 Reduced Elemental Iodine Removal in Compartment SD-3

The elemental iodine removal coefficient in compartment SD-3 was reduced by an order of magnitude to a value of 0.086 1/hr. Table 64 shows the changes to the SD-3 compartment input.

The RADTRAD case number for this ESBWR sensitivity model is e11.

Table 64. SD-3 Compartment Input (ESBWR) -- Reduced Elemental Iodine Removal

Compartment:	(1) SD-3
Type	3-other
Volume [ft^3]	1.0232E+04
Source term fraction [-]	2.301E-02
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES Powers Aerosol Model: 10%, BWR DBA Elemental Iodine: none
Time [hr]	Elemental I [1/hr]
0	0.0
2	**0.086**
720.0	0.0

4.1.4 No Aerosol Deposition in Compartments SD-1 and SD-2

No credit is taken for aerosol deposition in compartments SD-1 and SD-2. Table 65 and Table 66 show the changes to the SD-1 and SD-2 compartments, respectively.

The RADTRAD case number for this ESBWR sensitivity model is e12.

Table 65. SD-1 Compartment Input (ESBWR) -- No Aerosol Deposition

Compartment:	(1) SD-1
Type	3-other
Volume [ft^3]	1.0232E+04
Source term fraction [-]	3.506E-01
Sprays	NO
Recirculating Filters	NO
Natural Deposition	**NO**

Table 66. SD-2 Compartment Input (ESBWR) -- No Aerosol Deposition

Compartment:	(2) SD-2
Type	3-other
Volume [ft^3]	1.0232E+04
Source term fraction [-]	1.528E-01
Sprays	NO
Recirculating Filters	NO
Natural Deposition	**NO**

4.1.5 Reduced Aerosol Deposition in MSL and Condenser Compartments

The aerosol deposition coefficients in the MSL-M, MSL-O, and condenser compartments are reduced by an order of magnitude. Table 67, Table 68, and Table 69 show the changes to the MSL-M, MSL-O, and the Condenser compartment inputs, respectively.

Note that no modifications are made to the MSL-I compartment as no credit for aerosol deposition is taken in that compartment in the base case mode.

The RADTRAD case number for this ESBWR sensitivity model is e13.

Table 67. Middle Main Steam Line Compartment Input (ESBWR) -- Reduced Aerosol Deposition

Compartment:		(6) MSL-M
Type		3-other
Volume [ft^3]		7.3280E+01
Source term fraction [-]		0.0
Sprays		NO
Recirculating Filters		NO
Natural Deposition		YES User-defined coefficients
Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	**0.27**	0.0
0.67	**0.22**	0.0
1.67	**0.30**	0.0
2.67	**0.17**	0.0
3.67	**0.22**	0.0
5.67	**0.068**	0.0
7.67	**0.061**	0.0
11.67	**0.057**	0.0
15.67	**0.057**	0.0
19.67	**0.057**	0.0

Table 68. Outboard Main Steam Line Compartment Input (ESBWR) -- Reduced Aerosol Deposition

Compartment:	(7) MSL-O	
Type	3-other	
Volume [ft^3]	3.254E+02	
Source term fraction [-]	0.0	
Sprays	NO	
Recirculating Filters	NO	
Natural Deposition	YES User-defined coefficients	
Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	**0.30**	0.0
0.67	**0.14**	0.0
1.67	**0.033**	0.0
2.67	**0.051**	0.0
3.67	**0.048**	0.0
5.67	**0.087**	0.0
7.67	**015**	0.0
11.67	**0.043**	0.0
15.67	**0.044**	0.0
19.67	**0.044**	0.0

Table 69. Condenser Compartment Input (ESBWR) -- Reduced Aerosol Deposition

Compartment:	(8) Condenser
Type	3-other
Volume [ft^3]	4.18E+04
Source term fraction [-]	0.0
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES User-defined coefficients

Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	**0.073**	0.0
0.67	**0.057**	0.0
1.67	**0.045**	0.0
2.67	**0.035**	0.0
3.67	**0.030**	0.0
5.67	**0.026**	0.0
7.67	**0.018**	0.0
11.67	**0.013**	0.0
15.67	**0.020**	0.0
19.67	**0.028**	0.0

4.1.6 No Long-Term Aerosol Deposition in MSL and Condenser Compartments

No credit is taken for aerosol deposition in the MSL-M, MSL-O, and condenser compartments after 24 hr. Table 70, Table 71, and Table 72 show the changes to the MSL-M, MSL-O, and the Condenser compartment inputs, respectively.

Note that no modifications are made to the MSL-I compartment as no credit for aerosol deposition is taken in that compartment in the base case mode.

The RADTRAD case number for this ESBWR sensitivity model is e14.

Table 70. Middle Main Steam Line Compartment Input (ESBWR) -- No Long-Term Aerosol Deposition

Compartment:		(6) MSL-M
Type		3-other
Volume [ft^3]		7.3280E+01
Source term fraction [-]		0.0
Sprays		NO
Recirculating Filters		NO
Natural Deposition		YES User-defined coefficients
Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	2.7	0.0
0.67	2.2	0.0
1.67	3.0	0.0
2.67	1.7	0.0
3.67	2.2	0.0
5.67	0.68	0.0
7.67	0.61	0.0
11.67	0.57	0.0
15.67	0.57	0.0
24.0	**0.0**	0.0

Table 71. Outboard Main Steam Line Compartment Input (ESBWR) -- No Long-Term Aerosol Deposition

<table>
<tr><td colspan="2">Compartment:</td><td>(7) MSL-O</td></tr>
<tr><td colspan="2">Type</td><td>3-other</td></tr>
<tr><td colspan="2">Volume [ft^3]</td><td>3.254E+02</td></tr>
<tr><td colspan="2">Source term fraction [-]</td><td>0.0</td></tr>
<tr><td colspan="2">Sprays</td><td>NO</td></tr>
<tr><td colspan="2">Recirculating Filters</td><td>NO</td></tr>
<tr><td colspan="2">Natural Deposition</td><td>YES
User-defined coefficients</td></tr>
<tr><td>Time [hr]</td><td>Aerosol [1/hr]</td><td>Elemental I [1/hr]</td></tr>
<tr><td>0</td><td>3.0</td><td>0.0</td></tr>
<tr><td>0.67</td><td>1.4</td><td>0.0</td></tr>
<tr><td>1.67</td><td>0.33</td><td>0.0</td></tr>
<tr><td>2.67</td><td>0.51</td><td>0.0</td></tr>
<tr><td>3.67</td><td>0.48</td><td>0.0</td></tr>
<tr><td>5.67</td><td>0.87</td><td>0.0</td></tr>
<tr><td>7.67</td><td>1.5</td><td>0.0</td></tr>
<tr><td>11.67</td><td>0.43</td><td>0.0</td></tr>
<tr><td>15.67</td><td>0.44</td><td>0.0</td></tr>
<tr><td>24.0</td><td>0.0</td><td>0.0</td></tr>
</table>

Table 72. Condenser Compartment Input (ESBWR) -- No Long-Term Aerosol Deposition

Compartment:	(8) Condenser	
Type	3-other	
Volume [ft^3]	4.18E+04	
Source term fraction [-]	0.0	
Sprays	NO	
Recirculating Filters	NO	
Natural Deposition	YES User-defined coefficients	
Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	0.73	0.0
0.67	0.57	0.0
1.67	0.45	0.0
2.67	0.35	0.0
3.67	0.30	0.0
5.67	0.26	0.0
7.67	0.18	0.0
11.67	0.13	0.0
15.67	0.20	0.0
24.0	**0.0**	0.0

4.1.7 No Long-Term Aerosol or Elemental Iodine Deposition

No credit is taken for aerosol deposition in the MSL-M, MSL-O, and condenser compartments or for elemental iodine deposition in the SD-3 compartment after 24 hr. Table 70, Table 71, and Table 72 show the changes to the MSL-M, MSL-O, and the Condenser compartment inputs, respectively. Table 73 shows the changes made to the SD-3 compartment input.

Note that no modifications are made to the MSL-I compartment as no credit for aerosol deposition is taken in that compartment in the base case mode.

The RADTRAD case number for this ESBWR sensitivity model is e15.

Table 73. SD-3 Compartment Input (ESBWR) -- No Long-Term Elemental Iodine Removal

Compartment:	(1) SD-3
Type	3-other
Volume [ft^3]	1.0232E+04
Source term fraction [-]	2.301E-02
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES Powers Aerosol Model: 10%, BWR DBA Elemental Iodine: none

Time [hr]	Elemental I [1/hr]
0	0.0
2	0.86
24	**0.0**
720.0	0.0

4.1.8 No Condenser Compartment

No credit is taken for either hold-up or aerosol deposition in the condenser. This is implemented by

- modifying the MSL-O to Condenser transfer pathway to connect the MSL-O compartment to the environment (see Table 74).
- deleting the Condenser compartment
- deleting Condenser Leakage transfer pathway

Note that the flow rate used for this transfer pathway in this case is calculated from the MSL-O compartment to the condenser (see Appendix A).

The RADTRAD case number for this ESBWR sensitivity model is e16.

Table 74. MSL-O to Environment Transfer Pathway Input (ESBWR)

Transfer pathway:	**(9) MSL-O to Environment**
From compartment	MSL-O (7)
To compartment	**Environment (9)**
Transfer mechanism	piping; user-specified removal coefficients

Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	4.22	1.000E+00	1.000E+00	1.000E+00
24	4.22	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

4.1.9 Limited Duration Elemental Iodine Removal Rate

The elemental iodine removal rate (0.86/hr) in the SD-3 compartment is only applied between 2.0 hr and 8.5 hr (for a total of 6.5 hr). This application is similar to the 0.0 to 6.5 hr specification in Table 15.4-5 of the ESBWR DCD Rev 5 [8].

The RADTRAD case number for this ESBWR sensitivity model is e17.

Table 75. SD-3 Compartment Input (ESBWR) -- Limited Elemental Iodine Removal

Compartment:	(1) SD-3
Type	3-other
Volume [ft^3]	1.0232E+04
Source term fraction [-]	2.301E-02
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES Powers Aerosol Model: 10%, BWR DBA Elemental Iodine: see below
Time [hr]	Elemental I [1/hr]
0	0.0
2	0.86
8.5	**0.0**
720.0	0.0

4.1.10 Technical Specification Volumetric Flow Rates

The flow rates from the steam dome compartments to the MSL compartments and the condenser, are set equal the technical specification flow rate of 3.333 cfm [10].

The modifications to the transfer pathway inputs are shown in Table 76, Table 77, Table 78, Table 79, Table 80, Table 81, and Table 82.

The RADTRAD case number for this ESBWR sensitivity model is e00.

Table 76. SD-1 to MSL-I Transfer Pathway Input (ESBWR) – Tech Spec Flow Rate

Transfer pathway:		4 SD-1 to MSL-I		
From compartment		SD-1 (1)		
To compartment		MSL-I (5)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0.0	**3.333**	1.000E+00	1.000E+00	1.000E+00
0.5	0.000E+00	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 77. SD-2 to MSL-I Transfer Pathway Input (ESBWR) – Tech Spec Flow Rate

Transfer pathway:		(5) SD-2 to MSL-I		
From compartment		SD-2 (2)		
To compartment		MSL-I (5)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0.0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
0.5	**3.333**	1.000E+00	1.000E+00	1.000E+00
1.0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 78. SD-3 to MSL-I Transfer Pathway Input (ESBWR) – Tech Spec Flow Rate

Transfer pathway:		(6) SD-3 to MSL-I		
From compartment		SD-3 (3)		
To compartment		MSL-I (5)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
1.0	**3.333**	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 79. MSL-I to MSL-M Transfer Pathway Input (ESBWR) – Tech Spec Flow Rate

Transfer pathway:		(7) MSL-I to MSL-M		
From compartment		MSL-I (5)		
To compartment		MSL-M (6)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	**3.333**	1.000E+00	1.000E+00	1.000E+00
24	**3.333**	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 80. MSL-M to MSL-O Transfer Pathway Input (ESBWR) – Tech Spec Flow Rate

Transfer pathway:		(8) MSL-M to MSL-O		
From compartment		MSL-M (6)		
To compartment		MSL-O (7)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	**3.333**	1.000E+00	1.000E+00	1.000E+00
24	**3.333**	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 81. MSL-O to Condenser Transfer Pathway Input (ESBWR) – Tech Spec Flow Rate

Transfer pathway:		(9) MSL-O to Condenser		
From compartment		MSL-O (7)		
To compartment		Condenser (8)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	**3.333**	1.000E+00	1.000E+00	1.000E+00
24	**3.333**	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 82. Condenser Leakage Transfer Pathway Input (ESBWR) – Tech Spec Flow Rate

Transfer pathway:		(10) Condenser Leakage		
From compartment		Condenser (8)		
To compartment		Environment (9)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	**3.333**	1.000E+00	1.000E+00	1.000E+00
24	**3.333**	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

4.2 ABWR DG-1199 RADTRAD Analyses

The ABWR base case model as described in Section 3.2 was run using the RADTRAD v3.03 code. Additional sensitivity cases were also run in which various parameters/features of the base case model were changed to provide insight into their influence/importance. These sensitivity cases are discussed in Sections 4.2.2 through 4.2.10.

4.2.1 Base Case

The ABWR DG-1199 base case model (as described in Section 3.2) was run. The RADTRAD case number for the ABWR base case model is a18.

4.2.2 No Elemental Iodine Removal in Compartment SD-3

No credit is taken for elemental iodine removal in the SD-3 compartment. Table 83 shows the changes to the SD-3 compartment input.

The RADTRAD case number for this ABWR sensitivity case is a19.

Table 83. SD-3 Compartment Input (ABWR) -- No Elemental Iodine Removal

Compartment:	(1) SD-3
Type	3-other
Volume [ft^3]	8.330E+03
Source term fraction [-]	3.0778E-02
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES Powers Aerosol Model: 10%, BWR DBA Elemental Iodine: none
Time [hr]	Elemental I [1/hr]
0	0.0
2	**0.0**
720.0	0.0

4.2.3 Reduced Elemental Iodine Removal in Compartment SD-3

The elemental iodine removal coefficient in compartment SD-3 was reduced by an order of magnitude to a value of 0.086 1/hr. Table 84 shows the changes to the SD-3 compartment input.

The RADTRAD case number for this ABWR sensitivity model is a20.

Table 84. SD-3 Compartment Input (ABWR) -- Reduced Elemental Iodine Removal

<table>
<tr><td colspan="2">Compartment:</td><td>(1) SD-3</td></tr>
<tr><td colspan="2">Type</td><td>3-other</td></tr>
<tr><td colspan="2">Volume [ft^3]</td><td>8.330E+03</td></tr>
<tr><td colspan="2">Source term fraction [-]</td><td>3.0778E-02</td></tr>
<tr><td colspan="2">Sprays</td><td>NO</td></tr>
<tr><td colspan="2">Recirculating Filters</td><td>NO</td></tr>
<tr><td colspan="2">Natural Deposition</td><td>YES
Powers Aerosol Model: 10%, BWR DBA
Elemental Iodine: none</td></tr>
<tr><td>Time [hr]</td><td colspan="2">Elemental I [1/hr]</td></tr>
<tr><td>0</td><td colspan="2">0.0</td></tr>
<tr><td>2</td><td colspan="2">**0.086**</td></tr>
<tr><td>720.0</td><td colspan="2">0.0</td></tr>
</table>

4.2.4 No Aerosol Deposition in Compartments SD-1 and SD-2

No credit is taken for aerosol deposition in compartments SD-1 and SD-2. Table 85 and Table 86 show the changes to the SD-1 and SD-2 compartments, respectively.

The RADTRAD case number for this ABWR sensitivity model is a21.

Table 85. SD-1 Compartment Input (ABWR) -- No Aerosol Deposition

Compartment:	(1) SD-1
Type	3-other
Volume [ft^3]	8.330E+03
Source term fraction [-]	4.6905E-01
Sprays	NO
Recirculating Filters	NO
Natural Deposition	**NO**

Table 86. SD-2 Compartment Input (ABWR) -- No Aerosol Deposition

Compartment:	(1) SD-2
Type	3-other
Volume [ft^3]	8.330E+03
Source term fraction [-]	2.0436E-01
Sprays	NO
Recirculating Filters	NO
Natural Deposition	**NO**

4.2.5 Reduced Aerosol Deposition in MSL and Condenser Compartments

The aerosol deposition coefficients in the MSL-M, MSL-O, and condenser compartments are reduced by an order of magnitude from the base case model. Table 87, Table 88, and Table 69 show the changes to the MSL-M, MSL-O, and the Condenser compartment inputs, respectively.

Note that no modifications are made to the MSL-I compartment as no credit for aerosol deposition is taken in that compartment in the base case mode.

The RADTRAD case number for this ABWR sensitivity model is a22.

Table 87. Middle Main Steam Line Compartment Input (ABWR) -- Reduced Aerosol Deposition

Compartment:	(6) MSL-M	
Type	3-other	
Volume [ft^3]	7.3280E+01	
Source term fraction [-]	0.0	
Sprays	NO	
Recirculating Filters	NO	
Natural Deposition	YES User-defined coefficients	
Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	**0.27**	0.0
0.67	**0.22**	0.0
1.67	**0.30**	0.0
2.67	**0.17**	0.0
3.67	**0.22**	0.0
5.67	**0.068**	0.0
7.67	**0.061**	0.0
11.67	**0.057**	0.0
15.67	**0.057**	0.0
19.67	**0.057**	0.0

Table 88. Outboard Main Steam Line Compartment Input (ABWR) -- Reduced Aerosol Deposition

Compartment:	(7) MSL-O
Type	3-other
Volume [ft^3]	3.254E+02
Source term fraction [-]	0.0
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES User-defined coefficients

Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	**0.30**	0.0
0.67	**0.14**	0.0
1.67	**0.033**	0.0
2.67	**0.051**	0.0
3.67	**0.048**	0.0
5.67	**0.087**	0.0
7.67	**0.15**	0.0
11.67	**0.043**	0.0
15.67	**0.044**	0.0
19.67	**0.044**	0.0

Table 89. Condenser Compartment Input (ABWR) -- Reduced Aerosol Deposition

Compartment:	(8) Condenser
Type	3-other
Volume [ft^3]	4.18E+04
Source term fraction [-]	0.0
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES User-defined coefficients

Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	**0.073**	0.0
0.67	**0.057**	0.0
1.67	**0.045**	0.0
2.67	**0.035**	0.0
3.67	**0.030**	0.0
5.67	**0.026**	0.0
7.67	**0.018**	0.0
11.67	**0.013**	0.0
15.67	**0.020**	0.0
19.67	**0.028**	0.0

4.2.6 No Long-Term Aerosol Deposition in MSL and Condenser Compartments

No credit is taken for aerosol deposition in the MSL-M, MSL-O, and Condenser compartments after 24 hr. Table 90, Table 91, and Table 92 show the changes to the MSL-M, MSL-O, and the Condenser compartment inputs, respectively.

Note that no modifications are made to the MSL-I compartment as no credit for aerosol deposition is taken in that compartment in the base case mode.

The RADTRAD case number for this ABWR sensitivity model is a23.

Table 90. Middle Main Steam Line Compartment Input (ABWR) -- No Long-Term Aerosol Deposition

Compartment:		(6) MSL-M
Type		3-other
Volume [ft^3]		7.3280E+01
Source term fraction [-]		0.0
Sprays		NO
Recirculating Filters		NO
Natural Deposition		YES User-defined coefficients
Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	2.7	0.0
0.67	2.2	0.0
1.67	3.0	0.0
2.67	1.7	0.0
3.67	2.2	0.0
5.67	0.68	0.0
7.67	0.61	0.0
11.67	0.57	0.0
15.67	0.57	0.0
24.0	**0.0**	0.0

Table 91. Outboard Main Steam Line Compartment Input (ABWR) -- No Long-Term Aerosol Deposition

Compartment:	(7) MSL-O
Type	3-other
Volume [ft^3]	3.254E+02
Source term fraction [-]	0.0
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES User-defined coefficients

Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	3.0	0.0
0.67	1.4	0.0
1.67	0.33	0.0
2.67	0.51	0.0
3.67	0.48	0.0
5.67	0.87	0.0
7.67	1.5	0.0
11.67	0.43	0.0
15.67	0.44	0.0
24.0	**0.0**	0.0

Table 92. Condenser Compartment Input (ABWR) -- No Long-Term Aerosol Deposition

Compartment:	(9) Condenser	
Type	3-other	
Volume [ft^3]	4.18E+04	
Source term fraction [-]	0.0	
Sprays	NO	
Recirculating Filters	NO	
Natural Deposition	YES User-defined coefficients	
Time [hr]	Aerosol [1/hr]	Elemental I [1/hr]
0	0.73	0.0
0.67	0.57	0.0
1.67	0.45	0.0
2.67	0.35	0.0
3.67	0.30	0.0
5.67	0.26	0.0
7.67	0.18	0.0
11.67	0.13	0.0
15.67	0.20	0.0
24.0	**0.0**	0.0

4.2.7 No Long-Term Deposition

No credit is taken for aerosol deposition in the MSL-M, MSL-O, and condenser compartments or for elemental iodine deposition in the SD-3 compartment after 24 hr. Table 90, Table 91, and Table 92 show the changes to the MSL-M, MSL-O, and the Condenser compartment inputs, respectively.

Table 93 shows the changes made to the SD-3 compartment input.

Note that no modifications are made to the MSL-I compartment as no credit for aerosol deposition is taken in that compartment in the base case mode.

The RADTRAD case number for this ABWR sensitivity model is a24.

Table 93. SD-3 Compartment Input (ABWR) -- No Long-Term Elemental Iodine Removal

compartment:	1 SD-3
type	3-other
volume [ft^3]	1.0232E+04
source term fraction [-]	2.301E-02
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES Powers Aerosol Model: 10%, BWR DBA Elemental Iodine: none

Time [hr]	Elemental I [1/hr]
0	0.0
2	0.86
24	**0.0**
720.0	0.0

4.2.8 No Condenser Compartment

No credit is taken for either hold-up or aerosol deposition in the condenser. This is implemented by

- modifying the MSL-O to Condenser transfer pathway to connect the MSL-O compartment to the environment (see Table 94).
- deleting the Condenser compartment
- deleting Condenser Leakage transfer pathway

Note that the flow rate used for this transfer pathway in this case is that calculated from the MSL-O compartment to the condenser (see Appendix A).

The RADTRAD case number for this ABWR sensitivity model is a25.

Table 94. MSL-O to Environment Transfer Pathway Input (ABWR)

Transfer pathway:	**(9) MSL-O to Environment**
From compartment	MSL-O (7)
To compartment	**Environment (9)**
Transfer mechanism	piping; user-specified removal coefficients

Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	1.13	1.000E+00	1.000E+00	1.000E+00
24	1.13	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

4.2.9 Limited Duration Elemental Iodine Removal Rate

The elemental iodine removal rate (0.86/hr) in the SD-3 compartment is only applied between 2.0 hr and 8.5 hr (for a total of 6.5 hr). This application is similar to the 0.0 to 6.5 hr specification in Table 15.4-5 of the ESBWR DCD Rev 5 [8].

The RADTRAD case number for this ABWR sensitivity model is a26.

Table 95. SD-3 Compartment Input (ABWR) -- Limited Elemental Iodine Removal

Compartment:	(3) SD-3
Type	3-other
Volume [ft^3]	1.0232E+04
Source term fraction [-]	2.301E-02
Sprays	NO
Recirculating Filters	NO
Natural Deposition	YES Powers Aerosol Model: 10%, BWR DBA Elemental Iodine: see below
Time [hr]	Elemental I [1/hr]
0	0.0
2	0.86
8.5	**0.0**
720.0	0.0

4.2.10 Technical Specification Volumetric Flow Rates

The flow rates from the steam dome compartments to the MSL compartments, are set equal 0.588 cfm [7]. The flow rates from the steam dome compartments to the sink are set equal to 3x the technical specification flow rate (1.764 cfm). The flow rate from the condenser to the environment is set equal to the sum of leakage from all four MSLs (2.352 cfm).

The modifications to the transfer pathway inputs are shown in Table 96, Table 97, Table 98, Table 99, Table 100, Table 101, Table 102, Table 103, Table 104, and Table 105.

The RADTRAD case number for this ABWR sensitivity model is a27.

Table 96. SD-1 to MSL-I Transfer Pathway Input (ABWR) – Tech Spec Flow Rate

Transfer pathway:		(4) SD-1 to MSL-I		
From compartment		SD-1 (1)		
To compartment		MSL-I (5)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0.0	**0.588**	1.000E+00	1.000E+00	1.000E+00
0.5	0.000E+00	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 97. SD-2 to MSL-I Transfer Pathway Input (ABWR) – Tech Spec Flow Rate

Transfer pathway:		(5) SD-1 to MSL-I		
From compartment		SD-2 (2)		
To compartment		MSL-I (5)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0.0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
0.5	**0.588**	1.000E+00	1.000E+00	1.000E+00
1.0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 98. SD-3 to MSL-I Transfer Pathway Input (ABWR) – Tech Spec Flow Rate

Transfer pathway:		(6) SD-3 to MSL-I		
From compartment		SD-3 (3)		
To compartment		MSL-I (5)		
Transfer mechanism		piping; user-specified removal coefficients		
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
1.0	**0.588**	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 99. Balance of MSIV Leakage 1 Transfer Pathway Input (ABWR) – Tech Spec Flow Rate

Transfer pathway:	(13) Balance of MSIV Leakage 1			
From compartment	SD-1 (1)			
To compartment	Sink (10)			
Transfer mechanism	piping; user-specified removal coefficients			
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	**1.764**	1.000E+00	1.000E+00	1.000E+00
0.5	0.000E+00	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 100. Balance of MSIV Leakage 2 Transfer Pathway Input (ABWR) – Tech Spec Flow Rate

Transfer pathway:	(14) Balance of MSIV Leakage 2			
From compartment	SD-2 (2)			
To compartment	Sink (10)			
Transfer mechanism	piping; user-specified removal coefficients			
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
0.5	**1.764**	1.000E+00	1.000E+00	1.000E+00
1.0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 101. Balance of MSIV Leakage 3 Transfer Pathway Input (ABWR) – Tech Spec Flow Rate

Transfer pathway:	(12) Balance of MSIV Leakage 2			
From compartment	SD-3 (3)			
To compartment	Sink (10)			
Transfer mechanism	piping; user-specified removal coefficients			
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	0.000E+00	1.000E+00	1.000E+00	1.000E+00
1.0	**1.764**	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 102. MSL-I to MSL-M Transfer Pathway Input (ABWR) – Tech Spec Flow Rate

Transfer pathway:	(7) MSL-I to MSL-M			
From compartment	MSL-I (5)			
To compartment	MSL-M (6)			
Transfer mechanism	piping; user-specified removal coefficients			
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	**0.588**	1.000E+00	1.000E+00	1.000E+00
24	**0.588**	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 103. MSL-M to MSL-O Transfer Pathway Input (ABWR) – Tech Spec Flow Rate

Transfer pathway:	(8) MSL-M to MSL-O			
From compartment	MSL-M (6)			
To compartment	MSL-O (7)			
Transfer mechanism	piping; user-specified removal coefficients			
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	**0.588**	1.000E+00	1.000E+00	1.000E+00
24	**0.588**	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 104. MSL-O to Condenser Transfer Pathway Input (ABWR) – Tech Spec Flow Rate

Transfer pathway:	(9) MSL-O to Condenser			
From compartment	MSL-O (7)			
To compartment	Condenser (8)			
Transfer mechanism	piping; user-specified removal coefficients			
Time [hr]	Flow Rate [cfm]	Aerosol DF [-]	Elem I DF [-]	Organic I DF [-]
0	**0.588**	1.000E+00	1.000E+00	1.000E+00
24	**0.588**	1.000E+00	1.000E+00	1.000E+00
720.000	0.000E+00	1.000E+00	1.000E+00	1.000E+00

Table 105. Condenser Leakage Transfer Pathway Input (ABWR) – Tech Spec Flow Rate

Transfer pathway:	(10) Condenser Leakage
From compartment	Condenser (8)
To compartment	Environment (9)
Transfer mechanism	Air Leakage
Time [hr]	Flow Rate [cfm]
0	**2.352**
720.000	0.000E+00

5 RESULTS

The results from the ESBWR and ABWR RADTRAD models described in Section 4.1 and 4.2 are presented and discussed in this section.

In order to determine whether the results from the ESBWR DG-1199 analyses met the accident dose criteria in 10 CFR 50.34 and 52.47 for the CR, LPZ, and EAB, the total TEDE dose from previous GE RADTRAD ESBWR analyses [10] were subtracted from the dose criteria and the and previous GE RADTRAD ESBWR MSIV leakage results [10] were added in. This yields the margin which the results from the DG-1199 main steam line leakage pathway calculations cannot exceed (see Table 106).

Table 106. ESBWR Accident Dose Criteria and Margins

	LPZ TEDE [REM]	CR TEDE [REM]	EAB TEDE [REM]
Accident Dose Criterion (10 CFR 50.67)	25.00	5.000	25.000
total dose result	20.70	4.690	22.400
MSIV dose result	2.15	0.331	0.367
DG-1199 MSIV dose result margin	6.45	0.641	2.967

The ESBWR results in Table 107 have been compared against the margins in Table 106. Those cases in Table 107 which exceed their margin are highlighted in yellow.

As there are no analyses for the ABWR equivalent to the GE ESBWR RADTRAD analyses, no margin comparison is made with the ABWR results.

Sensitivity studies were performed using the RADTRAD base case models. These studies examined the impact of the following:

- elemental iodine deposition coefficient
- aerosol deposition coefficients in the MSL and condenser compartments
- hold-up and aerosol deposition in the condenser
- volumetric flow rates

The ESBWR sensitivity study results are discussed in the Sections 5.1 through 5.4 . The ABWR sensitivity study results are discussed in the Sections 5.5 through 5.8 .

Table 107. ESBWR DG-1199 Analysis RADTRAD Results

case	description	LPZ TEDE dose [rem]	CR TEDE dose [rem]	worst-case 2-hr EAB TEDE dose [rem]	time of worst-case 2-hr EAB TEDE dose [hr]
--	margins from Table 106	6.45E+00	6.41E-01	2.97E+00	n/a
ESBWR RADTRAD Model Per DG-1199					
e09	ESBWR DG-1199 **base case** (as described in Section 3.1)	8.29E-01	1.21E-01	5.54E-01	8
Sensitivity Cases					
e10	no elemental iodine removal in SD-3	4.59E+00	8.55E-01	1.42E+00	114
e11	elemental iodine removal in SD-3 equal to 0.086/hr	1.32E+00	2.04E-01	5.91E-01	8
e12	no aerosol deposition in SD-1 or SD-2	8.41E-01	1.22E-01	5.85E-01	8
e13	aerosol deposition coefficients in MSL and condenser compartments reduced by a factor of 10	2.71E+00	3.70E-01	2.62E+00	8
e14	no credit taken for aerosol deposition in MSL and condenser compartments after 24 hr (per the GE LTR Rev 3 analyses).	8.81E-01	1.30E-01	5.54E-01	8
e15	no credit taken for aerosol deposition in MSL and condenser compartments after 24 hr (per the GE LTR Rev 3 analyses) and no credit taken for elemental iodine removal in the SD-3 compartment after 24 hr.	8.81E-01	1.30E-01	5.54E-01	8
e16	no credit taken for hold-up or deposition in the condenser (i.e., the source term is released from the MSL directly to the environment)	1.73E+01	2.38E+00	5.65E+01	5
e17	elemental iodine removal rate (0.86/hr) only applied between 2.0 and 8.5 hr	8.42E-01	1.23E-01	5.54E-01	8
e00	tech spec flow rates	2.71E+00	3.74E-01	3.21E+00	

Table 108. ABWR DG-1199 Analysis RADTRAD Results

Case	Description	LPZ TEDE Dose [rem]	CR TEDE Dose [rem]	Worst Case 2-hr EAB TEDE Dose [rem]	Time of Worst Case 2-hr EAB TEDE dose [hr]
ABWR RADTRAD Model Per DG-1199					
a18	ABWR DG-1199 **base case** (as described in Section 3.2)	5.25E-01	2.31E-01	3.48E-01	69
Sensitivity Cases					
a19	no elemental iodine removal in SD-3	2.64E+00	9.49E-01	2.68E+00	122
a20	elemental iodine removal in SD-3 equal to 0.086/hr	9.17E-01	3.43E-01	7.97E-01	55
a21	no aerosol deposition in SD-1 or SD-2	5.32E-01	2.31E-01	3.48E-01	72
a22	aerosol deposition coefficients in MSL and condenser compartments reduced by a factor of 10	2.32E+00	5.27E-01	2.37E+00	28
a23	no credit taken for aerosol deposition in MSL and condenser compartments after 24 hr (per the GE LTR Rev 3 analyses).	1.02E+00	3.96E-01	1.00E+00	62
a24	no credit taken for aerosol deposition in MSL and condenser compartments after 24 hr (per the GE LTR Rev 3 analyses) and no credit taken for elemental iodine removal in the SD-3 compartment after 24 hr.	1.02E+00	3.96E-01	1.00E+00	60
a25	no credit taken for hold-up or deposition in the condenser (i.e., the source term is released from the MSL directly to the environment)	1.49E+01	1.80E+00	1.03E+01	15
a26	elemental iodine removal rate (0.86/hr) only applied between 2.0 and 8.5 hr (a total of 6.5 hr, similar to the 0.0 to 6.5 hr specification in Table 15.4-5 of the ESBWR DCD Rev 5)	5.31E-01	2.33E-01	3.54E-01	75
a27	Use Tech Spec flow rates	8.40E-01	3.23E-01	5.63E-01	15

5.1 Results of Elemental Iodine Deposition Coefficient Sensitivity Cases (ESBWR)

Case e10 examined the impact of taking no credit for elemental iodine removal. As expected, all of the doses substantially increased (from ~2.5x to ~7x). Also, the worst-case 2-hr EAB dose occurred much later (114 hr) than in the base case (8 hr). However, in terms of the dose margins, only the control room dose rose such that it exceeded its margin.

In Case e11 elemental iodine removal is credited, but only at 1/10th the rate (0.086/hr) used in the base case. Doses for this case are in between those from the base case and case e10, with none of the doses exceeding the dose margins.

Case e17 evaluated taking credit for elemental iodine removal for a limited time, specifically for 6.5 hr, which roughly corresponds to a decontamination factor of 200 (see Section 4.3.1 of Reference 10). In this case the LPZ and CR doses only increased marginally (~2%), with no change in the time or magnitude of the worst-case 2-hr EAB dose. None of the doses for this case exceeded their margin.

These results show that elemental iodine removal is important, but that values lower by an order-of-magnitude than what are credited in the base case yield acceptable results. The results also show that most of the elemental iodine has either been removed or been transported to the environment within the first 8.5 hours from the time of initial source term release.

Table 109. Elemental Iodine Deposition Coefficient Sensitivity Case Results(ESBWR)

Case	**Description**	**LPZ TEDE Dose [rem]**	**CR TEDE Dose [rem]**	**Worst-Case 2-hr EAB TEDE Dose [rem]**	**Time of Worst-Case 2-hr EAB TEDE Dose [hr]**
e09	ESBWR DG-1199 **base case** (as described in Section 3.1)	8.29E-01	1.21E-01	5.54E-01	8
e10	no elemental iodine removal in SD-3	4.59E+00	8.55E-01	1.42E+00	114
e11	elemental iodine removal in SD-3 equal to 0.086/hr	1.32E+00	2.04E-01	5.91E-01	8
e17	elemental iodine removal rate (0.86/hr) only applied between 2.0 and 8.5 hr	8.42E-01	1.23E-01	5.54E-01	8

5.2 Results of Aerosol Deposition Coefficient Sensitivity Cases (ESBWR)

Case e12 evaluated the impact of the Powers Aerosol model during the 0.0-to-0.5 hr and 0.5-to-1.0 hr time periods by shutting off the model in the SD-1 and SD-2 compartments. The doses from this case are only slightly higher (~2%) than the base case doses.

The impact of aerosol deposition in the MSL (e.g., MSL-M and MSL-O) and condenser compartments is examined in case e13 by reducing the aerosol deposition coefficients by an order-of-magnitude. This resulted in dose increases on the order of 3x to 5x. However, no dose exceeded its margin.

In case e14 no credit was taken for aerosol deposition in the MSL (e.g., MSL-M and MSL-O) and condenser compartments after 24 hours. Small (~6%) increases are seen in the LPZ and CR doses. No change occurred in the time or magnitude of the worst-case 2-hr EAB dose. None of the doses for this case exceeded their margin.

Similar to the elemental iodine removal sensitivity cases, these results show that aerosol deposition is important, but that lower values than what are credited in the base case yield acceptable results. Also, most of the aerosol source term has either been removed via deposition or been transported to the environment within the first 24 hours from the time of initial source term release.

Table 110. Aerosol Deposition Coefficient Sensitivity Case Results (ESBWR)

Case	Description	LPZ TEDE Dose [rem]	CR TEDE Dose [rem]	Worst-Case 2-hr EAB TEDE Dose [rem]	Time of Worst-Case 2-hr EAB TEDE Dose [hr]
e09	ESBWR DG-1199 **base case** (as described in Section 3.1)	8.29E-01	1.21E-01	5.54E-01	8
e12	no aerosol deposition in SD-1 or SD-2	8.41E-01	1.22E-01	5.85E-01	8
e13	aerosol deposition coefficients in MSL and condenser compartments reduced by a factor of 10	2.71E+00	3.70E-01	2.62E+00	8
e14	no credit taken for aerosol deposition in MSL and condenser compartments after 24 hr (per the GE LTR Rev 3 analyses).	8.81E-01	1.30E-01	5.54E-01	8

5.3 Results of Condenser Sensitivity Case (ESBWR)

Case e16 evaluated the impact of hold-up and deposition in the condenser by removing the condenser from the RADTRAD model and connecting the outboard MSL compartment (MSL-O) to the environment. The doses for this case are significantly higher than the base case, such that they exceed the margins.

This result shows that the taking credit for the condenser is necessary to prevent doses from exceeding the margins.

Table 111. Condenser Sensitivity Case Results (ESBWR)

Case	Description	LPZ TEDE Dose [rem]	CR TEDE Dose [rem]	Worst-Case 2-hr EAB TEDE Dose [rem]	Time of Worst-Case 2-hr EAB TEDE Dose [hr]
e09	ESBWR DG-1199 **base case** (as described in Section 3.1)	8.29E-01	1.21E-01	5.54E-01	8
e16	no credit taken for hold-up or deposition in the condenser (i.e., the source term is released from the MSL directly to the environment)	1.73E+01	2.38E+00	5.65E+01	5

5.4 Results of Volumetric Flow Sensitivity Case (ESBWR)

Case e00 evaluated the effect of using the technical specification flow rates rather than the flow rates calculated per the DG-1199 guidance (see Appendix A). Applying DG-1199 methodology decreases the flow rate through from the steam dome through the MSL-M and increases the tech spec flow rate between the MSL-O and Condenser compartments (see Table 112).

Results show an increase in dose between ~3x to 6x if the tech spec flow rates are used. Additionally the Worse-Case 2-hr EAB dose occurs slightly sooner at 7 hours in Case e00.

A comparison between the ESBWR base case and Case e00 is provided in Table 113.

Table 112. Tech Spec and DG-1199 Flow Rates (ESBWR)

Transfer Pathway	Tech Spec Flow Rate (cfm)	DG-1199 Flow Rate (cfm)
Steam Dome to MSL-I	3.333	1.01
MSL-I to MSL-M	3.333	1.40
MSL-M to MSL-O	3.333	1.40
MSL-O to Condenser	3.333	4.22
Condenser Leakage	3.333	2.77

Table 113. Volumetric Flow Sensitivity Case (ESBWR)

Case	Description	LPZ TEDE Dose [rem]	CR TEDE Dose [rem]	Worst-Case 2-hr EAB TEDE Dose [rem]	Time of Worst-Case 2-hr EAB TEDE Dose [hr]
e09	ESBWR DG-1199 **base case** (as described in Section 3.1)	8.29E-01	1.21E-01	5.54E-01	8
e00	tech spec flow rates	2.71E+00	3.74E-01	3.21E+00	7

5.5 Results of Elemental Iodine Deposition Coefficient Sensitivity Cases (ABWR)

Case a19 examined the impact of taking no credit for elemental iodine removal. As expected, all of the doses increased (from ~3.66x to ~6.33x). Also, the worst-case 2-hr EAB dose occurred much later at 97 hours than in the base case (50 hr).

In Case a20 elemental iodine removal is credited, but only at 1/10th the rate (0.086/hr) used in the base case. Doses for this case increased ~1.5x to 2.3x the base case. The worse-case 2-hr EAB dose occurred at approximately the same time (52 hours) as the base case (50 hours).

Case a26 evaluated taking credit for elemental iodine removal for a limited time, between 2.0 and 8.5 hours (a total of 6.5 hr). In this case the LPZ and CR doses only increased marginally (<1%), with a 6 hour change in the time of the worst-case 2-hr EAB dose.

These results show that elemental iodine removal is important, but that if the elemental iodine deposition coefficient is within an order-of-magnitude than what are credited in the base case, acceptable results can be obtained. The results of elemental iodine deposition coefficient sensitivity study are provided in Table 114.

Table 114. Elemental Iodine Deposition Coefficient Sensitivity Cases (ABWR)

Case	Description	LPZ TEDE Dose [rem]	CR TEDE Dose [rem]	Worst Case 2-hr EAB TEDE Dose [rem]	Time of Worst Case 2-hr EAB TEDE dose [hr]
a18	ABWR DG-1199 **base case** (as described in Section 3.2)	5.25E-01	2.31E-01	3.48E-01	69
a19	no elemental iodine removal in SD-3	2.64E+00	9.49E-01	2.68E+00	122
a20	elemental iodine removal in SD-3 equal to 0.086/hr	9.17E-01	3.43E-01	7.97E-01	55
a26	elemental iodine removal rate (0.86/hr) only applied between 2.0 and 8.5 hr (a total of 6.5 hr, similar to the 0.0 to 6.5 hr specification in Table 15.4-5 of the ESBWR DCD Rev 5)	5.31E-01	2.33E-01	3.54E-01	75

5.6 Results of Aerosol Deposition Coefficient Sensitivity Cases (ABWR)

Case a21 evaluated the impact of the Powers Aerosol model during the 0.0-to-0.5 hr and 0.5-to-1.0 hr time periods by shutting off the model in the SD-1 and SD-2 compartments. The doses from this case are only slightly higher (<1%) than the base case doses.

Case a22 examined the impact of aerosol deposition in the MSL (e.g., MSL-M and MSL-O) and condenser compartments by reducing the aerosol deposition coefficients by an order-of-magnitude. This resulted in dose increases on the order of ~2.5x to ~7.25x. The time of the worse-case 2-hr EAB dose was significantly impacted, decreasing from 50 hours in the base case to 28 hours in Case a22.

In Case a23 no credit was taken for aerosol deposition in the MSL (e.g., MSL-M and MSL-O) and condenser compartments after 24 hours. An increase in dose on the order of ~2x to 3x was observed. An 11-hour increase occurred in the time of the worst-case 2-hr EAB dose.

In Case a24 no credit was taken for aerosol deposition in the MSL and condenser after 24 hours and no credit was taken for elemental iodine removal after 24 hours as well. Dose in the CR and LPZ increased by ~3x and the worse-case 2-hr EAB dose increased by ~6x.

These results show that aerosol deposition is important, and that lower deposition values in the first 24 hours can significantly affect results, especially for the worst-case 2-hr EAB dose and time. Results show that most of the aerosol source term has either been removed via deposition or been transported to the environment between 0.5 hrs and 24 hours from the time of initial source term release.

A comparison of results for the base-case and Cases a21-a24 are shown in Table 115.

Table 115. Results of Aerosol Deposition Coefficient Sensitivity Cases (ABWR)

Case	Description	LPZ TEDE Dose [rem]	CR TEDE Dose [rem]	Worst Case 2-hr EAB TEDE Dose [rem]	Time of Worst Case 2-hr EAB TEDE dose [hr]
a18	ABWR DG-1199 **base case** (as described in Section 3.2)	5.25E-01	2.31E-01	3.48E-01	69
a21	no aerosol deposition in SD-1 or SD-2	5.32E-01	2.31E-01	3.48E-01	72
a22	aerosol deposition coefficients in MSL and condenser compartments reduced by a factor of 10	2.32E+00	5.27E-01	2.37E+00	28
a23	no credit taken for aerosol deposition in MSL and condenser compartments after 24 hr (per the GE LTR Rev 3 analyses).	1.02E+00	3.96E-01	1.00E+00	62
a24	no credit taken for aerosol deposition in MSL and condenser compartments after 24 hr (per the GE LTR Rev 3 analyses) and no credit taken for elemental iodine removal in the SD-3 compartment after 24 hr.	1.02E+00	3.96E-01	1.00E+00	60

5.7 Results of Condenser Sensitivity Case (ABWR)

Case a25 evaluated the impact of hold-up and deposition in the condenser by removing the condenser from the RADTRAD model and connecting the outboard MSL compartment (MSL-O) to the environment. The doses for this case are significantly higher than the base case (>30x higher for the LPZ and Worse-Case 2-hr EAB TEDE dose).

This result shows that the taking credit for the condenser is necessary to prevent significantly increased doses. The comparison between the ABWR DG-1199 base case and Case a25 are shown in Table 116.

Table 116. Results of Condenser Sensitivity Case (ABWR)

Case	Description	LPZ TEDE Dose [rem]	CR TEDE Dose [rem]	Worst Case 2-hr EAB TEDE Dose [rem]	Time of Worst Case 2-hr EAB TEDE dose [hr]
a18	ABWR DG-1199 **base case** (as described in Section 3.2)	5.25E-01	2.31E-01	3.48E-01	69
a25	no credit taken for hold-up or deposition in the condenser (i.e., the source term is released from the MSL directly to the environment)	1.49E+01	1.80E+00	1.03E+01	15

5.8 Results of Volumetric Flow Sensitivity Case (ABWR)

Case a27 evaluated the effect of using the technical specification flow rates through the MSL without applying DG-1199 scaling factors (see Appendix A: DG-1199 VOLUMETRIC FLOW RATE CALCULATIONS). Applying DG-1199 methodology decreases the flow rate through from the steam dome through the MSL-M and increases the tech spec flow rate between the MSL-O and Condenser compartments (see Table 117).

Results show an increase in dose between ~7x to 8x if the tech spec flow rates are used. Additionally the Worse-Case 2-hr EAB dose occurs sooner at 22 hours in Case a27.

A comparison between the ABWR base case and Case a27 is provided in Table 118.

Table 117. Tech Spec and DG-1199 Flow Rates (ABWR)

Transfer Pathway	Tech Spec Flow Rate (cfm)	DG-1199 Flow Rate (cfm)
Steam Dome to MSL-I	0.588	0.27
MSL-I to MSL-M	0.588	0.37
MSL-M to MSL-O	0.588	0.37
MSL-O to Condenser	0.588	1.13
Condenser Leakage	2.352	2.96

Table 118. Volumetric Flow Sensitivity Case (ABWR)

Case	Description	LPZ TEDE Dose [rem]	CR TEDE Dose [rem]	Worst Case 2-hr EAB TEDE Dose [rem]	Time of Worst Case 2-hr EAB TEDE dose [hr]
a18	ABWR DG-1199 **base case** (as described in Section 3.2)	5.25E-01	2.31E-01	3.48E-01	69
a27	Use Tech Spec flow rates	8.40E-01	3.23E-01	5.63E-01	15

6 CONCLUSIONS

RADTRAD models for ESBWR and ABWR MSIV leakage cases were developed using the methodology documented in DG-1199, Appendix A.5 [3]. The models – base case, as well as sensitivity cases – were run to calculate doses at the EAB, LPZ, and control room locations.

6.1 ESBWR Conclusions

Results from the ESBWR base case model, developed per DG-1199 methodology, show that results from the ESBWR DG-1199 analyses met the accident dose criteria in 10 CFR 50.34 and 52.47 for the CR, LPZ, and EAB (see Table 106). However, a sensitivity case performed (e16) concluded that credit for the condenser must be taken in order to meet the accident dose criteria.

Additionally, the MSIV margin for the Control Room was exceeded in Sensitivity Cases e10, which removed all elemental iodine removal coefficients in SD-3. The worse-case 2-hr EAB dose was also exceeded in Case e00. Case e00 tested the effects of using the MSIV leakage technical specification flow rates through the MSLs.

6.2 ABWR Conclusions

As there are no analyses for the ABWR equivalent to the GE ESBWR RADTRAD analyses, no margin comparison is made with the ABWR results. Results for the ABWR DG-1199 base case model and subsequent sensitivity analysis are discussed in Sections 5.5 through 5.8

7 REFERENCES

1. Arcieri W.C. 2002, *RADTRAD: A Simplified Model for RADionuclide Transport and Removal And Dose Estimation*, NUREG/CR-6604, Supplement 2, US Nuclear Regulatory Commission, Washington, D.C.

2. Bixler N.E. and Ericson, C.M. 1999, *RADTRAD: A Simplified Model for RADionuclide Transport and Removal And Dose Estimation*, NUREG/CR-6604, Supplement 1, US Nuclear Regulatory Commission, Washington, D.C.

3. Blumberg M. 2009, *Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors*, *Draft Regulatory Guide*, DG-1199, Revision 1, US Nuclear Regulatory Commission, Washington, D.C.

4. DiNunno *et al*. 1962, "Calculation of Distance Factors for Power and Test Reactor Sites," US AEC TID-14844, U.S. Atomic Energy Commission.

5. ERI 2009, *Analysis of the Toshiba Advanced Boiling Water Reactor Containment Response Under Design Basis Accident Conditions (Preliminary Report),* Energy Research Inc., Rockville, Maryland. MELCOR model reference.

6. Gauntt R.O. 2008, *Analysis of Main Steam Isolation Valve Leakage in Design Basis Accidents Using MELCOR 1.8.6 and RADTRAD*, SAND2008-6601, Sandia National Laboratories, Albuquerque, NM.

7. GE 1997, 1983, *Advanced Boiling Water Reactor, Design Control Document, Accident Analysis,* Tier 2, Revision 0, Chapter 15, General Electric Company.

8. GE Hitachi Nuclear Energy, 2008, *ESBWR Design Control Document, Tier, 2, Chapter 15, Safety Analyses*, 26A6642BP, Revision 5, General Electric Nuclear, Wilmington, NC.

9. GE Hitachi Nuclear Energy, 2008, *ESBWR Design Control Document, Tier, 2, Chapter 6, Engineered Safety Features*, 26A6642AT, Revision 5, General Electric Nuclear, Wilmington, NC.

10. GE Hitachi Nuclear Energy, 2009, *ESBWR Containment Fission Product Removal Evaluation Model*, NEDE-33279P, Revision 3, General Electric Nuclear, Wilmington, NC.

11. GE Hitachi Nuclear Energy, 1997, *ABWR Design Control Document*, Revision 4, General Electric Nuclear, Wilmington, NC.

12. Kalinich D.A. 2008, *Analysis of Aerosol Deposition in the ESBWR Containment and Main Steam Lines*, SAND2008-4961, Sandia National Laboratories, Albuquerque, NM.

13. Ridgely J.N. and Wohl, M.L. 1986, *Resolution of Generic Issue C-8, An Evaluation of Boiling Water Reactor Main Steam Line Isolation Valve Leakage and the Effectiveness of Leakage Treatment Methods*, NURGE-1169, US Nuclear Regulatory Commission, Washington, D.C.

14. L. Soffer *et al*. 1995, *Accident Source Terms for Light Water Nuclear Power Plants*, NUREG-1465, US Nuclear Regulatory Commission, Washington, D.C.

15. US NRC 2000, *Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors*, Regulatory Guide 1.183, US Nuclear Regulatory Commission, Washington, D.C.

16. VTT 2007, *Estimation and Modeling of Effective Fission Product Decontamination Factor for ESBWR Containment - Part 3,* VTT Technical Research Centre of Finland, Espoo, Finland.

17. Wark 1983, *Thermodynamics, Fourth Edition,* McGraw-Hill Book Company, New York.

APPENDIX A: DG-1199 VOLUMETRIC FLOW RATE CALCULATIONS

This appendix explains how the methodology in Reference [6] is used to develop the transfer pathway volumetric flow rates that are used in the ESBWR and ABWR DG-1199 RADTRAD models.

1. Based on the technical specification MSIV leakage test conditions, determine the MSIV leak area assuming 1-D, adiabatic, compressible, ideal gas flow.
2. Evaluate the MSIV mass flow rate (and associated volumetric flow rate) under accident conditions using the MSIV leak area previously calculated
3. Assuming the mass flow rate is constant throughout the MSL/condenser system, determine volumetric flow rates based on the local thermodynamic conditions.

In the first section of this appendix each calculation step will be explained in general. The second and third sections will show the application of the calculation steps to the ESBWR and ABWR, respectively.

General Calculation Methodology

Determine the MSIV Leak Area

The mass flow rate associated with the tech spec volumetric leakage rate is

$$\dot{m}_{std} = Q_{std}\rho_{std} \tag{1}$$

where

$\dot{m}_{std}$ - mass flow rate at standard conditions [kg/s]
Q_{std} - volumetric flow rate at standard conditions [m^3/s]
P_{atm} - atmospheric pressure [Pa]
P_{test} - pressure at test conditions [Pa]
ρ_{test} - density at test conditions [kg/m^3]

Using the ideal gas law to express the density in terms of the standard pressure and temperature yields

$$\dot{m}_{std} = Q_{std}\left[\frac{P_{std}}{\frac{R_u}{MW}T_{std}}\right] \tag{2}$$

where

P_{std} - standard pressure [Pa]
R_u - ideal gas constant [(m^3 Pa)/(kg mol)]
MW - molecular weight [kg/mol]
T_{std} - standard temperature [K]

The mass flow rate per unit area for 1-D, adiabatic, compressible, ideal gas flow is

$$G = \sqrt{2P_{up}\rho_{up}\left(\frac{k}{k-1}\right)\left[\left(\frac{P_{dn}}{P_{up}}\right)^{\frac{2}{k}} - \left(\frac{P_{dn}}{P_{up}}\right)^{\frac{k+1}{k}}\right]} \tag{3}$$

where

G - mass flow rate per unit area [kg/(s m^2)]
P_{up} - pressure upstream of the MSIV [Pa]
P_{dn} - pressure downstream of the MSIV [Pa]
k - ratio of specific heats [-]

If the downstream pressure is less than the critical pressure, then the flow is choked (i.e., at is maximum value) and the downstream pressure in (3) is set equal to the critical pressure

$$P_{crit} = p_{up}\left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} \tag{4}$$

$$P_{dn} = P_{crit} \quad if \quad P_{dn} < P_{crit} \tag{5}$$

The density in (3) is calculated using the ideal gas law using the upstream pressure and temperature.

$$\rho = \frac{P}{\frac{R_u}{MW}T} \tag{6}$$

where

ρ - density [kg/m^3]

The MSIV leak area is determined by dividing the mass flow rate calculated by (1) by the mass flow rate per unit area calculated by (3) at the test conditions

$$A_{MSIV} = \frac{\dot{m}}{G} \tag{7}$$

where

A_{MSIV} - leak area of the MSIV [m^2]

Determine the MSIV Mass and Volumetric Flow Rate Under Accident Conditions

The mass flow rate through the leaking MSIV under accident conditions is given by

$$\dot{m}_{MSIV} = GA_{MSIV} \tag{8}$$

where

$\dot{m}_{MSIV}$ - mass flow rate through the MSIV under accident conditions [kg/s^2]

and mass flow rate per unit area is calculated using (3) with accident conditions. The associated volumetric flow rate through the leaking MSIV is then equal to

$$Q = \frac{\dot{m}_{MSIV}}{\rho} \tag{9}$$

where the density is found from steam table data based on the pressure and temperature conditions upstream of the MSIV.

Determine Other MSL/Condenser Volumetric Flow Rates

The volumetric flow rate at locations other than the MSIV can be determined using (9) with the density evaluated at the local thermodynamic conditions upstream of the transfer pathway.

Application of the General Methodology to ESBWR

The ESBWR MSIV leakage technical specification parameters are given in Table A-119.

The values for the ratio of specific heats of air, the molecular weight of air, and the ideal gas constant are taken from Reference 17.

Table A-119. ESBWR MSIV Leakage Tech Spec Parameters.

input variable	input	input (SI value)	description
k	1.4	1.4	ratio of specific heats (air)
MW	29 kg/mol	29 kg/mol	molecular weight (air)
P_{std}	1 atm	101,300 Pa	standard pressure
T_{std}	20 C	293 K	standard temperature
Q_{std}	200 scfh	1.573E-03 m^3/s	MSIV tech spec volumetric leak rate
P_{test}	45 psia	411,617 Pa	MSIV test pressure
R_u	$8314\frac{m^3\ Pa}{K\ mol}$	$8314\frac{m^3\ Pa}{K\ mol}$	ideal gas constant
T_{test}	20 C	293 K	MSIV test temperature

The steam dome pressure is taken from Figure 6.2-12a1 of Reference 8 (as a point-estimate of the pressure over the 72-hr duration shown in the figure). It is assumed that over the duration of the accident the steam dome temperature will be close to that of the drywell. As such, the drywell temperature from Figure 6.2-12b1 Reference 9 is used as the steam dome temperature.

The pressure in the MSL compartments upstream of the leaking MSIV (i.e., the outboard MSIV) is assumed to be equal to the steam dome pressure. The temperature in those compartments is assumed to be equal to that used for those compartments in Section 5.4 of Reference 6.

The pressure in the MSL compartment downstream of the leaking MSIV is assumed to be equal to atmospheric pressure. The temperature in that compartment is assumed to be equal to that used for that compartment in Section 5.4 of Reference 6.

The pressure in the condenser is assumed to be equal to atmospheric pressure. The temperature is assumed to be equal to the saturation temperature at atmospheric pressure.

These conditions are listed in Table A-120, along with the density for those conditions.

Table A-120. ESBWR Accident Conditions.

location	pressure	temperature (input)	temperature (SI)	density (kg/m^3)
steam dome	300,000 Pa	140 C	413 K	1.621
MSL upstream of the leaking MSIV	300,000 Pa	551 F	561 K	1.167
MSL downsteam of the leaking MSIV	101,300 Pa	551 F	561 K	0.387
condenser	101,300 Pa	100 C	373 K	0.590
environment	101,300 Pa	20 C	293 K	--

Determine the ESBWR MSIV Leak Area

The mass flow rate is determined using (2) at the ESBWR MSIV tech spec conditions (noting that the test pressure appears in the numerator and denominator and hence cancel out)

$$\dot{m} = (200\ SCFH)\left[\frac{101300\ Pa}{\frac{\left(8314\frac{m^3\ Pa}{K\ mol}\right)}{\left(29\frac{kg}{mol}\right)}(293\ K)}\right]\left[\frac{1\ hr}{3600\ s}\right]\left[\frac{0.02832\ m^3}{1 ft^3}\right]$$

$$\dot{m} = 1.897 \times 10^{-3}\frac{kg}{s}$$

The mass flow rate per unit area for the ESBWR MSIV is calculated using (6), (5), (4), and (3) with the ESBWR MSIV tech spec conditions

$$\rho = \frac{(411617\ Pa)}{\frac{\left(8314\frac{m^3\ Pa}{K\ mol}\right)}{\left(29\frac{kg}{mol}\right)}(293\ K)} = 4.90\frac{kg}{m^3}$$

$$P_{crit} = (411617\ Pa)\left(\frac{2}{1.4+1}\right)^{\frac{1.4}{1.4-1}} = 217450\ Pa$$

$$101300\ Pa < 217450\ Pa \quad \therefore \quad P_{dn} = 217450\ Pa$$

$$G = \sqrt{2(411617\ Pa)\left(4.90\frac{kg}{m^3}\right)\left(\frac{1.4}{1.4-1}\right)\left[\left(\frac{217450\ Pa}{411617\ Pa}\right)^{\frac{2}{1.4}} - \left(\frac{217450\ Pa}{411617\ Pa}\right)^{\frac{1.4+1}{1.4}}\right]}$$

$$G = 972.5\frac{kg}{s\ m^2}$$

Finally, (7) is used to calculate the MSIV leak area based on the mass flow rate and the mass flow rate per unit area under the tech spec conditions

$$A_{MSIV} = \frac{\left(1.897 \times 10^{-3}\frac{kg}{s}\right)}{\left(972.5\frac{kg}{s\ m^2}\right)} = 1.951 \times 10^{-6}\ m^2$$

Determine the ESBWR MSIV Mass and Volumetric Flow Rate Under Accident Conditions

The MSIV mass flow rate per unit area under ESBWR accident conditions is calculated using (5), (4), and (3).

$$\rho = 1.167\frac{kg}{m^3}\quad (from\ steam\ tables)$$

$$P_{crit} = (300000\ Pa)\left(\frac{2}{1.3+1}\right)^{\frac{1.3}{1.3-1}} = 163718\ Pa$$

$$101300\ Pa < 163718\ Pa \quad \therefore \quad P_{dn} = 163718\ Pa$$

$$G = \sqrt{2(300000\ Pa)\left(1.167\frac{kg}{m^3}\right)\left(\frac{1.3}{1.3-1}\right)\left[\left(\frac{163718\ Pa}{300000\ Pa}\right)^{\frac{2}{1.3}} - \left(\frac{163718\ Pa}{300000\ Pa}\right)^{\frac{1.3+1}{1.3}}\right]}$$

$$G = 394.9\frac{kg}{s\ m^2}$$

The mass flow rate through the leaking MSIV is calculated using (8) under ESBWR accident conditions

$$\dot{m}_{MSIV} = \left(394.9 \frac{kg}{s\,m^2}\right)\left(1.951 \times 10^{-6}\ m^2\right) = 7.704 \times 10^{-4}\ \frac{kg}{s}$$

while the volumetric flow rate through the leaking MSIV is calculated using (9) under the ESBWR accident conditions

$$Q = \frac{\left(7.704 \times 10^{-4}\ \frac{kg}{s}\right)}{1.167 \frac{kg}{m^3}} \left[\frac{60\ s}{1\ min}\right]\left[\frac{35.315\ ft^3}{1\ m^3}\right] = 1.40\ cfm$$

The density in the compartments in the system are determined from steam tables and the temperature and pressure conditions in the compartments (see Table A-120).

The volumetric flow rate through transfer pathways are calculated using (9) with the density from the upstream compartment

steam dome to MSL-I

$$Q = \frac{\left(7.704 \times 10^{-4}\ \frac{kg}{s}\right)}{1.621 \frac{kg}{m^3}} \left[\frac{60\ s}{1\ min}\right]\left[\frac{35.315\ ft^3}{1\ m^3}\right] = 1.01\ cfm$$

MSL-I to MSL-M

$$Q = \frac{\left(7.704 \times 10^{-4}\ \frac{kg}{s}\right)}{1.167 \frac{kg}{m^3}} \left[\frac{60\ s}{1\ min}\right]\left[\frac{35.315\ ft^3}{1\ m^3}\right] = 1.40\ cfm$$

MSL-O to condenser

$$Q = \frac{\left(7.704 \times 10^{-4}\ \frac{kg}{s}\right)}{0.387 \frac{kg}{m^3}} \left[\frac{60\ s}{1\ min}\right]\left[\frac{35.315\ ft^3}{1\ m^3}\right] = 4.22\ cfm$$

condenser to environment

$$Q = \frac{\left(7.704 \times 10^{-4}\ \frac{kg}{s}\right)}{1.21\frac{kg}{m^3}}\left[\frac{60\ s}{1\ min}\right]\left[\frac{35.315\ ft^3}{1\ m^3}\right] = 2.77\ cfm$$

Application of the General Methodology to ABWR

The ABWR MSIV leakage tech spec parameters are given in Table A-121.

The values for the ratio of specific heats of air, the molecular weight of air, and the ideal gas constant are taken from Reference 17.

Table A-121. ABWR MSIV Leakage Tech Spec Parameters.

input variable	input	input (SI value)	description
k	1.4	1.4	ratio of specific heats (air)
MW	29 kg/mol	29 kg/mol	molecular weight (air)
P_{std}	1 atm	101,300 Pa	standard pressure
T_{std}	20 C	293 K	standard temperature
Q_{std}	1 m^3/hr	2.778E-04 m^3/s	ABWR MSIV tech spec volumetric leak rate
P_{test}	0.170 MPa(g)	271300 Pa	ABWR MSIV test pressure
R_u	$8314\frac{m^3\ Pa}{K\ mol}$	$8314\frac{m^3\ Pa}{K\ mol}$	ideal gas constant
T_{test}	20 C	293 K	ABWR MSIV test temperature

It is assumed that the ESBWR accident conditions (see Table A-120) are valid used for calculating the ABWR volumetric flow rates. Those conditions are repeated in Table A-122.

Table A-122. ABWR Accident Conditions.

location	pressure	temperature (input)	temperature (SI)	density (kg/m^3)
steam dome	300,000 Pa	140 C	413 K	1.621
MSL upstream of the leaking MSIV	300,000 Pa	551 F	561 K	1.167
MSL downsteam of the leaking MSIV	101,300 Pa	551 F	561 K	0.387
condenser	101,300 Pa	100 C	373 K	0.590
environment	101,300 Pa	20 C	293 K	--

Determine the ABWR MSIV Leak Area

The mass flow rate is determined using (2) at the ABWR MSIV tech spec conditions (noting that the test pressure appears in the numerator and denominator and hence cancel out)

$$\dot{m} = \left(1.0\ \frac{m^3}{hr}\right)\left[\frac{101300\ Pa}{\frac{\left(8314\frac{m^3\ Pa}{K\ mol}\right)}{\left(29\frac{kg}{mol}\right)}(293\ K)}\right]\left[\frac{1\ hr}{3600\ s}\right]$$

$$\dot{m} = 3.350 \times 10^{-4}\frac{kg}{s}$$

The mass flow rate per unit area for the ABWR MSIV is calculated using (6), (5), (4), and (3) with the ABWR MSIV tech spec conditions

$$\rho = \frac{(271300\ Pa)}{\frac{\left(8314\frac{m^3\ Pa}{K\ mol}\right)}{\left(29\frac{kg}{mol}\right)}(293\ K)} = 3.23\frac{kg}{m^3}$$

$$P_{crit} = (271300\ Pa)\left(\frac{2}{1.4+1}\right)^{\frac{1.4}{1.4-1}} = 143323\ Pa$$

$$101300\ Pa < 143323\ Pa \quad \therefore \quad P_{dn} = 143323\ Pa$$

$$G = \sqrt{2(271300\ Pa)\left(4.90\frac{kg}{m^3}\right)\left(\frac{1.4}{1.4-1}\right)\left[\left(\frac{143323\ Pa}{271300\ Pa}\right)^{\frac{2}{1.4}} - \left(\frac{143323\ Pa}{271300\ Pa}\right)^{\frac{1.4+1}{1.4}}\right]}$$

$$G = 641.0\frac{kg}{s\ m^2}$$

Finally, (7) is used to calculate the MSIV leak area based on the mass flow rate and the mass flow rate per unit area under the tech spec conditions

$$A_{MSIV} = \frac{\left(3.350 \times 10^{-4} \frac{kg}{s}\right)}{\left(641.0 \frac{kg}{s\, m^2}\right)} = 5.226 \times 10^{-7}\ m^2$$

Determine the ABWR MSIV Mass and Volumetric Flow Rate Under Accident Conditions

The MSIV mass flow rate per unit area under ABWR accident conditions is calculated using (5), (4), and (3).

$$\rho = 1.167 \frac{kg}{m^3} \quad (from\ steam\ tables)$$

$$P_{crit} = (300000\ Pa)\left(\frac{2}{1.3+1}\right)^{\frac{1.3}{1.3-1}} = 163718\ Pa$$

$$101300\ Pa < 163718\ Pa \quad \therefore \quad P_{dn} = 163718\ Pa$$

$$G = \sqrt{2(300000\ Pa)\left(1.167 \frac{kg}{m^3}\right)\left(\frac{1.3}{1.3-1}\right)\left[\left(\frac{163718\ Pa}{300000\ Pa}\right)^{\frac{2}{1.3}} - \left(\frac{163718\ Pa}{300000\ Pa}\right)^{\frac{1.3+1}{1.3}}\right]}$$

$$G = 394.9 \frac{kg}{s\, m^2}$$

The mass flow rate through the leaking MSIV is calculated using (8) under ABWR accident conditions

$$\dot{m}_{MSIV} = \left(394.9 \frac{kg}{s\, m^2}\right)\left(5.226 \times 10^{-7}\ m^2\right) = 2.064 \times 10^{-4}\ \frac{kg}{s}$$

while the volumetric flow rate through the leaking MSIV is calculated using (9) under the ESBWR accident conditions

$$Q = \frac{\left(2.064 \times 10^{-4}\ \frac{kg}{s}\right)}{1.167 \frac{kg}{m^3}}\left[\frac{60\ s}{1\ min}\right]\left[\frac{35.315\ ft^3}{1\ m^3}\right] = 0.37\ cfm$$

The density in the compartments in the system are determined from steam tables and the temperature and pressure conditions in the compartments (see Table A-122).

The volumetric flow rate through transfer pathways are calculated using (9) with the density from the upstream compartment

steam dome to MSL-I

$$Q = \frac{\left(2.064 \times 10^{-4}\ \frac{kg}{s}\right)}{1.621\,\frac{kg}{m^3}}\left[\frac{60\ s}{1\ min}\right]\left[\frac{35.315\ ft^3}{1\ m^3}\right] = 0.27\ cfm$$

MSL-I to MSL-M

$$Q = \frac{\left(2.064 \times 10^{-4}\ \frac{kg}{s}\right)}{1.167\,\frac{kg}{m^3}}\left[\frac{60\ s}{1\ min}\right]\left[\frac{35.315\ ft^3}{1\ m^3}\right] = 0.37\ cfm$$

MSL-O to condenser

$$Q = \frac{\left(2.064 \times 10^{-4}\ \frac{kg}{s}\right)}{0.387\,\frac{kg}{m^3}}\left[\frac{60\ s}{1\ min}\right]\left[\frac{35.315\ ft^3}{1\ m^3}\right] = 1.13\ cfm$$

condenser to environment

$$Q = \frac{\left(2.064\times10^{-4}\,\frac{kg}{s}\right)}{1.21\frac{kg}{m^3}}\left[\frac{60\ s}{1\ min}\right]\left[\frac{35.315\ ft^3}{1\ m^3}\right] = 0.74\ cfm \text{ per MSL}$$

4 MSL, so

Q (total) = (0.74)(4)

Q (total) = 2.96 cfm

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