Appendix C
Debris Generation Evaluation for the U.S. EPR

C.1 Introduction

Appendix C documents the process and results of the debris generation evaluation for the U.S. EPR. The evaluation utilizes the guidance of NRC Regulatory Guidance 1.82 Rev.3 (Reference 2) and information presented in Nuclear Energy Institute (NEI) 04-07 (Reference 1).

This effort is in response to an ongoing concern by the Nuclear Regulatory Commission (NRC) detailed in Generic Safety Issue 191 (GSI-191). Debris generated by a postulated LOCA or high energy line break (HELB) can be transported to the containment building sump and potentially impede the performance of the Emergency Core Cooling Systems (ECCS) during recirculation.

The analysis determines the quantity of debris released in the containment building by the LOCA or HELB prior to the start of recirculation. The primary debris source is thermal insulation installed on the piping and equipment within containment. Coatings, latent debris, and miscellaneous debris are considered additional elements of the debris load.

The LOCA break is the limiting break that requires long term ECCS recirculation. This assessment analyzes seven break locations for a postulated LOCA, tabulates the debris generation totals, and identifies the limiting pipe breaks with respect to GSI-191 for the U.S. EPR. The debris generation results serve as serve as a basis and input to the Chemical Effects Evaluation (Appendix D) and ECCS Strainer Performance Testing (Appendix E).

C.2 Assumptions

C.2.1 Industry Assumptions

The following industry assumptions are employed to conservatively account for debris generation.

1. Zone of influence (ZOI) determinations based on experimentally observed or conservatively established destruction pressures are assumed to adequately define the spatial volume within which debris is generated.

2. ZOI determinations are based on experimentally observed or conservatively established destruction pressures and are assumed to define the spatial volume within which debris is generated.

3. Qualified coatings outside the ZOI will remain intact (Reference 1).

4. Structural concrete does not contribute to the debris source term. Structural concrete is assumed to be impervious to the effects of a LOCA. This was observed during testing that supported the NRC Staff Review Guidance regarding GL 2004-02, “Closure in the Area of Coatings Evaluation,” March 2008. The quantity of concrete dust generated by the LOCA blast is assumed to be insignificant with respect to the quantity of latent debris present in containment prior to the LOCA.

5. Destruction pressures documented in Table 3-2 of NEI 04-07 Volume 2 (Reference 1) are assumed to be applicable. In cases where Table 3-2 of Volume 2 does not specifically list the debris type of interest, Table 4-1 of NEI 04-07 Volume 1 (Reference 1) is consulted to ascertain the experimentally determined destruction pressure of the debris type. This destruction pressure is then reduced per guidance in Section 3.4.2.2 of NEI 04-07 Volume 2 (Reference 1).

6. Insulation jacketing is assumed to make no significant contribution to the debris generation load. Insulation jacketing is typically made of stainless steel sheet

metal. Knowledge based tests have not identified jacketing as a significant source of debris fines. Larger sizes of jacketing debris are unlikely to transport under typical pool fill or recirculation conditions.

C.2.2 Plant Specific Assumptions

The following plant specific assumptions are applied to this evaluation.

1. Qualified coatings within containment consist mainly of epoxy with an approximate 94 lb_m/ft^3 density. In high temperature areas where epoxy coatings are not practical, inorganic zinc (IOZ) coatings with an approximate 457 lb_m/ft^3 density will be applied in lieu of epoxy coatings. The coating thicknesses are assumed to be 3 mils for IOZ coatings and 12 mils for the epoxy coatings. The use of unqualified coatings within the U.S. EPR containment is not planned. However, for conservatism, 250 lb_m of unqualified coatings is assumed to fail in containment.

2. Miscellaneous debris source materials (tags, tape, labels, etc.) are assumed. An assumed miscellaneous debris amount of 100 ft^2 (tags, tape, labels, etc.) is added to the total debris source term.

3. For determining the volume of insulation on pipe segments (spool pieces), centerline-to-centerline coding of the pipe lengths is used. This practice conservatively adds 5% to 15% more insulation volume to each pipe segment versus using the actual pipe lengths and elbow insulation volumes.

4. Insulation volume for valve and instrument covers is bounded by the conservative insulation volume of the centerline-to-centerline pipe length assumption.

5. Piping with a nominal diameter of one-half inch or less will be insulated with reflective metal insulation (RMI) and contributes an insignificant amount of insulation compared to the overall total debris generated from a postulated LOCA. RMI on one-half inch or less piping is not included in this evaluation.

6. The reflective metal insulation (RMI) thickness and number of foils selected for RCS piping and major equipment are based on vendor proposal information.

7. Within the ZOIs, the plant piping and equipment insulation will consist of stainless steel RMI.

8. The following system piping is assumed to be non-insulated:

   - component cooling water
   - central gas distribution
   - gaseous waste
   - compressed air
   - fuel pool purification
   - fuel handling
   - nuclear sampling
   - drains
   - reactor coolant pump seal injection

C.2.3 Implicit Assumptions

The following conservatisms are incorporated into the debris generation evaluation.

1. No credit is taken for shadowing effects by equipment such as steam generators and reactor coolant pumps.

2. Solid structural barriers such as the primary bioshield are assumed to protect debris source materials on one side from the blast effects emanating from the other side.

3. For the purposes of computing the pipe insulation volume, the pipe outer diameter is assumed to be the inner diameter of the insulation.

4. ZOI sizing is based on the outer diameter of the pipe except for breaks occurring in the RCS hot, cold, and crossover leg piping. The hot, cold, and crossover leg piping has an outer diameter of 36 inches and an inner diameter of 30.71 inches. As a conservative measure, a 31 inch inside diameter will be utilized for the RCS hot, cold, and crossover leg piping ZOI.

C.3 Computer Software

AREVA NP computer software is used for the U.S. EPR debris generation evaluation.

The AREVA NP software program determines the quantity of various insulation materials that reside within a given distance of a specified LOCA or HELB of interest. The output of the program provides the input to the debris generation analysis.

C.4 Technical Approach

C.4.1 Background

The U.S. EPR is a PWR design that incorporates an in-containment refueling water storage tank (IRWST) to achieve design objectives that promote a robust response to accident scenarios. The design uses the IRWST in the ECCS recirculation path following a LOCA. The IRWST is located in the containment, below the four RCS loop vaults. The design takes advantage of this location to develop the following staggered “defense in depth” strategy against ECCS sump suction clogging.

- four protective weir / trash rack structures to retain large debris in the RCS loop vaults.
- four retention baskets in the IRWST under the trash racks to retain small debris carried through the trash racks by ECCS recirculation flow.
- four large surface area ECCS strainers with small screen mesh sized to minimize debris bypass that may potentially impact or clog downstream fuel or critical equipment.

There are four steam generators (SG) each served by a single reactor coolant pump (RCP). The wall structures surrounding the SGs and RCPs within the primary containment walls are symmetrical in design. The pressurizer is connected to loop 3 on the hot leg by a 16 inch surge line and is connected to the cold leg with a 4 inch spray line on the discharge side of the RCP. The U.S. EPR containment building uses RMI as the primary insulation for the RCS loops and major equipment.

C.4.2 Work Scope

The debris generation evaluation utilizes a U.S. EPR-specific three dimensional model of piping and equipment with insulation. Based on modeling information, a debris source inventory database is developed for use as input to debris generation analysis. Several analytical methods are employed to determine the maximum anticipated debris load for selected LOCA break locations. The specific break locations are selected based on industry guidance and impact to ECCS sump screen head loss. The latent and miscellaneous debris present within containment are conservatively estimated and are consistent with current industry practice.

C.4.3 Methodology

This section details the methodology for determining the quantity of insulation debris generated during a LOCA. The methodology complies with NEI 04-07 guidance (Reference 1). The methodologies used to categorize the gross quantities of containment insulation debris by size are explained in the following sections.

C.4.3.1 *Break Location Selection*

To assure that the ECCS can perform its safety functions, the magnitude of the debris load introduced to containment for LOCA breaks must be quantified.

NRC Regulatory Guide 1.82 Rev 3, Section 1.3.2.3 (Reference 2) provides the following guidance:

A sufficient number of breaks in each high-pressure system that relies on recirculation should be considered to reasonably bound variations in debris generation by the size, quantity, and type of debris. As a minimum, the following postulated break locations should be considered.

- Breaks in the reactor coolant system (e.g., hot leg, cold leg, pressurizer surge line) and, depending on the plant licensing basis, main Steam and main feedwater lines with the largest amount of potential debris within the postulated ZOI,
- Large breaks with two or more different types of debris, including the breaks with the most variety of debris, within the expected ZOI,
- Breaks in areas with the most direct path to the sump,
- Medium and large breaks with the largest potential particulate debris to fibrous insulation ratio by weight, and
- Breaks that generate an amount of fibrous debris that, after its transport to the sump screen, could form a uniform thin bed that could subsequently filter sufficient particulate debris to create a relatively high head loss referred to as the 'thin-bed effect.' The minimum thickness of fibrous debris needed to form a thin bed has typically been estimated at 1/8 inch thick based on the nominal insulation density (NUREG/CR-6224) (Reference 3).

Regulatory Guide 1.82 guidance is applied to the U.S. EPR by examining breaks in the RCS piping proximate to major equipment such as the steam generators (Process 1). Since the RCS lines are the largest-bore lines in containment, they result in the largest ZOIs with the greatest quantities of potential debris. The RCS lines also maximize the number of different types of thermal insulation (and other debris sources) that are affected by a break. Break locations centered at connections to the SG nozzles have ZOIs that envelope nearly the entire steam generator as well as the reactor coolant pump(s). Break locations farther from the SG nozzles result in lesser quantities of debris because their ZOIs envelope smaller portions of the steam generators.

Break locations at RCS connections to the reactor vessel (RV) nozzles are also examined. Due to the location inside the primary bioshield, breaks at the RV nozzles do not present the same degree of debris accumulation that is credited for breaks in RCS piping outside the primary bioshield.

Main steam and feedwater lines need only be analyzed as potential break locations in plants where ECCS recirculation is required to mitigate the effects of breaks in these lines. For the U.S. EPR, ECCS recirculation is not required for main steam or feedwater line breaks. Accordingly, main steam and feedwater lines are not analyzed as potential break locations for the U.S. EPR for GSI-191.

The U.S. EPR has four symmetrical loops with the pressurizer surge line connected to loop 3. Since the four loops of the plant are symmetrical, only piping and equipment within loops 3 and 4 are modeled. The limiting break locations are determined to occur in loop 3 which contains the pressurizer surge line connection. Applying the foregoing break selection methodology, the following break locations have been evaluated as potential limiting debris load cases:

Table C.4-1 Pipe Break Selections

Pipe Break	Pipe Break Location
1. RCS hot leg 3	SG3 inlet nozzle
2. RCS cold leg 3	RCP3 outlet nozzle
3. Pressurizer surge line	Hot leg 3 connection
4. Pressurizer surge line	Above cold leg 3
5. RCS crossover leg 3	SG3 outlet nozzle
6. Largest safety injection line	Above the loop 3 trash rack
7. RCS hot leg 3	Pressurizer surge line connection

The pipe break selections of Table C.4-1 fulfill the first four objectives of Regulatory Guide 1.82 Section 1.3.2.3. These selections are also consistent with the selection of break locations discussed in Section 3.3.4 of NEI 04-07 (Reference 1). For primary piping, NEI 04-07 suggests that break locations be evaluated at five-foot intervals along the pipe being considered. This methodology is intended to determine the limiting break location with respect to:

- maximum volume of debris generated and transported to the sump, and
- most limiting combination of debris generated and transported to the sump.

The break selection methodology has been validated and shows conservative results with respect to maximum debris loads and variety of debris types generated for a typical PWR.

C.4.3.2 *Zone of Influence (ZOI)*

With break locations defined, it becomes necessary to determine how much debris is generated by the jet of fluid issuing from the break. This is done by determining the spatial volume about the break in which the expanding jet retains sufficient energy to cause damage to the various debris source materials and summing the quantity of debris source materials that are physically within that spatial volume. This volume is referred to as the ZOI. Modeling the ZOI as a spherical shape is an industry and regulatory accepted approach. An analytical refinement to the calculated ZOI is the methodology used for this analysis in accordance with Section 4.2.2 of NEI 04-07 Volume 2 (Reference 1). This methodology includes a multiple ZOI approach at the specified break location whereby each ZOI spherical radius is dependent on the insulation surrounding the break location.

Modeling the spherical ZOI volume considers the thermodynamic conditions of the fluid released from a given break location and the destruction pressure experimentally observed for selected debris source materials. This approach is consistent with the references identified in Regulatory Guide 1.82 Rev 3 Section 1.3.2.2 (Reference 2) which are based on ANSI/ANS-58.2-1988 “Design Basis for Protection of Light Water Nuclear Power Plants against the Effects of Postulated Pipe Rupture” (Reference 4). ANSI/ANS-58.2-1988 provides an accepted model of the geometry and thermodynamic conditions characterizing the expanding jet downstream of a ruptured pipe. This model is used to determine the isobaric contours of the jet for all of the destruction pressures of interest. The volume enclosed by these contours is then determined by numerical integration. The volume enclosed by a destruction pressure contour of interest defines the volume of the ZOI for debris types of that particular destruction pressure. With the ZOI volume defined, the radial dimension of the ZOI is determined.

Since there are two jets for a double ended guillotine break (DEGB) in RCS piping, the volume calculated for a single jet is doubled and considered to be the volume of the spherical ZOI. The ANSI/ANS-58.2-1988 methodology (Reference 4) considers the critical flow through a given break; this tends to limit the size of the jet that develops for smaller breaks in such a way that when total jet volume is set equal to spherical ZOI volume, the ratio of the spherical ZOI radius to the diameter of the pipe break is constant. AREVA NP independently documents application of this approach to typical PWR conditions. This approach is consistent with the process outlined in Section 3.4.2.1 of NEI 04-07 (Reference 1). Summation of the quantity of debris sources that are within the respective material-specific ZOIs and not shielded from the LOCA blast effects by robust structural barriers determines the total debris generated within the ZOI for that break.

The AREVA NP methodology utilizes ZOIs based on the destruction pressures established for respective debris source materials of interest. The destruction pressures provided in Table 3-2 of NEI 04-07 Volume 2 (Reference 1) are assumed to be applicable. In the cases where Table 3-2 of Volume 2 does not specifically list the debris type of interest, Table 4-1 of NEI 04-07 Volume 1 (Reference 1) is consulted to ascertain the experimentally determined destruction pressure of the debris type. This destruction pressure is then reduced by 40% per guidance in Section 3.4.2.2 of NEI 04-07 Volume 2 (Reference 1).

C.4.3.3 *Piping*

The following steps are involved in processing the piping insulation. Pertinent containment piping is identified based on, but not limited to, insulation types and their location, the location of the trash racks leading to the ECCS sump, the location of the pressurizer, and the postulated break locations. The necessary information pertaining to the pipes of interest is entered into a database for processing. The exact break locations are specified and appropriate ZOIs defined. Finally, the portions of the piping falling within the ZOIs and the corresponding volume of insulation are calculated.

C.4.3.3.1 Data Collection

Compiled piping information and data is obtained from plant drawings. The completed piping database includes the start and end point information of each individual straight leg of insulated pipe including the pipe diameters. Information concerning the type and thickness of insulation installed on each length of pipe is also recorded or conservatively applied, if unknown. This process requires coding each pipe segment by proximity zone. The proximity zone is a pre-defined zone used to indicate its location in containment relative to both potential break locations and robust structural barriers such as walls and floors.

To analyze debris generation for a given break location, all compartments exposed to the break of interest are evaluated and all of the lines in each of theses compartments are included in the input data for processing.

C.4.3.3.2 Data Processing

An AREVA NP methodology is used to calculate the surface area of RMI and the volume of other thermal insulation debris that could be generated during a LOCA inside containment.

Inputs include the pipe break location coordinates, pipe diameters, and the ZOI L/D value for each insulation type of interest. The method uses a series of geometric and conditional arguments to examine each individual line to calculate the quantity of thermal insulation on the line and inside the ZOI. The results provide a tabulation of the quantity of thermal insulation debris generated from the break.

C.4.3.4 *Plant Equipment*

Thermal insulation installed on major plant equipment is a significant portion of the debris generated during a LOCA. This equipment includes SGs, RCPs, and the pressurizer. Insulation surrounding the reactor vessel is not addressed because its location inside the primary bioshield renders it not transportable.

AREVA NP utilizes a developed method to accurately determine the quantity of debris that originates from thermal insulation on major plant equipment. The debris generation result for each piece of equipment that intersects a particular ZOI is added to the debris generation results from piping for that ZOI.

C.4.3.5 *Latent Debris*

This evaluation will use 150 pounds of latent debris. The guidance in NEI 04-07, Volume 2 states that results from plant-specific walkdowns should be used to determine a realistic amount of dust and dirt in containment and to monitor cleanliness metrics that may be necessary following the overall sump-screen blockage vulnerability assessment. The U.S. EPR insulation and cleanliness programs are designed to address GSI-191 issues and limit the potential for debris that may cause sump blockage or debris bypass. The plant will have programs to establish and maintain a plant with a latent debris source term of less than 150 pounds. Based on Section 3.5.2.3 of NEI 04-07 Volume 2 (Reference 1), 85 percent of the latent debris is considered particulate, and 15 percent is considered fibrous.

C.4.3.6 *Miscellaneous Debris*

This evaluation defines miscellaneous debris as debris that is placed inside containment for some operational, maintenance, or engineering purpose. Such debris materials include tape, tags, stickers, adhesive labels used for component identification, fire barrier materials, and a variety of other materials such as rope, fire hoses, ventilation filters, plastic sheeting, etc. Some miscellaneous debris source materials are distinctly two-dimensional with a very thin cross-section (e.g., tape, tags, stickers, labels). This evaluation employs an engineering judgment to provide a practical means of accounting for the potential miscellaneous debris that may be generated by the effects of a postulated LOCA (Assumption C.2.2.3).

C.4.3.7 *Coatings Debris*

Qualified coating amounts are consistent with the guidance outlined in Section 3.4.2.1 of NEI 04-07 Volume 2 (Reference 1). The guidance specifies an L/D value for coatings equal to 10D, or a plant specific analysis may be used to determine the size of the coatings ZOI. Per the latter guidance, testing was conducted to justify reducing the ZOI values for specific types of coatings. Testing demonstrated several coatings that qualified for a ZOI reduction to 4D. The same tests did not show that IOZ coatings could withstand destruction pressures within a 4D ZOI. Therefore, containment IOZ coatings without a topcoat will use a 10D ZOI destruction radius.

The U.S. EPR design will utilize an epoxy topcoat with a 4D ZOI as determined from the testing. The 4D ZOI for epoxy and 10D ZOI for IOZ are used to determine a spherical surface area based on the largest possible pipe break. Section 3.4.3.4 of NEI 04-07 Volume 2 (Reference 1) indicates that plant specific coatings thicknesses must be evaluated. The exact thicknesses of protective coatings in the U.S. EPR design are not yet specified. Therefore, plant specific assumption C.2.2.2 is used to conservatively determine the amount of protective coatings generated from a postulated LOCA. The coating surface area is multiplied by the thickness associated with the qualified coatings to generate the total amount of coatings debris. Though unqualified coatings are not planned within the U.S. EPR containment, a small amount of unqualified coatings are assumed to be present; all of which are assumed to fail.

C.4.3.8 *Additional Debris from Equipment and Major RCS Piping*

The steam generator upper lateral supports are located approximately 43 ft above major RCS piping and require insulation other than RMI. K-wool insulation, or insulation with equivalent destructive pressure, will be used around the steam generator upper lateral supports. Based on Section 3.4.2.2 of NEI 04-07 Volume 2 (Reference 1), K-wool has a ZOI radius of 5.4 times the pipe break diameter. Considering the RCS piping diameter, the ZOI for K-wool generated by a break is 14 ft.

The main RCS piping reaches a high point elevation of 22 ft. Therefore, K-wool insulation at any elevation above 36 ft will not be affected by a main RCS pipe break. Additionally, RCS piping greater than 2 inches does not exist in the area of the steam generator upper lateral supports.

Because the reactor coolant pump support interferes with the crossover leg RMI insulation, an alternate means of insulation at the interference section is required. The approximate volume of the crossover leg interference with the reactor coolant pump support as 0.65 ft^3. Microtherm, or similar microporous insulation, will be installed at this interference point. For conservatism, 1 ft^3 of microtherm insulation will be added to the overall debris source term for all break scenarios.

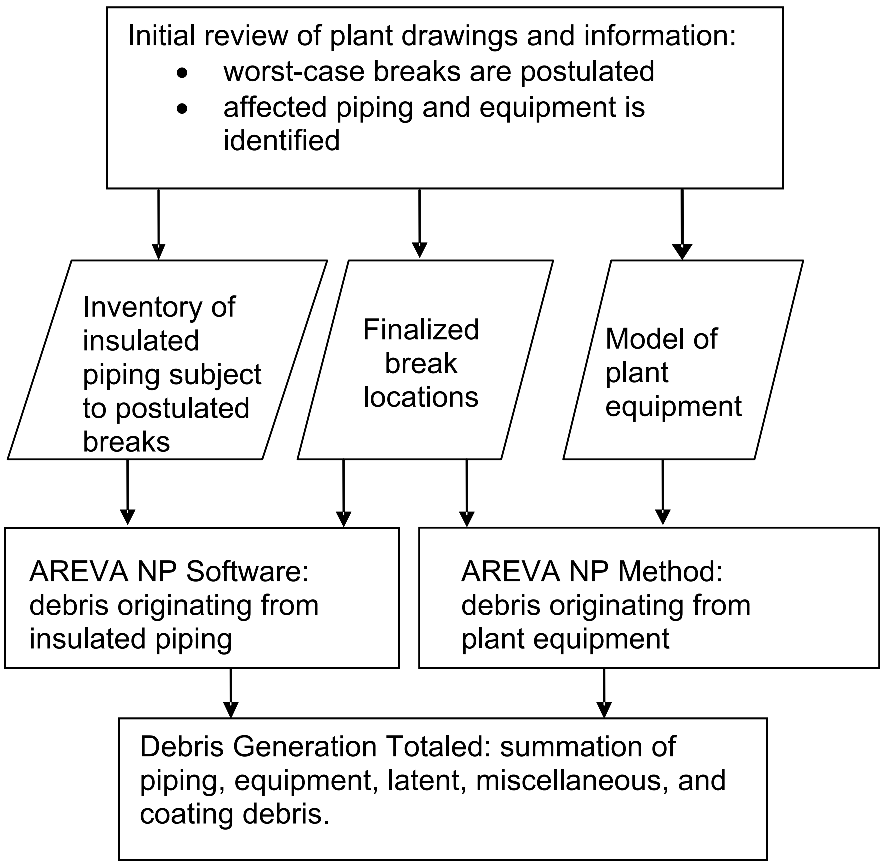
C.4.4 Debris Sizing

Size distribution of generated debris is conservatively estimated based on the guidance in Section 3.4.3 of NEI 04-07 (Reference 1). This guidance employs a two-part distribution of debris sizes for materials generated inside the ZOI of a break. Post-LOCA pool flows have the potential to erode some debris materials and disintegrate other debris materials. Since all fibrous small fines are essentially treated as individual fibers, this evaluation considers the erosion and disintegration of fibrous debris.

C.5 Evaluation Technique

This section details how the technical approach in Section C.4 is implemented for the U.S. EPR debris generation analysis. Figure C.5-1 depicts the process to perform the debris generation analysis.

Figure C.5-1 Debris Generation Analysis Process



C.5.1 Initial Review of Plant Information

Source documentation includes U.S. EPR mechanical and civil layout drawings and containment isometric drawings. When available, the insulation specified by vendor proposals was used to calculate the intended type and amount of insulation. The thickness of the unknown piping insulation is conservatively based on insulation thicknesses of various pipe diameters at other PWR plants.

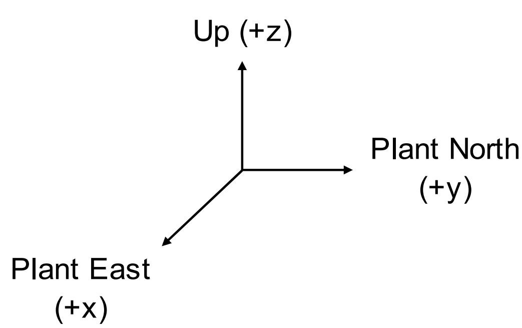
C.5.2 Piping Inventory

A piping inventory database catalogs pertinent information for insulated piping that is potentially affected by the postulated breaks. The piping on the isometric drawings is divided into segments and given a unique identifying descriptor. The pipe segments are defined as a continuous section of pipe going in the same direction with the same diameter and type of insulation.

On each isometric drawing, a starting point is identified in space by a Cartesian coordinate (X, Y, Z format) relative to a spatial reference point. An indication of “N” or “North” on the isometrics, unless otherwise noted, represents plant north and is given a positive “y” axis. Plant east is set as the positive “x” axis, and the “z” axis origin is set at the elevation datum level defined for the U.S. EPR.

Using the Figure C.5-2 Coordinate System, start and end coordinates are determined for each pipe segment, including the lengths of the pipe sections and offset angles as indicated on the isometric drawings.

Figure C.5-2 Pipe Coordinate System



A description of the pipe section, its nominal pipe diameter (or outer diameter for RCS line), insulation type and thickness, number of RMI foils, proximity zone, and other relevant information is collected along with the pipe segment starting and ending coordinates. This information is compiled into a master database and is used as input into the debris generation software tool.

C.5.3 Break Selection Process

The break selection process utilizes the technical approach outlined in Section C.4.3.1 to determine the break locations for the U.S. EPR.

The process postulates break locations that introduce the most critical debris load to the ECCS sump screen. The largest volumes of insulation are located on the steam generators, reactor coolant pumps, pressurizer, and RCS piping within the RCS loop compartments.

The closer the break locations are to the major sources of insulation, the greater the volume of insulation debris generated. The larger the break ZOI, the greater potential to generate insulation debris. The areas affected are directly related to the size of the ruptured pipe. Since the plant is symmetrical in design, the largest potential for debris generation is loop 3 that is connected to the pressurizer. Therefore, loop 3 is used for the break selection process. Because the pressurizer is encased by robust barriers, the pressurizer and piping within the pressurizer zones are not included in the debris generation totals.

Using the technical approach outlined in Section C.4.3.1 combined with large pipes as the source of the LOCA close to the insulated equipment, the break locations are determined. Table C.5-1 provides the basis for each U.S. EPR pipe break selection.

Table C.5-1 Basis for Pipe Break Selections

Pipe Break	Basis for Pipe Break Selection
1. RCS hot leg at SG3 inlet nozzle	a. consistent with NRC RG 1.82 Rev 3 guidance to postulate a hot leg break b. steam generator is a significant potential source of insulation debris and this location is the closest point on the hot leg to the steam generator.
2. RCS cold leg at RCP3 outlet nozzle	a. consistent with NRC RG 1.82 Rev. 3 guidance to postulate a cold leg break
3. Pressurizer surge line at hot leg 3 connection	a. consistent with NRC RG 1.82 Rev 3 guidance to postulate a surge line break b. break has the potential to produce a significant amount of debris because of its proximity to the hot leg and steam generator
4. Pressurizer surge line above cold leg 3	a. consistent with NRC RG 1.82 Rev 3 guidance to postulate a surge line break b. selected as a supplement to Break 3 because of its potential to produce significant debris c. break has the potential to produce significant debris because of its proximity to the cold leg
5. RCS crossover leg 3 at SG3 outlet nozzle	a. analyze at least one break in each of the three legs of the RCS loop b. break has the potential to produce a significant amount of debris because it is a large bore break in close proximity to both the steam generator and the reactor coolant pump
6. Largest safety injection line above the loop 3 trash rack	a. break is the largest bore piping nearest the trash rack with most direct debris path to ECCS sump
7. RCS hot leg 3 at pressurizer surge line connection	a. break has potential to generate significant debris from large bore piping with close proximity to surge line insulation

C.5.4 Piping Insulation Debris

The amount of piping insulation debris is calculated using AREVA NP software. L/D values for the insulation types are determined as discussed in Section 3.4.2.2 of NEI 04-07 Volume 2 (Reference 1). Table C.5-2 provides the L/D values for each insulation type.

Table C.5-2 L/D Values for Each Insulation Type

Insulation Type	Destruction pressure (psig)	ZOI L/D
RMI	114	2.0
Jacketed Nukon® with Sure-Hold® bands	90	2.4
K-wool	24	5.4
Jacketed Nukon® with standard bands	6	17.0

Details for the specific pipe breaks are described in Section C.5.3. Pipe break inputs used in this evaluation are provided in Table C.5-3.

Table C.5-3 Pipe Break Inputs

Pipe Break	Approximate Break Coordinates			Broken Pipe Nominal Diameter (inches)
	X	Y	Z	
1. RCS hot leg at SG3 inlet nozzle	31.113	10.348	21.906	31
2. RCS cold leg at RCP3 outlet nozzle	23.520	27.841	18.504	31
3. Pressurizer surge line at hot leg 3 connection	23.445	8.150	21.276	16
4. Pressurizer surge line above cold leg 3	15.420	21.372	30.066	16
5. RCS crossover leg 3 at SG3 outlet nozzle	35.997	17.397	21.073	31
6. Largest safety injection line above the loop 3 trash rack	42.053	22.59	6.877	12
7. RCS hot leg 3 at pressurizer surge line connection	23.445	8.150	18.504	31

Depending on the break location and size of the ZOIs being considered, certain proximity zones may be excluded if they are shielded by a robust barrier or are found to not intersect with the ZOIs of interest.

C.5.5 Plant Equipment Insulation Debris

The insulation installed on the steam generators, reactor coolant pumps, and pressurizer is modeled using an AREVA NP method. This method calculates the volume of insulation on a piece of equipment enveloped by a spherical ZOI.

The following are methods employed to develop geometric models of the insulation installed on plant equipment.

C.5.5.1 *Steam Generator Model*

The U.S. EPR steam generators are insulated with approximately 5 inch thick RMI which has an L/D value of 2 (Table 3-2 of NEI 04-07 Volume 2 {Reference 1}). For conservatism, 6 inch thick RMI is used for this evaluation.

The steam generator is modeled in six distinct sections to accommodate its geometric configuration. Table C.5-4 provides the section descriptions of the steam generator model.

Table C.5-4 Section Descriptions of the Steam Generator Model

Section Number	Description	Top Elevation (feet)	Bottom Elevation (feet)
1	Top of outlet nozzle: modeled as a cylinder with an insulated radius	101.66	98.90
2	SG top bowl: modeled as a half ellipsoid with an insulated major axis	98.90	94.16
3	SG upper straight section: modeled as a cylinder with an insulated radius	94.16	72.50
4	SG tapered middle section: modeled as a truncated cone with an upper insulated radius and a lower insulated radius	72.50	65.50
5	SG lower straight section: modeled as a cylinder with an insulated radius	65.50	27.79
6	SG bottom bowl: modeled as half sphere with an insulated radius	27.79	21.47

The software program for determining plant equipment insulation debris requires the horizontal cross-sections of plant equipment be circular and the insulation along any given cross-section be of uniform thickness. To fulfill this requirement and to introduce added conservatism, the hot leg nozzle and the crossover leg nozzle openings are assumed to be covered with insulation. The inclusion of these additional insulation quantities represents a very small percentage of the total insulation installed on a steam generator and offsets the quantity not specifically included for nozzles and raised covers.

The software program requires the X and Y coordinates corresponding to the vertical centerline of the steam generator. Table C.5-5 provides the centerlines of the steam generators relative to the reactor pressure vessel centerline.

Table C.5-5 Vertical Center Line of Steam Generators

Equipment	X_{center} (feet)	Y_{center} (feet)
SG 1	-35.90	-11.72
SG 2	-35.90	11.72
SG 3	35.90	11.72
SG 4	35.90	-11.72

C.5.5.2 *Reactor Coolant Pump Model*

The U.S. EPR reactor coolant pumps are insulated with approximately 9.5 inch thick RMI which has an L/D value of 2 (Table 3-2 of NEI 04-07 Volume 2 {Reference 1}). For conservatism, 10 inch thick RMI is used for this evaluation.

The insulated portion of the reactor coolant pump is modeled in four distinct sections to accommodate its geometric configuration. Table C.5-6 provides the section descriptions of the reactor coolant pump model.

Table C.5-6 Section Descriptions of the Reactor Coolant Pump Model

Section Number	Description	Top Elevation (feet)	Bottom Elevation (feet)
1	RCP top: modeled as a cylinder with an insulated radius	22.60	21.51
2	RCP upper sides of casing: modeled as a cylinder with an insulated radius	21.51	19.78
3	RCP center sides of casing: modeled as a cylinder with an insulated radius	19.78	17.22
4	RCP lower sides of casing: modeled as a truncated cone with an upper insulated radius and a lower insulated radius	17.22	14.62

The X and Y coordinates corresponding to the vertical centerline of the reactor coolant pump are also required for this analysis. Table C.5-7 provides the centerlines of the reactor coolant pumps relative to the reactor pressure vessel centerline.

Table C.5-7 Vertical Centerline of Reactor Coolant Pumps

Equipment	X_{center} (feet)	Y_{center} (feet)
RCP 1	-27.79	-31.36
RCP 2	-27.79	31.36
RCP 3	27.79	31.36
RCP 4	27.79	-31.36

C.5.5.3 *Pressurizer Model*

The U.S. EPR pressurizer is insulated with approximately 5.5 inch thick RMI which has an L/D value of 2 (Table 3-2 of NEI 04-07 Volume 2 {Reference 1}). For conservatism, a 6 inch RMI thickness is used for this evaluation.

The pressurizer is modeled in five distinct sections to accommodate its geometric configuration. Table C.5-8 provides the section descriptions of the pressurizer model.

Table C.5-8 Section Descriptions of the Pressurizer Model

Section Number	Description	Top Elevation (feet)	Bottom Elevation (feet)
1	PZR top: modeled as cylinder with an insulated radius	85.42	85.10
2	PZR vessel head: modeled as a half sphere with an insulated radius	85.10	80.74
3	PZR sides: modeled as cylinder with an insulated radius	80.74	45.51
4	PZR bottom bowl: modeled as a half sphere with an insulated radius	45.51	41.15
5	PZR bottom: modeled as cylinder with an insulated radius	41.15	39.44

Table C.5-9 provides the centerline of the pressurizer relative to the reactor pressure vessel centerline.

Table C.5-9 Vertical Centerline of Pressurizer

Equipment	X_{center} (feet)	Y_{center} (feet)
Pressurizer	12.24	44.13

C.5.5.4 *Calculation of Equipment Insulation in the ZOI of a Given LOCA Break*

Using the equipment model information provided in Sections C.5.5.1, C.5.5.1, and C.5.5.3, the volume of equipment insulation in the ZOI for a LOCA break is calculated using AREVA developed methodology. The quantities of equipment insulation debris generated for each LOCA break are summarized in Section C.6.

C.5.6 Insulation from Other Sources

Sections C.4.3.5 through C.4.3.7, of this appendix discuss the technical approach for determining the amounts of latent, miscellaneous, and coatings debris.

C.5.6.1 *Latent Debris*

A conservative value of 150 lb_m of latent debris is used for this evaluation. Based on Section C.4.3.5, the breakdown of latent debris into particulate and fibrous matter is as follows:

latent particulate = 150 lb_m x 0.85 = 127.5 lb_m particulate

latent fibrous = 150 lb_m x 0.15 = 22.5 lb_m fibrous

C.5.6.2 *Miscellaneous Debris*

100 ft^2 of miscellaneous debris (tags, tape, labels, etc.) are added to the debris total of each break location. Most tags and labels within the U.S. EPR containment will be made of stainless steel.

C.5.6.3 *Coatings*

Qualified coatings amounts are consistent with the guidance of Section 3.4.3.4 of NEI 04-07 (Reference 1). This guidance determines the surface area of the spherical ZOI for qualified coatings and multiplies that area by the thickness associated with each type coating. For the U.S. EPR design, 3 mils of an IOZ primer and 12 mils of an epoxy top coat is assumed per plant specific assumption number 1 (Section C.2.2). Outside the ZOI, qualified coatings are assumed to remain intact. Based on Section C.4.3.7, the qualified coatings debris is calculated using a ZOI radius/break diameter multiplier of 10 for the IOZ coatings and 4 for the epoxy coatings. Based on the above guidance and assumptions, the qualified coatings amounts are determined to be 126.3 lb_m for qualified epoxy coatings and 958.7 lb_m for qualified IOZ coatings. Unqualified coatings are assumed to make up 250 lb_m of the total debris source term per plant specific assumption number 1 (Section C.2.2).

C.5.6.4 *Additional Debris from Equipment and RCS Piping*

K-wool insulation located on the steam generator upper lateral supports is not affected by any break location. Therefore, K-wool is not a source of generated debris. For conservatism, an estimated 1 ft^3 of Microtherm, or similar microporous insulation, is added to all break cases as described in Section C.4.3.8.

C.5.7 Debris Size Breakdown

Table C.5-10 provides the breakdown of debris based on the methodology described in Section C.4.4.

Table C.5-10 Size and Distribution of Debris Within the ZOI

Debris Source Type	Debris Size Distribution	
	Small Fines (%)	Large Pieces (%)
RMI	75	25
Microtherm	100	0

C.6 Results

The U.S. EPR debris generation evaluation utilizes the guidance of RG 1.82 Rev. 3 and information presented in NEI 04-07. The debris generation results are derived from the process detailed in Figure C.5-1.

The results of the debris generation process for each break location are presented in the following subsections. The first table in each subsection details and totals the amount and type of piping and equipment insulation. The second table in each subsection provides the total amount of debris generated from each break location.

As detailed in the following Section C.6 Tables, the generated debris totals for coatings, latent debris, and miscellaneous debris are the same for all break locations. The bounding break location is determined by insulation debris generated from the piping and equipment. Table C.6-14 (Break 7) is the bounding break for RMI generation.

C.6.1 Break 1: RCS Hot Leg at SG3 Inlet Nozzle

Table C.6-1 and Table C.6-2 provide the debris generation results for Break 1.

Table C.6-1 Break 1 Insulation Totals

Insulation Type	RMI (ft^2)	Microtherm (ft^3)
Piping	1078.92	
Steam generator	578.41	
Pressurizer	0	
Reactor Coolant Pump	0	
1/2" Piping		
Other from Equipment		1.00
Total	1657.33	**1.00**

Table C.6-2 Break Debris Generation Totals

Debris Source	Particulate	Small Fines	Large Pieces	Total
RMI (ft^2)	0	1243	414.33	**1657.33**
Microtherm (ft^3)	1.00	0	0	**1.00**
Qualified Epoxy Coatings (lb_m)	126.30	0	0	**126.30**
Qualified IOZ Coatings (lb_m)	958.70	0	0	**958.70**
Unqualified Coatings (lb_m)	250.00	0	0	**250.00**
Latent Debris (lb_m)	127.50	22.50	0	**150.00**
Miscellaneous (ft^2)	0	0	100.00	**100.00**

C.6.2 Break 2: RCS Cold Leg at RCP3 Outlet Nozzle

Table C.6-3 and Table C.6-4 provide the debris generation results for Break 2.

Table C.6-3 Break 2 Insulation Totals

Insulation Type	RMI (ft^2)	Microtherm (ft^3)
Piping	852.16	
Steam Generator	0	
Pressurizer	0	
Reactor Coolant Pump	1109.79	
1/2" Piping		
Other from Equipment		1.00
Total	**1961.95**	**1.00**

Table C.6-4 Break 2 Debris Generation Totals

Debris Source	Particulate	Small Fines	Large Pieces	Total
RMI (ft^2)	0	1471.46	490.49	**1961.95**
Microtherm (ft^3)	1.00	0	0	**1.00**
Qualified Epoxy Coatings (lb_m)	126.30	0	0	**126.30**
Qualified IOZ Coatings (lb_m)	958.70	0	0	**958.70**
Unqualified Coatings (lb_m)	250.00	0	0	**250.00**
Latent Debris (lb_m)	127.50	22.50	0	**150.00**
Miscellaneous (ft^2)	0	0	100.00	**100.00**

C.6.3 Break 3: Pressurizer Surge Line at Hot Leg 3 Connection

Table C.6-5 and Table C.6-6 provide the debris generation results for Break 3.

Table C.6-5 Break 3 Insulation Totals

Insulation Type	RMI (ft^2)	Microtherm (ft^3)
Piping	201.06	
Steam Generator	0	
Pressurizer	0	
Reactor Coolant Pump	0	
1/2" Piping		
Other from Equipment		1.00
Total	**201.06**	**1.00**

Table C.6-6 Break 3 Debris Generation Totals

Debris Source	Particulate	Small Fines	Large Pieces	Total
RMI (ft^2)	0	150.80	50.26	**201.06**
Microtherm (ft^3)	1.00	0	0	**1.00**
Qualified Epoxy Coatings (lb_m)	126.30	0	0	**126.30**
Qualified IOZ Coatings (lb_m)	958.70	0	0	**958.70**
Unqualified Coatings (lb_m)	250.00	0	0	**250.00**
Latent Debris (lb_m)	127.50	22.50	0	**150.00**
Miscellaneous (ft^2)	0	0	100.00	**100.00**

C.6.4 Break 4: Pressurizer Surge Line Above Cold Leg 3

Table C.6-7 and Table C.6-8 provide the debris generation results for Break 4.

Table C.6-7 Break 4 Insulation Totals

Insulation Type	RMI (ft^2)	Microtherm (ft^3)
Piping	400.48	
Steam Generator	0	
Pressurizer	0	
Reactor Coolant Pump	0	
1/2" Piping		
Other from Equipment		1.00
Total	**400.48**	**1.00**

Table C.6-8 Break 4 Debris Generation Totals

Debris Source	Particulate	Small Fines	Large Pieces	Total
RMI (ft^2)	0	300.36	100.120	**400.48**
Microtherm (ft^3)	1.00	0	0	**1.00**
Qualified Epoxy Coatings (lb_m)	126.30	0	0	**126.30**
Qualified IOZ Coatings (lb_m)	958.70	0	0	**958.70**
Unqualified Coatings (lb_m)	250.00	0	0	**250.00**
Latent Debris (lb_m)	127.50	22.50	0	**150.00**
Miscellaneous (ft^2)	0	0	100.00	**100.00**

C.6.5 Break 5: RCS Crossover Leg 3 at SG3 Outlet Nozzle

Table C.6-9 and Table C.6-10 provide the debris generation results for Break 5.

Table C.6-9 Break 5 Insulation Totals

Insulation Type	RMI (ft^2)	Microtherm (ft^3)
Piping	1103.74	
Steam Generator	445.33	
Pressurizer	0	
Reactor Coolant Pump	0	
1/2" Piping		
Other from Equipment		1.00
Total	**1549.07**	**1.00**

Table C.6-10 Break 5 Debris Generation Totals

Debris Source	Particulate	Small Fines	Large Pieces	Total
RMI (ft^2)	0	1144.87	381.62	**1526.49**
Microtherm (ft^3)	1.0	0	0	**1.00**
Qualified Epoxy Coatings (lb_m)	126.30	0	0	**126.30**
Qualified IOZ Coatings (lb_m)	958.70	0	0	**958.70**
Unqualified Coatings (lb_m)	250.00	0	0	**250.00**
Latent Debris (lb_m)	127.50	22.50	0	**150.00**
Miscellaneous (ft^2)	0	0	100.00	**100.00**

C.6.6 Break 6: Largest Safety Injection Line Above the Loop 3 Trash Rack

Table C.6-11 and Table C.6-12 provide the debris generation results for Break 6.

Table C.6-11 Break 6 Insulation Totals

Insulation Type	RMI (ft^2)	Microtherm (ft^3)
Piping	200.69	
Steam Generator	0	
Pressurizer	0	
Reactor Coolant Pump	0	
1/2" Piping		
Other from Equipment		1.00
Total	**200.69**	**1.00**

Table C.6-12 Break 6 Debris Generation Totals

Debris Source	Particulate	Small Fines	Large Pieces	Total
RMI (ft^2)	0	150.52	50.17	200.69
Microtherm (ft^3)	1	0	0	**1.00**
Qualified Epoxy Coatings (lb_m)	126.30	0	0	**126.30**
Qualified IOZ Coatings (lb_m)	958.70	0	0	**958.70**
Unqualified Coatings (lb_m)	250.00	0	0	**250.00**
Latent Debris (lb_m)	127.50	22.50	0	**150.00**
Miscellaneous (ft^2)	0	0	100.00	**100.00**

C.6.7 Break 7: RCS Hot Leg 3 at Pressurizer Surge Line Connection

Break 7 generates the most RMI. Table C.6-13 and Table C.6-14 provide the debris generation results for Break 7.

Table C.6-13 Break 7 Insulation Totals

Insulation Type	RMI (ft^2)	Microtherm (ft^3)
Piping	2119.03	
Steam Generator	0	
Pressurizer	0	
Reactor Coolant Pump	0	
1/2" Piping		
Other from Equipment		1.00
Total	**2119.03**	**40.00**

Table C.6-14 Break 7 Debris Generation Totals

Debris Source	Particulate	Small Fines	Large Pieces	Total
RMI (ft^2)	0	1589.27	529.76	2119.03
Microtherm (ft^3)	1.00	0	0	**1.00**
Qualified Epoxy Coatings (lb_m)	126.30	0	0	**126.30**
Qualified IOZ Coatings (lb_m)	958.70	0	0	**958.70**
Unqualified Coatings (lb_m)	250.00	0	0	**250.00**
Latent Debris (lb_m)	127.50	22.50	0	**150.00**
Miscellaneous (ft^2)	0	0	100.00	**100.00**

C.7 References

1. NEI 04-07, “Pressurized Water Reactor Sump Performance Evaluation Methodology,” Volumes 1 (Methodology) and 2 (Safety Evaluation), December 2004.

2. Regulatory Guide 1.82 Rev 3, "Water Sources for Long-Term Recirculation Cooling following a Loss-Of-Coolant Accident," November 2003.

3. NUREG/CR-6224, "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris," October 1995.

4. ANSI/ANS-58.2-1988, "Design Basis for Protection of Light Water Nuclear Power Plants against the Effects of Postulated Pipe Rupture."