From: Severance, Sandra N
To: Cotton, Karen
Cc: Handrick, Mark C
Subject: [External_Sender] FW: NRC request to receive Oconee LOCA Sumamry Report
Date: Friday, June 26, 2015 2:00:30 PM
Attachments: 86-9150446-000_ONS Full-Core HTP LOCA Summary Report.pdf

---

LOCA Summary Report 86-9150446-000 is being provided in support of NRC review of the license amendment request to revise Oconee Nuclear Station Technical Specification 3.5.2. The report is non-proprietary; however, certain references within the document contain proprietary information. Such information is subject to withholding from public disclosure per the requirements of 10 CFR 2.390.

Please feel free to contact me if you have further questions or requests.

Sandra N. Severance
Oconee Regulatory Affairs
864-873-3466
Sandra.Severance@duke-energy.com

AREVA

CALCULATION SUMMARY SHEET (CSS)

Document No. 86 - 9150446 - 000 Safety Related: ☒ Yes ☐ No

Title ONS Full-Core Mark-B-HTP, Gadolinia Fuel, & 24 Month Cycle LOCA Summary Report

PURPOSE AND SUMMARY OF RESULTS:

Duke Energy Carolinas, LLC (Duke Energy) operates the B&W-designed plants Oconee Nuclear Stations 1, 2 and 3 (ONS). Duke Energy has transitioned their ONS units to AREVA Inc. (AREVA) Mark-B-HTP fuel. As part of this effort, AREVA has performed new loss-of-coolant accident (LOCA) linear heat rate (LHR) limit analyses to support this transition. These analyses consider a full-core of Mark-B-HTP fuel at five core elevations at beginning-of-life (BOL), middle-of-life (MOL), and end-of-life (EOL) conditions. The major cycle changes for these LOCA analyses are the integration of a full-core of Mark-B-HTP fuel, incorporating Gadolinia fuel, increased steam generator tube plugging (SGTP), and use of the RELAP5 default actinide model. The purpose of this document is to summarize the results of these analyses and demonstrate compliance with the 10 CFR 50.46 criteria.

The full-core Mark-B-HTP LBLOCA analyses with Gadolinia fuel for a 24-month fuel cycle for ONS at 102% power were performed to define the allowable LOCA LHR limits and determine the corresponding PCTs. The limiting PCT was calculated to be 1913 F at the 2.506 ft peak power elevation at BOL condition, where the LHR limit should not exceed 17.8 kW/ft. The other LHR limits are given for each core elevation for UO_2 and Gadolinia fuels, in all time in life (TIL) of the fuel. Moreover, it was determined from previous analyses that the full power LBLOCA case is limiting to the partial power case.

A full break size spectrum for SBLOCA analyses was performed with an axial peak of 10.811-ft and a 1.7 power shape, to determine the limiting PCT for the Mark-B-HTP fuel design in a full-core configuration. The limiting PCT of 1597.5 F was produced by the 0.15 ft^2 Cold Leg Pump Discharge (CLPD) break with a Loss of Offsite Power (LOOP) for ONS 102% power SBLOCA analyses. In addition, the analyses were performed to determine the maximum break size used in the Mark-B-HTP SBLOCA spectrum. The results of this analysis concluded that the maximum break size for the Mark-B-HTP spectrum for ONS 102% power is the 0.5 ft^2 CLPD break size. Moreover, the Mark-B-HTP full core 52% full power analysis was also performed for a SBLOCA scenario to ensure that ONS units can safely operate at 52% power while it repairs one of its HPI pumps. The limiting PCT of 1480.2 F for ONS 52% full power SBLOCA analysis was produced by the 0.072 ft^2 CLPD break with LOOP.

The ONS plants have been shown to be in compliance with the five criteria of 10 CFR 50.46 for both the LBLOCA and SBLOCA analyses. Compliance with the first three criteria of 10 CFR 50.46 has been demonstrated based on analyses with the LOCA evaluation model (EM) described in BAW-10192P-A (Reference [1]). Compliance with the remaining two criteria of 10 CFR 50.46 is demonstrated through a combination of evaluations, analyses, monitoring and testing.

THE FOLLOWING COMPUTER CODES HAVE BEEN USED IN THIS DOCUMENT:

CODE/VERSION/REV	CODE/VERSION/REV
N/A	

THE DOCUMENT CONTAINS ASSUMPTIONS THAT SHALL BE VERIFIED PRIOR TO USE

☐ YES
☒ NO

Review Method: ☒ Design Review (Detailed Check)
☐ Alternate Calculation

Signature Block

Name and Title (printed or typed)	Signature	P/R/A and LP/LR	Date	Pages/Sections Prepared/Reviewed/Approved
A M Spontarelli Engineer II	[signature]	LP	7/20/11	All
A J Busocker Engineer I	[signature]	P	7/20/11	LBLOCA and SBLOCA full power information.
B M Smith Engineer III	[signature]	LR	7/20/11	All
A Jirapongmed Engineer III	[signature] for A. Jirapongmed	R	7/21/2011	LBLOCA and SBLOCA full power information.
G S Uyeda LOCA, ECCS & BWR Manager	[signature] for G.S. Uyeda	A	7/22/2011	All/ Reviewer Independence

Note: P/R/A designates Preparer (P), Reviewer (R), Approver (A);
LP/LR designates Lead Preparer (LP), Lead Reviewer (LR)

Project Manager Approval of Customer References (N/A if not applicable)

Name (printed or typed)	Title (printed or typed)	Signature	Date
Jason St.Clair	Project Manager	[signature]	7/22/11

Record of Revision

Revision No.	Date	Pages/Sections/ Paragraphs Changed	Brief Description / Change Authorization
000	7/2011	All	Initial Release

Table of Contents

Table of Contents
(continued)

Page

List of Tables

Page

List of Tables
(continued)

Page

List of Figures

Page

List of Figures
(continued)

List of Figures
(continued)

List of Figures
(continued)

1.0 INTRODUCTION AND PURPOSE

Duke Energy Carolinas, LLC (Duke Energy) operates the B&W-designed plants Oconee Nuclear Stations 1, 2 and 3 (ONS). Duke Energy has transitioned their ONS units to AREVA NP Inc. (AREVA) Mark-B-HTP fuel. As part of this effort, AREVA has performed new loss-of-coolant accident (LOCA) linear heat rate (LHR) limit analyses to support this transition. The major cycle changes for these LOCA analyses are the integration of a 24-month cycle full-core of Mark-B-HTP fuel incorporating Gadolinia fuel, increased steam generator tube plugging (SGTP), and use of the RELAP5 default actinide model.

This document summarizes the large break LOCA (LBLOCA) analyses, considering a full-core of Mark-B-HTP fuel. The large break analyses were performed to determine the allowable LHR limits as a function of core elevation for all times in life (TIL) of fuel operation (up to 62 GWd/mtU rod average burnup). In addition, this document summarizes small break LOCA (SBLOCA) analyses performed with an 11-ft axial power peak to define the maximum peak cladding temperature (PCT) for the entire break spectrum for Mark-B-HTP fuel in a full-core configuration. The first SBLOCA analysis is performed at full power with 2 high pressure injection (HPI) pumps available, and the other at 52% full power (50% plus 2% uncertainty) with a single HPI pump out of service (therefore only 1 HPI available after single failure assumption). In addition, steam generator (SG) blowdown from one atmospheric dump valve (ADV) was credited to open at 25 minutes after engineered safety features actuation system (ESFAS) for 52% full power SBLOCA analyses.

The purpose of this document is to summarize the results of these analyses and demonstrate compliance with the Nuclear Regulatory Commission (NRC) 10 Code of Federal Regulator (CFR) 50.46 criteria.

2.0 KEY ASSUMPTIONS

There are no key assumptions associated with this document. The boundary conditions and operator actions considered in the LOCA analyses are discussed in Section 5.0.

3.0 SUMMARY OF RESULTS

Analyses were performed with the NRC-approved RELAP5/MOD2-B&W evaluation model (EM) as amended by NRC-approved code topical revisions and associated approved changes with 10 CFR 50.46 preliminary safety concerns (PSCs) (summarized in Section 4.0) for ONS. These analyses demonstrate compliance with the acceptance criteria for breaks up to and including the double-ended severance of the largest primary coolant pipe. They also generate allowable core LHR limits for the full-core Mark-B-HTP fuel. These limits are valid for the Oconee units with ROTSGs and LPI cross-tie modification for a plant symmetric steam generator tube plugging up to 7%. An initial core power level of 1.02 times 2568 MWt was analyzed. A summary of the results is presented in the following subsections.

A SBLOCA spectrum at 52% full power (50% plus 2% uncertainty) was also analyzed for a single HPI pump out of service. With only 1 HPI pump available, adequate core cooling was assured by crediting SG blowdown from 1 ADV at 25 minutes after ESFAS. A summary of the partial power SBLOCA analyses is presented in the following subsections as well.

3.1 Adherence to 10 CFR 50.46 Criteria

10 CFR 50.46 specifies that the emergency core cooling system for a commercial nuclear power plant must meet five criteria:

1. The calculated peak cladding temperature (PCT) is less than 2200 F.
2. The maximum calculated local cladding oxidation is less than 17.0%.
3. The maximum amount of core-wide oxidation does not exceed 1.0% of the fuel cladding.
4. The cladding remains amenable to cooling.
5. Long-term cooling is established and maintained after the LOCA.

These criteria are discussed in detail in the following subsections.

3.1.1 Peak Cladding Temperature

The first criterion of 10 CFR 50.46 requires that the calculated peak cladding temperature remains below 2200 F. The peak cladding temperature results for the full-core Mark-B-HTP analyses are summarized in Table 3-1 and Table 3-2. For all LOCA cases, the PCT was calculated to be less than 2200 F.

The limiting full-core Mark-B-HTP 102% full power LBLOCA PCT was calculated to be 1913 F at the 2.506 ft peak power elevation at BOL (Section 10.5, Reference [8]). The limiting full-core Mark-B-HTP 102% full power SBLOCA PCT of was calculated to be 1597.5 F with a 0.15 ft^2 size break, at the CLPD, with a LOOP (Section 11.0, Reference [9]). The limiting full-core Mark-B-HTP 52% full power SBLOCA PCT of was calculated to be 1480.2 F with a 0.072 ft^2 size break, at the cold-leg pump discharge (CLPD), with break initiation coincident with loss-of-offsite power (LOOP) (Section 10.0, Reference [10]). Therefore, this criterion is satisfied for a full-core of Mark-B-HTP fuel.

3.1.2 Local Cladding Oxidation

The second criterion of 10 CFR 50.46 requires that the maximum degree of local cladding oxidation not exceed 17%. Compliance with this criterion is obtained by evaluating the results of the calculation of peak cladding temperature. In the calculation, the local cladding oxidation is computed as long as the cladding temperature remains above 1000 F.

The hot channel local oxidation values for the Mark-B-HTP full-core LBLOCA analyses are summarized in Table 3-1. In all cases, the LBLOCA hot channel local cladding oxidation was less than 3%, which is significantly less than 17%. For SBLOCAs, the results summarized in Table 3-2 confirmed that the amount of local cladding oxidation is less than 1%, which is also significantly less than 17%. Therefore, this criterion is satisfied for a full-core of Mark-B-HTP fuel.

The oxidation values were calculated using a conservative (minimum) initial oxide thickness to maximize the cladding temperature response due to metal-water reaction. In response to Question 24 in Appendix I of the M5® cladding topical report (Reference [2]), AREVA committed to perform a supplemental local oxidation check that uses realistic pre-accident initial oxidation values in combination with the accident transient oxidation to confirm that the 17% criteria is not violated. Reference [11] provides a set of guidelines to check the local oxidation limits with respect to realistic initial oxidation. These checks were performed in Section 10.5.2 of Reference [8] for LBLOCA, Section 11.2 of Reference [9] for SBLOCA at full power, and Section 9.2 of Reference [10] for SBLOCA at 52% full power analyses.

3.1.3 Whole-Core Oxidation and Hydrogen Generation

The third criterion of 10 CFR 50.46 states that the calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel reacted, excluding the cladding surrounding the plenum volume.

Whole-core hydrogen generation was determined based on the method outlined in Section 6 of the evaluation model (Reference [1]). The maximum LBLOCA whole-core hydrogen generation for Mark-B-HTP fuel assemblies in a full-core configuration was calculated to be less than 0.16% for all cases, as summarized in Table 3-1. For the full and partial power SBLOCA analyses, the maximum whole-core hydrogen generation rate was calculated to be less than 0.04% for all cases as summarized in Table 3-2.

The LOCA cases summarized in this report encompass achievable steady state power distributions for a range of fuel burnups. The maximum possible oxidation increase that can occur during a LOCA has been enveloped for ONS units and a significant margin has been demonstrated to the 1% limit contained in the third criterion of 10 CFR 50.46. Therefore, this criterion is satisfied for a full-core of Mark-B-HTP fuel (Section 10.5 Reference [8], Section 11.0 of Reference [9], and Section 9.3 of Reference [10]).

3.1.4 Coolable Core Geometry

The fourth acceptance criterion of 10 CFR 50.46 states that calculated changes in core geometry shall be such that the core remains amenable to cooling. Compliance with this criterion is based on considerations that include the condition of the fuel rods and assembly just prior to the LOCA transient, plus, any changes in geometry predicted as a result of the mechanical or thermal effects from the LOCA. Therefore, the effects of fuel rod bowing,

mechanical deformation from LOCA plus seismic (safe shutdown after an earthquake) dynamic loads, and the swelling and rupture alterations of the fuel pins and assembly flow area from the thermal effects during a LOCA are evaluated. These considerations must be examined to ensure that any geometry changes that occur will not result in gross core blockage or disfiguration that impairs or hinders control rod operation to less than that which is credited in the LOCA analyses.

The effects of fuel rod bowing on assembly flow area and control rod guide tubes are considered in the fuel assembly and fuel rod designs, which minimize the potential for rod bow. The effects of rod bowing on pin peaking limits must also be considered as part of the maneuvering analyses to verify that minor adjustment of fuel pin pitch due to rod bowing does not alter the fuel assembly flow area substantially, and the average channel sub-channel flow area is preserved until the LOCA transient is initiated.

When the LOCA is initiated, the mechanical loads on the reactor vessel from the break opening results in short-term or dynamic loads that, given a large enough amplitude, could cause disfiguration or distortion of the core support structures, reactor vessel internals and the fuel assemblies. The maximum assembly loading occurs before the fuel pin experiences any significant heat-up. Therefore, the mechanical effects are evaluated separately from the LOCA PCT analyses. Stress analyses of these dynamic blowdown effects, in combination with the seismic loads from an earthquake, are used to evaluate the mechanical loads on these components. The leak-before-break (LBB) methodology in BAW-2292 (Reference [14]), as approved in Reference [15], is used in determining the LOCA and seismic impact loads. The spacer grid impact loads, and the stresses and loads for all other components must be shown to be less than the allowed limits from the combined mechanical loading of the LOCA and seismic events, to demonstrate fuel coolability and control rod insertion are assured. Revision 4 of Reference [40] evaluated the impact loads and stresses and concluded that the component loads remained in the elastic ranges such that there was no initial deformation of the fuel bundle or core geometry from the LOCA plus seismic loads.

The RELAP5/MOD2-B&W and BEACH, 10 CFR 50.46 calculations directly assess the alterations in core geometry from the clad swelling and rupture during a LOCA. These calculations demonstrate that the fuel pin is cooled successfully during the short-term phase of the LOCA. For the Mark-B-HTP fuel, the hot assembly flow area reduction at rupture is less than 50% for all analyzed LBLOCA cases (Page B-30, Reference [8]), and is less than 71% for all analyzed SBLOCA cases (References [9] and [10]). Furthermore, the upper limit of possible channel blockage for all LOCA, based on NUREG-0630 and Reference [2], is 90% since the rupture in a fuel assembly is distributed between the grid spans and does not become coplanar across the assembly. Therefore, the assembly retains a pin-coolant-channel arrangement that is capable of passing coolant along the pin to provide cooling for all regions of the assembly.

The consequences of both mechanical and thermal deformation of the fuel assemblies in the core have been assessed. The resultant deformations have been shown to maintain control rod operation and coolable core configurations to successfully demonstrate that the coolable geometry requirements of 10 CFR 50.46 have been met and that the core is shown to remain amenable to core cooling.

3.1.5 Long-Term Core Cooling

The fifth acceptance criterion of 10 CFR 50.46 states that the calculated core temperature shall be maintained at an acceptably low value, and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core. Compliance with this criterion is generally not dependent on the fuel design in use. Demonstration that the entire core has quenched, and the cladding temperatures have returned to approximately the saturation temperature; shows successful initial operation of the emergency core cooling system (ECCS) as augmented by the emergency feedwater (EFW) induced steam generator heat removal.

Thereafter, long-term cooling is achieved by following plant-specific Emergency Operating Procedure (EOP) guidance to maintain the operation of the pumped ECCS injection systems while taking suction from the borated water storage tank (BWST) and the EFW system (if the break size is not capable of removing the core generated energy). As the BWST empties, successful transfer of the HPI pump source to the discharge of the low pressure injection (LPI) pumps (if required based on the plant specific Emergency Operation Procedure guidance) and successful suction transfer of the LPI source from the BWST to the containment emergency sump ensures a continuous ECCS flow to the core. The operators must either refill the EFW water supply, or transfer the suction to other sources for small break sizes that require steam generator heat removal to augment the break energy discharge for very small break sizes. The continuous ECCS flow (and EFW, as required) ensures adequate to abundant core cooling. The pumped injection systems, including the piping arrangements, are redundant and should be capable of providing a continuous flow of ECCS water to the open coolant channels in the fuel assemblies or EFW to the steam generator even with the most limiting single failure. The redundancy should allow for alternate alignments that could be used to facilitate any maintenance needed to support system operation until no longer needed.

Additional areas which are examined and related to Long-Term Cooling, include the evaluation of the effect of debris accumulation in critical locations (via GSI-191), the potential for boron precipitation to block core or any other vital coolant paths, perform maintenance necessary for long-term core cooling, and the consequences of a LOCA that results in tube loads that cause consequential steam generator tube rupture (Preliminary Safety Concern (PSC) 2-98). These items are discussed below in more detail.

<u>GSI-191</u> - The concerns expressed about continuous long-term core cooling associated with debris, GSI-191, must be adequately addressed. This includes the evaluation of the content and quantity of debris generated by the LOCA, evaluation of its transport and potential for obstruction of the sump screen, and evaluation of the downstream effects of debris that passes through the sump screen. A portion of this issue was addressed in the evaluation of downstream effects for ONS (Reference [17]). Other activities related to GSI-191 are being performed by Duke Energy to support the compliance with this criterion.

<u>Boron Precipitation</u> - For a cold leg break, or any scenario for which core exit subcooling is not reestablished, the concentration of boric acid within the core might induce a crystalline precipitation, which could prevent the coolant flow from reaching certain portions of the core. The concentration of dissolved solids must be limited to acceptable levels through both passive and active means that initiate an adequate flow through the core. The assured passive means may include loop refill and restoration of liquid natural circulation or liquid recirculation through the reactor vessel vent valves. The loop refill is not a viable alternative for larger break sizes in the cold leg discharge piping. In these cases core exit subcooling is not restored and long term core cooling is provided when the operators establish active methods specified in the plant EOPs.

The current LOCA boron concentration controls established by Duke Energy must provide direction to ensure that there is forced flow through the reactor vessel to dilute any boron concentration buildup. These controls must contain both passive and active means to ensure long-term cooling is established and maintained. The implementation of the Mark-B-HTP fuel assembly design should be considered by Duke Energy to ensure it does not affect the ability to control boron concentration utilizing the methods established by Duke Energy.

<u>PSC 2-98: Design LOCA Loads for OTSG Tube Repair Products</u> - Historically, the OTSGs were evaluated against the RV nozzle LBLOCA transient but consideration of this transient was dropped following the approval of leak-before-break (LBB) methodologies. Following the generic LBB approval, the OTSG tube repair products utilized the tensile loads on the SG tubes resulting from a main steam line break transient. The purpose of PSC 2-98 was to examine various attached pipe LOCA transients that could result in tube loads approaching or exceeding those from a main steam line break transient (Reference [16]). The resolution of the PSC resulted in a re-evaluation of the main steam line break and limiting LOCA attached line breaks. A LOCA in the pressurizer

surge line was determined to be the most limiting attached pipe breaks for lowered loop B&W plants (Pages 1-3, Reference [18]). However, the NRC did not accept a limiting attached pipe break as the limiting LOCA scenario and they continued to press for the hot leg U-bend transient to be included in the ROTSG tube load assessments. Duke Energy must ensure that the commitments to the NRC regarding PSC 2-98 attached pipe LOCAs and the hot leg U-bend LOCAs are successfully fulfilled by considering the loads from these three transients in the ROTSGs or ROTSG tube repair products. Further, Duke Energy must demonstrate long-term cooling is established and maintained by ensuring that a SG tube rupture as a consequence of the refill from a LOCA either does not occur or if it is postulated to occur, does not result in primary-to-secondary leakage that can deplete the sump liquid inventory needed to preserve the net positive suction head (NPSH) for the LPI pumps.

Compliance with this long-term cooling criterion is not explicitly demonstrated by the 10 CFR 50.46 LOCA analyses for the systems and components specific to the ONS plants. Compliance is implied in this section and augmented by a variety of supporting analyses, most of which are controlled by Duke Energy. The initial phase of core cooling has been shown by the LOCA analyses to result in acceptable cladding and fuel temperatures. Long-term core cooling relies primarily on the plant operators and their EOP guidelines and training to maintain the required pumped injection flow rates and to successfully manage the core boron concentration to keep the reactor shutdown and prevent boron precipitation in the core. All actions specified in the plant specific EOPs should be performed to successfully mitigate the consequences of the LOCA and ensure that long-term cooling is assured. The implementation of the Mark-B-HTP fuel assembly design should not affect the ability to maintain long-term cooling after a postulated LOCA.

3.2 Summary of LBLOCA Results

For LBLOCA analyses, five axial power peaks centered at the middle of the five grid spans (at elevations of 2.506, 4.264, 6.021, 7.779, and 9.536-ft) were analyzed with a constant axial peak of 1.7; the radial peak was adjusted to obtain an allowable LHR limit. The initial fuel conditions for the desired peaking conditions are obtained from the approved steady-state fuel code (in this case TACO3 (Reference [3]) for UO_2 fuel and GDTACO (Reference [45]) for Gadolinia fuel).

Generally, the LHR limit for beginning of life (BOL) and middle of Life (MOL) LBLOCA analyses was determined by adjusting the LHR to achieve a PCT within the range of 1950 F to 2050 F. While there is a target PCT range for LBLOCA, the LHR limits may be reduced to support the maximum power limits imposed on the BEACH code reflooding power peaking or by SBLOCA upper elevation limits. These five core elevations are analyzed at both BOL and MOL to produce the PCT-limited LHR limits. However, at end of life (EOL), the TACO3 LOCA initialization is limited to a LHR that achieves a maximum initial pin pressure, because it is generally not limited by the LOCA PCT. One representative LBLOCA analysis is performed to confirm that EOL is not PCT limited.

The BOL analyses were analyzed at 0 GWd/mtU. The MOL analyses were analyzed at a rod average burnup of 34 GWd/mtU, which supports a hot spot burnup of approximately 40 GWd/mtU while the EOL analyses were analyzed at a rod average burnup of 62 GWd/mtU supporting a hot spot burnup of approximately 74 GWd/mtU.

The LBLOCA calculations for Mark-B-HTP fuel in a full-core configuration with the ROTSGs and the LPI cross-tie modification are documented in Reference [8]. These LOCA analyses demonstrate compliance to the first three 50.46 criteria for a full core of Mark-B-HTP fuel assemblies with 2, 4, 6 and 8 weight percent (w/o) Gadolinia fuel rods. Table 3-3 and Figure 3-1 specify the UO_2 LHR limits that were determined for the entire length of the core at all time-in-life (TIL) (for rod average burnups up to 62 GWd/mtU). How the core inlet and outlet LHR limits were determined is discussed in Section 6.2.3.6. The Gadolinia fuel has lower fuel thermal conductivity and volumetric heat capacities than the UO_2 fuel, and therefore will respond more slowly to changes in the thermal environment. The allowed peaking or LHR limits for Gadolinia is developed based on targeting PCTs similar to the UO_2 fuel. The derived Gadolinia LHR limits are given in Table 3-4 to Table 3-7 and Figure 3-2 to

Figure 3-5 for 2, 4, 6 and 8 w/o enriched Gadolinia fuel rods. A detailed discussion of these results is presented in Section 6.2.3.4.

Steady-state and transient energy deposition factors (EDFs) specific to the time in life were used for the hot channel and hot pin. The EDFs considered in each analysis are summarized in the notes to each Table. Additional details on the sequence of events and summary of results for each LBLOCA case are provided in Section 6.0.

Other considerations for application of the LOCA LHR limits are the moderator temperature coefficient (MTC), fuel assembly bounding power history, and radial and axial core peaking factors for PCT limited BOL and MOL cases. These parameters preserve EM limitations and restrictions and ensure the calculated PCTs are not violated. The MTC for each fuel cycle must be equal to or below the MTC versus power level limit shown in Figure 3-6. This MTC ensures that the full power peak cladding temperatures remain bounding for lower power LOCA applications with positive MTCs. Verification that the core design remains below the MTC curve is performed on a cycle specific basis for each fuel reload.

The core power distribution analyses must consider variations in the radial and axial peaking for scenarios with limiting LOCA LHR margins to comply with an EM limitation and restriction. In some cases, the LHR limit may need to be reduced to ensure that the calculated PCT produced by an axial peak of 1.7 is limiting. Table 3-1 summarizes compliance with 10 CFR 50.46 for the LBLOCA analysis. Section 8.0 provides additional details on the required adjustments to meet this EM limitation.

3.3 Summary of SBLOCA Results

For the SBLOCA analyses an axial peaking factor of 1.7 with a power shape skewed to 11 ft is considered. This approach maximizes the cladding temperature increase during the time of core uncovering. Both the full power and partial power analyses utilized a LHR limit of 17.3 kW/ft with a steady-state EDF of 0.973 and a transient EDF of 1.0 (References [9] and [10]).

Gadolinia fuel has lower fuel thermal conductivity and volumetric heat capacities than the UO_2 fuel. The allowed peaking or LHR limits for Gadolinia are reduced to control the LBLOCA PCTs. The reduction in LHR limits for Gadolinia is larger than the volumetric heat capacity differences between Gadolinia and UO_2. Since the LHR limit reduction for Gadolinia is greater than the volumetric heat capacity ratio, the PCTs for Gadolinia rods will be lower, so they are not explicitly included in the SBLOCA analyses.

The small break LOCA calculations for the full-core Mark-B-HTP fuel with the ROTSGs and the LPI cross-tie modification are documented in References [9] and [10]. The most limiting full-core Mark-B-HTP SBLOCA is a 0.15-ft^2 break in the cold leg pump discharge piping (CLPD) with LOOP at full power. A SBLOCA spectrum at 52% full power (50% plus 2% uncertainty) produces a peak cladding temperature for a break size of 0.072 ft^2 in the CLPD with LOOP. Table 3-2 summarizes compliance with 10 CFR 50.46 for both SBLOCA analyses. The full sequence of events and analytical results for each SBLOCA case analyzed are provided in Section 7.0.

Table 3-1: Summary of 10 CFR 50.46 Compliance for Mark-B-HTP Full-Core LBLOCA

Criteria	Acceptance Criteria	Mark-B-HTP (Reference [8])
PCT	2200 F	1913 F
Maximum Local Oxidation	17 %	< 3%
Whole Core H_2 Generation	1%	< 0.16%
Coolable Geometry	Core remains amenable to cooling	Section 3.1.4
Long Term Cooling	LTC shall be established and maintained	Section 3.1.5

Table 3-2: Summary of 10 CFR 50.46 Compliance for Mark-B-HTP Full-Core SBLOCA

Criteria	Acceptance Criteria	Mark-B-HTP (Reference [9] and [10])	
		102% Full Power	52 % Full Power
PCT	2200 F	1597.5 F	1480.2 F
Maximum Local Oxidation	17 %	< 1.0%	< 1.0%
Whole Core H_2 Generation	1%	< 0.04%	< 0.01 %
Coolable Geometry	Core remains amenable to cooling	Section 3.1.4	
Long Term Cooling	LTC shall be established and maintained	Section 3.1.5	

Table 3-3: Summary of Mark-B-HTP UO_2 LHR Limits

(Table 10-12 of Reference [8])

Elevation ft	BOL (0 GWd/mtU)		MOL (34 GWd/mtU)		EOL (62 GWd/mtU)	
	LOCA LHR Limit kW/ft	PCT F	LOCA LHR Limit kW/ft	PCT F	LOCA LHR Limit kW/ft	PCT F
0.0	*16.9*	*< 1913.2*	*16.9*	*< 1879.0*	*12.3*	*< 1688.3*
2.506	**17.8**	**1913.2**	**17.8**	**1879.0**	**12.3**	**1618.3**
4.264	**17.8**	**1897.2**	**17.8**	**1858.3**	*12.3*	*1618*
6.021	**17.8**	**1907.0**	**17.8**	**1873.6**	*12.3*	*1618*
7.779	**17.8**	**1905.7**	**17.8**	**1863.3**	*12.3*	*1618*
9.536	**17.3**	**1864.5**	**17.3**	**1805.2**	*12.3*	*1668*
12.0	*16.4*	*< 1864.5*	*16.4*	*< 1805.2*	*12.3*	*< 1738*

Notes:

1. The LHR limits presented above represent the power generated by the pin, i.e. all sources of usable energy caused by the fission process.

2. All analyzed LHR limits and PCTs are shown in bold font, whereas all estimated LHR limits and PCTs are shown in italicized font.

3. Analyses at BOL and MOL used a steady-state EDF of 0.973 for initial core energy and a transient EDF of 1.0 for UO_2. The analysis at EOL used a steady-state EDF of 0.993 for initial core energy and a transient EDF of 1.089 for UO_2.

4. Linear interpolation for LHR limits is allowed between elevations and times in life.

5. The PCT-limited LHR limits below 2.506 ft are reduced by 0.95 × $LHR_{2.506}$ at 0.0 feet at BOL and MOL. The PCT-limited LHR limits above 9.536 ft are reduced by 0.95 × $LHR_{9.536}$ at 12.0 feet at BOL and MOL. At EOL, a PCT increase of 70 F was applied to the adjacent elevation PCT (2.506 ft or 9.536 ft) for the 0.0 feet and 12.0 feet elevations since the LHR limits were not reduced.

Figure 3-1: ONS Mark-B-HTP UO_2 LOCA LHR Limits with Burnup

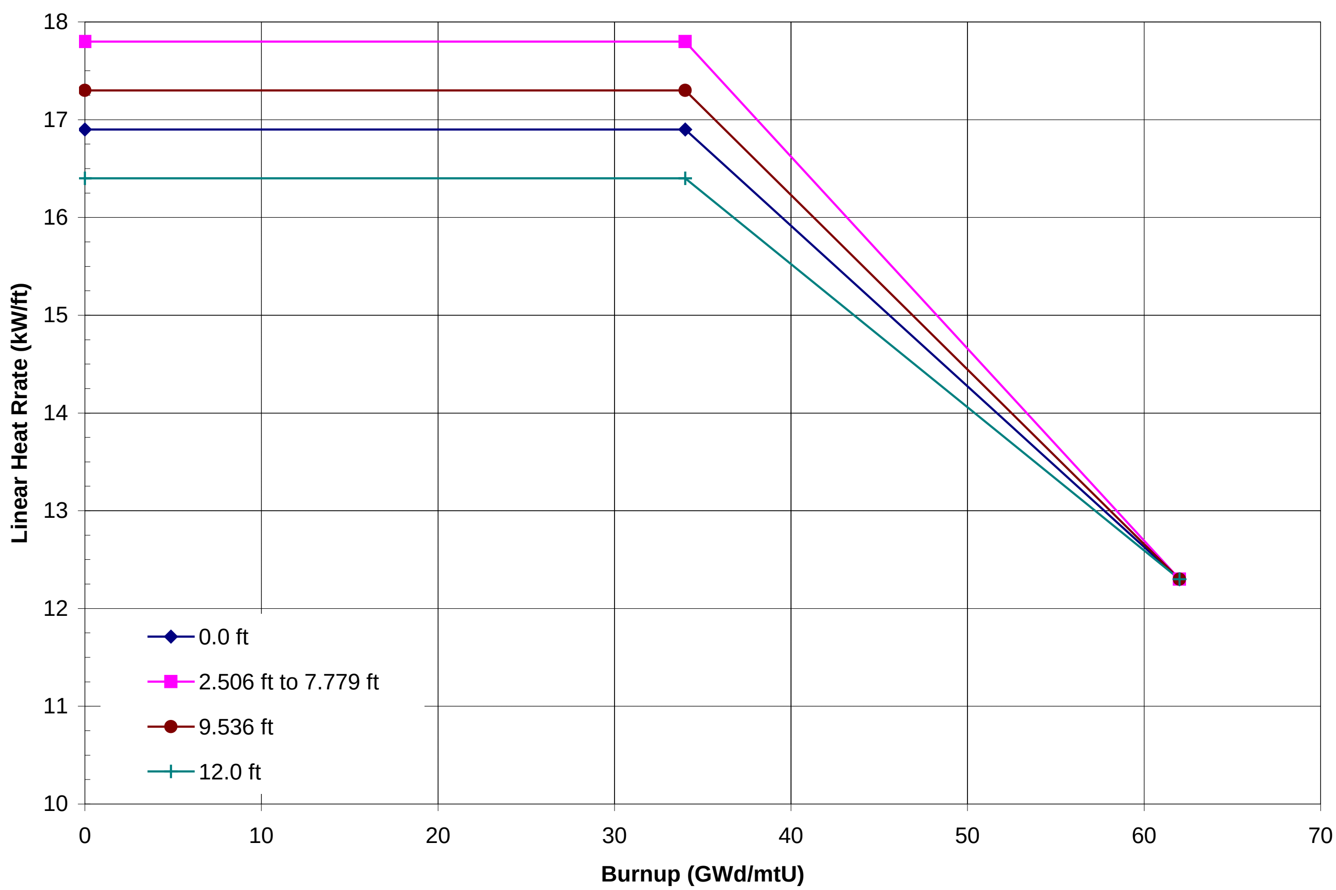


Table 3-4: Summary of Mark-B-HTP 2 $^{W}/_{0}$ Gad LHR Limits

(Table 10-13 of Reference [8])

Elevation ft	BOL (0 GWd/mtU)		MOL (34 GWd/mtU)		EOL (62 GWd/mtU)	
	LOCA LHR Limit kW/ft	PCT F	LOCA LHR Limit kW/ft	PCT F	LOCA LHR Limit kW/ft	PCT F
0.0	*16.0*	*< 1858.6*	*16.0*	*< 1833.4*	*11.6*	*< 1641.8*
2.506	**16.9**	**1858.6**	**16.9**	**1833.4**	**11.6**	**1581.8**
4.264	*16.9*	*1843*	*16.9*	*1813*	*11.6*	*1582*
6.021	*16.9*	*1852*	*16.9*	*1828*	*11.6*	*1582*
7.779	*16.9*	*1851*	*16.9*	*1818*	*11.6*	*1582*
9.536	*16.4*	*1810*	*16.4*	*1760*	*11.6*	*1632*
12.0	*15.5*	*< 1810*	*15.5*	*< 1760*	*11.6*	*< 1692*

Notes:

1. The LHR limits presented above represent the power generated by the pin, i.e. all sources of usable energy caused by the fission process.

2. All analyzed LHR limits and PCTs are shown in bold font, whereas all estimated LHR limits and PCTs are shown in italicized font.

3. Analyses at BOL and MOL used a steady-state EDF of 0.973 for initial core energy and a transient EDF of 1.018 for 2 $^{W}/_{0}$ Gad. The analysis at EOL used a steady-state EDF of 0.986 for initial core energy and a transient EDF of 1.084 for 2 $^{W}/_{0}$ Gad.

4. Linear interpolation for LHR limits is allowed between elevations and times in life.

5. The PCT-limited LHR limits below 2.506 ft are reduced by 0.95 × $LHR_{2.506}$ at 0.0 feet at BOL and MOL. The PCT-limited LHR limits above 9.536 ft are reduced by 0.95 × $LHR_{9.536}$ at 12.0 feet at BOL and MOL. At EOL, a PCT increase of 60 F was applied to the adjacent elevation PCT (2.506 ft or 9.536 ft) for the 0.0 feet and 12.0 feet elevations since the LHR limits were not reduced.

6. The estimated LHR limits are based on a Gad Factor of 0.95.

Figure 3-2: ONS Mark-B-HTP 2 $^{w}/_{0}$ Gad LOCA LHR Limits with Burnup

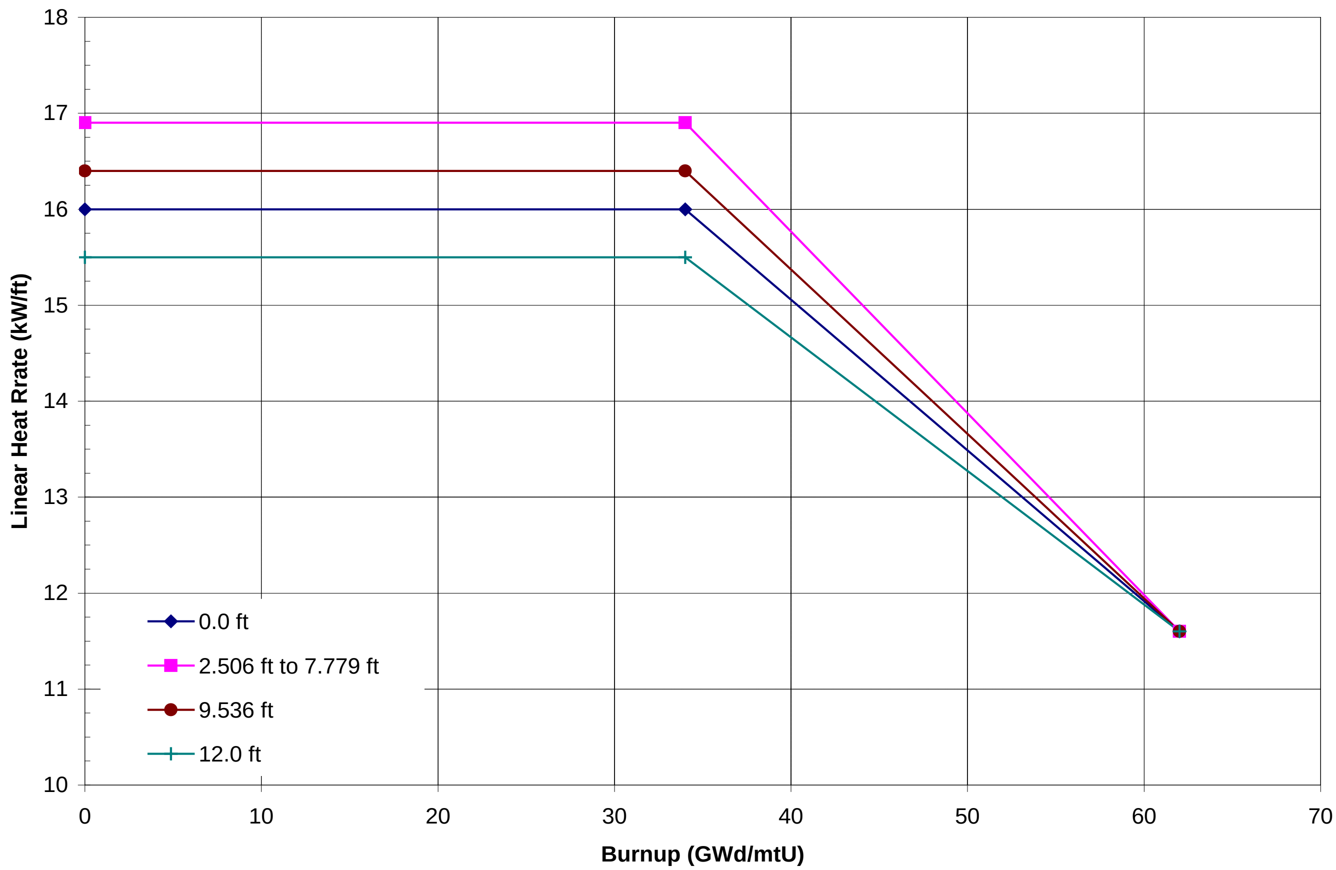


Table 3-5: Summary of Mark-B-HTP 4 $^{W}/_{0}$ Gad LHR Limits

(Table 10-14 of Reference [8])

Elevation ft	BOL (0 GWd/mtU) LOCA LHR Limit kW/ft	BOL (0 GWd/mtU) PCT F	MOL (34 GWd/mtU) LOCA LHR Limit kW/ft	MOL (34 GWd/mtU) PCT F	EOL (62 GWd/mtU) LOCA LHR Limit kW/ft	EOL (62 GWd/mtU) PCT F
0.0	*15.2*	*< 1862.7*	*15.2*	*< 1856.2*	*11.1*	*< 1641.3*
2.506	**16.1**	**1862.7**	**16.1**	**1856.2**	**11.1**	**1581.3**
4.264	*16.1*	*1847*	*16.1*	*1836*	*11.1*	*1581*
6.021	*16.1*	*1857*	*16.1*	*1851*	*11.1*	*1581*
7.779	*16.1*	*1855*	*16.1*	*1841*	*11.1*	*1581*
9.536	*15.7*	*1814*	*15.7*	*1782*	*11.1*	*1631*
12.0	*14.9*	*< 1814*	*14.9*	*< 1782*	*11.1*	*< 1691*

Notes:

1. The LHR limits presented above represent the power generated by the pin, i.e. all sources of usable energy caused by the fission process.

2. All analyzed LHR limits and PCTs are shown in bold font, whereas all estimated LHR limits and PCTs are shown in italicized font.

3. Analyses at BOL and MOL used a steady-state EDF of 0.973 for initial core energy and a transient EDF of 1.035 for 4 $^{W}/_{0}$ Gad. The analysis at EOL used a steady-state EDF of 0.988 for initial core energy and a transient EDF of 1.103 for 4 $^{W}/_{0}$ Gad.

4. Linear interpolation for LHR limits is allowed between elevations and times in life.

5. The PCT-limited LHR limits below 2.506 ft are reduced by 0.95 × $LHR_{2.506}$ at 0.0 feet at BOL and MOL. The PCT-limited LHR limits above 9.536 ft are reduced by 0.95 × $LHR_{9.536}$ at 12.0 feet at BOL and MOL. At EOL, a PCT increase of 60 F was applied to the adjacent elevation PCT (2.506 ft or 9.536 ft) for the 0.0 feet and 12.0 feet elevations since the LHR limits were not reduced.

6. The estimated LHR limits are based on a Gad Factor of 0.91.

Figure 3-3: ONS Mark-B-HTP 4 $^{W}/_{0}$ Gad LOCA LHR Limits with Burnup

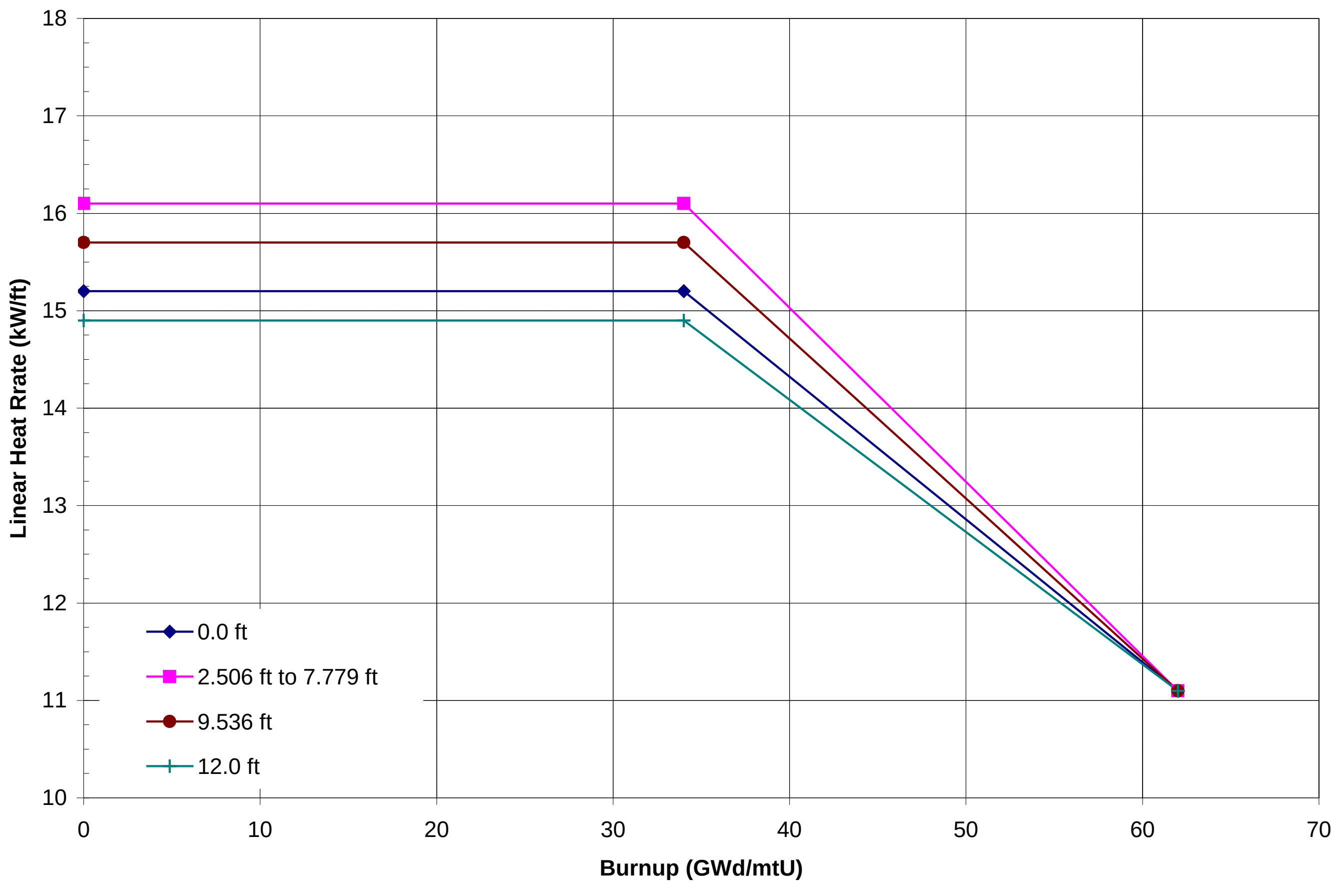


Table 3-6: Summary of Mark-B-HTP 6 $^{W}/_{0}$ Gad LHR Limits

(Table 10-15 of Reference [8])

Elevation ft	BOL (0 GWd/mtU)		MOL (34 GWd/mtU)		EOL (62 GWd/mtU)	
	LOCA LHR Limit kW/ft	PCT F	LOCA LHR Limit kW/ft	PCT F	LOCA LHR Limit kW/ft	PCT F
0.0	*14.8*	*< 1874.3*	*14.8*	*< 1848.8*	*10.8*	*< 1658.0*
2.506	**15.6**	**1874.3**	**15.6**	**1848.8**	**10.8**	**1598.0**
4.264	*15.6*	*1858*	*15.6*	*1828*	*10.8*	*1598*
6.021	*15.6*	*1868*	*15.6*	*1843*	*10.8*	*1598*
7.779	*15.6*	*1867*	*15.6*	*1833*	*10.8*	*1598*
9.536	*15.2*	*1826*	*15.2*	*1775*	*10.8*	*1648*
12.0	*14.4*	*< 1826*	*14.4*	*< 1775*	*10.8*	*< 1708*

Notes:

1. The LHR limits presented above represent the power generated by the pin, i.e. all sources of usable energy caused by the fission process.

2. All analyzed LHR limits and PCTs are shown in bold font, whereas all estimated LHR limits and PCTs are shown in italicized font.

3. Analyses at BOL and MOL used a steady-state EDF of 0.974 for initial core energy and a transient EDF of 1.048 for 6 $^{W}/_{0}$ Gad. The analysis at EOL used a steady-state EDF of 0.989 for initial core energy and a transient EDF of 1.119 for 6 $^{W}/_{0}$ Gad.

4. Linear interpolation for LHR limits is allowed between elevations and times in life.

5. The PCT-limited LHR limits below 2.506 ft are reduced by 0.95 × $LHR_{2.506}$ at 0.0 feet at BOL and MOL. The PCT-limited LHR limits above 9.536 ft are reduced by 0.95 × $LHR_{9.536}$ at 12.0 feet at BOL and MOL. At EOL, a PCT increase of 60 F was applied to the adjacent elevation PCT (2.506 ft or 9.536 ft) for the 0.0 feet and 12.0 feet elevations since the LHR limits were not reduced.

6. The estimated LHR limits are based on a Gad Factor of 0.88.

Figure 3-4: ONS Mark-B-HTP 6 $^{w}/_{0}$ Gad LOCA LHR Limits with Burnup

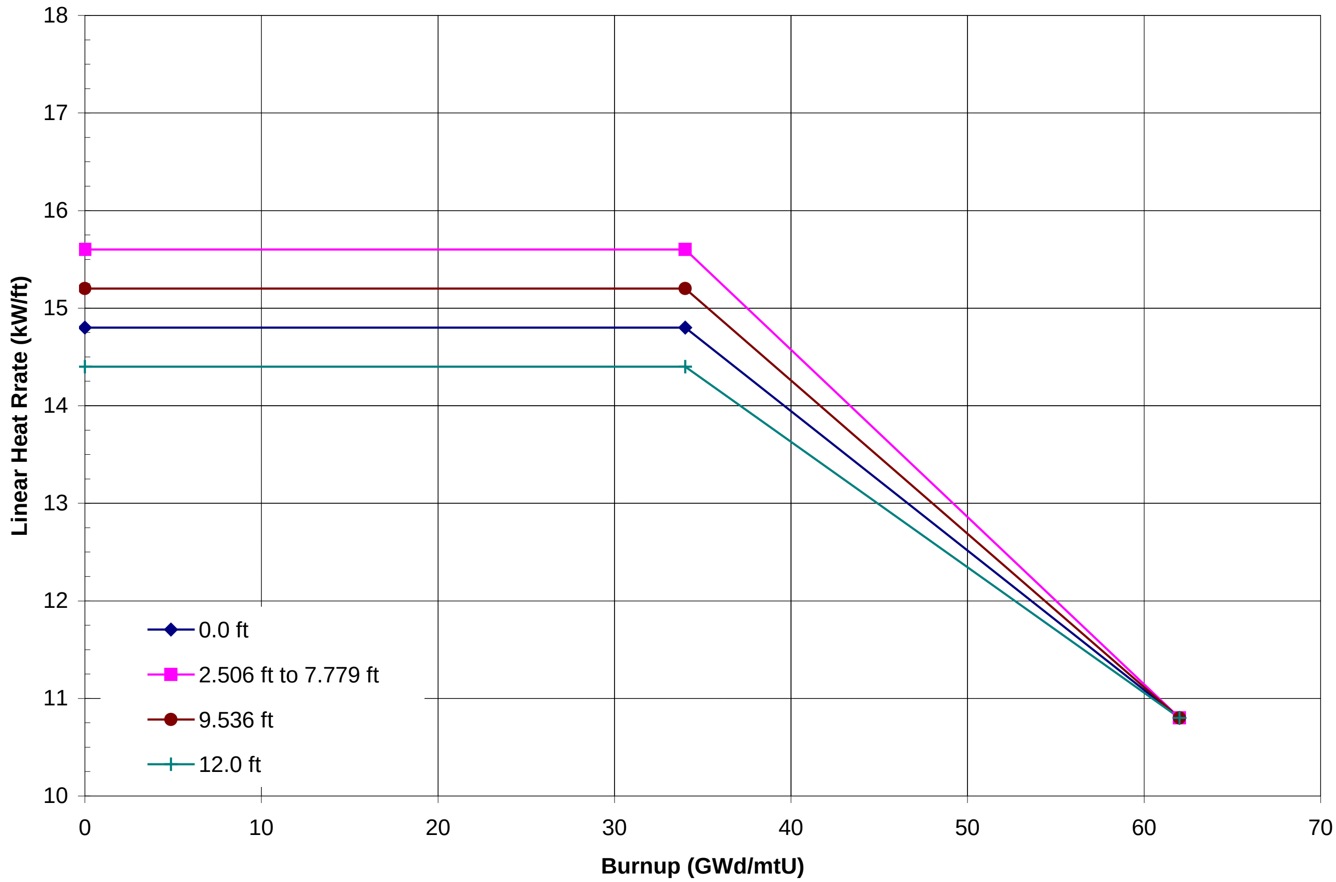


Table 3-7: Summary of Mark-B-HTP 8 $^{W}/_{0}$ Gad LHR Limits

(Table 10-16 of Reference [8])

Elevation ft	BOL (0 GWd/mtU) LOCA LHR Limit kW/ft	BOL (0 GWd/mtU) PCT F	MOL (34 GWd/mtU) LOCA LHR Limit kW/ft	MOL (34 GWd/mtU) PCT F	EOL (62 GWd/mtU) LOCA LHR Limit kW/ft	EOL (62 GWd/mtU) PCT F
0.0	*14.3*	*< 1881.1*	*14.3*	*< 1806.0*	*10.4*	*< 1654.5*
2.506	**15.1**	**1881.1**	**15.1**	**1806.0**	**10.4**	**1594.5**
4.264	*15.1*	*1865*	*15.1*	*1785*	*10.4*	*1595*
6.021	*15.1*	*1875*	*15.1*	*1801*	*10.4*	*1595*
7.779	*15.1*	*1874*	*15.1*	*1790*	*10.4*	*1595*
9.536	*14.7*	*1832*	*14.7*	*1732*	*10.4*	*1645*
12.0	*13.9*	*< 1832*	*13.9*	*< 1732*	*10.4*	*< 1705*

Notes:

1. The LHR limits presented above represent the power generated by the pin, i.e. all sources of usable energy caused by the fission process.

2. All analyzed LHR limits and PCTs are shown in bold font, whereas all estimated LHR limits and PCTs are shown in italicized font.

3. Analyses at BOL and MOL used a steady-state EDF of 0.975 for initial core energy and a transient EDF of 1.062 for 8 $^{W}/_{0}$ Gad. The analysis at EOL used a steady-state EDF of 0.991 for initial core energy and a transient EDF of 1.135 for 8 $^{W}/_{0}$ Gad.

4. Linear interpolation for LHR limits is allowed between elevations and times in life.

5. The PCT-limited LHR limits below 2.506 ft are reduced by 0.95 × $LHR_{2.506}$ at 0.0 feet at BOL and MOL. The PCT-limited LHR limits above 9.536 ft are reduced by 0.95 × $LHR_{9.536}$ at 12.0 feet at BOL and MOL. At EOL, a PCT increase of 60 F was applied to the adjacent elevation PCT (2.506 ft or 9.536 ft) for the 0.0 feet and 12.0 feet elevations since the LHR limits were not reduced.

6. The estimated LHR limits are based on a Gad Factor of 0.85.

Figure 3-5: ONS Mark-B-HTP 8 $^{w}/_{0}$ Gad LOCA LHR Limits with Burnup

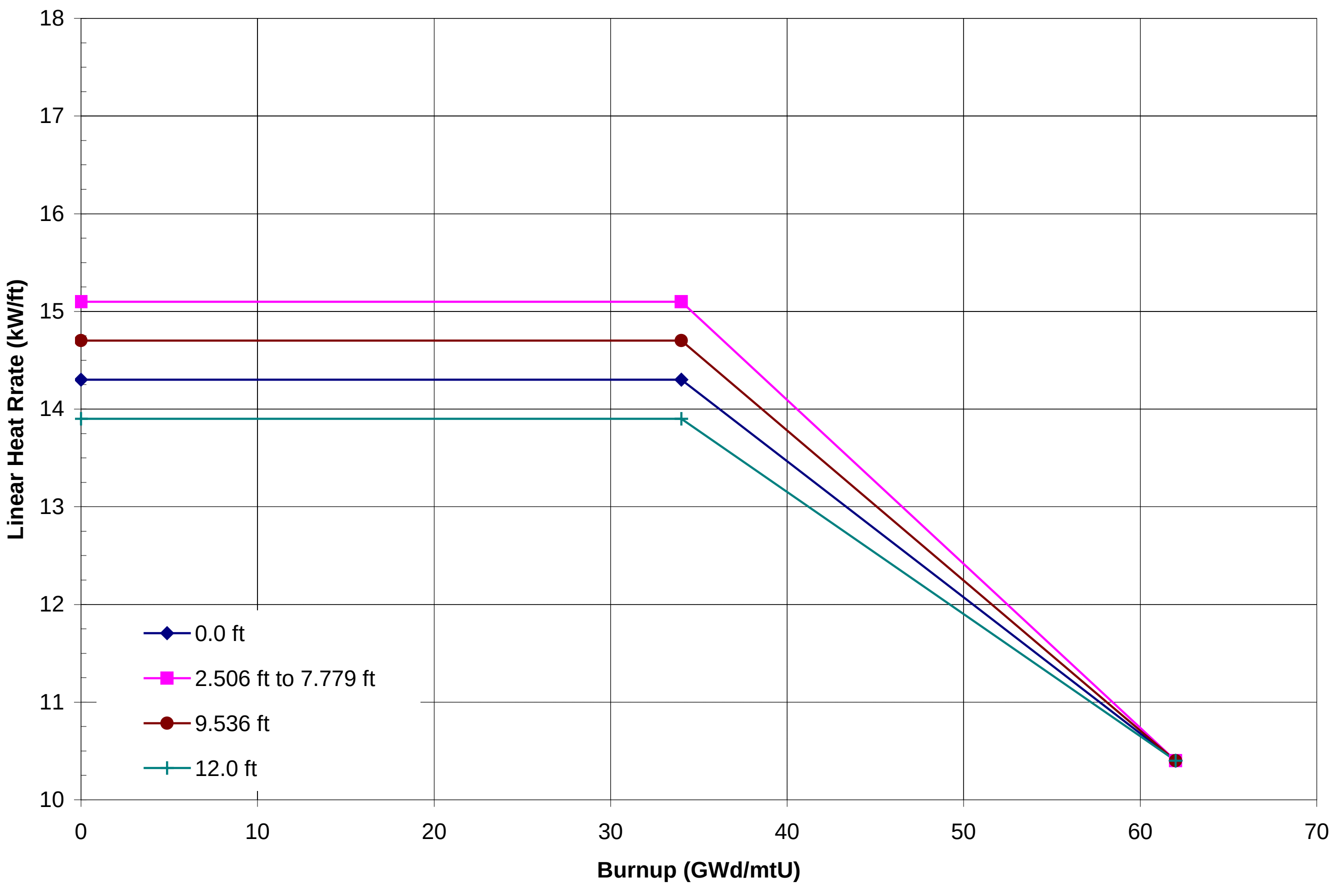


Table 3-8: ONS 102% Full Power Full-Core SBLOCA PCT versus Break Size

Table 8-15 of Reference [9]

Offsite Power	Break Location	Break Size (ft^2)	Mark-B-HTP PCT (F)
LOOP	CLPD	0.01	711.92
		0.04	711.92
		0.07	711.92
		0.1	1288.2
		0.125	1515.4
		0.15	**1597.5**
		0.175	1565.9
		0.2	1474.1
		0.3	1310.3
		0.4	1126.3
		0.5	1103.5
	HPI	0.02464	711.92
	CFT	0.44	711.92
2-Minute RCP Trip	CLPD	0.3	711.92
		0.4	1175.9
		0.5	1255.5
	CFT	0.44	1072.8

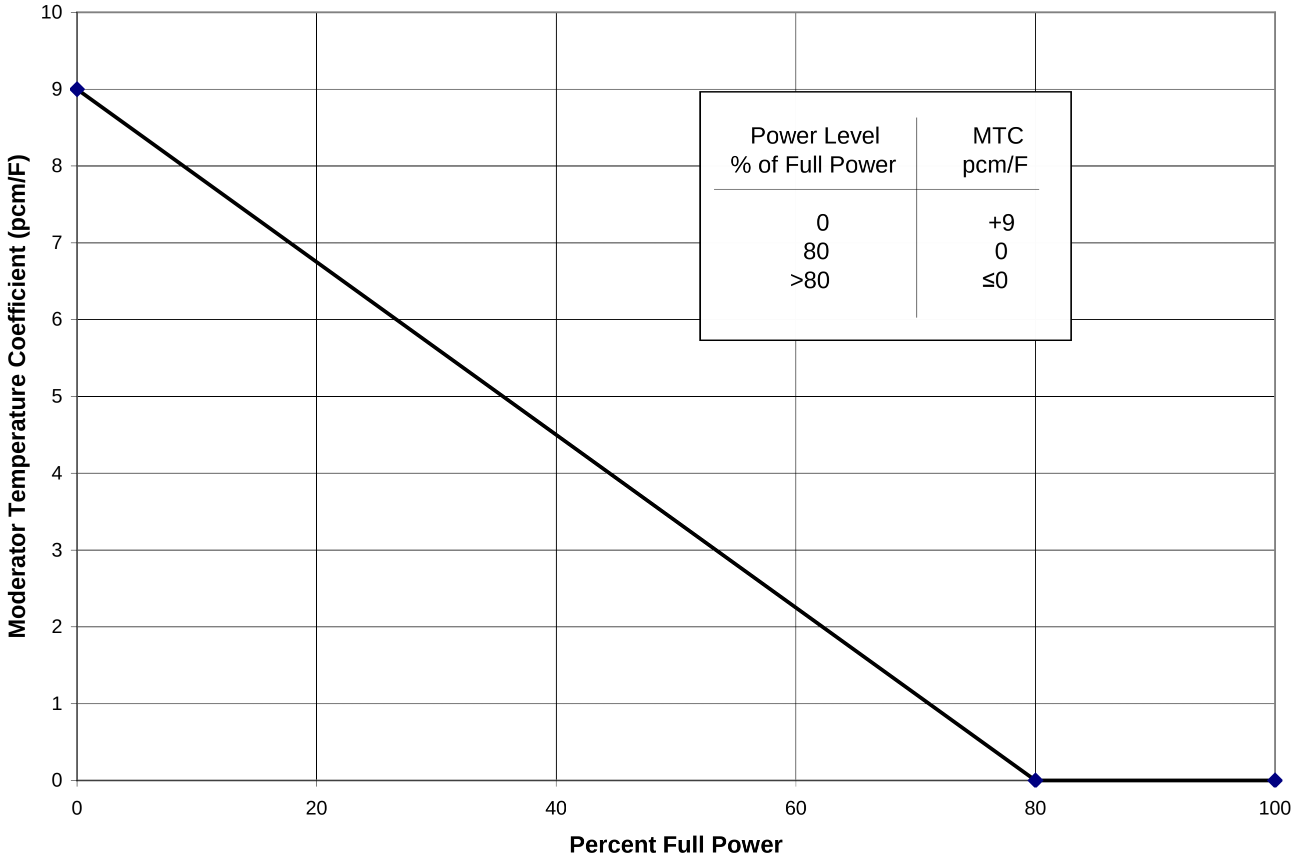
Table 3-9: ONS 52% Full Power Full-Core SBLOCA PCT versus Break Size

Table 6-1 of Reference [10]

Offsite Power	Break Location	Break Size (ft^2)	Mark-B-HTP PCT (F)
LOOP	CLPD	0.01	711.92
		0.04	711.92
		0.06	1401.5
		0.07	1446.5
		0.072	**1480.2**
		0.08	1359.1
		0.10	1288.9
		0.13	1126.4
		0.20	756.89
		0.40	711.92
	HPI	0.02464	711.92
	CFT	0.44	712(1)
2-Minute RCP Trip	CLPD	0.30	712(1)
		0.40	1010.0
		0.50	1090(1)
	CFT	0.44	907(1)

Note 1: The PCT reported is an estimated value.

Figure 3-6: MTC Limit vs. Power Level Note



Note: This graph is derived from the information on the table shown within the figure. This information is from Section 5.13.2 of Reference [19]

Figure 3-7: ONS Mark-B-HTP Full-Core SBLOCA PCT versus Break Size (102% Full Power)

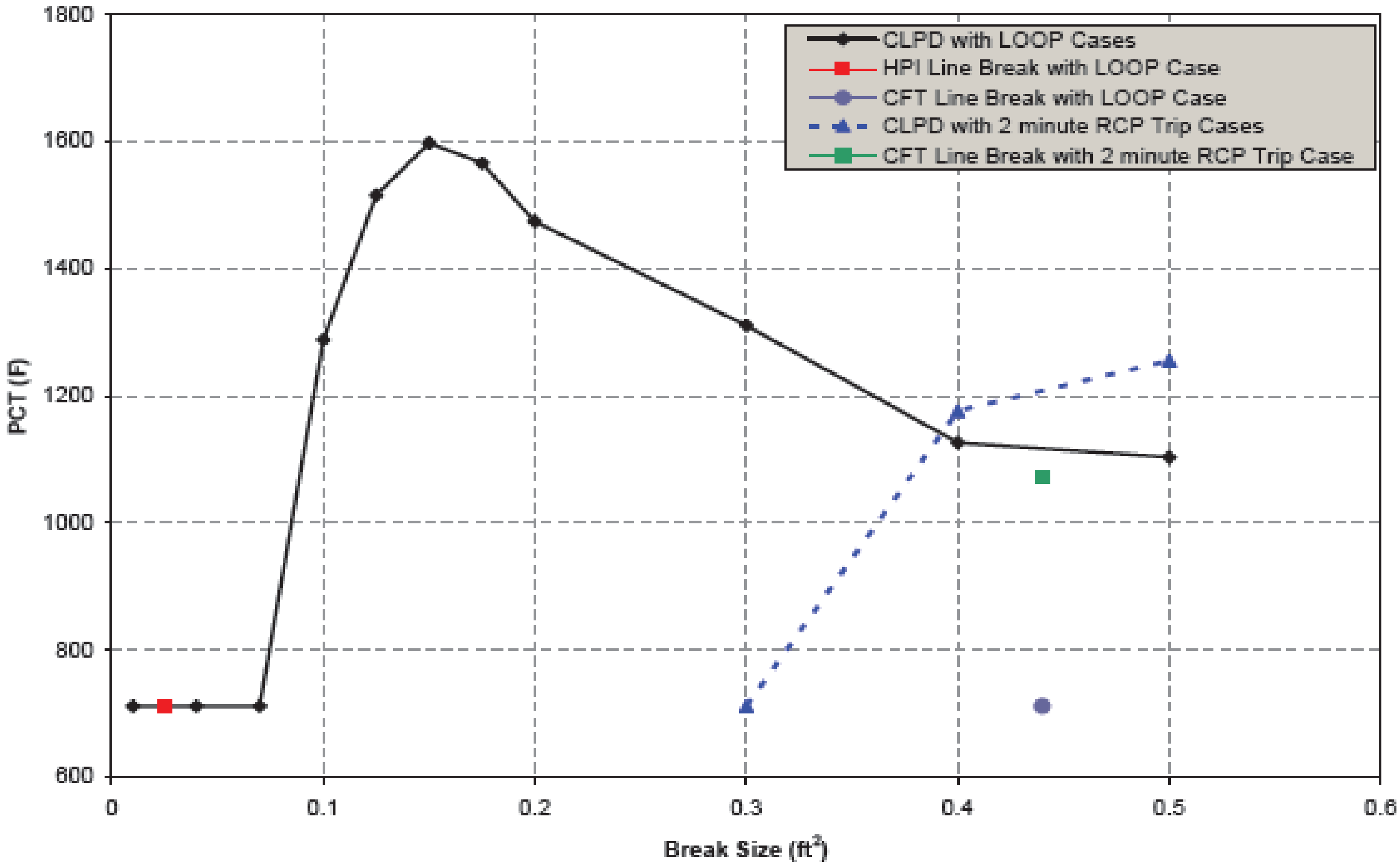
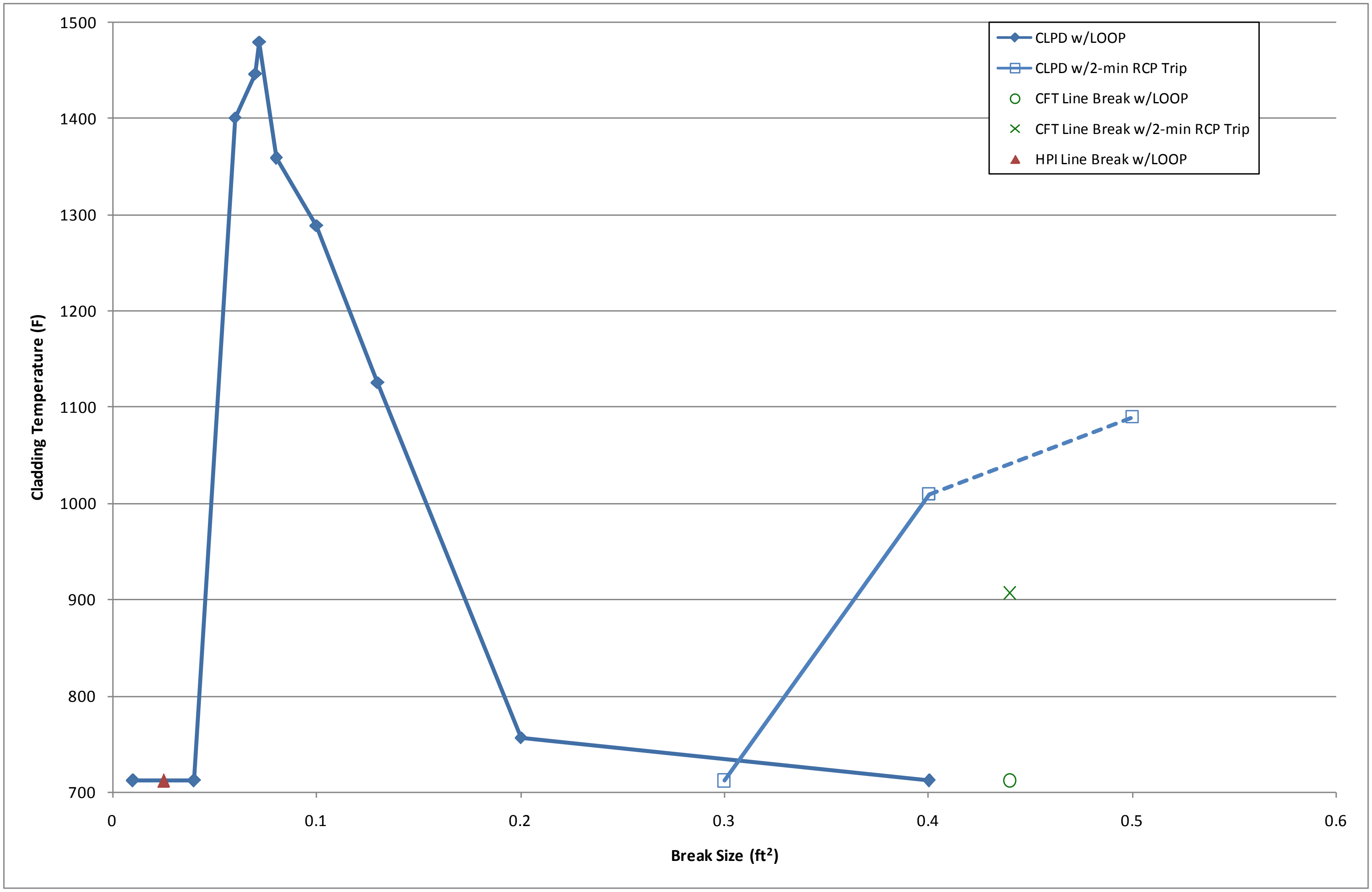


Figure 3-8: ONS Mark-B-HTP Full-Core SBLOCA PCT versus Break Size (52% Full Power)



4.0 ANALYTICAL METHODOLOGY

The LOCA analyses summarized herein were performed according to the NRC-approved RELAP5-based Evaluation Model (EM) contained in BAW-10192P-A, Revision 0 (Reference [1]) as amended by NRC-approved code topical revisions, 10 CFR 50.46 changes made associated with preliminary safety concern (PSC) resolutions, and method changes related to the NRC-approved topical reports. The methods applied are consistent with Revision 2 of BAW-10192P (Reference [44]), which is currently being reviewed by the NRC.

The full sequence of events and analytical results for each LBLOCA case are provided in Section 6.0, and for each SBLOCA case analyzed are provided in Section 7.0.

4.1 LBLOCA Analyses

The ONS-specific LBLOCA applications use the NRC-approved methods contained in Volume I of BAW-10192P-A (Reference [1]). The NRC-approved topical reports identified in BAW-10192P-A are:

- BAW-10162P-A, Rev. 0, TACO3 (Reference [3]).
- BAW-10095-A, Rev. 1, CONTEMPT (Reference [4]).
- BAW-10164P-A, Rev. 3, RELAP5/MOD2-B&W (Revision 3 of Reference [5]).
- BAW-10171P-A, Rev. 3, REFLOD3B (Reference [6]).
- BAW-10166P-A, Rev. 4, BEACH (Revision 4 of Reference [7]).

Since the approval of BAW-10192P-A, Revision 0, the codes and methods have evolved through approved code revisions, identification of specific codes not identified in the EM, and the addition of new methods and error corrections made under 10 CFR 50.46. The following NRC-approved topical reports have been added as part of the EM for LBLOCA analyses, and they are included in the new revision of the EM topical report that is being reviewed by the NRC (BAW-10192P, Revision 2, Reference [44]).

- BAW-10164P-A, Rev. 4, RELAP5/MOD2-B&W (Revision 4 of Reference [5]).
  - Hot pin modeling, decreased fuel temperature uncertainty in the hot assembly and average channel.
- BAW-10164P-A, Rev. 6, RELAP5/MOD2-B&W (Reference [5]).
  - B-HTP CHF correlation.
- BAW-10166P-A, Rev. 5, BEACH (Revision 5 of Reference [7]).
  - Extended ranges of application.
- BAW-10227P-A, Rev. 0, M5 Cladding (Revision 0 of Reference [2]).
  - M5 cladding properties (Rev. 1 not necessary for B&W plants).
- BAW-10184P-A, Rev. 0, GDTACO (Reference [45]).
  - Gadolinium steady-state fuel conditions.

The LBLOCA analyses also used several EM changes made under 10 CFR 50.46 to assure that 10 CFR 50 Appendix K requirements are met. These items and others are discussed in Section 6.2.4.4.

1. Uncertainty adjusted core flood tank parameters (PSC 5-94) discussed in the 1994 and 1995 Draft B&W Annual ECCS Report (References [23] and [24]).
2. LBLOCA reactor coolant pump two-phase degradation modeling (PSC 1-99) discussed in the 1998 and 1999 Draft B&W Annual ECCS Reports (References [25] and [26]).

The LBLOCA methodology uses four computer codes to analyze the transient and steady-state fuel pin data from the NRC-approved TACO3 or GDTACO codes. The RELAP5/MOD2-B&W code calculates system thermal-hydraulics, core power generation, and the clad temperature response during the blowdown portion of the transient. The REFLOD3B initial conditions represent the end-of-blowdown conditions from the RELAP5/MOD2-B&W case to determine the length of the refill period and the core reflooding rate. Through iteration, CONTEMPT uses the mass and energy release from RELAP5 and REFLOD3B to determine the appropriate containment pressure boundary conditions. Finally, the BEACH code, which is the RELAP5/MOD2-B&W core model with the reflood fine-mesh rezoning option activated, determines the clad temperature response during the reflood period with input from REFLOD3B analysis. Demonstration that the analyses are in compliance with the limitations and restrictions placed on the EM and associated computer codes is provided by the information contained in the most recent revision of Reference [20] and a completed checklist from this reference is included in the documented LOCA analyses.

4.2 SBLOCA Analyses

The ONS specific SBLOCA applications used the NRC-approved methods contained in Volume II of BAW-10192P-A, Revision 0 (Reference [1]). The NRC-approved topical reports identified in BAW-10192P-A are:

1. BAW-10162P-A, Rev. 0, TACO3 (Reference [3]).
2. BAW-10164P-A, Rev. 3, RELAP5/MOD2-B&W (Revision 3 of Reference [5])
3. BAW-10095-A, Rev. 1, CONTEMPT (Reference [4])

Since the approval of BAW-10192P-A, Revision 0, the codes and methods have evolved through approved code revisions and the addition of new methods and error corrections made under 10 CFR 50.46. The following NRC-approved topical reports have been added as part of the EM for SBLOCA analyses, and they are included in the new revision of the EM topical report that is being reviewed by the NRC (BAW-10192, Revision 2, Reference [44]).

4. BAW-10164P-A, Rev. 4, RELAP5/MOD2-B&W (Revision 4 of Reference [5]).
   - void-dependent cross-flow mode, and supplemental pins.
5. BAW-10227P-A, Rev. 0, M5 Cladding (Revision 0 of Reference [2]).
   - M5 cladding (Rev. 1 not necessary for B&W plants).
6. BAW-10164P-A, Rev. 6, RELAP5/MOD2-B&W (Reference [5]).
   - B-HTP CHF correlation.

The SBLOCA analyses also used several EM changes made under the NRC regulation, 10 CFR 50.46, to assure that 10 CFR 50 Appendix K requirements of that regulation are met. Those 50.46 changes that have not subsequently been approved within a revised topical report include use of:

1. Uncertainty-adjusted core flood tank parameters (PSC 5-94) discussed in the 1994 and 1995 Draft B&W Annual ECCS Report (References [23] and [24]).
2. SBLOCA reactor coolant pump two-phase degradation modeling (PSC 2-00) was described in the 2000 and 2001 B&W Annual ECCS Reports (References [29] and [30]). The SER on PSC 2-00 (Reference [31]) imposed a limitation that required that the two-phase degradation model used in the SBLOCA analyses be demonstrated to the NRC to justify application of the pump model to the B&W plants. In response to additional information provided to the NRC (Reference [32]), the NRC revised the SER to remove this limitation (Reference [33]). Therefore, the results of PSC 2-00 and associated SER are generically applicable to the B&W plants.
3. A new consideration regarding axial power shapes was developed while performing scoping studies for SBLOCA analyses. The potential of extended core uncovery was called to question for the bounding nature of the EM axial power shapes. It was found that the location for the most bounding power shape of 1.7 for any time during the cycle is now found to be 11-ft, which is located in the control volume, centered about 10.811 ft (Reference [13]). Therefore, the Mark-B-HTP full-core SBLOCA analyses used a skewed end-of-cycle (EOC) 11-ft axial peak of 1.7 (References [9] and [10]).

The SBLOCA methodology uses only the RELAP5/MOD2-B&W code to calculate the system thermal-hydraulics. Demonstration that the analyses are in compliance with the limitations and restrictions placed on the EM and associated computer codes is provided by the information contained in the most recent revision of Reference [20] and a completed checklist from this reference is included in the documented LOCA analyses.

5.0 PLANT PARAMETERS AND INPUTS

The plant parameters and inputs applicable to the Mark-B-HTP full-core LOCA analyses are discussed in detail in Reference [19] and summarized in Table 5-1 through Table 5-14, unless otherwise noted. The containment pressure response utilized in the full-core Mark-B-HTP LBLOCA analyses (Reference [8]) taken from Reference [21] is shown in Figure 5-1.

Table 5-1: LOCA Inputs and Boundary Conditions

Parameter	Value		
	102% Power LBLOCA	**102% Power SBLOCA**	**52% Power SBLOCA**
General Parameters			
Single Failure	• PCT: failure of transformer CT-4 (results in a longer delay time (10 sec) until ECCS fluid reaches the RCS) • Minimum containment pressure: no single failure is considered such that a conservatively low pressure is calculated for input to the PCT analyses.		
Offsite Power	LOOP at break opening	• LOOP at reactor trip for all cases, plus • non-LOOP also considered for Category 5 breaks	
Loss-of-Subcooling Margin (LSCM)	$(T_{sat} - T)_{hot\ leg} = 0$		
Steady-State Conditions			
Nominal Rated Core Power, MWt	2568		1284
Core Power Uncertainty, %	2		
Analyzed Core Power, MWt	2619.36		1335.36
RCP Power, MWt/pump	4 (16 Total for all pumps combined)		
SG Heat Removal, MWt	2635 (Core power + Total RCP Power)		1351
RCS Average Temperature, F	579		
Total RCS Flow Rate, gpm	106.5% of design flow 374,880 gpm at RCP suction		
Core Bypass Percentage, %	7.7		
Makeup and Letdown	Not Modeled		
RCS Pressure, psia	2170		
Indicated Pressurizer Level, in	220 on 400-in scale		
PZR Heater and Sprays	Not Modeled		

<table>
<tr><th rowspan="2">Parameter</th><th colspan="3">Value</th></tr>
<tr><th>102% Power LBLOCA</th><th>102% Power SBLOCA</th><th>52% Power SBLOCA</th></tr>
<tr><td>PSV and PORV</td><td colspan="3">Not Modeled</td></tr>
<tr><td>MFW Temperature, F</td><td colspan="2">460</td><td>385</td></tr>
<tr><td>MFW Flow Rate, lbm/s/SG^{Note}</td><td>1558
(Reference [8])</td><td>1570
(Reference [9])</td><td>720
(Reference [22])</td></tr>
<tr><td>SG Tube Plugging</td><td colspan="3">7% Symmetric, 50% of EFW wetted region plugged</td></tr>
<tr><td>Turbine Header Pressure, psia^{Note}</td><td>914
(Reference [8])</td><td>920.5
(Reference [9])</td><td>935
(Reference [22])</td></tr>
<tr><td colspan="4">Decay Heat</td></tr>
<tr><td>Decay Heat Standard</td><td colspan="3">ANS 1971 + 20%</td></tr>
<tr><td>Actinides</td><td colspan="3">RELAP5 default</td></tr>
<tr><td colspan="4">Reactor Coolant Pump (RCP) Parameters</td></tr>
<tr><td>RCP Type, Single-Phase Head Difference</td><td colspan="3">Westinghouse</td></tr>
<tr><td>Two-Phase Fully-Degraded Head Difference</td><td colspan="3">RELAP5</td></tr>
<tr><td>Two-Phase Void Dependent Multiplier</td><td colspan="3">M3-Modified</td></tr>
<tr><td>RCP Trip</td><td>LOOP</td><td colspan="2">• LOOP
• For non-LOOP cases: 2 minutes after LSCM</td></tr>
<tr><td>RC Pump Trip Delay, s</td><td colspan="3">0</td></tr>
<tr><td>RCP Rated Conditions</td><td colspan="3">Consistent with Appendix B of Reference [20]</td></tr>
<tr><td>RCP Spillover Elevation</td><td colspan="3">25.75 ft above UFLTS of OTSG</td></tr>
<tr><td colspan="4">Steam Generator (SG) Parameters</td></tr>
<tr><td>MFW Trip</td><td colspan="3">LOOP or Reactor Trip for no-Loop Cases</td></tr>
<tr><td>MFW Trip Delay, s</td><td colspan="3">0</td></tr>
<tr><td>MFW Coastdown, s</td><td colspan="3">Linear ramp from full flow to zero over 12.5 seconds</td></tr>
<tr><td>EFW Wetted Region</td><td>Not Modeled</td><td colspan="2">Peripheral 10% of SG tubes</td></tr>
<tr><td colspan="4">Turbine and Main Steam System Parameters</td></tr>
<tr><td>Turbine Trip</td><td colspan="3">On Reactor Trip</td></tr>
<tr><td>Turbine Trip Delay, s</td><td colspan="3">0.0</td></tr>
<tr><td>Turbine Stop Valve Stroke Time, s</td><td colspan="3">0.1</td></tr>
<tr><td>MSSVs Out of Service</td><td colspan="3">Valve with lowest lift pressure for each SG</td></tr>
</table>

Parameter	Value		
	102% Power LBLOCA	102% Power SBLOCA	52% Power SBLOCA
Nominal MSSV Setpoint & Valve Capacity	1/SG at 1065 psia (considered inoperable) 1/SG at 1080 psia 1/SG at 1095 psia 1/SG at 1105 psia 2/SG at 1115 psia 2/SG at 1119 psia Valve capacity is 220 lbm/sec for saturated steam at 1065 psia.		
SG Depressurization via ADV	Not Modeled		Valve rated at 225,000 lbm/hr at 162 psia Inner Diameter of 9.75 in
Emergency Feedwater (EFW) and Post-LOCA SG Level Control			
Post-LOCA SG Level Control Setpoint, ft	Not Modeled	• Natural Circulation = 20.7 • LSCM = 27.7	
SG Level Control Action	Not Modeled	• Automatic for Natural Circulation • LSCM = Operator Action	
EFW Source, F	Not Modeled	• MFW Available: MFW then EFW • MFW Not Available: EFW fill only	
EFW Temperature, F	Not Modeled	• MFW Source: 460 • EFW Source: 130	• MFW Source: 385 • EFW Source: 130
EFW Flow Rate, gpm/SG	Not Modeled	• MFW Source: 1040 • EFW Source: Min flows from Table 5-2	
SG Level Control Modeling	Not Modeled	EFW fill to Natural Circulation setpoint for SG-2, then EFW fill to SG-2 LSCM setpoint	MFW fill to Natural Circulation setpoint for SG-1 & SG-2, then EFW fill to SG-2 LSCM setpoint
EFW Delay, sec	Not Modeled	69 (after LOOP)	Not Modeled
AFIS Low Steam Line Pressure Setpoint, psia	Not Modeled	585	
AFIS Depressurization Rate, psi/s	Not Modeled	$\geq$ 2.7 (over 10 seconds)	
Reactor Protection System (RPS)			
Reactor Trip Setpoint, psia	1780		

<table>
<tr><th rowspan="2">Parameter</th><th colspan="3">Value</th></tr>
<tr><th>102% Power LBLOCA</th><th>102% Power SBLOCA</th><th>52% Power SBLOCA</th></tr>
<tr><td>Reactor Trip Delay Time, sec</td><td colspan="3">0.5</td></tr>
<tr><td colspan="4">Engineered Safety Features Actuation System (ESFAS)</td></tr>
<tr><td>ESFAS “Low” RCS Trip Setpoint, psia</td><td colspan="3">1515</td></tr>
<tr><td>HPI Delay, sec</td><td colspan="3">48 after “Low” RCS Trip Setpoint</td></tr>
<tr><td>ESFAS “Low-Low” RCS Trip Setpoint, psia</td><td colspan="3">365</td></tr>
<tr><td>LPI Delay, sec</td><td>38 after “Low” RCS Trip Setpoint</td><td colspan="2">74 after “Low-Low” RCS Trip Setpoint</td></tr>
<tr><td colspan="4">Emergency Core Cooling System (ECCS) Parameters</td></tr>
<tr><td>BWST Maximum Liquid Temperature, F</td><td colspan="3">115</td></tr>
<tr><td>BWST Minimum Liquid Temperature, F</td><td colspan="3">45</td></tr>
<tr><td>BWST Nominal Liquid Volume, gal</td><td colspan="3">320,000</td></tr>
<tr><td>BWST Minimum / Maximum Usable Liquid Volume, gal</td><td colspan="3">269,000 / 367,000</td></tr>
<tr><td>HPI Flow Rate</td><td>Not Modeled
(PCT)
Maximum
(Containment)</td><td colspan="2">CLPD: Table 5-3
HPI Line: Table 5-4
CFT Line: Table 5-5</td></tr>
<tr><td>LPI Flow Rate</td><td colspan="3">Table 5-6</td></tr>
<tr><td>CFT Liquid Volume, ft^3</td><td colspan="3">975 – 1085
1085 analyzed. (Section 5.12.4 of Reference [19])</td></tr>
<tr><td>CFT Cover Gas Pressure, psia</td><td colspan="3">CLPD and HPI Line: 565 – 665
CFT Line: 562 – 665
Analyzed pressure is a minimum pressure (Section 5.12.4 of Reference [19]).
565 psia for the CLPD and HPI Line; and 562 for the CFT Line breaks.</td></tr>
<tr><td>CFT Liquid Temperature, F</td><td colspan="3">130</td></tr>
<tr><td>CFT Average Line Length, ft</td><td colspan="3">88.20</td></tr>
<tr><td>CFT Line Area, ft^2</td><td colspan="3">0.7213</td></tr>
</table>

Parameter	Value		
	102% Power LBLOCA	102% Power SBLOCA	52% Power SBLOCA
CFT Average Δz, in	-15.13 A negative elevation change represents an increase in elevation from the bottom of the CFT to the RV injection location.		
CFT Line Resistance	5.7	• 570: CLPD and HPI Line Breaks • 5.7: CFT Line Break	
Reactivity Control Parameters			
Control Rod Worth, %Δk/k	3.50		
Control Rod Insertion Curve	Table 5-7		
MTC Curve, pcm/F	0		+5
MTC Reactivity vs. Density	Table 5-8		
Doppler Reactivity Curve	Table 5-9		
β-effective	0.007		
Prompt Neutron Generation Time, μs	19.5		
Fuel Pin Energy Deposition			
Steady-State	0.973 for UO_2 fuel at BOL and MOL. Calculated for EOL and Gad in Reference [8]	0.973	
Transient	1.0 for UO_2 fuel at BOL and MOL. Calculated for EOL and Gad in Reference [8]	1.0	
Fuel Parameters			
Fuel Design	Mark-B-HTP		
Enrichment, w/o	3.0 – 5.0 central region 2.0 – 2.5 blanket region		
Gadolinia Concentration, $^w/_0$	2, 4, 6, and 8	Not Modeled	
Maximum Fuel Rod Burnup, MWd/mtU	62,000		

Parameter	Value		
	102% Power LBLOCA	**102% Power SBLOCA**	**52% Power SBLOCA**
Containment Parameters			
Containment Parameters	Table 6-1, Reference [21]	• Choked: 70 psia • Unchoked: For larger SBLOCA, reduced linearly from 70 psia to 14.7 psia over 600 seconds	
Operator Actions			
Operator Actions	Table 5-14		

Note: The AIS (Reference [19]) MFW flow rate of 1500 lbm/s per SG, and SG secondary side turbine header pressure of 900 psia were adjusted to obtain a steady-state heat balance prior to the start of the transient analyses to account for the core power and the RCP heat.

Table 5-2: EFW Flows

EFW Flows for LOCA Analyses	
Pressure (psia)	Available EFW Flow Total MINIMUM from one pump (Note 1) (gpm)
15	400
1000	400
1064	375
1123	325
1178	0

EFW Flows for Maximum Flow Sensitivity Studies		
Pressure (psia)	Available EFW Flow MAXIMUM (gpm)	
	Motor Driven One Pump	Turbine Driven One Pump (Note 2)
15	1095	844
100	1059	828
200	1013	809
300	968	785
400	920	765
500	871	738
600	823	702
700	773	661
800	721	619
900	668	571
1000	613	519
1100	552	458

Notes:
1. If flow to 2 SGs, the above flows should be divided by 2 for supply to each SG.
2. Turbine driven EFW to be used for maximum EFW flow cases only.

Table 5-3: HPI Flow Rates – CLPD Break

102% Full Power SBLOCA				
Pressure (psia)	Before 10 Min		After 10 Min	
	Broken Cold Leg Flow (gpm)	Intact Cold Leg Flow (gpm)	Broken Cold Leg Flow (gpm)	Intact Cold Leg Flow (gpm)
15	243	185	243	574
615	243	185	243	574
1215	189	144	189	464
1515	167	127	167	406
1615	159	121	159	385
1815	142	108	142	340
2415	69	53	72	158

52% Full Power SBLOCA		
Pressure (psia)	Broken Cold Leg Flow (gpm)	Intact Cold Leg Flow (gpm)
15	223	167
615	223	167
1215	174	130
1515	151	113
1615	142	106
1815	124	93
2415	48	36

Table 5-4: HPI Flow Rate – HPI Line Break

102% Full Power SBLOCA

Pressure (psia)	Before 10 Min		After 10 Min	
	Broken Cold Leg Flow (gpm)	Intact Cold Leg Flow (gpm)	Broken Cold Leg Flow (gpm)	Intact Cold Leg Flow (gpm)
15	259	181	259	570
615	320	124	320	513
1215	382	47	383	366
1515	408	0	407	279
1615	408	0	407	264
1815	408	0	407	232
2415	408	0	407	103

52% Full Power SBLOCA

Pressure (psia)	Broken Cold Leg Flow (gpm)	Intact Cold Leg Flow (gpm)
15	236	165
315	269	134
615	303	101
1215	377	15
1515	385	0
1615	385	0
1815	385	0
2415	385	0

Table 5-5: HPI Flow Rates – CFT Line Break

102% Full Power SBLOCA		
Pressure (psia)	Total Flow to RCS (gpm)	
	Before 10 Min	After 10 Min
15	428	817
615	428	817
1215	333	653
1515	294	573
1615	280	544
1815	250	482
2415	127	230

52% Full Power SBLOCA	
Pressure (psia)	Total Flow to RCS (gpm)
15	389
615	389
1215	303
1515	262
1615	248
1815	216
2415	84

Table 5-6: LPI Flow Rates

LBLOCA LPI Flow Ramp				
Pressure (psia)	LPI Flow (gpm)			
	+4 Seconds	+8 Seconds	+16 Seconds	+36 Seconds
15	1551	2180	2776	2870
40	727	1306	2458	2667
65	665	1194	2248	2439
90	595	1068	2010	2181
115	513	921	1733	1881
140	412	741	1394	1513
165	275	494	930	1010
177.5	180	324	610	662
185	0	0	0	0

SBLOCA LPI Flow for CLPD and HPI Line Break		**SBLOCA LPI Flow for CFT Line Break with LPI Cross-Tie**		
Pressure (psia)	LPI Flow ¼ BWST Level (gpm)	Pressure (psia)	LPI Flow ½ BWST Level (gpm)	
15	2792		Intact Line Flow	Broken Line Flow
40	2579	15	1359	1541
65	2340	40	1209	1604
90	2067	65	1042	1670
115	1744	86	852	1729
140	1337	108	622	1797
165	718	131	298	1879
171	449	140	0	1914
175	0	-	-	-

Table 5-7: SBLOCA Control Rod SCRAM Curve

% Reactivity (Note)	Time (sec)
0.0	0.0
0.58	0.2
0.99	0.3
1.83	0.4
5.29	0.6
12.33	0.8
21.41	1.0
33.09	1.2
50.75	1.4
72.96	1.6
91.30	1.8
99.26	2.0
99.99	2.2
100.0	2.3

Note: The reactivity in $ is calculated using a β-effective and total rod worth provided in Table 5-1.

Table 5-8: Moderator Density vs. Reactivity

Density Fraction	+0 pcm/F HFP MTC %Δk/k	+5 pcm/F HFP MTC %Δk/k
0.0000	-50.0000 (Note 1)	-50.0000 (Note 1)
0.1383	-21.7898	-19.2109
0.2235	-13.9183	-11.6179
0.3101	-9.1373	-7.1124
0.3966	-5.9666	-4.2107
0.4832	-3.8057	-2.3103
0.5684	-2.3246	-1.0849
0.6550	-1.3163	-0.3290
0.7416	-0.6604	-0.0892
0.8282	-0.2423	0.2593
0.9134	-0.0425	0.2074
0.9567	-0.0027	0.1220
0.9791	0.0033	0.0657
1.0000	0.0000	0.0
1.0321	-0.0119	-0.1028
1.10	-0.0500 (Note 2)	-0.4000 (Note 3)
1.20	-0.3000 (Note 2)	-0.9000 (Note 3)
1.40	-1.2000 (Note 2)	-2.0000 (Note 3)

Notes:

1. The 0.0 density fraction was conservatively extrapolated to -50 %Δk/k.
2. These values were extended based on the +0 pcm/F 102% SBLOCA values.
3. These values were determined based on the trend between the evaluated extended reactivity points for the 0 pcm/F MTC curve and the estimated extended points from the +1 pcm/F and +5pcm/F MTC curves.

Table 5-9: Doppler Coefficients

Fuel Temperature (F)	Doppler Coefficient (pcm/F)	Reactivity ($) β=0.007
100	--	3.216
452	-2.18	--
603	--	1.65
754	-1.88	--
952	--	0.71
1150	-1.67	--
1250	--	0.0
1350	-1.56	--
3500	--	-5.01

Note: The reactivity is calculated using a β-effective of 0.0070.

Table 5-10: Containment Parameters – LBLOCA Minimum Containment Backpressure Analysis

Parameter	Value
Initial Containment Pressure, psia	13.7
Initial Containment Temperature, F	90 (Note 1)
Humidity, %	100 (Note 2)
Outside Ambient Temperature, F	40
Containment Free Volume, ft^3 (inc. 5% uncertainty)	1.9005×10^6 (Note 4)
Paint Thickness, mils	Table 5-11
ECCS Injection	Maximum
HPI Injection through Spray	Spilled HPI Flow (Note 3)
RB Areas, Thicknesses	Table 5-11
Thermal Conductivities and Heat Capacities	Generic Values, Table 5-13
Number of RBCUs, RBCU Performance Curve	3 Fan Coolers, Table 5-12
RBCU Delay, sec	0.0
RBCU Temperature, F	45
Number of RB Spray Headers	2
Maximum RB Spray Flow Rate, gpm for 2 Headers	2500 + Broken Loop HPI Flow (Note 5)
RB Spray Delay, sec	26
RB Spray Water Temperature, F	45

Notes:

1. Representative value.
2. Standardized value
3. Since larger ECCS flow to containment provides a more conservative pressure response, spilled HPI flow is added to the RB spray flow. The intact HPI flow is included in the REFLOD3 model.
4. Containment free volume of 1.8281×10^6 ft^3 from Reference [36] includes a 1% uncertainty. This value was recalculated based on a 5% uncertainty to be 1.9005×10^6 ft^3.
5. The maximum RB spray flow rate is 1250 gpm per header based on plant modification to prevent pump runout. This provides a maximum of 2500 gpm for 2 headers.

Table 5-11: Containment Heat Sinks

Category	Surface Area, ft^2	Thickness, ft	Material
RB Cylinder	61,353	0.0208 3.75 8.33E-4	Steel Concrete Paint
RB Dome	16,230	0.0208 3.25 5.83E-4	Steel Concrete Paint
RB Base	8,890	0.0208 8.5 5.83E-4	Steel Concrete Paint
RB Internal Concrete	66,231	1.76 8.33E-4	Concrete Paint
RB Internal Painted Steel	165,400	0.0316 5.83E-4	Steel Paint
RB Internal Unpainted Steel	63,727	0.0097	Steel
Refueling Canal	8,628	0.0396	Stainless Steel
Elevator Shaft Siding	9,892	0.0022	Aluminum
Not Specific	727	0.057	Copper

Note: The surface areas represent best-estimate values. An uncertainty of 5% has been applied to these values.

Table 5-12: Reactor Building Cooling Unit (RBCU) Performance Data

Temperature (F) 100% Relative Humidity	1 Cooler, 0 Fouling, 45 F[Note] ($x10^6$ Btu/hr)	
	Original Data	Including 10% Increase
286	134.8862	149
240	100.3035	111
200	67.6553	75
160	42.0349	47
120	20.8644	23
80	5.5440	7
75	0.0000	0

Note: The CONTEMPT analyses that provided containment pressure response for use in the Mark-B-HTP LBLOCA analysis utilized the original data including a 10% increase (Reference [21]).

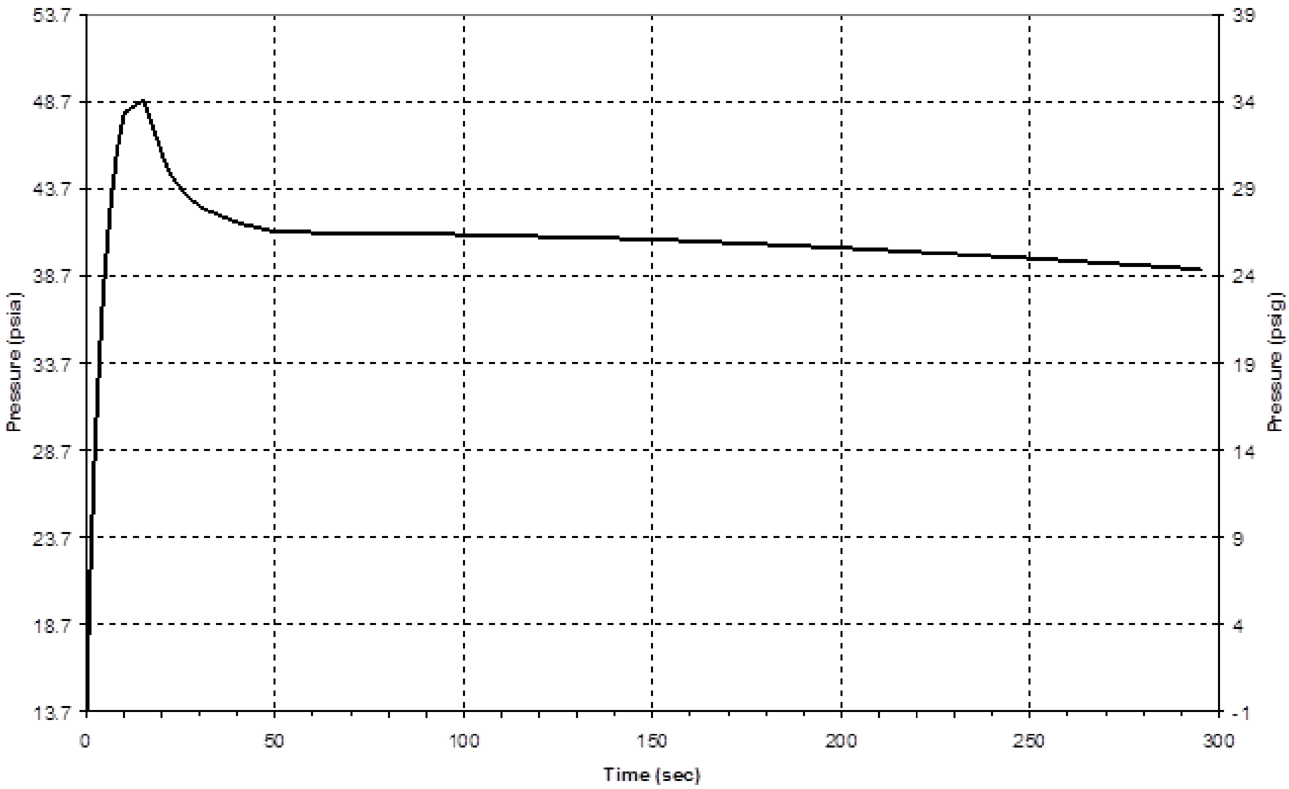
Table 5-13: Containment Heat Sink Thermophysical Properties

Material	Thermal Conductivity, BTU/hr-ft-F	Heat Capacity, BTU/ft^3-F
Concrete	0.92	22.62
Steel	27.0	58.8
Stainless Steel	9.1836	54.263
Paint (Plasite)	0.6215	40.42

Table 5-14: Assumed Operator Actions

LBLOCA Operator Actions	
1	A continuous ECCS source is maintained, such as through transferring ECCS suction from the BWST to the sump for long-term cooling.
2	Appropriate boron concentration control is maintained to prevent precipitation or recriticality and to ensure long-term cooling.
SBLOCA Operator Actions	
1	Raising the EFW secondary level setpoint from the natural circulation setpoint to the loss of subcooling margin setpoint of 27.7 ft above the UFLTS with respect to the OTSG (datum for the RELAP5 model). The delay after reactor trip is 20 minutes for the first SG and (if modeled) 30 minutes for the second SG.
2	For the smallest breaks that are not specifically analyzed (partial HPI line and CLPD < 0.01 ft^2), manual initiation of HPI at 10 minutes after LSCM assures that the consequences of these breaks are less severe than those break sizes that are explicitly analyzed.
3	For SBLOCA analyses that do not postulate LOOP, operator action to trip the RCPs at 2 minutes following LSCM is credited.
4	Operator action to assure flow from second HPI pump at 10 minutes after ESFAS is credited for the full power SBLOCA analyses.
5	Operator action block AFIS and to modulate the ADV opening in the SG being fed with EFW at 25 minutes after ESFAS such that a main steam pressure of 315 psia is maintained indefinitely is credited for the 52% power SBLOCA CLPD, CFT line and HPI line breaks.
6	If there is a loss of main or emergency feedwater (via AFIS, for example), the operators will restore EFW if there is a loss of subcooled margin. The restoration of EFW means that the operators should make sure that at least one EFW pump is operating with an assured suction source and a pump discharge flow path available to at least one SG. EFW flow is verified to be operating or restored for all conditions with a loss of subcooling margin (including an AFIS actuation).
7	Operator action to bypass AFIS before raising the SG level to the LSCM setpoint and ensure continued availability of EFW flow to raise and control the SG level.
8	A continuous ECCS source is maintained, such as through transferring ECCS suction from the BWST to the sump for long-term cooling.
9	Appropriate boron concentration control is maintained to prevent precipitation or recriticality and to ensure long-term cooling.

Figure 5-1: LBLOCA Containment Pressure Note



Note: Appendix D of Reference [8] evaluated the applicability of the containment pressure performed in Appendix J, Reference [21] and concluded that it remains applicable to the full-core Mark B-HTP LBLOCA analyses.

6.0 LBLOCA SENSITIVITY STUDIES AND ANALYSES

LBLOCA licensing analyses are completed with a model that is constructed based on Volume I of the NRC-approved BWNT LOCA Evaluation Model (Reference [1]) and any changes required are based on the information contained in Section 4.0. There are a variety of sensitivity studies that are performed to demonstrate model convergence and conservatism before the LBLOCA analyses are performed. Many of the studies are generic in nature and reported in the BWNT LOCA EM topical. Other studies are applicable to a specific plant-type (i.e., lowered-loop 177-FA plant category which includes the ONS plant). In some special circumstances there are plant-specific studies that are required because of unique design features of the plant. The LBLOCA sensitivity studies are addressed in Section 6.1. The transient results for the Mark-B-HTP fuel assemblies are presented in Section 6.2.

6.1 LBLOCA Sensitivity Studies

LBLOCA analyses require that various sensitivity studies be performed with the evaluation model to demonstrate model convergence and to identify the most limiting set of boundary conditions or break locations that should be used to show compliance with the first three criteria in 10 CFR 50.46. As part of the LBLOCA EM, AREVA performed numerous LBLOCA sensitivity studies to confirm modeling techniques and methods. Although the EM was based on a slightly different plant design (205-FA RL), the safety evaluation report for BAW-10192P-A (Reference [1]) supports the application of the EM to the 177-FA plants. AREVA has determined that the generic LBLOCA sensitivity studies performed in the EM are directly applicable to and appropriate for use in the ONS LBLOCA analyses.

AREVA also performed the necessary plant-type specific sensitivity studies to confirm that the most limiting set of plant boundary conditions were applied to the licensing analyses.

6.1.1 EM Generic Studies

The majority of the LBLOCA sensitivity studies presented in the EM topical report (Reference [1, Volume I]) are generic and apply to any LBLOCA analysis for the B&W-designed nuclear steam system. An example is the RELAP5/MOD2-B&W time-step study, which showed that the automatic time step selection in RELAP5/MOD2-B&W would produce converged results. This demonstration need not be repeated for plant-specific applications in which the modeling techniques used are represented by those in the EM studies. The following list identifies the generic sensitivity studies and provides a more detailed discussion regarding the application of the sensitivity study results to the LBLOCA analyses performed for a core full of Mark-B-HTP fuel. For convenience, each discussion is referenced to the section in the EM topical report where the study is documented.

1. RELAP5/MOD2-B&W Time-Step Study
2. RELAP5/MOD2-B&W Pressurizer Location Study
3. RELAP5/MOD2-B&W Break Noding Study
4. RELAP5/MOD2-B&W Core Crossflow Study
5. RELAP5/MOD2-B&W Core Noding Study
6. RELAP5/MOD2-B&W ECCS Bypass Study
7. REFLOD3B Loop Noding Study
8. REFLOD3B RCP Locked versus Free-Spinning Rotor Study
9. BEACH Time Step Study
10. BEACH Axial Fuel Segmentation Study
11. Axial versus Radial Core Peaking Factor Study

6.1.1.1 RELAP5/MOD2-B&W Time-Step Study

The study using the generic EM, documented in BAW-10192P-A (Reference [1], Volume I, Appendix A, Section A.2.1), verified that, for light water reactor geometry, the RELAP5 time-step controller governs the code solution sufficiently to assure convergent results. In RELAP5/MOD2-B&W, the user specifies a maximum time step that can be modified internally by the code in the event of convergence or Courant limitations. The LBLOCA EM time-step studies justified use of a 2.5-millisecond maximum time-step size for the first two seconds of the transient and a 25-milisecond maximum time-step size thereafter as appropriate for B&W-plant LBLOCA analyses. The EM controls the plant input models such that no significant deviation in the number or size of the control volumes or heat structures critical to the model results can be included between plant designs. Since the LBLOCA analytical model is similar to the model used for the EM time-step study, and the maximum time-step size in the ONS LBLOCA analyses is the same as or less than that used in the EM time-step study, the RELAP5/MOD2 time-step controller will also adequately control the problem advancement for these applications. The EM study remains valid, therefore, and this study does not have to be repeated.

6.1.1.2 RELAP5/MOD2-B&W Pressurizer Location Study

Studies performed with the LBLOCA EM (BAW-10192P-A, Volume I, Appendix A, Section A.2.2) showed that there is little difference in results when the pressurizer is connected to the broken loop instead of the intact loop. This result is expected since the LBLOCA transient is dominated by such factors as leak flow and initial fuel stored energy. Therefore, the pressurizer location study performed with the EM is applicable to the ONS LBLOCA analyses and this study does not have to be repeated.

6.1.1.3 RELAP5/MOD2-B&W Break Noding Study

This study (BAW-10192P-A, Volume I, Appendix A, Section A.2.3) verified that hydraulic stability is achieved by providing at least one control volume in the pipe between any adjacent component and the break node and by maintaining an L/D greater than approximately 1.5 in the break control volumes. This lower limit is suggested by the benchmarks to the Marviken Tests (Reference [56]). The calculated L/Ds for the LBLOCA model are 2.8 (Reference [8]). Therefore, the break noding study performed with the EM is applicable to the ONS LBLOCA analyses and this study does not have to be repeated.

6.1.1.4 RELAP5/MOD2-B&W Core Crossflow Study

The core cross-flow is modeled in the base model through the use of R5/M2 cross-flow junctions between the hot and average channels in the core region. The core cross-flow study (BAW-10192P-A, Volume I, Appendix A, Section A.2.4) verified that a cross-flow k-factor of 72.0 in a B&W-type reactor produced converged results and is reasonable for two-channel EM applications. The conclusions of this study were later confirmed in Revision 0 of Reference [48] for the new EM method in which a separate heat structure was introduced to represent the hottest pin in the hot channel. This new EM method includes a new modeling approach for the stored energy of the hot and average channels. The results of these studies were dominated by the axial core flow response to the large cold leg break and not strongly dependent on the fuel design. As discussed in Section 5.7 in Revision 0 of Reference [48], the LBLOCA causes large differential pressures axially across the core. The reactor vessel vent valves diffuse the magnitude of the axial pressure differential by providing an additional flow path for liquid and vapor flow out of the core (reactor vessel vent valve to the break or lower plenum to the break). When axial flow is dominant, the cross-flow resistance (radial flow) has little effect on the results. Therefore, it is concluded that results of the core cross-flow sensitivity study are applicable to the ONS LBLOCA analyses with Mark-B-HTP fuel and this study does not have to be repeated.

6.1.1.5 RELAP5/MOD2-B&W Core Noding Study

In conjunction with the core crossflow study, this study (BAW-10192P-A, Volume I, Appendix A, Section A.2.5) verified that modeling the reactor core with two fluid channels adequately predicted the blowdown transient. The results of the study showed that the axial modeling detail used in the two channel model were of sufficient detail to adequately calculate the cladding temperature response to the LOCA transient. The results were not strongly dependent on the fuel design, and they are applicable to all plants considered by the evaluation model. Therefore, the study is applicable to the ONS LBLOCA analyses with Mark-B-HTP fuel and this study does not have to be repeated.

6.1.1.6 RELAP5/MOD2-B&W ECCS Bypass Study

This study (BAW-10192P-A, Volume I, Appendix A, Section A.2.8) verified a non-mechanistic bypass model based on Upper Plenum Test Facility (UPTF) test results to remove the ECCS liquid injected during blowdown. This study is applicable to all plants with downcomer injection and reactor vessel vent valves. Therefore, the study is applicable to the LBLOCA ONS analyses with Mark-B-HTP fuel and this study does not have to be repeated.

6.1.1.7 REFLOD3B Loop Noding Study

This study (BAW-10192P-A, Volume I, Appendix A, Section A.3.1) verified the noding detail used in the REFLOD3B code. It is applicable to all plants considered by the evaluation model. A minor change from the EM noding arrangement was included in this lowered-loop noding arrangement. The intact cold legs were combined in the 205-FA RL EM model, but were separated for application of the 177 FA LL plants (shown in Figure 4-5 on page LA-133 of Reference [1], Volume III) to accommodate a single blocked loop seal if predicted. The analyses performed for ONS, however, did not predict any loop seal formations. Therefore, the study is applicable to the ONS LBLOCA analyses with Mark-B-HTP fuel and need not be repeated.

6.1.1.8 REFLOD3B RCP Locked versus Free-Spinning Rotor Study

This study (BAW-10192P-A, Volume I, Appendix A, Section A.3.2) showed a considerable reduction in flooding rate under a locked-rotor assumption. The study affirms the generally held understanding of loop resistance effects on reflooding rates and is applicable for all plant types covered by the evaluation model. Therefore, the study is applicable to the ONS LBLOCA analyses with Mark-B-HTP fuel and this study does not have to be repeated.

6.1.1.9 BEACH Time Step Study

This study (BAW-10192P-A, Volume I, Appendix A, Section A.4.1) verified that the BEACH (RELAP5/MOD2-B&W) time-step controller would check and adjust time step size sufficiently to assure converged results provided the set of inputs described as the “Decreased Time Step” case on Table A-10 of BAW-10192P-A is used. In response to NRC Question 16 on the evaluation model (BAW-10192P-A, Volume III), a reanalysis of the BEACH time-step study was performed with the BEACH inlet subcooling methodology. The results of the revised study also confirm that the time-step inputs given in Table A-10 of Volume 1 of BAW-10192P-A produce converged results. Alternate plant designs within the range of designs covered by the evaluation model will not change these results. Therefore, the study is applicable to the ONS LBLOCA analyses with Mark-B-HTP fuel and this study does not have to be repeated.

6.1.1.10 BEACH Axial Fuel Segmentation Study

This study (BAW-10192P-A, Volume I, Appendix A, Section A.4.2) verified that the use of eight fine-mesh intervals was sufficient to produce converged results. Alternate plant designs within the range of designs covered by the evaluation model will not change that result. Therefore, the study is applicable to the ONS LBLOCA analyses with Mark-B-HTP fuel and this study does not have to be repeated.

6.1.1.11 Axial versus Radial Core Peaking Factor Study

This study (BAW-10192P-A, Volume I, Appendix A, Section A.5) showed that representative LOCA limits were obtained with a method that specifies a constant axial peak of 1.7 and adjusts the radial peaking factor to give the maximum allowable linear heat rate limit. Typical core power distribution analyses obtain radial and axial peaking factors similar to those used in the EM. Therefore, AREVA NP views this technique to be reasonable for all EM applications; however, the NRC has imposed a restriction to this method. AREVA NP has developed a method that considers the available LOCA margin from the core power distribution analyses. The method reduces the LOCA LHR limit to preserve the limiting PCT if the radial and axial peaks are not within the defined criteria based on EM sensitivity studies. Section 8.0 provides the criteria needed to show compliance with the LOCA restriction on peaking.

The effect of the axial peaking factor on the LOCA transient is from two blowdown effects and one reflood effect (Section 3 of Reference [60]): CHF timing, elevation of dryout during core flow reversal, and reflood carryout rate. The method described in Reference [60] was based on Mark-B9/B10 fuel rod analyses. Reference [61] confirmed that the method remained applicable to the Mark-B11 fuel rod design. Furthermore, the study performed in Revision 4 of Reference [59] demonstrated that similar CHF behavior is observed for the Mark-B-HTP and Mark-B9 fuel rod designs. Since very similar trends were seen for the Mark B9/B10 (BWC CHF correlation), the Mark-B11 (BWCMV CHF correlation) and Mark-B-HTP (BHTP CHF correlation), it can be concluded that the CHF correlation does not significantly impact the observed trends and that the CHF timing is primarily set by the initial enthalpy distribution in the channel and the local fuel pin power distribution. Hence, the methods provided in Reference [60] are valid for any current or past Mark-B fuel type including the Mark-B-HTP. Consequently the axial versus radial core peaking factor sensitivity study of Reference [59] is applicable to the ONS LBLOCA analyses with Mark-B-HTP fuel and this study does not have to be repeated.

6.1.2 EM Plant-Type Studies

Although a considerable portion of the analysis inputs and assumptions are set or controlled by the evaluation model and its sensitivity studies, some parameters are dependent on inputs specific to a plant type and should be established by separate studies. These studies are performed to identify a limiting case to use in determining the LBLOCA LHR limits. This section presents the studies performed with the LBLOCA evaluation model for the 177-FA LL plant that helped to define the final plant model configuration used in the ONS LBLOCA LHR limit analyses.

1. RELAP5/MOD2-B&W Pump Degradation Study
2. RELAP5/MOD2-B&W RC Pump Power Study
3. LBLOCA Break Spectrum Study
4. CFT Initial Conditions Study

6.1.2.1 RELAP5/MOD2-B&W Pump Degradation Study

This study was performed as part of the generic evaluation model sensitivity studies contained in BAW-10192P-A (Volume I, Appendix A, Section A.2.6), which were based on the 205-FA RL plant design. The results established a limiting, maximum pump degradation multiplier set (M1) to be used in all EM analyses. PSC 1-99

identified that the 177-FA LL plants could produce significantly higher PCTs when a minimum two-phase pump degradation model is used (M3-modified). These mixed conclusions resulted in subsequent supporting analyses performed for the Oconee units confirming this assertion (Reference [57]).

The results of the Oconee study clearly demonstrated that the minimum two-phase degradation (M3-modified curve) produces more severe results than the maximum degradation case (M1 curve). The minimum degradation multiplier reduces the resistance of the pumps in the HVN octant of the pump homologous curves. As a result, the core flow reverses direction later in the transient and produces lower core flow rates. The decrease in removal of fuel stored energy leads to higher fuel temperatures at end of blowdown than for the maximum degradation case. Furthermore, there is less liquid available for input to REFLOD3B in the lower plenum of the reactor vessel. As a result, the adiabatic heatup time will be longer resulting in a PCT increase. From these results it is concluded that for all Category 1 plants, the minimum pump two-phase degradation will produce more severe results than the maximum pump degradation.

The current ONS LBLOCA analyses model ROTSGs which have a different mass, flow resistance, and tube plugging compared to the OTSGs with which the RCP degradation study was performed. The core model is also separated into a hot pin, hot channel, and average channel with different uncertainties on the initial fuel temperature. The conclusions of the RCP degradation study are dependent only on the pump characteristics, which are not changed for the ONS LBLOCA analyses. If the ROTSGs and core model modifications were incorporated into the RCP degradation study, the effect on each case would not change the conclusions. Therefore, the RCP degradation study is applicable to the ONS LBLOCA analyses with the ROTSGs and the new core model and need not be repeated.

6.1.2.2 RELAP5/MOD2-B&W RC Pump Power Study

In the evaluation model (BAW-10192P-A, Volume I, Appendix A, Section A.2.7), this study indicated that the RCS response with the pumps powered is less severe, from a core cooling perspective; than the configuration with the pumps unpowered. To confirm this pump configuration for the 177-FA LL plants, a pumps-powered analysis was performed based on the Oconee units (Reference [43]).

The results of the Oconee study clearly demonstrated that the pumps-tripped case produces more severe results than the pumps powered case. With the pumps powered, the core flow was more positive in the first few seconds of the blowdown because the pumps produced higher loop flows. During this first portion of blowdown, the increase in the core flow allows for removal of additional fuel stored energy, decreasing the end-of-blowdown fuel temperatures. Also, in the pumps-powered case, more liquid was available for input to REFLOD3B in the lower plenum of the reactor vessel, so the adiabatic heatup period is shorter. From these results, it is concluded that for all Category 1 plants, the pumps-tripped configuration will produce more severe results than the pumps-powered configuration.

The current analyses model ROTSGs that have a different mass, flow resistance, and tube plugging compared to the OTSGs with which the RCP degradation study was performed. The core model is also separated into a hot pin, hot channel, and average channel with different uncertainties on the initial fuel temperature. The current ONS LBLOCA analyses also use the Mark-B-HTP fuel design compared to the Mark-B-11 fuel design used for the RCP power study. The conclusions of this study are dependent only on the pump characteristics, which are not changed for the ONS LBLOCA analyses. If the ROTSGs and core model modifications were incorporated into the study, they would have a similar effect on each case in this study and the conclusions would be unchanged. Therefore, the implementation of the ROTSGs and the new core model will not affect the conclusions of this study.

6.1.2.3 LBLOCA Break Spectrum Study

The 10 CFR 50, Appendix K requires that a spectrum of breaks be considered in determining the worst-case break size, configuration, and location. Results of analyses documented in the EM (Reference [1]) determined that the typical worst break is a full-area double-ended guillotine (DEG) break located in the CLPD piping with a discharge coefficient (C_D) of 1.0. This break location causes a significant reduction in the core flow and fuel pin heat removal during the first third of the blowdown period. The proximity of the break to the ECCS injection location also maximizes the potential for ECCS bypass during the later stages of blowdown. These two effects result in less fuel pellet stored energy removal and an increase in the reactor vessel lower plenum refill time. To confirm these results for a 177-FA LL B&W plant, a break spectrum analysis, which considered break size, configuration, and location, was performed for the Oconee plant using the LOCA evaluation model (Reference [58]).

Discharge Coefficient Analysis – The case with a C_D of 1.0 resulted in the smallest positive hot spot core flow between one and eight seconds of the blowdown phase. The smaller flow reduced the fuel pin surface heat transfer. The liquid mass remaining in the lower plenum at the end of blowdown was also a minimum for this analysis, requiring a longer refill time during which the fuel pins heat up adiabatically. The calculated hot rod PCT was produced by the ruptured cladding segment. The calculated PCTs declined with decreasing discharge coefficient and switched to an unruptured segment, directly adjacent to the ruptured location. Further reductions in the discharge coefficient would result in additional surface heat transfer that would continue to reduce the calculated PCT. Therefore, no other calculations with small discharge coefficients were warranted. These results also confirmed that the transition break sizes discussed in the LBLOCA EM did not need to be analyzed. The full-area, DEG CLPD break with a discharge coefficient of 1.0 produced the most limiting results of the discharge coefficients studied. Since the results of this study can be applied to all Category 1 plants, it is not necessary to demonstrate these results for the ONS LBLOCA analyses and need not be repeated.

Break Type Analysis - Appendix K of 10 CFR 50 requires that instantaneous double-ended guillotine and longitudinal split break configurations be considered. The guillotine break is modeled as an instantaneous severance of the pipe, allowing separate discharges through the full pipe area from each side of the break without flow interference between the two broken pipes. The split break assumes discharge from a split in the pipe through an area up to twice the cross-sectional pipe area. Because the pipe does not totally separate, flow is allowed to continue through the split pipe. The blowdown rates and system flow splits are somewhat different for the two break types, which can lead to differences in core flows and fuel pin heat removal.

Both breaks use discharge coefficients of 1.0. The split break produced higher core down flows during the later portion of blowdown, leading to better cooling and lower end-of-blowdown fuel pin and clad temperatures. The lower pin temperatures produce less boiling, decreasing the liquid carryout, such that a higher core flooding rate is obtained. Consequently, the calculated PCT for the full-area split break with a discharge coefficient of one is lower than that produced by the guillotine break.

Split breaks with smaller discharge coefficients would increase the positive core flows during the first portion of blowdown. These higher flows would improve the cladding heat removal and cause additional reductions in the calculated PCTs. Therefore, CLPD split breaks will not produce core thermal-hydraulic conditions that can result in a PCT higher than that calculated for the guillotine break with a discharge coefficient of 1.0. Since the results of this study can be applied to all Category 1 plants, it is not necessary to demonstrate these results for the ONS LBLOCA analyses and need not be repeated.

Break Location Analysis - There are three locations to consider for the large break LOCA: the hot leg piping, the cold leg pump suction piping, and the cold leg pump discharge piping. The hot leg break has been consistently shown to result in peak cladding temperatures far below those predicted for cold-leg breaks (see BAW-10192P-A, Section A.6.5). The large positive core flow and no ECCS bypass combine to provide high fuel pin heat removal

for all hot leg breaks. Therefore, a hot leg LOCA analysis is not required to demonstrate that a hot leg break is not limiting for the 177-FA LL plant.

The pump suction break was analyzed to compare with the cold leg pump discharge break to determine the worst break location. The broken leg pump provided a significant resistance to flow trying to reach the break through the broken leg (RV side). The liquid was forced to reach the break via the hot legs, leading to positive core flows throughout blowdown and significantly increased hot pin heat removal. The lower pin temperatures allowed a higher core flooding rate and faster quench front advancement, and the amount of liquid remaining in the reactor vessel at EOB led to a significantly shortened adiabatic heatup time. The PCT for the pump suction break was significantly lower than that for the pump discharge break. Therefore, a break in the CLPD will produce more severe results. Since the results of this study can be applied to all Category 1 plants, the study is applicable to the ONS LBLOCA analyses and need not be repeated.

Transition Breaks - Although not considered a separate category, the LBLOCA spectrum is divided into two break ranges for the purpose of EM methods: breaks large enough to initially exceed DNB up to 2.0 ft^2 and breaks greater than 2.0 ft^2. The smaller range is analyzed using the transition LOCA method. A set of LBLOCAs at the lower end of the spectrum were analyzed to verify the larger, double-ended breaks were more limiting and to demonstrate the transition methodology. A 2.0-ft^2 CLPD analysis was performed using both the large break methodology and the transition methodology to provide a comparison of methods. Additionally, 1.5-, 1.0- and 0.75-ft^2 CLPD split breaks were analyzed using the transition methodology. The results of these analyses are provided in the LOCA EM (see Section A.6.4, Volume 1 of BAW-10192P-A). A comparison of the results show that the transition breaks are typically much less limiting than the larger break sizes in terms of the PCT consequences. Since the results of this study can be applied to all Category 1 plants, the study is applicable to the ONS LBLOCA analyses and need not be repeated.

6.1.2.4 CFT Initial Conditions Study

This study was not performed as part of the generic evaluation model sensitivity studies contained in BAW-10192P-A. A study was performed, however, for the Oconee plants to investigate which combination of CFT initial pressure and liquid inventory was most conservative for use in the LBLOCA analyses being performed with the evaluation model (Reference [47], Revisions 01 and 02). Four cases were included in the Oconee study: (1) minimum inventory with minimum pressure, (2) maximum inventory with minimum pressure, (3) maximum inventory with maximum pressure, and (4) nominal inventory with nominal pressure.

The results of the Oconee study showed that the maximum inventory with minimum pressure case produced the most conservative set of initial CFT conditions. These initial conditions combine to produce the smallest initial gas volume and mass. As the CFT empties, the nitrogen overpressure reduces more quickly, resulting in a lower CFT flow during the lower plenum refill or adiabatic heatup period. The lower flow delays the time of beginning of core recovery (BOCR). Since the PCT is predicted shortly after the end of adiabatic heatup (EOAH), a longer adiabatic heatup results in the highest PCT.

The CFT initial condition sensitivity study also demonstrated that the LPI flow reduction was not sufficient to hinder the reflooding rate such that a higher limiting PCT was produced at a later time. This was true for both the limiting PCT maximum level, minimum pressure case; as well as the non-limiting maximum pressure, minimum level cases. While the core flooding rate with the reduced LPI flow was somewhat reduced compared to previous analyses, the flooding rate was sufficient to maintain adequate long-term heat transfer so that the cladding temperatures were kept below the peaks predicted before LPI begins. Therefore, the LPI system modifications and slight flow changes did not adversely impact the ability to predict acceptable LOCA consequences with respect to the 10 CFR 50.46 criteria.

The CFT initial conditions sensitivity study is directly applicable to the ONS LBLOCA analyses and need not be repeated.

6.1.3 EM Plant-specific Studies

Although a considerable portion of the analysis inputs and assumptions are set or controlled by the evaluation model and its sensitivity studies, some parameters are dependent on inputs specific to a plant and should be established by separate studies. These studies are performed to identify a limiting case to use in calculating the LBLOCA LHR limits. This section presents the studies performed with the LBLOCA evaluation model for ONS that helped to define the final plant model configuration used in the LHR limit analyses. These LBLOCA EM plant-specific sensitivity studies are listed below:

1. Containment Pressure and ECCS Configuration Study
2. RCP Type Study

6.1.3.1 Containment Pressure and ECCS Configuration Study

The results of Volume I, Appendix A, Section A.10 of BAW-10192P-A recommended that this study be performed for each plant classification for specific LOCA applications studies. This study was reanalyzed for Oconee considering the ROTSGs and the LPI cross-tie modification, because of the changes to the RCS mass and energy (lower SG tube plugging) and ECCS system. This study compared both maximum (two trains) and minimum (one train) ECCS injection with a corresponding containment pressure (Reference [21]). Both analyses calculated minimum containment pressure by incorporating the assumptions identified in Section 4.3.6.1 of BAW-10192P-A.

During blowdown, the containment pressure response is essentially the same for both the minimum and maximum ECCS cases. This is expected since the end of blowdown occurs well before pumped ECCS injection begins. Consequently, pumped ECCS injection has little effect on the PCT. The net result, when the ECCS injection is consistent between the containment calculation and the reflood calculation, is a complex set of interactions that make it difficult to ensure a conservative calculation. Therefore, LBLOCA applications frequently use a composite set of boundary conditions to cover a variety of possible system configurations based on a myriad of potentially limiting single failures.

A minimum containment pressure consistent with maximum pumped injection is used during the reflood phase because the lower containment pressure creates more steam binding that results in lower core flooding rates. The lower core flooding rate delays the whole core quench time and generally maximizes the local oxidation and whole core hydrogen generation calculated during the transient. The flooding rate is also a strong function of the downcomer level. A maximum pumped injection rate generally keeps the downcomer full, while a minimum pumped injection rate may not. If the downcomer level is not full with the minimum ECCS flow, then this assumption produces the lowest flooding rates. If the downcomer is full with the minimum ECCS flow, then the maximum ECCS flow acts to reduce the long-term core flooding rate by reducing the elevation head via increased condensation in the upper downcomer region.

The ONS LBLOCA analyses were performed with a composite set of pumped ECCS boundary conditions. Specifically, the containment pressure was minimized by using a maximum pumped ECCS flow from two ECCS trains to increase the steam binding and generate the most limiting condition for the long-term flooding rate. Since the composite approach produces more limiting results, the containment pressure and ECCS configuration sensitivity study need not be repeated for the ONS LBLOCA analyses.

6.1.3.2 RCP Type Study

Two different types of RCPs and motor types are used in the three ONS units. Specifically, Unit 1 has pumps manufactured by Westinghouse with Allis-Chalmers motors, while Units 2 and 3 have pumps manufactured by Bingham with Westinghouse motors (Reference [20]). Therefore, each unit has different pump parameters and motor constants that must be considered. Since a bounding analysis is performed for all three ONS units, a sensitivity study to determine the most conservative pump type was performed.

The resolution to PSC-1-99 discusses the LBLOCA sensitivity studies performed to determine the limiting pump type (Reference [57]). For the ONS units, the Westinghouse pump was found to be limiting. The Westinghouse pump type exhibits a more degraded positive flow performance with a lower rated flow. As a result, the case with the Westinghouse pump exhibits significantly less cooling during the positive core flow period of blowdown such that the cladding temperatures are worse than for the case with the Bingham pump type. Therefore, the analyses incorporate the specific parameters for the Westinghouse pump.

The current ONS LBLOCA analyses model ROTSGs that have a different mass, flow resistance, and tube plugging compared to the OTSGs. The core model is also separated into a hot pin, hot channel, and average channel with different uncertainties on the initial fuel temperature. The conclusions of the RCP type study are dependent only on the pump characteristics, which is not changed for the ONS LBLOCA analyses. If the ROTSGs and core model modifications were incorporated into the study, the effect on each case would be similar and the conclusions would be unchanged. Therefore, the RCP type study is applicable to the ONS LBLOCA analyses with the ROTSGs and the new core model and need not be repeated.

6.2 LBLOCA Analyses

The LBLOCA analyses are performed to show compliance with 10 CFR 50.46 requirements for the limiting core power and peaking conditions that are used to set core operational limits and trip setpoints (i.e.,. the LOCA limits). These LBLOCA analyses serve as the bases for the allowable local power. Numerous cases are analyzed to determine a curve of allowable peak LHR limits as a function of core elevation for all times in life of fuel operation. This curve is either contained in or referenced by the plant technical specifications.

LBLOCA analyses require the minimum containment pressure response calculated by the CONTEMPT code (Reference [4]). The previous ONS containment pressure response analysis was performed for the ONS mixed-core Mark-B-HTP analyses (appendix J of Reference [21]). Appendix D of Reference [8] addressed the applicability of this analysis to the full-core Mark-B-HTP LBLOCA and it showed that the Containment Pressure Analysis from Reference [21] is applicable to the full-core Mark-B-HTP LBLOCA analyses.

The LBLOCA analyses provide elevation-specific limits that span the entire core and cover up to 62 GWd/mtU for the Mark-B-HTP fuel assembly. MOL conditions are established at a rod average burnup of 34 GWd/mtU, which supports a hot spot burnup of approximately 40 GWd/mtU. For EOL conditions, a rod average burnup of 62 GWd/mtU supports a hot spot burnup of approximately 74 GWd/mtU. The LHR limits defined by these LBLOCA analyses and evaluations provide adequate detail that can be interpolated for other elevations and burnups to provide a continuous LHR limit surface that will ensure compliance with all the 10 CFR 50.46 criteria.

6.2.1 Base Model

The results of the evaluation model and plant classification sensitivity studies define the base model configuration for the Oconee Mark-B-HTP full-core LBLOCA LHR limit analyses. The base case is a full double-area, guillotine break in the cold leg pump discharge piping at the elevation of the reactor vessel inlet nozzle. A discharge coefficient of 1.0 maximizes the break flow and produces the highest PCT.

A loss of off-site power is assumed at the time of break opening, so the reactor coolant pumps and main feedwater pumps are not powered during the transient. The Westinghouse homologous head flow curves with RELAP5 Semiscale two-phase head difference curves and head degradation using the M3-modified two-phase multiplier maximizes the PCT (minimizes core cooling during blowdown). Replacement steam generators with seven percent tube plugging in each steam generator are considered.

The non-mechanistic ECCS bypass method is used during blowdown to discard the ECCS liquid injection prior to predicting the end of bypass. The maximum delay of 38 seconds after the ESFAS RCS low-low pressure trip setpoint is assumed to initiate pumped ECCS injection (LPI). The LPI flow begins with a 36 second flow ramp to model the opening of the LPI valves. The full flows are based on the LPI cross-tie modification.

HPI flow versus pressure is not modeled in the LBLOCA PCT analysis; however, it is considered via the momentum loss at the ECCS injection from steam-water interaction. (HPI flow is modeled to determine the minimum containment pressure.) Additionally, while HPI is not explicitly credited for long-term cooling, its use for that purpose may be considered should the need (e.g., component failure, emergent maintenance, etc.) arise and conditions (i.e., RCS pressure) permit.

For the refill and reflood system analysis, the reactor coolant pump rotors are assumed to be in a fixed position. The maximum ECC fluid temperature is assumed to minimize the core cooling potential. Minimum ECCS flows with a minimum containment pressure response was used to produce more conservative PCTs and fuel rod oxidation/hydrogen generation.

The CFT initial conditions are set to maximum inventory and minimum initial gas pressure to assure a conservative calculation of PCT. The core contains Mark-B-HTP fuel that has M5® cladding. Additional plant conditions specific to ONS Mark-B-HTP full-core analyses are summarized in Section 5.0.

The LBLOCA model considers three heat structures in the core. As allowed by the RELAP5/MOD2-B&W Topical (Reference [5]), a hot pin heat structure has been separated from the hot bundle heat structure and both are connected to the hot assembly fluid channel. The radial and axial power factors used for the hot pin are identical to that used for the hot bundle. The only difference is in the initial fuel temperature uncertainty. The hot pin considers an uncertainty of 11.51% on the best-estimate fuel temperature from TACO3 (or GDTACO) and the hot bundle considers an uncertainty of 3% with a BOL burnup. Four additional hot pins are modeled in the hot assembly to represent rods with different Gadolinia weight fractions. For all cases, the average channel uses the best-estimate fuel temperature. The core channels with Mark-B-HTP fuel utilize the BHTP CHF correlation, and this correlation is described in Reference [5].

LOCA analyses performed with the BWNT LOCA EM typically consider batch fuel pin enrichments in the range of 3 to approximately 5 percent. The method of analysis bounds the fuel initial temperatures and decay heat contributions for fuel pin enrichments in this range. Bulk or batch fuel assembly enrichments lower than this range can be used, provided justification of appropriate fuel initial temperatures near BOL and bounding actinide decay contributions for both the local assembly power and the total core decay heat are included in the LOCA analyses or evaluations.

6.2.2 LBLOCA Transient Progression

LBLOCA can be treated analytically in three separate phases: blowdown, refill and reflood. The blowdown phase is characterized by the rapid depressurization of the reactor coolant system to a condition nearly in pressure equilibrium with its containment surroundings. Core flow is variable and dependent on the nature, size and location of the break. The CLPD guillotine break with a discharge coefficient of 1.0 is chosen in determining the LBLOCA core LHR limits since it provides limiting results due to the location and size of the break. The break area is 8.6822 ft^2 which is equivalent to twice the hot flow area of the CL piping. Departure from nucleate boiling (DNB) is calculated to occur very quickly at the high power locations, and core cooling is by a film boiling process. Since film boiling amounts to only a small fraction of the core decay heat cooling, the cladding temperature increases by 600 F to 1200 F. CFT flow begins after the RCS depressurizes below the CFT fill pressure. Steam condensation caused by the CFT liquid aids the negative core flows that reduce the fuel pin temperatures during the middle-blowdown period. During the last phases of blowdown, cooling is by convection to steam, and the cladding temperature begins to rise again.

Following blowdown, a period of time is required for the CFTs to refill the bottom of the reactor vessel before the final core cooling mode can be established. During this period, core cooling is marginal, and the cladding experiences a near-adiabatic heatup. This period is designated as the refill phase, because the CFT flow is refilling the reactor vessel lower plenum. When the water level reaches the bottom of the active core, the reflood phase begins. Core cooling is by steam generated below the rising core water level. The cladding temperature excursion is generally terminated before a particular elevation is covered by water since the steam-water mixture is sufficient to remove the relatively low decay heat power being generated at this time. A two-phase mixture eventually covers the core, and the path to long-term cooling is established through initiation of LPI flow near the time that the CFTs empty and subsequent operator action to maintain pumped injection.

The RELAP5/MOD2-B&W code (Reference [5]) calculates system thermal-hydraulics, core power generation, and the clad temperature response during blowdown. The REFLOD3B code (Reference [6]) determines the length of the refill period and the core flooding rate during reflood. BEACH (Reference [7]), which is the RELAP5/MOD2-B&W core model with the 2-dimensional reflood fine-mesh rezoning option activated, determines the clad temperature response during the refill and reflood period with input from REFLOD3B. The CONTEMPT code (Reference [4]) is used to determine the minimum containment pressure response based on the mass and energy release from the RCS as predicted by RELAP5 and REFLOD3B. The containment pressure is developed via several iterations between the mass and energy releases and containment pressure boundary conditions with these three codes.

6.2.3 Full-Core Mark-B-HTP LOCA LHR Limits

A LBLOCA LHR limit analysis was performed to support a core full of Mark-B-HTP fuel, Reference [8]. This section provides the LHR limits and PCTs applicable to UO_2 and Gad pins for the unanalyzed elevations associated with the BOL, MOL, and EOL analyses. Figure 6-1 identifies the axial power shapes analyzed, (References [10] and [71]). A total of five elevations were analyzed at BOL and MOL conditions, while only one elevation was analyzed at EOL conditions. Specifically, UO_2 pins were analyzed for LHR limits at the 2.506 ft, 4.264 ft, 6.021 ft, 7.779 ft, and 9.536 ft elevations for BOL and MOL conditions, and at the 2.506 ft elevation for EOL conditions. On the other hand, the Gad pins were analyzed for LHR limits at the 2.506 ft elevation for BOL, MOL, and EOL conditions.

The resulting LOCA LHR limits and corresponding PCTs for a full core of Mark-B-HTP fuel are summarized in Table 6-1 through Table 6-9 (Appendix S, Reference [8]). The maximum peak clad temperature is 1913 F for a

core full of Mark-B-HTP fuel. The maximum percentage of local cladding oxidation is < 3 % for a core full of Mark-B-HTP fuel. The whole core hydrogen generation is < 0.16 % for a core full of Mark-B-HTP.

6.2.3.1 Beginning of Life (BOL)

The BOL UO_2 hot pin initial conditions from TACO3 for each elevation are presented in Table 6-1. The results of the UO_2 BOL LOCA limit analyses are tabulated in Table 6-2.

Four different weight percent Gadolinia fuels were analyzed in 2.506-ft peak power case. The results of the Gadolinia BOL analyses are tabulated in Table 6-6 through Table 6-9. The BOL Gadolinia pin initial conditions from TACO3 for each elevation are presented in Table 6-5. These cases are documented in Reference [8].

The LHR limit of 17.8 kW/ft used in the analyses produces a hot spot decay heat power during the reflooding phase that is at the maximum power range for which BEACH application is approved (Appendix B of Reference [7]). The LHR limit of 17.3 kW/ft at the 9.536-ft peak location was set to be the same as the LHR limit at the 11-ft peak location used for the SBLOCA analyses. The BOL UO_2 and Gadolinia endpoint LHR limits (0.0- and 12.0-ft elevations) and associated PCTs are discussed in Section 6.2.3.6.

6.2.3.2 Middle of Life (MOL)

Previous LOCA analyses have shown that BOL LHR limits can be held constant until the MOL burnup where the fuel volume-averaged temperature is roughly 100 F less than the BOL value to obtain similar PCTs at BOL and MOL. These time-in-life studies, documented in BAW-10192P-A, Volume I, Section A.7, are appropriate provided mid-blowdown rupture is not predicted. The time-in-life analyses performed for ONS are justified by maintaining the BOL allowable LHR limits for all core elevations at constant values up to a burnup of 34 GWd/mtU. The UO_2 hot pin initial conditions obtained from TACO3 for each elevation at MOL are shown in Table 6-1. The results of the MOL UO_2 LOCA limit analyses are tabulated in Table 6-3.

Four different weight percent Gadolinia fuels were analyzed in 2.506-ft peak power case. The MOL Gadolinia pin initial conditions from TACO3 for each elevation are presented in Table 6-5. The results of the Gadolinia MOL analyses are tabulated in Table 6-6 through Table 6-9. These cases are documented in Reference [8]. The MOL UO_2 and Gadolinia endpoint LHR limits (0.0- and 12.0-ft elevations) and associated PCTs are discussed in Section 6.2.3.6.

6.2.3.3 End of Life (EOL)

At EOL, the UO_2 LHR limits are established based on TACO3 fuel pin initializations that keep the pin pressure below the ‘licensing above system pressure’ (LASP) limit. The EOL LOCA LHR that preserves the LASP limit is typically much lower than the MOL LHR limits. Therefore, the initial fuel temperature and analyzed PCT is much lower than the BOL or MOL values. The results are not PCT limited.

The UO_2 hot pin initial conditions obtained from TACO3 for each elevation at EOL are shown in Table 6-1. The EOL UO_2 LOCA limits results are tabulated in Table 6-4 and confirm that the EOL analysis is not PCT- limited. The EOL UO_2 LHR limits were held constant for all elevations. Unlike the BOL and MOL UO_2 0.0- and 12.0-ft elevations, which reduce the endpoint LHR limits and keep the PCTs the same as the adjacent elevations, a PCT increase was added to the adjacent elevations and then applied to the endpoints as discussed in more detail in Section 6.2.3.6. The remaining elevations, 4.264- through 9.536-ft, had PCT estimates based on the PCT trends observed among the elevations at BOL and MOL.

The LHR limits at EOL condition include increased uncertainty factors on the fuel volume-average temperature to account for decreases in the fuel thermal conductivity. For the EOL (62 GWd/mtU) case, the uncertainty factor used was 1.2171 for the hot pin and 1.1320 for the hot assembly (Section 9.1.1.3, Reference [8]).

6.2.3.4 Gadolinia

The fuel cycle designers frequently use a small number of Gadolinia doped-fuel pins for plants with longer cycle lengths to control the assembly pin peaks. These Gadolinia fuel pins are distributed within the assembly that remains primarily UO_2 fuel pins. The Gadolinia fuel pin geometries are effectively identical to the UO_2 fuel pins, however, some of the fuel properties remain different. Therefore, a subset of LOCA analyses are performed to develop the allowed Gadolinia LOCA LHR limits for use in the core power peaking analyses with these pins and to assure that these pins remain within the 10 CFR 50.46 acceptance criteria.

Four separate Gadolinia concentrations (2-, 4-, 6- and 8-w/o) were analyzed at the 2.506-ft axial power peak location for all TIL with a constant axial peak of 1.7 for the Mark-B-HTP fuel design. The Gadolinia fuel has a slightly lower thermal conductivity and volumetric heat capacity versus that of UO_2. These small property differences are accounted for by reducing the LHR limits for the Gadolinia fuel to keep the calculated results for Gadolinia fuel pins similar to UO_2 results.

The LBLOCA LHR limit analyses modeled four Gadolinia hot pins in the UO_2 hot bundle LOCA model with the 2.506-ft elevation axial peak of 1.7. The initial fuel conditions for the Gadolinia fuel were determined by the GDTACO fuel performance code. The Gadolinia pin initial conditions for each weight percent are presented in Table 6-2. The results for the 2, 4, 6, and 8 w/o Gadolinia analyses for all TIL performed at the 2.506-ft elevation are presented in Table 6-6 through Table 6-9. These cases are documented in Reference [8].

Analyses that considered Gadolinia fuel pins were not explicitly performed for the other core elevations because of the similarities between the UO_2 and Gadolinia fuel. The analyses show that the LHR limit reductions for the Gadolinia fuel compensates for the small property differences at the 2.506-ft axial peak and the similar results are expected at the other core axial elevations. The core inlet power shape was used for the Gadolinia confirmation cases because the LOCA core inlet axial peaks are generally the only ones that could set the core operating limits for fuel cycle operation. LOCA LHRs are checked in the core power distribution analyses, but they are generally not limiting at any other core axial elevations.

The Gadolinia LHR limits for all TIL were obtained by multiplying the UO_2 LHR limits at that TIL by the Gd-to-UO_2 ratio used in the 2.506-ft analyses. The analyses showed that this reduction in the LHR compensates for the thermal conductivity and volumetric heat capacity property differences. The PCT differences between the Gadolinia and the UO_2 fuel predicted by the 2.506-ft at BOL was applied to the UO_2 PCTs at all other elevations to establish estimated Gadolinia BOL PCTs for every elevation. A similar technique was used for the MOL Gadolinia limit with the MOL specific Gd-to-UO_2 LHR limit ratio and PCT difference applied to establish the MOL limits and results.

At BOL and MOL for Gadolinia concentrations, the differences between the UO_2 and each analyzed Gadolinia concentration at the 2.506-ft elevation is used with the corresponding UO_2 results at the other axial peaks to establish the Gadolinia results for the unanalyzed elevations. The UO_2 LHR limits are generally multiplied by the Gd-to-UO_2 LHR ratios to set the Gadolinia LHR limits. These differences in the analyzed Gadolinia and UO_2 PCTs are added to the UO_2 PCTs for all other core elevations to develop the Gadolinia PCTs. The analyzed and estimated Gadolinia LHR limits and PCTs are given in Tables 3-4 through 3-7.

At EOL, the Gadolinia LHR limits are established based on consideration of the Gd-to-UO_2 LHR limit ratios and fuel pin initializations that keep the pin pressure below the LASP limit. Since the EOL LOCA LHR is typically

limited in terms of the pin pressure instead of the PCT, this method maintains substantially lower PCTs for both the UO_2 and Gadolinia pins. In addition, Gadolinia LHR limits after 34 GWd/mtU include increased uncertainty factors on the fuel volume-average temperature to account for decreases in the fuel thermal conductivity as discussed in Section 6.2.4.2. For the EOL (62 GWd/mtU) case, the uncertainty factor used was 1.2171 for the Gadolinia pins (Reference [8])

The Gadolinia LHR limits at EOL were maintained constant for all of the remaining elevations. The EOL Gadolinia PCT estimates were determined by applying the same PCT delta added to the remaining UO_2 EOL elevations.

6.2.3.5 Partial Power Study

Core power distribution analyses are performed at different core power levels for plant operation with four RCPs and also with three RCPs in operation. The LOCA analyses must establish LHR limits to support these power distribution analyses. In addition, the LOCA analyses need to confirm that the calculated LOCA consequences at 100 percent full power is bounding for all other power levels for both three and four RCP operation. At partial power levels, the goal is to maintain the full power LHR limit for all core power levels above 50-percent full power. By preserving the full power LHR limit, the allowable peaking margins are increased in inverse proportion to the power level. The main challenge to maintaining a bounding PCT at the full power LHR limit is related to increases in the moderator temperature coefficient as power level decreases.

The LBLOCA partial power study serves to confirm that the LOCA consequences at full rated power are bounding for partial power conditions. The ONS LBLOCA partial power study was performed in Reference [46] and demonstrated that the LOCA consequences at full rated power are bounding of partial power conditions, considering three and four pump partial power levels and appropriate MTC values. The study concluded that full rated power LBLOCA LHR limits could be utilized at partial power levels without any penalty.

The potential for a penalty exists when there are significant differences in the core inlet and exit temperature at the partial power level. At partial power levels, the RCS average temperature and RCS flow rate are held constant. As a result, the core inlet temperature increases, while the core exit temperature decreases. The temperature differences may promote a beneficial delay in CHF for higher power levels, and an earlier CHF at partial power levels resulting in worse LOCA consequences. The ONS partial power study modeled the Mark-B11 fuel design, which utilizes the BWCMV CHF correlation. Although the Mark-B-HTP fuel utilizes a different correlation, the BHTP CHF correlation, a partial power study would utilize the same CHF correlation at full rated power as well as at partial power levels. Thus any differences between the CHF correlations would equally affect each partial power level analysis. Provided that the CHF correlations are shown to exhibit similar trends, the conclusions of the studies performed in Reference for the Mark-B11 fuel with BWCMV CHF correlations would be equally applicable with the Mark-B-HTP fuel using BHTP CHF correlations. As discussed previously (see EM axial versus radial peaking factor study, Reference [1], the BTHP (Mark-B-HTP) and BWCMV (Mark-B11) CHF correlations exhibit similar trends. Therefore, the partial power study is applicable to the ONS LBLOCA analyses with Mark-B-HTP fuel and need not be repeated. The results of the study showed that the calculated PCTs for the most limiting three-pump case would be bounded by the four-pump operation 100 percent full-power case.

6.2.3.6 Core Inlet and Exit LHR Limits

LHR limits at elevations between the 2.506-ft and the 9.536-ft elevation can be determined by linear interpolation using the five LBLOCA elevations analyzed at BOL and MOL. Reference [47] contains a sensitivity study that was performed to establish the LHR limits below the 2.506 ft core elevation and above the 9.536 ft core elevation for B&W-designed 177 FA lowered-loop plants. The conclusion of that study determined that the allowable LHR

at the bottom (0.0 ft) and top (12.0 ft) of the core can be conservatively specified as 95 percent of the calculated LHR at the 2.506 ft and 9.536 ft elevations, respectively. This technique precluded the necessity of performing calculations at elevations beyond the five elevations commonly analyzed. The results are extrapolated to apply to the ONS units with the ROTSGs, the LPI system modifications, and the new EM models in Section 5.2.6 of Revision 0 of Reference [12].

At EOL, there is substantial PCT margin since the LHR limits are determined by maximizing the fuel pin internal pressure to approximately 3000 psia at 62 GWd/mtU. This margin can be used to avoid a reduction to the EOL LHR limits at the core endpoints. If the EOL endpoint LHR limits are not decreased as performed for the BOL and MOL endpoints, then an estimate of the impact upon the PCT must be assessed. The PCTs at the inlet and exit are increased conservatively in Reference [48] from the PCT at the adjacent core elevation to account for the reduced core cooling effects observed in the sensitivity study (Reference [47]).

6.2.3.7 End of Cycle T_{ave} Reduction

An analysis was performed to assess the conditions under which an end-of-cycle (EOC) T_{ave} reduction maneuver could be performed (Reference [49]). The B&W Owners Group (BWOG) 177-FA LL EOC reduction in T_{ave} LBLOCA analyses was completed at a core power of 2568 MWt at the 2.506 ft elevation with an RCS average temperature of 567 F, which is the nominal RCS T_{ave} of 579 F reduced by 12 F. With a moderator temperature coefficient profile at −10 pcm/F, the results show that the fuel and clad at or near the peak power elevation are lower in temperature than for the nominal T_{ave} analysis. This produces a lower PCT for the reduced T_{ave} analysis. In the event that an EOC T_{ave} reduction maneuver is planned, operation at a reduced T_{ave} at the end of a cycle with a MTC of no greater than -10 pcm/F is bounded by operation at a zero MTC with a nominal T_{ave}.

The RELAP5/M2 analyses are applicable to the B&W-designed 177-FA LL plants, including ONS units, in the event that an EOC T_{ave} reduction maneuver is planned for any fuel cycle. The nominal T_{ave} LHR limits are bounding for any T_{ave} reduction less than 10 F, with a ±2 F uncertainty, when the MTC is more negative than −10 pcm/F. Other uncertainties may be considered, but the maximum reduction must be less than 12 F.

The RELAP5/M2 analyses were performed for the Mark-B10 fuel type, which utilizes the BWC CHF correlation. The ONS LBLOCA analyses utilize the BHTP CHF correlation for the Mark-B-HTP fuel. Although there are differences in the CHF correlations and the fuel types, any new EOC T_{ave} reduction analyses with the Mark-B-HTP fuel would utilize the appropriate CHF correlation and fuel parameters. Thus the differences in the fuel type and CHF correlations would be equally observed in the nominal as well as the EOC T_{ave} reduction sensitivity study cases. The BHTP CHF correlation has been shown to exhibit similar trends (see axial versus radial peaking factor study in Section 6.1.1.11) compared with the BWC CHF correlation. Therefore, the EOC T_{ave} reduction study is applicable to the ONS LBLOCA analyses with Mark-B-HTP fuel and need not be repeated.

6.2.4 Discussion of LBLOCA EM Inputs and Changes

Several items affecting generic LBLOCA analysis inputs and methods have been addressed and incorporated in the current analyses consistent with the methodology described in Section 4.0. These changes are characterized as either input changes consistent with the EM, new reload licensing checks to confirm the EM analyses are applicable, or EM changes made to remain in compliance with 10 CFR 50 Appendix K. Each of these items is applied consistent with what is included and described in BAW-10192P, Revision 2 [44]. Input changes consist of use of more conservative steady state and transient energy deposition factors (EDFs), compensation for fuel thermal conductivity degradation as a function of burnup, and use of a more conservative actinide decay heat model are discussed in Sections 6.2.4.1, 6.2.4.2, and 6.2.4.3, respectively. This includes provision for LHR limit changes related to fuel pin enrichments outside the normal range of 3 to 5 percent as discussed in Section 6.2.4.3.

Discussion of changes incorporated to address preliminary safety concerns (PSCs) to ensure the results are in compliance with 10 CFR 50 Appendix K are discussed in Section 6.2.4.4.

6.2.4.1 Energy Deposition Factors

The energy deposition factor (EDF) is defined as the energy absorbed (thermal source) in the fuel pellet and clad divided by the energy produced by the pellet (nuclear source).

$$EDF = P_{thermal\ source} / P_{nuclear\ source}$$

The BWNT LOCA evaluation model reports that an EDF of 0.973 will be used for the steady-state initialization and during the blowdown portion of the transient, and an EDF of 0.96 will be used during reflood for LBLOCA analyses. New methods and predictions for the EDFs appropriate for use in LOCA analyses at various times in life have been evaluated by AREVA (References [50] and [64]). These calculations do not support the 0.973 steady-state EDF values for high burnup, low power fuel or fuel that may be surrounded by higher power fuel. As a result, the LOCA evaluations may use higher EDFs, depending on the time in life and allowed LHR limits. The LOCA transient EDF values of 0.973 and 0.96 are not supported for some transient applications. The transient EDF is increased for most LOCA applications and in some cases it may exceed a value of 1.0.

The steady-state and transient EDF values for the ONS LBLOCA analyses were calculated using the methods described in [50]. The values used are included on the results tables. It is important to note that the RELAP5-based LOCA LHR limits are reported based on nuclear source power and the EDF is accounted for in the LOCA EM transient calculations. Therefore, the LHR limits provided in Section 3.0 represent the total power generated by the fuel pin (i.e., represent the nuclear source). In the core maneuvering analyses, the LOCA LHR limit should be greater than or equal to the LHR calculated at the limits of normal operation in the peaking analysis.

$$LHRLOCA \geq LHR_{peaking\ analysis} = Fq_{peak} * F_{aug} * LHR_{ave}$$

Where:

Fq_{peak} = the product of the axial peak and the radial peak

F_{aug} = the product of all augmentation factors (including committed LOCA target margin)

LHR_{ave} (core average LHR) = $EDF * [(P_{rated} * FOP) / (N_{pin} * N_{assy} * L_{fuel})]$

Where:

N_{pin} = the number of fuel pins in an assembly

N_{assy} = the number of fuel assemblies in the core

L_{fuel} = the length of the active fuel

The LHR_{ave} (and hence the LHR in the peaking analysis) is in terms of the energy produced ($P_{nuclear\ source}$) when the EDF is not applied (or EDF = 1.0). The LHR limits are reported in this document in terms of energy generated by the pin (nuclear source). As long as the limits are defined this way, an EDF would not be used in calculating the core average linear heat rate that is used in a peaking margin calculation to convert the peak calculated by the nuclear design code to a calculated LHR. Therefore, the maneuvering analysis should set the EDF to 1.0 for an appropriate calculation of margin to the reported LOCA LHR limits.

6.2.4.2 Burnup Fuel Thermal Conductivity

The NRC-approved fuel performance codes (Reference [3 and 45]) use a conductivity model that varies only with temperature and not with burnup. SIMFUEL data has been used to adjust the fuel temperature uncertainty factor to demonstrate that the effect of fuel thermal conductivity decreases with extended burnup (Reference [51]) is accounted for in the applications. The TACO3 and GDTACO fuel models are based on a BOL fuel thermal conductivity curve. In the evaluation of Condition Report WebCAP 2009-4152, which is related to NRC Information Notice 2009-23, AREVA confirmed that the method of LOCA initialization (e.g., bounding power histories and 1000 GWd/mtU hold at LOCA power peaks) and use of increased fuel volume-average temperatures at high burnups provide appropriate to conservative inputs for use in LOCA analyses. Justification for not using a variable thermal conductivity versus burnup model in TACO3 and GDTACO is supported by high power fuel pin benchmarks and the increases in the fuel volume-average temperature uncertainty factor for pin burnups exceeding 40 GWd/mtU. The NRC, as discussed in the technical evaluation report (TER), has approved this method for BAW-10186 (Reference [51]). The value of the increased uncertainty factors used in the LHR calculations at burnups greater than 40 GWd/mtU are discussed in Section 6.2.3.3 and 6.2.3.4 for the EOL analyses for UO2 and Gadolinia fuel.

6.2.4.3 Actinide Decay Heat for Low Enrichment

LOCA analyses performed with the BWNT LOCA EM typically consider batch fuel pin enrichments in the range of 3 to approximately 5 percent for the fuel volume average temperatures. This method of analysis bounds the fuel initial temperatures for fuel pin enrichments in this range. The actinide decay heat contribution is also a function of fuel pin enrichments. The average core bulk or batch fuel assembly enrichments have a smaller range of burnup and core average enrichment than the hot pin values considered. The BOC average core burnup are generally in the 10 to 15 GWd/mtU range while the EOC burnup range from 35 to 40 GWd/mtU. The RELAP5 default actinide model utilized in the RELAP5-based LBLOCA analyses bounds the actinide contributions over this burnup range at the average core enrichments. The ONS-2 Cycle 26 will be a two-year cycle, in turn, it will have higher fuel enrichments than the 18 month cycle plants. The PCT-limited cases at BOL or MOL are evaluated based on the hot pin local actinide power to ensure the RELAP5 default actinide model is conservative to bounding for both the hot pin powers and the total core decay heat are included in the LOCA analyses or evaluations.

Historically, the B&W heavy actinide model was utilized in the LBLOCA analyses, a discussion of which can be found in Section 6.2.6.1 of Reference [39]. However, Reference [70] shows that the RELAP5 default actinide model is more conservative than the B&W heavy actinide model and it covers the entire licensed burnup range from 0 to 62 GWd/mtU for enrichments of 2.28 w/o and higher for hot pin, hot bundle, and average core actinide contributions. It is for this reason that the LBLOCA analyses now use the RELAP5 default actinide model.

6.2.4.4 Preliminary Safety Concerns

Since the EM described in BAW-10192P-A has been approved, a number of PSCs have been generated. The results of these PSCs have been incorporated into the LOCA analyses to ensure the LOCA results include the considerations in 10 CFR 50 Appendix K. This section summarizes the LBLOCA PSCs and indicates how they have been used to change the inputs or methods of analyses for the ONS LBLOCA analyses.

<u>PSC 4-94 – MTC for Partial Power Operation</u>
Interpretation of the B&W plant Tech Specs on MTC versus power level can lead to the conclusion that a +9 pcm/F MTC is allowable at power levels below 95 percent. This interpretation led to the initiation of PSC 4-94.

As a result of this PSC, an MTC versus power level curve has been provided to the B&W plants (Figure 3-6), which shows the conditions under which the full power LOCA analyses remain limiting. A discussion of these studies is presented in Section 6.2.3.5.

PSC 5-94 Uncertainties on CFT and PZR

The EM allows the initial Core Flood Tank and Pressurizer inventories and pressures to be set by nominal operation design levels. The PZR has active methods to control to the nominal value, therefore maintaining a nominal level for analyses is appropriate. However, the CFT does not have an active method for controlling to nominal conditions. PSC 5-94 identified that the CFT initial conditions would affect the transient results as applied to the CRAFT2-based evaluation model. Therefore, the B&W plant analyses performed with the RELAP5-based evaluation model also evaluated the combination of minimum and maximum CFT initial liquid volumes and gas pressures for each plant type. A discussion of these studies is provided in Section 6.1.2.4.

PSC 1-99 – Two Phase RCP Degradation (M1 versus M3)

The EM states that the “M1” two-phase degradation multiplier is used for LBLOCAs. This was determined based on sensitivity studies related to the 205-FA RL plant type. Similar sensitivity studies on the 177-FA LL and 177-FA RL plants show that the M3-modified curve provides limiting results. The NRC was notified that the limiting curve would be used based on plant-type specific sensitivity studies. A discussion of these studies is provided in Section 6.1.2.1.

PSC 2-98 – Design LOCA Loads for OTSG Tube Repair Products

This PSC only pertained to the original OTSGs, not the ROTSGs. Since the OTSGs have been replaced this concern is no longer applicable. The challenges to the steam generator tube integrity following a hot leg U-bend LOCA has been ensured by Duke Energy and B&W Canada. Reference [54] comprises the proprietary justifications used for this purpose.

Table 6-1: Hot Pin Initial Conditions Used in the Mark-B-HTP Full Core LBLOCA Analyses

Parameter	2.506 ft	4.264 ft	6.021 ft	7.779 ft	9.536 ft
BOL Initial Conditions					
Peak LHR, kW/ft (Note)	17.8	17.8	17.8	17.8	17.3
Pin Pressure, psia	683	681	679	678	670
Peak Fuel Temperature, F	2433	2447	2447	2447	2399
Inside Oxide Thickness, ft	$9.15x10^{-7}$	$9.15x10^{-7}$	$9.15x10^{-7}$	$9.15x10^{-7}$	$9.15x10^{-7}$
Outside Oxide Thickness, ft	$7.59x10^{-7}$	$7.59x10^{-7}$	$7.59x10^{-7}$	$7.59x10^{-7}$	$7.59x10^{-7}$
MOL Initial Conditions					
Peak LHR, kW/ft (Note)	17.8	17.8	17.8	17.8	17.3
Pin Pressure, psia	1898	1853	1817	1818	1792
Peak Fuel Temperature, F	2322	2333	2324	2324	2264
Inside Oxide Thickness, ft	$1.74x10^{-5}$	$1.74x10^{-5}$	$1.74x10^{-5}$	$1.74x10^{-5}$	$1.74x10^{-5}$
Outside Oxide Thickness, ft	$6.35x10^{-6}$	$6.35x10^{-6}$	$6.35x10^{-6}$	$6.35x10^{-6}$	$6.35x10^{-6}$
EOL Initial Conditions		N/A	N/A	N/A	N/A
Peak LHR, kW/ft (Note)	12.3				
Pin Pressure, psia	2971				
Peak Fuel Temperature, F	1987				
Inside Oxide Thickness, ft	$2.49x10^{-5}$				
Outside Oxide Thickness, ft	$1.19x10^{-5}$				

Note: The LHR limits presented represent the power generated by the pin (i.e. nuclear source).

Table 6-2: Summary of BOL Mark-B-HTP Full-Core LBLOCA LHR Limit Analyses

Parameter	2.506 ft		4.264 ft		6.021 ft		7.779 ft		9.536 ft	
Burnup, GWd/mtU	0		0		0		0		0	
Peak LHR (Note), kW/ft	17.8		17.8		17.8		17.8		17.3	
Steady-State EDF	0.973		0.973		0.973		0.973		0.973	
Transient EDF	1.0		1.0		1.0		1.0		1.0	
End of Bypass, s	20.4		20.4		20.3		20.3		18.3	
End of Blowdown (EOB), s	22.3		22.3		22.2		22.2		22.1	
Liquid Mass in RV Lower Plenum at EOB, lbm	17095		16957		16675		16913		16591	
RV Lower Plenum Filled (EOAH), s	29.3		29.3		29.3		29.3		29.3	
LPI Flow Begins, s	42.1		42.1		42.1		42.1		42.1	
CFTs Empty, s	48.9		48.9		48.9		48.8		48.8	
	HP	*HA*	*HP*	*HA*	*HP*	*HA*	*HP*	*HA*	*HP*	*HA*
Clad Rupture Time, s	22.3	24.4	23.1	25.9	22.8	24.9	23.7	26.1	25.5	28.2
Unruptured Segment	7	9	9	9	13	13	15	15	16	16
PCT, F	1849.5	1785.6	1867.4	1804.4	1887.0	1824.3	**1905.7**	1842.1	**1864.5**	1840.3
Time, s	35.1	70.1	37.7	37.7	36.9	39.8	39.1	39.1	74.7	74.7
Local Oxidation, %	1.103	1.215	1.430	1.240	1.582	1.394	1.826	1.637	1.870	1.707
Ruptured Segment	6	6	10	10	12	12	14	14	18	18
PCT, F	**1913.2**	1782.6	**1897.2**	1757.5	**1907.0**	1770.7	1857.6	1741.5	1841.7	1742.5
Time, s	29.8	29.8	29.8	29.8	31.2	31.2	29.7	29.7	36.2	38.5
Local Oxidation, %	1.891	1.248	1.986	1.286	2.386	1.606	2.075	1.418	2.012	1.436
Average Oxidation Increase, %										
Hot Channel	0.363		0.367		0.385		0.425		0.379	
Average Channel	0.003		0.005		0.007		0.009		0.010	
Whole-Core Hydrogen Generation, %	<0.14		<0.14		< 0.15		< 0.16		< 0.15	
Average Channel Quench Time, s	160.2		169.1		172.4		176.0		174.6	

Note: The LHR limits presented represent the power generated by the pin (i.e. nuclear source).

Table 6-3: Summary of MOL Mark-B-HTP Full-Core LBLOCA LHR Limit Analyses

Parameter	**2.506 ft**		**4.264 ft**		**6.021 ft**		**7.779 ft**		**9.536 ft**	
Burnup, GWd/mtU	34		34		34		34		34	
Peak LHR (Note), kW/ft	17.8		17.8		17.8		17.8		17.3	
Steady-State EDF	0.973		0.973		0.973		0.973		0.973	
Transient EDF	1.0		1.0		1.0		1.0		1.0	
End of Bypass, s	20.4		20.4		20.3		20.3		20.3	
End of Blowdown (EOB), s	22.4		22.3		22.2		22.2		22.1	
Liquid Mass in RV Lower Plenum at EOB, lbm	17143		17065		16659		16845		16527	
RV Lower Plenum Filled (EOAH), s	29.3		29.3		29.3		29.3		29.3	
LPI Flow Begins, s	42.1		42.1		42.1		42.1		42.1	
CFTs Empty, s	48.9		48.8		48.9		48.8		48.7	
	_HP_	_HA_	_HP_	_HA_	_HP_	_HA_	_HP_	_HA_	_HP_	_HA_
Clad Rupture Time, s	19.7	20.8	21.3	23.0	20.8	22.2	22.2	23.6	24.4	26.3
Unruptured Segment	7	7	10	10	13	13	15	15	16	16
PCT, F	**1879.0**	1754.1	**1858.3**	1740.0	1863.9	1764.2	**1863.3**	1765.8	**1805.2**	1774.0
Time, s	31.9	34.8	37.0	37.1	36.8	36.8	36.3	38.9	72.1	72.2
Local Oxidation, %	1.847	1.595	2.027	1.750	2.109	1.909	2.328	2.118	2.274	2.145
Ruptured Segment	6	6	9	9	12	12	14	14	18	18
PCT, F	1864.3	1697.1	1776.3	1656.1	**1873.6**	1710.3	1766.7	1652.2	1707.7	1623.6
Time, s	31.7	31.7	31.7	31.7	31.6	31.7	36.1	36.2	38.4	38.4
Local Oxidation, %	2.106	1.585	1.875	1.525	2.314	1.735	1.926	1.569	1.735	1.501
Average Oxidation Increase, %										
Hot Channel	0.186		0.185		0.193		0.216		0.185	
Average Channel	0.003		0.005		0.007		0.009		0.010	
Whole-Core Hydrogen Generation, %	<0.07		<0.07		< 0.08		< 0.09		< 0.08	
Average Channel Quench Time	160.6		160.1		172.4		176.2		174.6	

Note: The LHR limits presented represent the power generated by the pin (i.e. nuclear source).

Table 6-4: Summary of EOL Mark-B-HTP Full-Core LBLOCA LHR Limit Analyses

Parameter	2.506 ft	
Burnup, GWd/mtU	62	
Peak LHR (Note), kW/ft	12.3	
Steady-State EDF	0.993	
Transient EDF	1.089	
End of Bypass, s	20.4	
End of Blowdown (EOB), s	22.3	
Liquid Mass in RV Lower Plenum at EOB, lbm	16966	
RV Lower Plenum Filled (EOAH), s	29.3	
LPI Flow Begins, s	42.1	
CFTs Empty, s	48.9	
	HP	*HA*
Clad Rupture Time, s	24.8	25.2
Unruptured Segment	7	7
PCT, F	1577.0	1522.1
Time, s	31.8	31.7
Local Oxidation, %	1.812	1.787
Ruptured Segment	6	6
PCT, F	**1618.3**	1559.7
Time, s	31.6	31.4
Local Oxidation, %	1.921	1.857
Average Oxidation Increase, %		
Hot Channel	0.032	
Average Channel	0.003	
Whole-Core Hydrogen Generation, %	<0.03	
Average Channel Quench Time, s	161.1	

Note: The LHR limits presented represent the power generated by the pin (i.e. nuclear source).

Table 6-5: ONS Mark-B-HTP Gadolinia Initial Conditions Used for the LOCA LHR Limit Analyses

Parameter	2.506 ft	2.506 ft	2.506 ft	2.506 ft	2.506 ft
BOL Initial Conditions	UO_2	2 $^w/_o$	4 $^w/_o$	6 $^w/_o$	8 $^w/_o$
Peak LHR, kW/ft (Note)	17.8	16.9	16.1	15.6	15.1
Pin Pressure, psia	683	676	675	675	675
Peak Fuel Temperature, F	2433	2376	2397	2416	2437
Inside Oxide Thickness, ft	$9.15x10^{-7}$	$9.15x10^{-7}$	$9.15x10^{-7}$	$9.15x10^{-7}$	$9.15x10^{-7}$
Outside Oxide Thickness, ft	$7.59x10^{-7}$	$7.59x10^{-7}$	$7.59x10^{-7}$	$7.59x10^{-7}$	$7.59x10^{-7}$
MOL Initial Conditions	UO_2	2 $^w/_o$	4 $^w/_o$	6 $^w/_o$	8 $^w/_o$
Peak LHR, kW/ft (Note)	17.8	16.9	16.1	15.6	15.1
Pin Pressure, psia	1898	1745	1823	1770	1697
Peak Fuel Temperature, F	2322	2291	2328	2342	2308
Inside Oxide Thickness, ft	$1.74x10^{-5}$	$1.74x10^{-5}$	$1.74x10^{-5}$	$1.74x10^{-5}$	$1.74x10^{-5}$
Outside Oxide Thickness, ft	$6.35x10^{-6}$	$6.52x10^{-6}$	$6.47x10^{-6}$	$6.59x10^{-6}$	$6.54x10^{-6}$
EOL Initial Conditions	UO_2	2 $^w/_o$	4 $^w/_o$	6 $^w/_o$	8 $^w/_o$
Peak LHR, kW/ft (Note)	12.3	11.6	11.1	10.8	10.4
Pin Pressure, psia	2971	2694	2706	2797	2749
Peak Fuel Temperature, F	1987	1962	1984	2018	2022
Inside Oxide Thickness, ft	$2.49x10^{-5}$	$3.03x10^{-5}$	$3.46x10^{-5}$	$3.43x10^{-5}$	$3.23x10^{-5}$
Outside Oxide Thickness, ft	$1.19x10^{-5}$	$1.29x10^{-5}$	$1.37x10^{-5}$	$1.37x10^{-5}$	$1.33x10^{-5}$

Note: The LHR limits presented represent the power generated by the pin (i.e. nuclear source).

Table 6-6: ONS 2 $^{w}/_{o}$ Mark-B-HTP Gad LOCA LHR Limits Summary

Parameter	BOL	MOL	EOL
Burnup, GWd/mtU	0	34	62
Peak LHR (Note), kW/ft	16.9	16.9	11.6
Axial Peak Elevation, ft	2.506	2.506	2.506
Steady-State EDF	0.973	0.973	0.986
Transient EDF	1.02	1.02	1.08
Peak Initial Fuel Temperature, F	2376	2291	1962
Initial Pin Pressure, psia	676	1745	2694
End of Bypass, s	20.4	20.4	20.4
End of Blowdown (EOB), s	22.3	22.4	22.3
Liquid Mass in RV Lower Plenum at EOB, lbm	17095	17143	16966
RV Lower Plenum Filled (EOAH), s	29.3	29.3	29.3
LPI Flow Begins, s	42.1	42.1	42.1
CFTs Empty, s	48.9	48.9	48.9
Clad Rupture Time, s	23.2	20.5	25.0
Unruptured Segment	7	7	7
PCT, F	1814.4	**1833.4**	1556.4
Time, s	35.1	31.9	31.8
Local Oxidation, %	0.968	1.715	2.096
Ruptured Segment	6	6	6
PCT, F	**1858.6**	1793.8	**1581.8**
Time, s	29.8	31.7	31.5
Local Oxidation, %	1.570	1.841	2.176
Average Channel Quench Time, s	160.2	160.6	161.1

Note: The LHR limits presented represent the power generated by the pin (i.e. nuclear source).

Table 6-7: ONS 4 $^{w}/_{o}$ Mark-B-HTP Gad LOCA LHR Limits Summary

Parameter	BOL	MOL	EOL
Burnup, GWd/mtU	0	34	62
Peak LHR (Note), kW/ft	16.1	16.1	11.1
Axial Peak Elevation, ft	2.506	2.506	2.506
Steady-State EDF	0.973	0.973	0.988
Transient EDF	1.03	1.03	1.10
Peak Initial Fuel Temperature, F	2397	2328	1984
Initial Pin Pressure, psia	675	1823	2706
End of Bypass, s	20.4	20.4	20.4
End of Blowdown (EOB), s	22.3	22.4	22.3
Liquid Mass in RV Lower Plenum at EOB, lbm	17095	17143	16966
RV Lower Plenum Filled (EOAH), s	29.3	29.3	29.3
LPI Flow Begins, s	42.1	42.1	42.1
CFTs Empty, s	48.9	48.9	48.9
Clad Rupture Time, s	23.2	20.3	25.0
Unruptured Segment	7	7	7
PCT, F	1812.2	**1856.2**	1566.7
Time, s	35.1	31.9	31.8
Local Oxidation, %	0.949	1.756	2.340
Ruptured Segment	6	6	6
PCT, F	**1862.7**	1826.0	**1581.3**
Time, s	29.8	31.7	31.5
Local Oxidation, %	1.582	1.945	2.414
Average Channel Quench Time, s	160.2	160.6	161.1

Note: The LHR limits presented represent the power generated by the pin (i.e. nuclear source).

Table 6-8: ONS 6 $^{w}/_{o}$ Mark-B-HTP Gad LOCA LHR Limits Summary

Parameter	BOL	MOL	EOL
Burnup, GWd/mtU	0	34	62
Peak LHR (Note), kW/ft	15.6	15.6	10.8
Axial Peak Elevation, ft	2.506	2.506	2.506
Steady-State EDF	0.974	0.974	0.989
Transient EDF	1.05	1.05	1.12
Peak Initial Fuel Temperature, F	2416	2342	2018
Initial Pin Pressure, psia	675	1770	2797
End of Bypass, s	20.4	20.4	20.4
End of Blowdown (EOB), s	22.3	22.4	22.3
Liquid Mass in RV Lower Plenum at EOB, lbm	17095	17143	16966
RV Lower Plenum Filled (EOAH), s	29.3	29.3	29.3
LPI Flow Begins, s	42.1	42.1	42.1
CFTs Empty, s	48.9	48.9	48.9
Clad Rupture Time, s	23.1	20.4	24.8
Unruptured Segment	7	7	7
PCT, F	1813.8	**1848.8**	1578.7
Time, s	35.1	31.9	31.8
Local Oxidation, %	0.946	1.728	2.338
Ruptured Segment	6	6	6
PCT, F	**1874.3**	1821.9	**1598.0**
Time, s	29.8	31.7	31.5
Local Oxidation, %	1.632	1.926	2.416
Average Channel Quench Time, s	160.2	160.6	161.1

Note: The LHR limits presented represent the power generated by the pin (i.e. nuclear source).

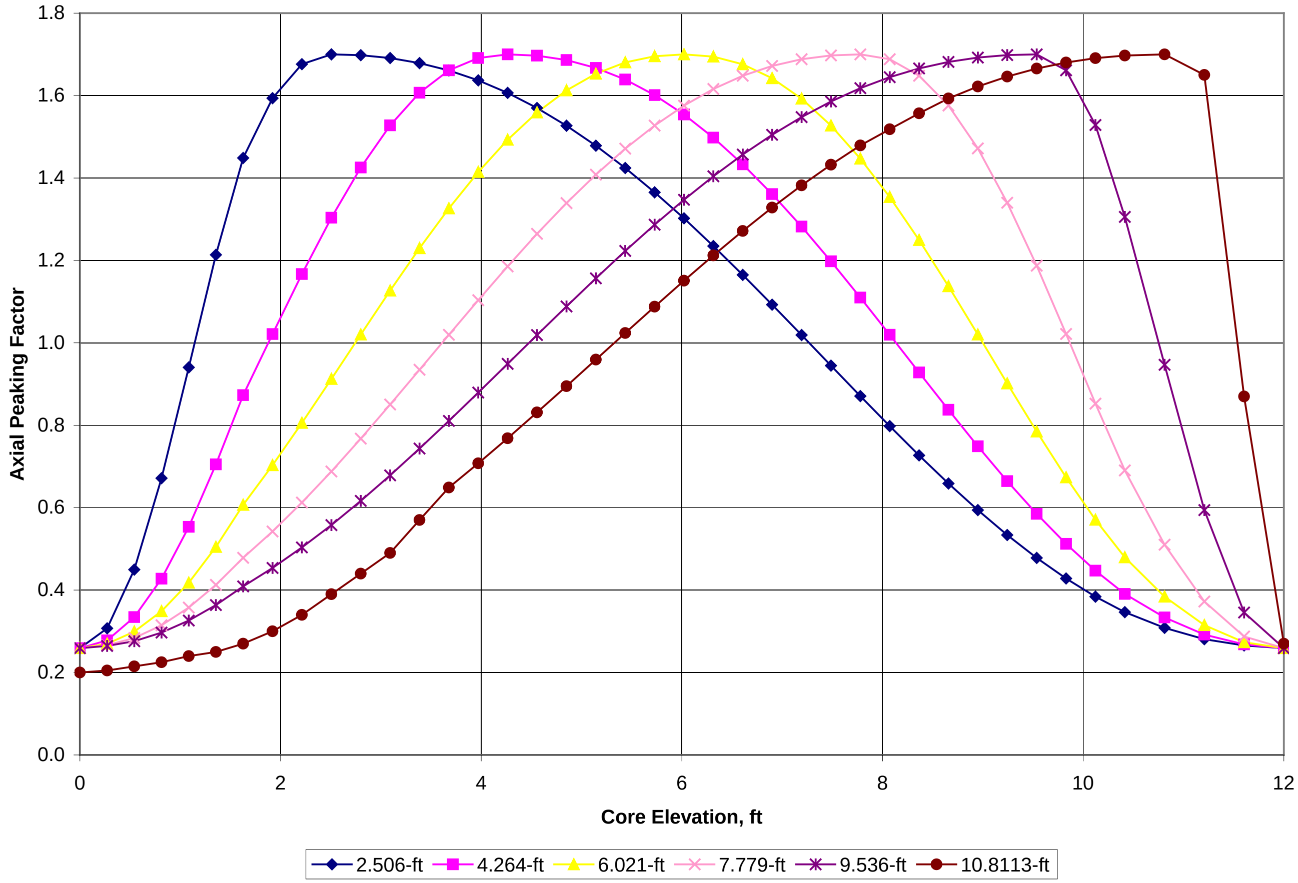
Table 6-9: ONS 8 $^{w}/_{o}$ Mark-B-HTP Gad LOCA LHR Limits Summary

Parameter	BOL	MOL	EOL
Burnup, GWd/mtU	0	34	62
Peak LHR (Note), kW/ft	15.1	15.1	10.4
Axial Peak Elevation, ft	2.506	2.506	2.506
Steady-State EDF	0.975	0.975	0.991
Transient EDF	1.06	1.06	1.14
Peak Initial Fuel Temperature, F	2437	2308	2022
Initial Pin Pressure, psia	675	1697	2749
End of Bypass, s	20.4	20.4	20.4
End of Blowdown (EOB), s	22.3	22.4	22.3
Liquid Mass in RV Lower Plenum at EOB, lbm	17095	17143	16966
RV Lower Plenum Filled (EOAH), s	29.3	29.3	29.3
LPI Flow Begins, s	42.1	42.1	42.1
CFTs Empty, s	48.9	48.9	48.9
Clad Rupture Time, s	23.1	21.1	24.9
Unruptured Segment	7	7	7
PCT, F	1814.2	**1806.0**	1575.8
Time, s	35.090	31.9	31.8
Local Oxidation, %	0.93835	1.624	2.223
Ruptured Segment	6	6	6
PCT, F	**1881.1**	1771.9	**1594.5**
Time, s	29.836	31.7	31.5
Local Oxidation, %	1.6596	1.754	2.302
Average Channel Quench Time, s	160.2	160.6	161.1

Note: The LHR limits presented represent the power generated by the pin (i.e. nuclear source).

Figure 6-1: Axial Power Shape

(Reference [71])



Note: The 10.811-ft peak is used in the SBLOCA analysis only.

Figure 6-2: 2.506-ft Mark-B-HTP Full-Core BOL LBLOCA Case – Reactor Vessel Upper Plenum Pressure

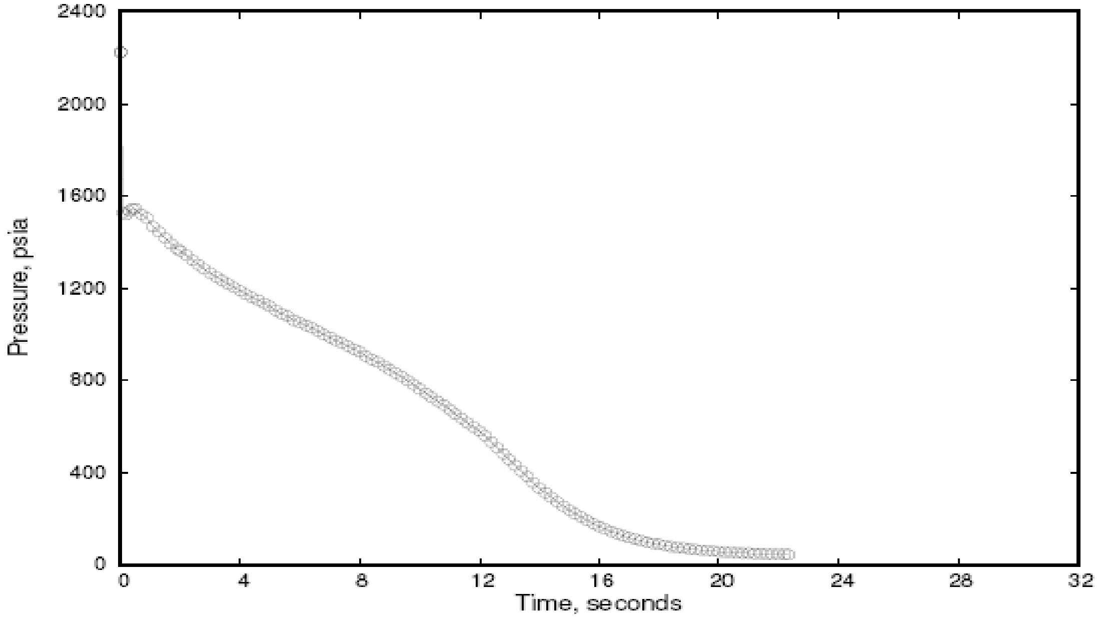


Figure 6-3: 2.506-ft Mark-B-HTP Full-Core BOL LBLOCA Case – Break Mass Flow Rates

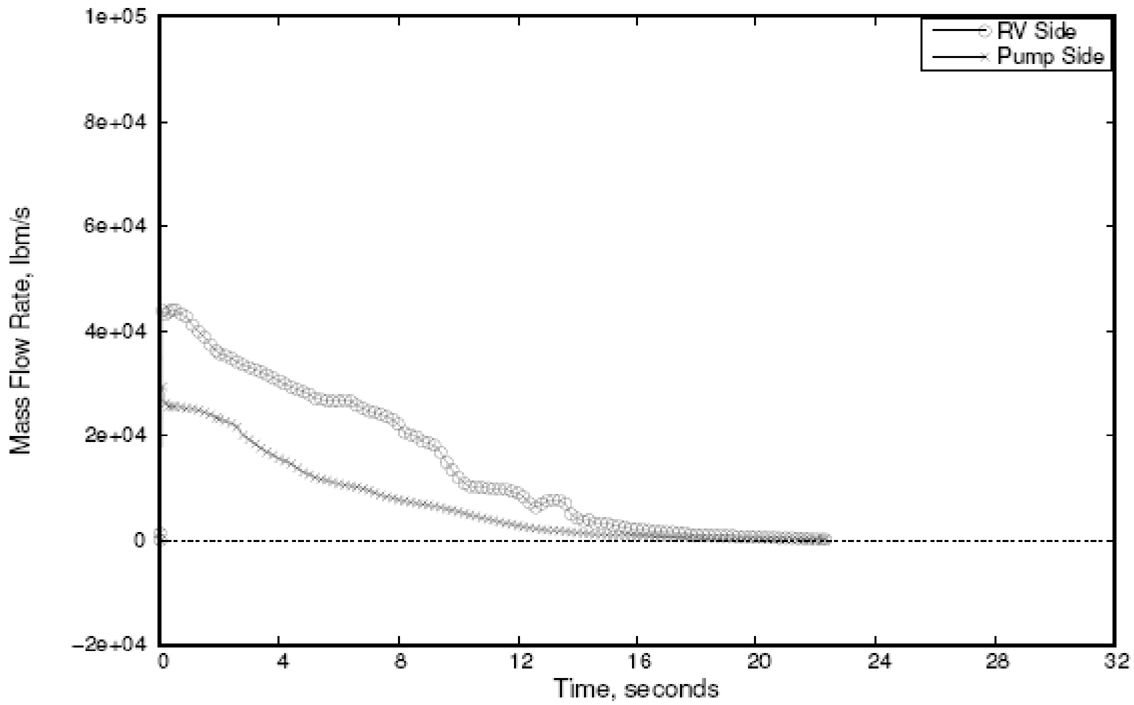


Figure 6-4: 2.506-ft Mark-B-HTP Full-Core BOL LBLOCA Case – Hot Channel Mass Flow Rates

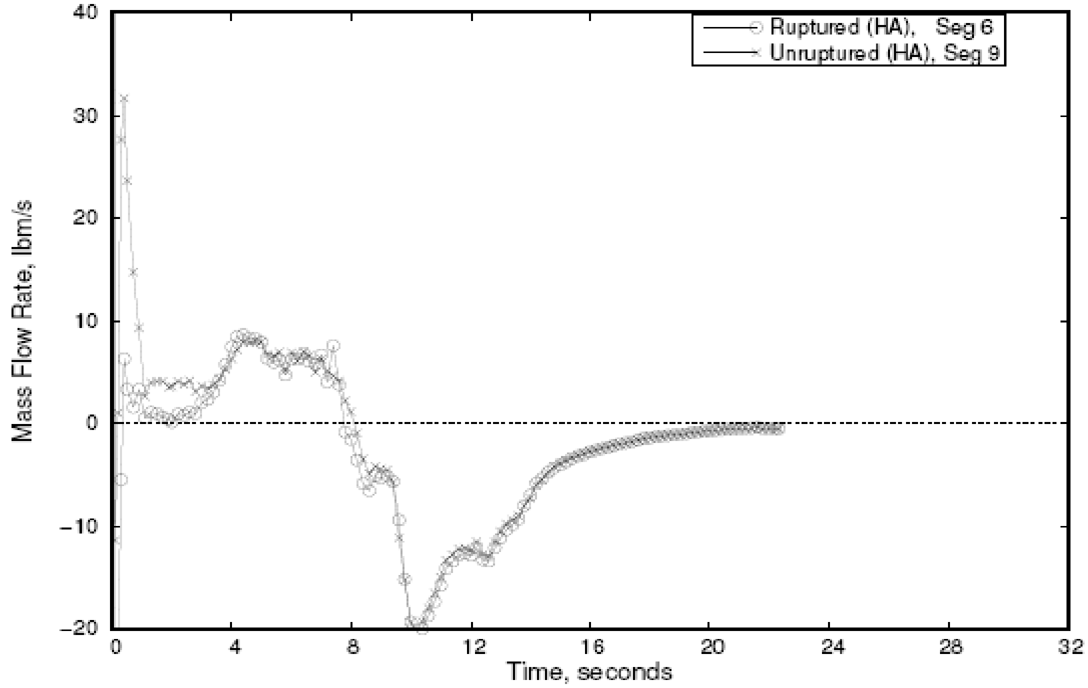


Figure 6-5: 2.506-ft Mark-B-HTP Full-Core BOL LBLOCA Case – Core Flooding Rate

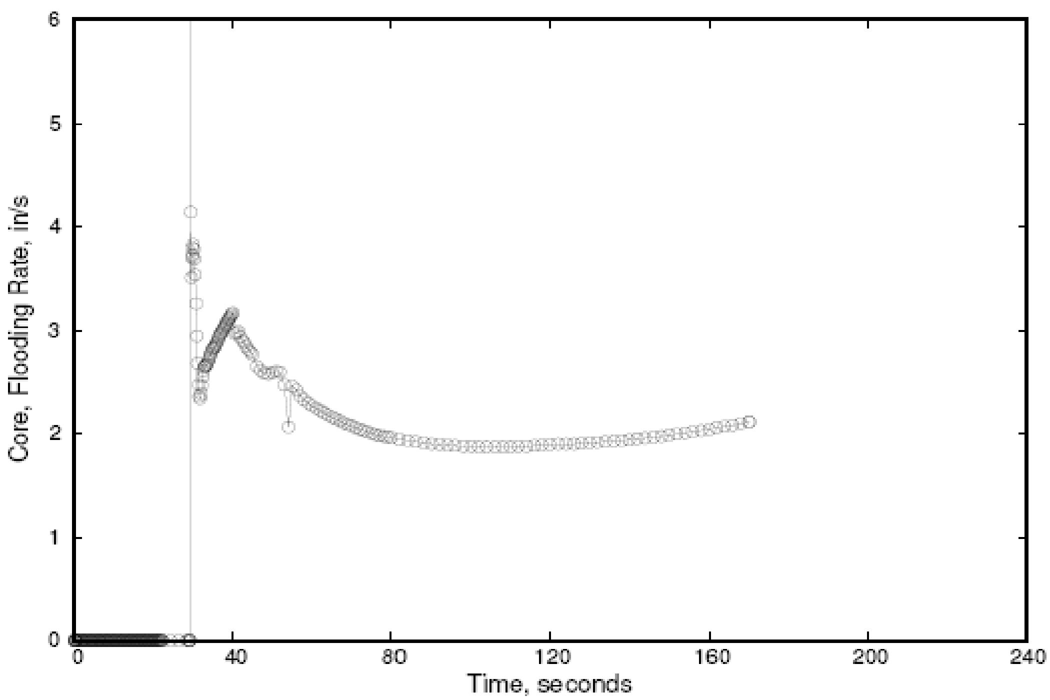


Figure 6-6: 2.506-ft Mark-B-HTP Full-Core BOL LBLOCA Case – HP Fuel & Clad Temperatures at Ruptured Location

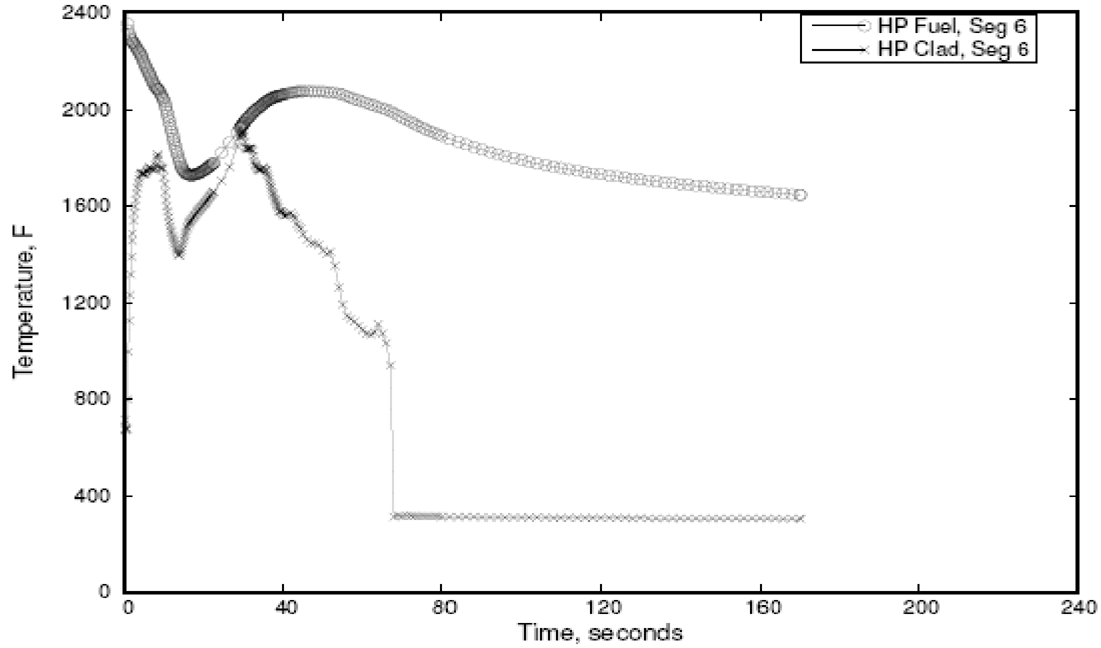


Figure 6-7: 2.506-ft Mark-B-HTP Full-Core BOL LBLOCA Case – HP Fuel & Clad Temperatures at Peak Unruptured Location

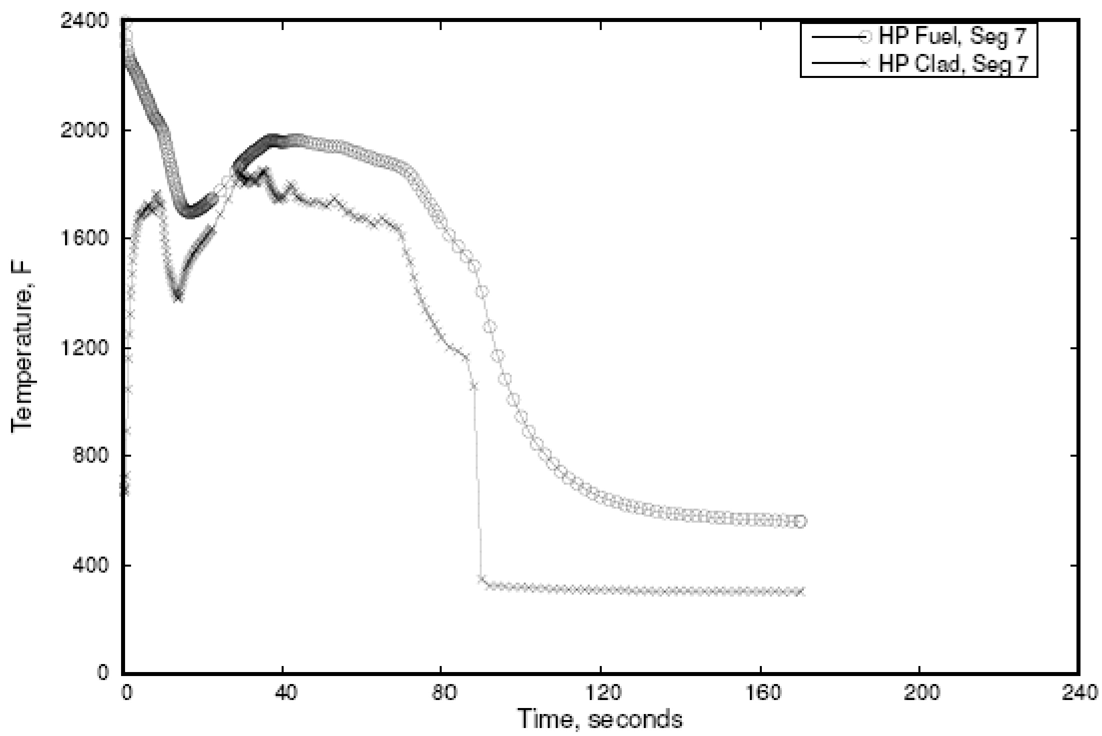


Figure 6-8: 2.506-ft Mark-B-HTP Full-Core BOL LBLOCA Case – HA Fuel & Clad Temperatures at Ruptured Location

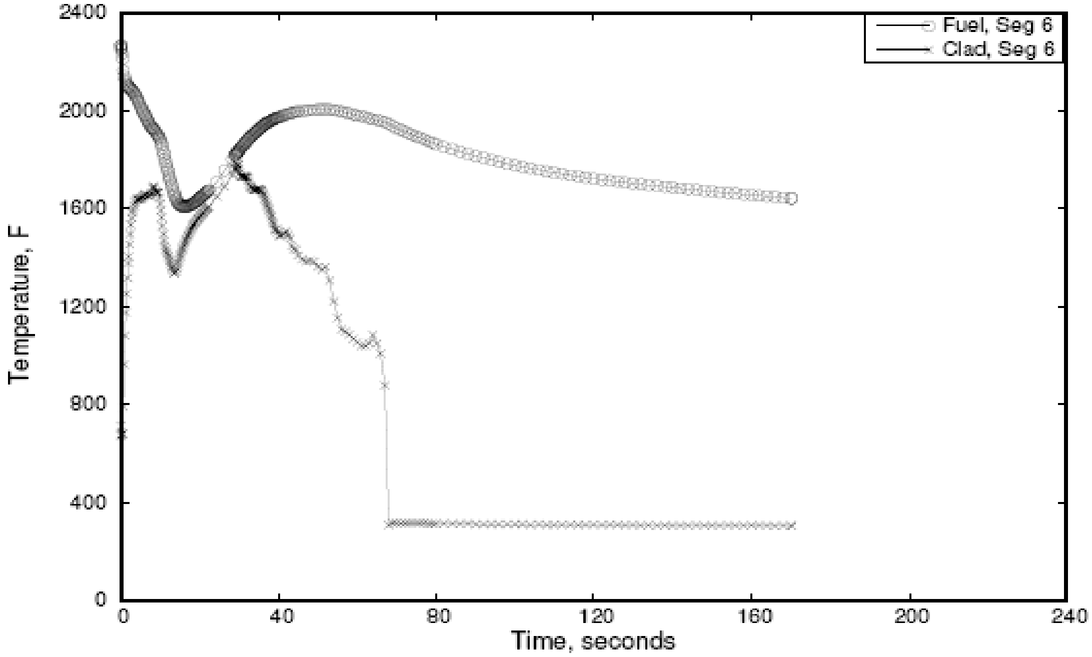


Figure 6-9: 2.506-ft Mark-B-HTP Full-Core BOL LBLOCA Case – HA Fuel & Clad Temperatures at Peak Unruptured Location

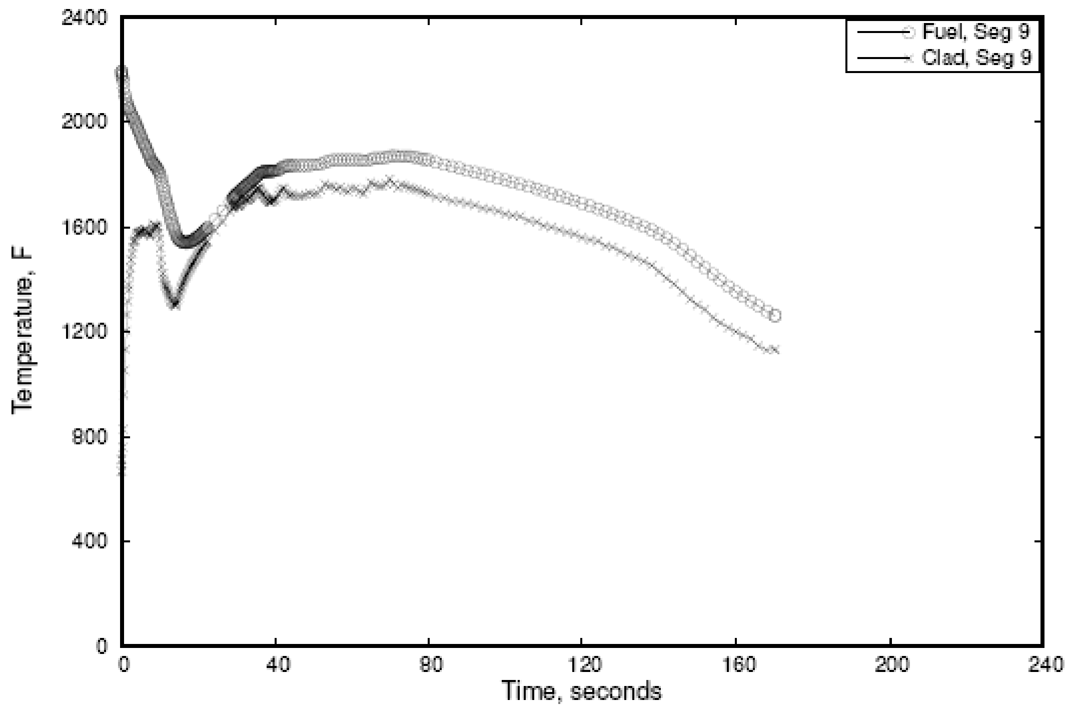


Figure 6-10: 2.506-ft Mark-B-HTP Full-Core BOL LBLOCA Case – Quench Front Advancement

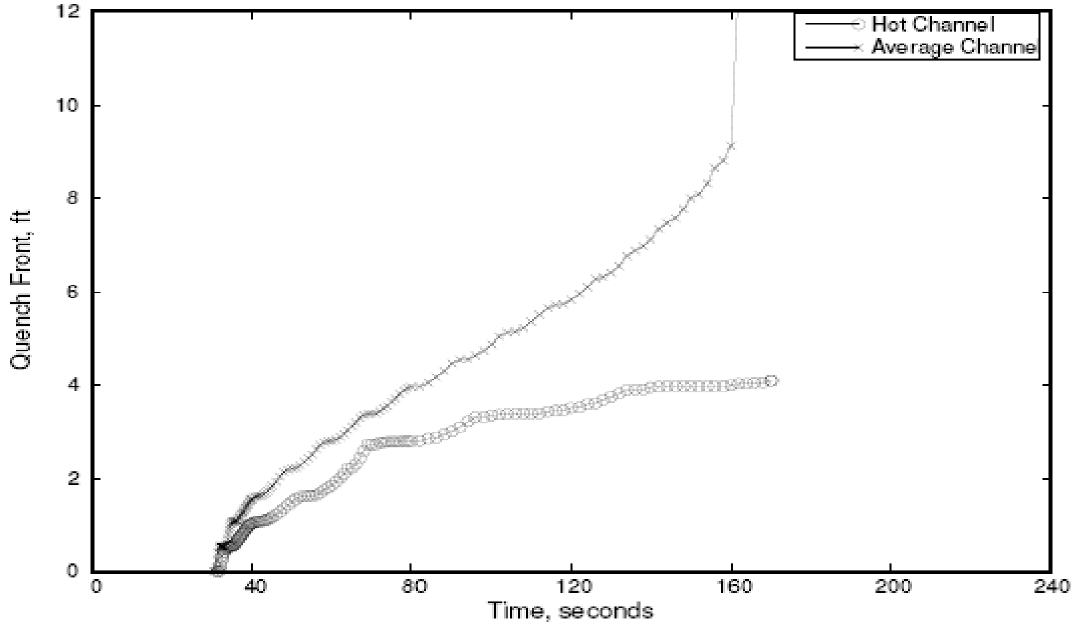


Figure 6-11: 2.506-ft Mark-B-HTP Full-Core BOL LBLOCA Case – HP Heat Transfer Coefficients

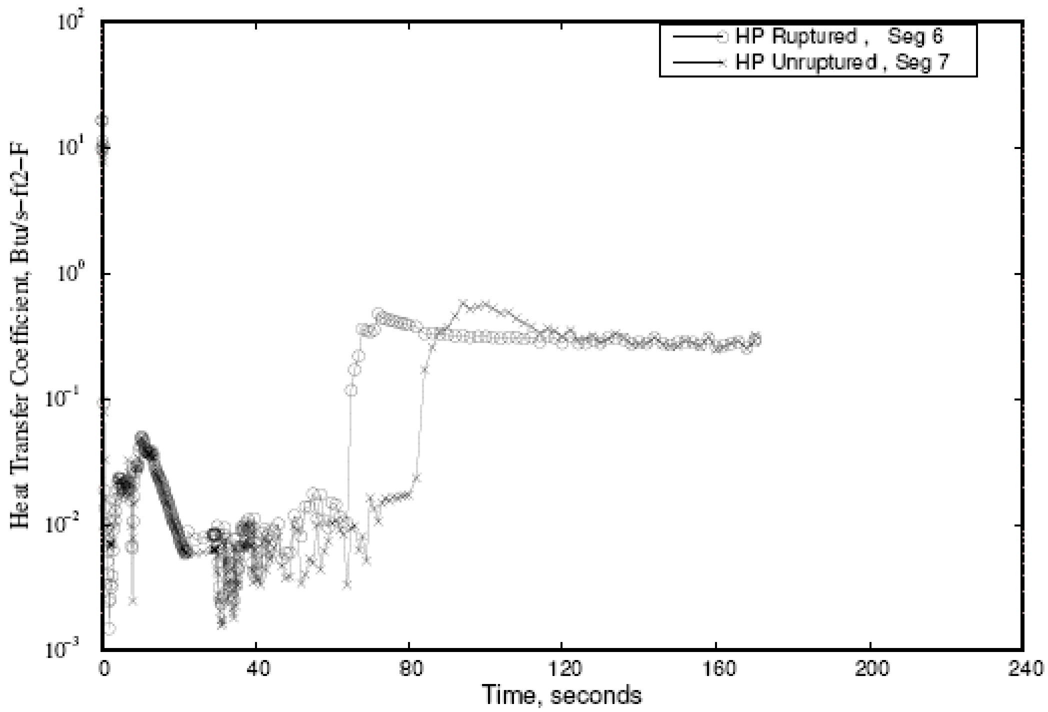


Figure 6-12: 2.506-ft Mark-B-HTP Full-Core MOL LBLOCA Case – Reactor Vessel Upper Plenum Pressure

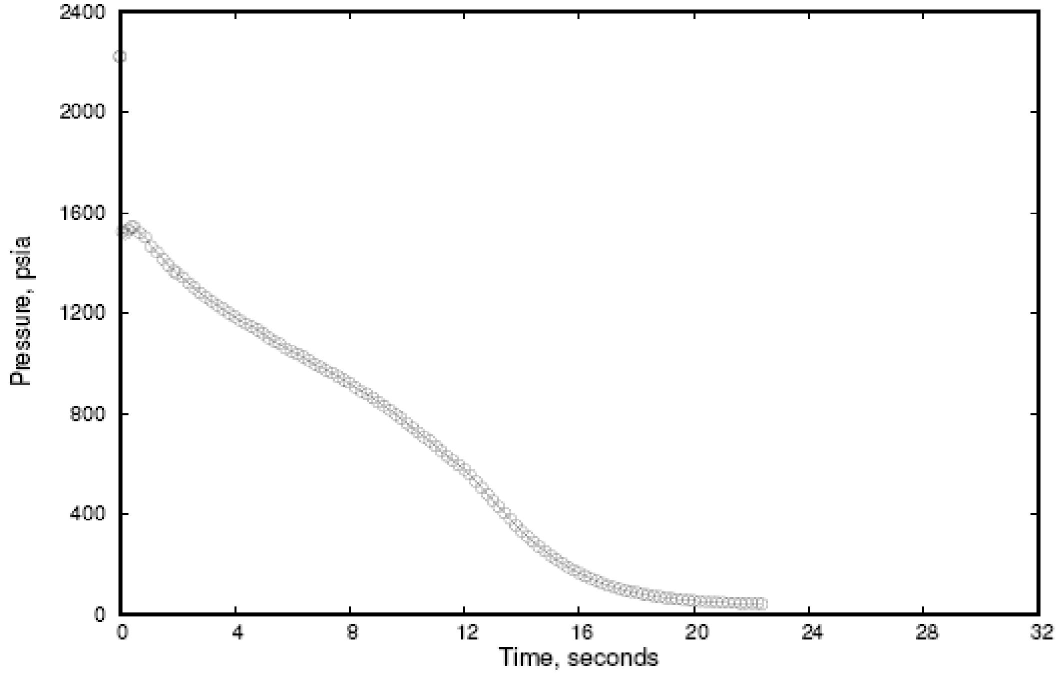


Figure 6-13: 2.506-ft Mark-B-HTP Full-Core MOL LBLOCA Case – Break Mass Flow Rates

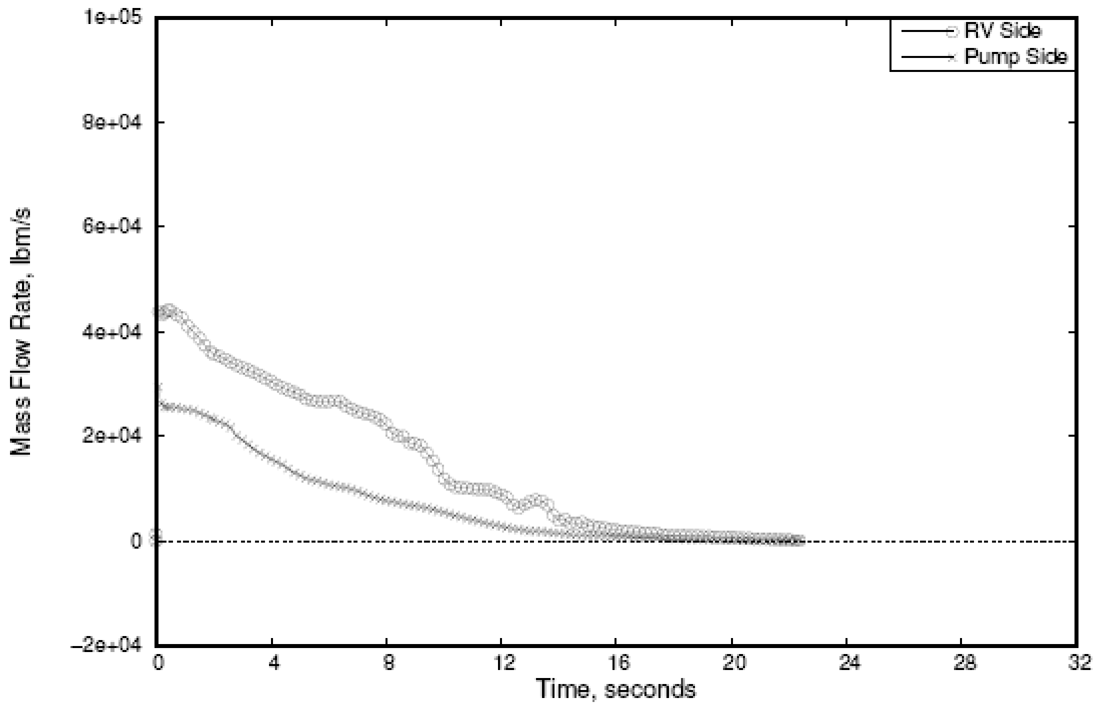


Figure 6-14: 2.506-ft Mark-B-HTP Full-Core MOL LBLOCA Case – Hot Channel Mass Flow Rates

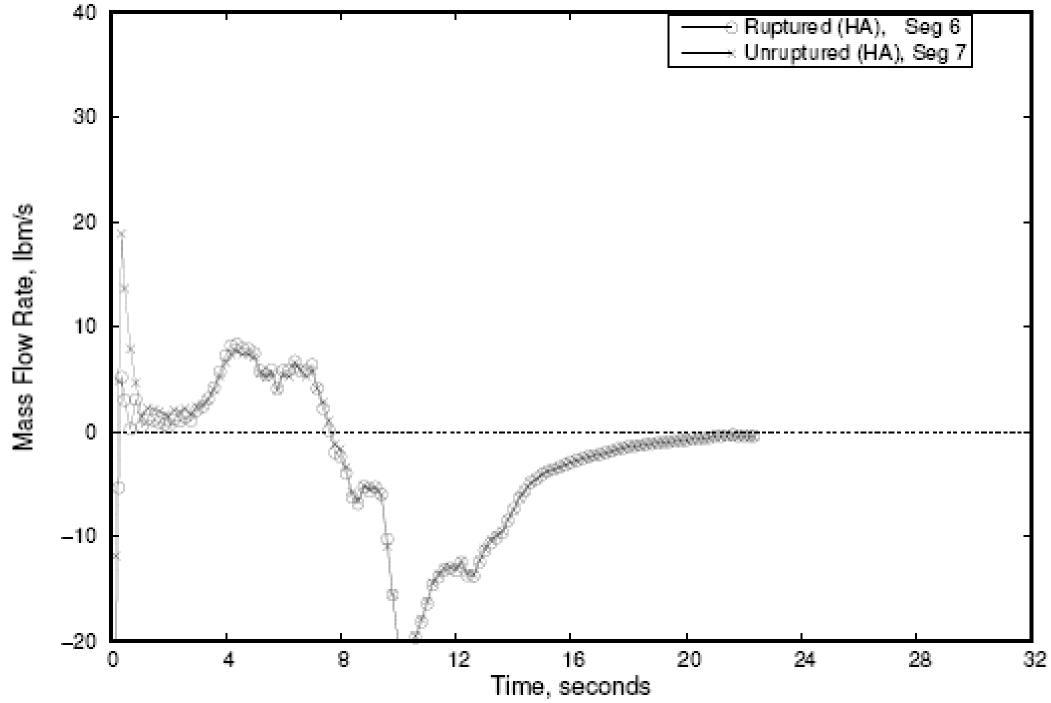


Figure 6-15: 2.506-ft Mark-B-HTP Full-Core MOL LBLOCA Case – Core Flooding Rate

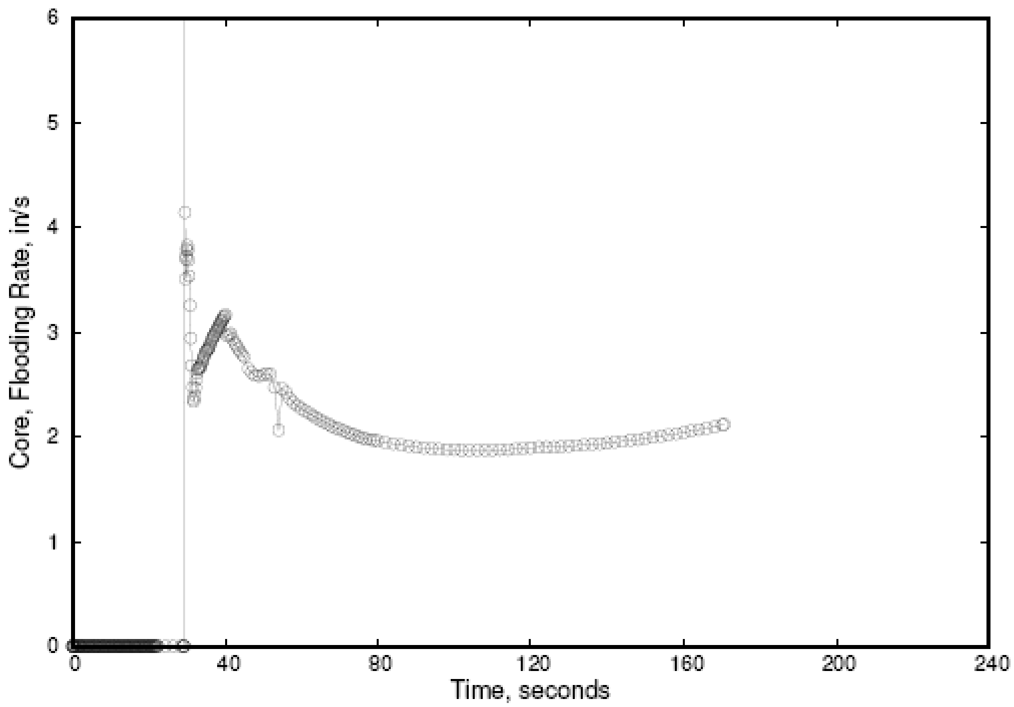


Figure 6-16: 2.506-ft Mark-B-HTP Full-Core MOL LBLOCA Case – HP Fuel & Clad Temperatures at Ruptured Location

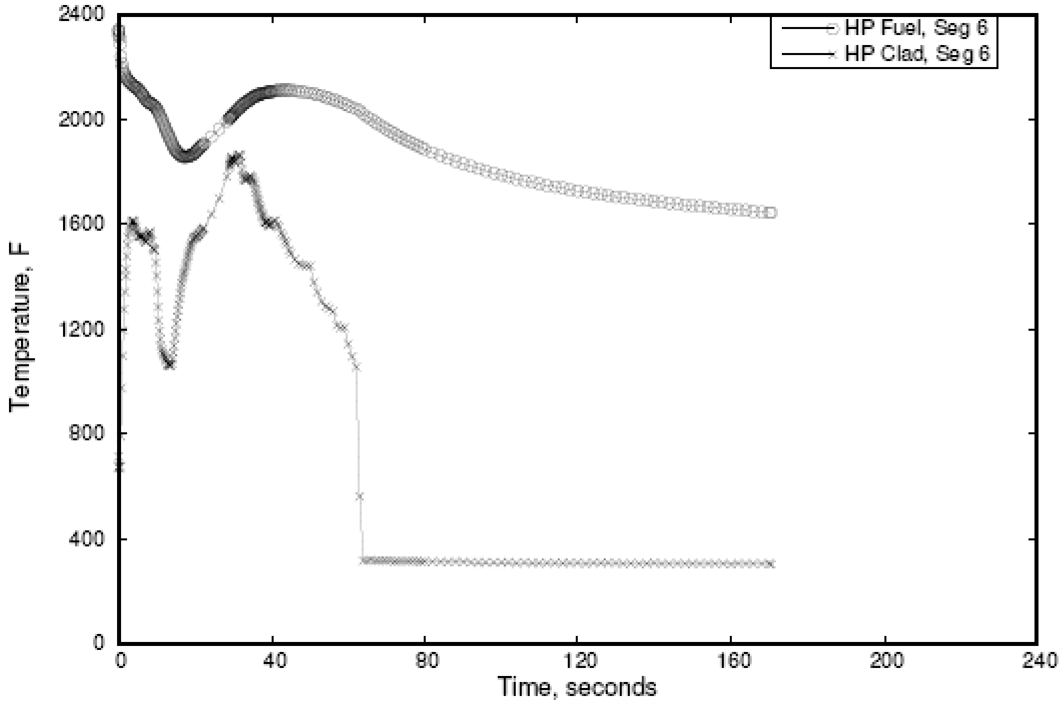


Figure 6-17: 2.506-ft Mark-B-HTP Full-Core MOL LBLOCA Case – HP Fuel & Clad Temperatures at Peak Unruptured Location

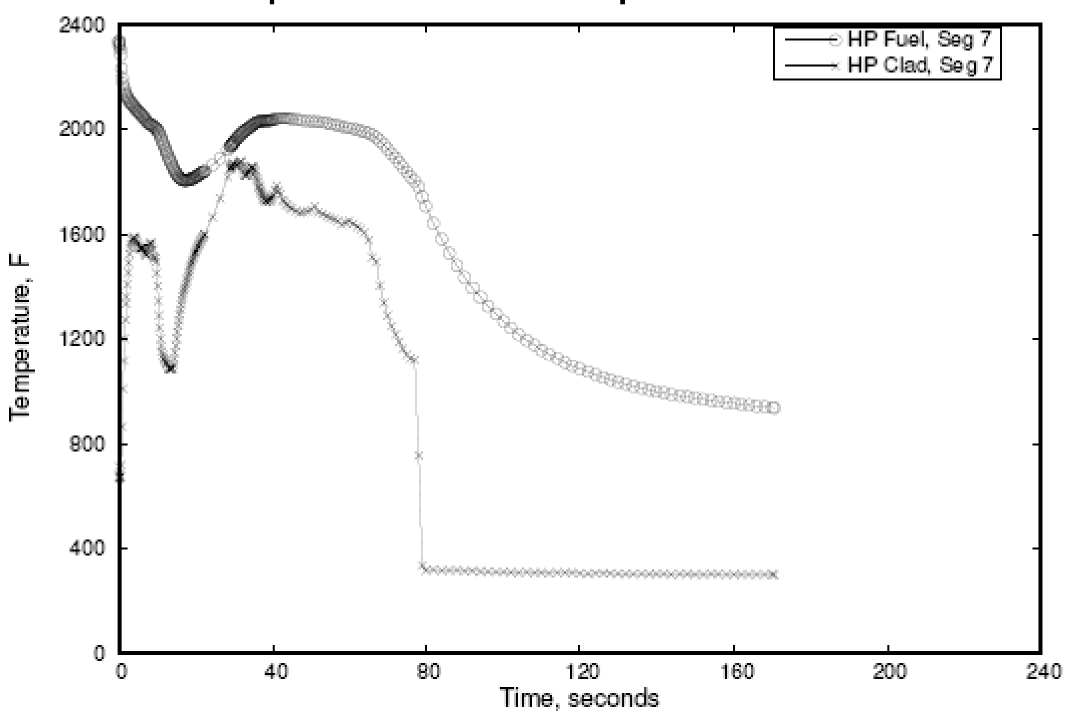


Figure 6-18: 2.506-ft Mark-B-HTP Full-Core MOL LBLOCA Case – HA Fuel & Clad Temperatures at Ruptured Location

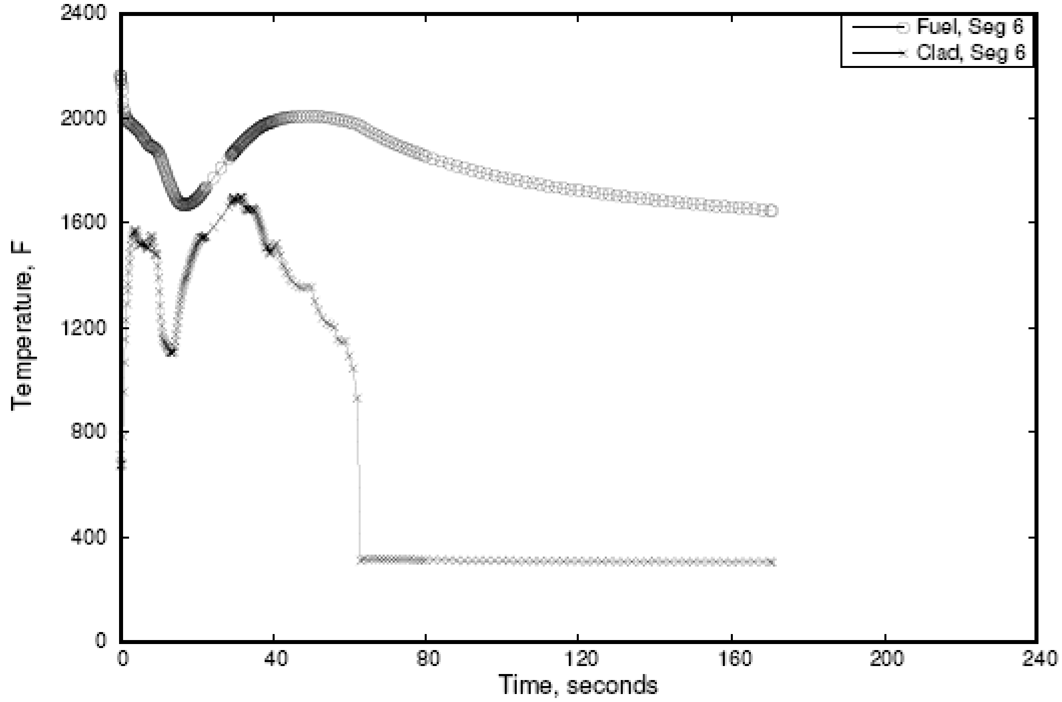


Figure 6-19: 2.506-ft Mark-B-HTP Full-Core MOL LBLOCA Case – HA Fuel & Clad Temperatures at Peak Unruptured Location

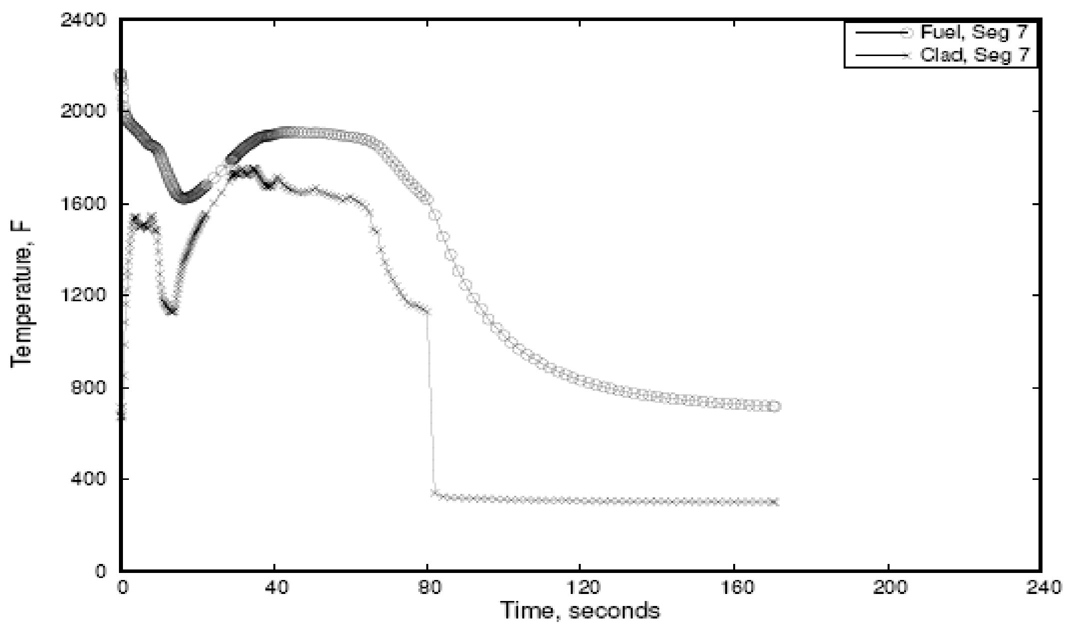


Figure 6-20: 2.506-ft Mark-B-HTP Full-Core MOL LBLOCA Case – Quench Front Advancement

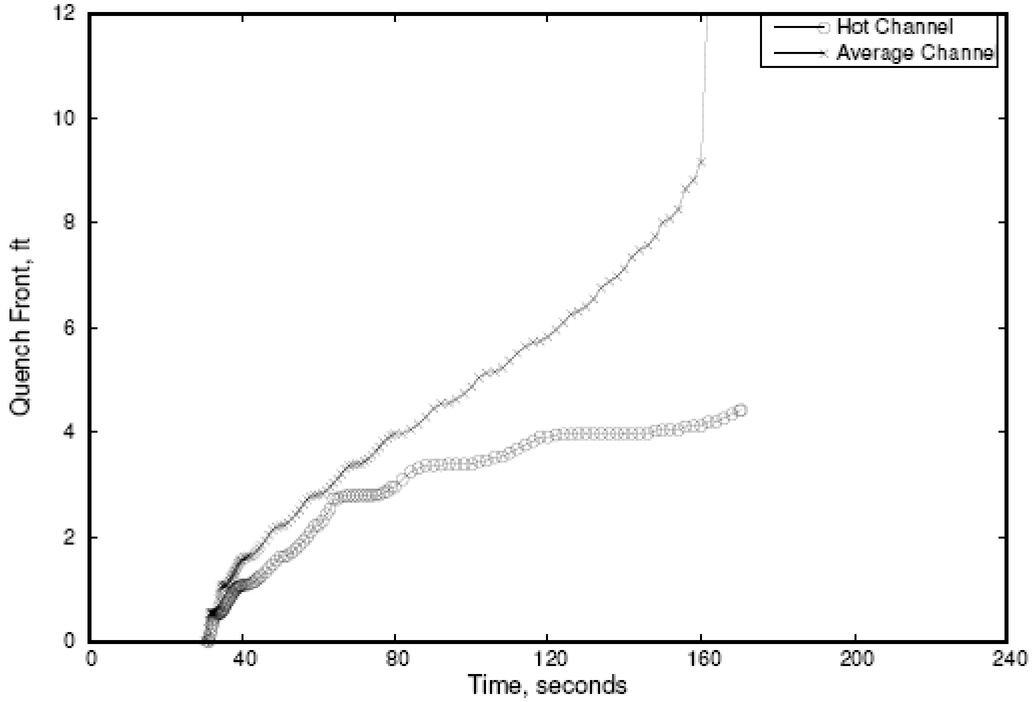
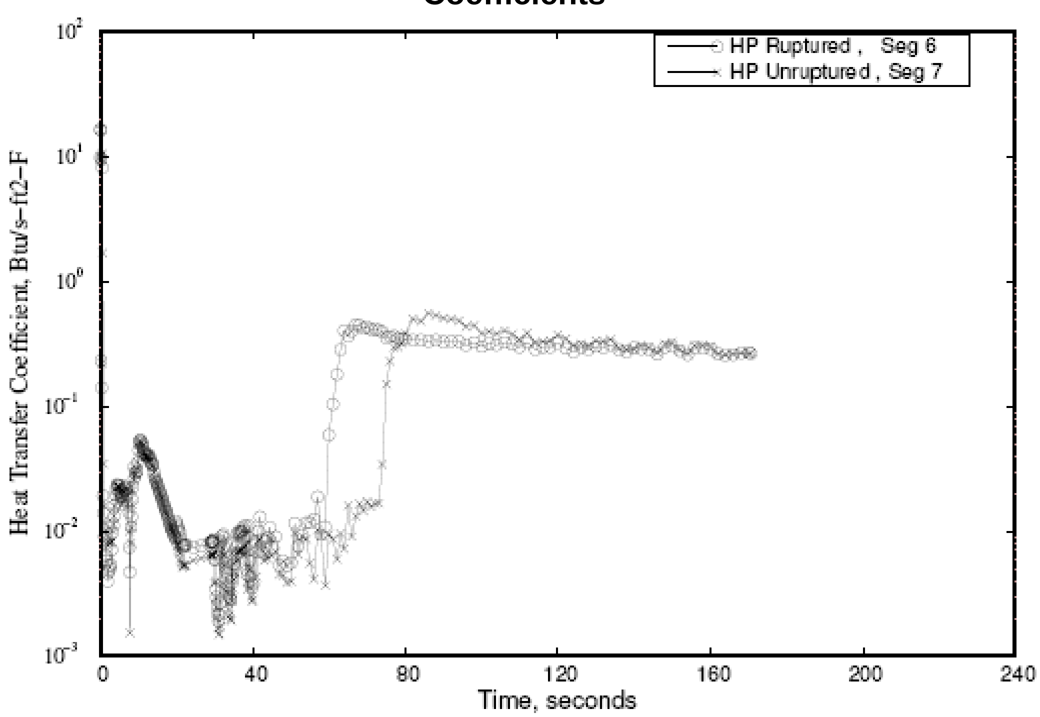


Figure 6-21: 2.506-ft Mark-B-HTP Full-Core MOL LBLOCA Case – HP Heat Transfer Coefficients



7.0 SBLOCA SENSITIVITY STUDIES AND ANALYSES

SBLOCA licensing analyses are completed with a model that is constructed based on Volume II of the NRC-approved BWNT LOCA Evaluation Model (Reference [1]). There are a variety of sensitivity studies that are performed to demonstrate model convergence and conservatism before the SBLOCA analyses are performed. Many of the studies are generic in nature and reported in the BWNT LOCA EM topical report. Other studies are applicable to a specific plant-type (i.e., lowered-loop 177-FA plant category which includes the ONS plant). In some special circumstances there are plant-specific studies that are required because of unique design features of the plant. The SBLOCA sensitivity studies are addressed in Section 7.1. The transient results for the Mark-B-HTP fuel assembly analyses are presented in Section 7.2.

7.1 SBLOCA Sensitivity Studies

SBLOCA analyses require that various sensitivity studies be performed with the evaluation model to demonstrate model convergence and to identify the most limiting set of boundary conditions or break locations that should be used in demonstrating compliance with the first three criteria in 10 CFR 50.46. As part of the SBLOCA EM, AREVA performed numerous SBLOCA sensitivity studies to confirm modeling techniques and methods. Although the EM was based on a slightly different design, the safety evaluation report for BAW-10192P-A (Reference [1]) supports the application of the EM to the 177-FA plants, and AREVA has determined that the SBLOCA sensitivity studies performed in the EM are directly applicable to, and appropriate for, use in the ONS SBLOCA analyses. A number of sensitivity studies, both generic and plant specific, have been discussed in the SBLOCA EM (Reference [1]) and ONS LOCA Summary Report (Reference [12]). These studies have been evaluated to remain applicable to the ONS models for the full-core Mark-B-HTP SBLOCA analyses (References [9] and [10]).

The most important changes associated with the full-core Mark-B-HTP ONS SBLOCA performed herein are full-core of Mark-B-HTP fuel, increase SG tube plugging to 7%, 1.7 peak at 11 ft axial power shape, and a decay heat prediction based on RELAP5 default actinide model. The applicability of the generic sensitivity studies to the full-core of Mark-B-HTP fuel analyses is discussed in Section 7.1.1. The applicability of the plant-type specific sensitivity studies is reviewed in Section 7.1.2.

7.1.1 EM Generic Studies

The generic sensitivity studies applicable to the ONS SBLOCA analyses documented in the EM, Reference [1], Volume II, Appendix A. These SBLOCA EM generic sensitivity studies are listed below:

1. SBLOCA Time-Step Study
2. SBLOCA Pressurizer Location Study
3. SBLOCA Core Cross-flow Resistance Study
4. SBLOCA Core Channel Noding Study
5. SBLOCA CFT Line Resistance Study
6. SBLOCA Break Discharge Coefficient Study

7.1.1.1 SBLOCA Time-Step Study

The study using the generic EM, documented in BAW-10192P-A, Volume II, Appendix A, Section A.2, verified that, for light water reactor geometry, the RELAP5 time-step controller governs the code solution sufficiently to assure convergent results. In RELAP5/MOD2-B&W, the user specifies a maximum time step that can be modified internally by the code in the event of convergence or Courant limitations. The SBLOCA EM time-step studies justified use of a 20-millisecond maximum time-step size as appropriate for B&W-plant SBLOCA

analyses. The EM controls the plant input models such that no significant deviation in the number or size of the control volumes or heat structures, critical to the model results, will be made to the different plant designs. Since the ONS full-core Mark-B-HTP SBLOCA analytical model is similar to the model used for the EM time-step study, and the maximum time-step size is 20 milliseconds in the SBLOCA analyses, then the RELAP5/MOD2 time-step controller will also adequately control the problem advancement for these applications. The EM study remains valid, therefore, and this study does not have to be repeated.

7.1.1.2 SBLOCA Pressurizer Location Study

Previous configuration studies performed with the SBLOCA EM (BAW-10192P-A, Volume II, Appendix A, Section A.3) showed that there is little difference in results when the pressurizer is connected to the broken loop instead of the intact loop. This result is expected since the SBLOCA transient is dominated by such factors as leak flow, decay heat generation rate, initial primary liquid inventory, and ECCS injection rates. Therefore, the pressurizer location study performed with the EM is applicable to the ONS full-core Mark-B-HTP 102% SBLOCA analyses and this study does not have to be repeated.

7.1.1.3 SBLOCA Core Crossflow Resistance Study

Core crossflow is modeled in the base model through the use of RELAP5/MOD2-B&W crossflow junctions between the hot and average channels in the core region. The crossflow areas are calculated based upon the actual flow area exposed by the three-by-four matrix of fuel assemblies in the hot channel, and the junction form loss factors are input based on the method discussed in the EM (BAW-10192P-A, Volume II, Appendix A, Section A.4). This scheme was found to increase the flow diversion out of the hot channel while restricting the flow of lower temperature steam from the average to the hot channel during core uncovering, thereby, maximizing the hot channel peak clad temperature prediction.

The ONS Mark-B-HTP SBLOCA analysis has updated the cross flow areas between the hot channel and the average channel as a result of incorporating Mark-B-HTP fuel in the average channel. Additionally, the ONS Mark-B-HTP SBLOCA analyses use the implementation of void-dependent cross flow logic, which is not part of the EM cases evaluation. The void-dependent cross flow logic option uses EM cross flow modeling philosophy to standardize the cross flow modeling implementation by allowing the core cross flow to vary depending on the mixture level, Revision 4 of Reference [5], as opposed to the fixed cross flow resistances shown in Table A-3 of Reference [1]. This improvement retains the prescribed core cross flow conservatisms while removing the likelihood of PCT variation because of the fixed nature of the constant cross flow model specification while at the same time ensure adequate cross flow predictions for updated cross flow junction areas based on Mark-B-HTP fuel design. Consequently, the void-dependent cross flow model improves the implementation of conservatisms of the EM cross flow resistances. It remains consistent with the current EM discussions and has been approved by the NRC (Reference [5]). Therefore, the studies performed for the EM remain applicable and do not need to be repeated.

7.1.1.4 SBLOCA Core Channel Modeling Study

The core noding in the ONS ROTSG model used 20 axial nodes to model the heated fuel assembly region with twelve assemblies in the hot channel and the remaining assemblies lumped into the average channel. In addition, each channel included an unheated segment at the inlet and exit. The EM study (BAW-10192P-A, Volume II, Appendix A, Section A.5) used a similar model, which was shown to ensure calculation of a conservative peak clad temperature for those cases in which the mixture level descends into the heated core region. Since the ONS full-core Mark-B-HTP SBLOCA analytical model is similar to the model used for the EM, this study does not have to be repeated for this application.

7.1.1.5 SBLOCA CFT Line Resistance Study

The core flooding system consists of two pressurized CFTs that are each connected to the reactor vessel downcomer by a surge line containing two check valves and an isolation valve. During a SBLOCA, the primary system may depressurize to the CFT fill pressure, allowing flow from the tanks and lines to enter the RV downcomer at a variable rate, depending on the CFT line resistance and the pressure drop between the CFTs and the RV downcomer. The CFT line resistance study performed with the EM (BAW-10192P-A, Volume II, Appendix A, Section A.7) included analyses of the base 0.1-ft^2 break and a larger 1.0-ft^2 break. This study confirmed that a CFT line resistance of one-hundred times the nominal value is appropriately conservative and acceptable for use for all SBLOCA analyses, except for the CFT line break. The CFT line break analysis uses the nominal resistance as stated in Section A.7 of the SBLOCA EM. Since the geometry, phenomena, and modeling of the reactor vessel downcomer region are similar between the current applications and the EM cases, the EM CFT line resistance study remains appropriate and applicable to the ONS full-core Mark-B-HTP SBLOCA analyses.

7.1.1.6 SBLOCA Break Discharge Coefficient Study

The break discharge coefficient study performed with the EM (BAW-10192P-A, Volume II, Appendix A, Section A.8) confirmed that all classical EM applications should be performed with the set of high break void discharge coefficients. In the ONS Mark-B-HTP analyses, all break flow discharge coefficients were set equal to 1.0. The classical EM applications include the reactor coolant pump discharge location with the reactor coolant pumps tripped. The break discharge coefficient studies performed with the EM confirmed that, during the boiling pot of a CLPD SBLOCA, the break volume void fraction was approximately 98 to 99 percent. Additionally, Reference [1], Volume II, Section 4.3.2.4 states that the high break voiding discharge coefficient range should be used for all classical EM SBLOCA applications. The ONS Mark-B-HTP SBLOCA analyses use a high break void model for majority of the transients including the limiting PCT case. Therefore, the EM results for the high void discharge coefficient method remain applicable.

7.1.2 EM-Plant Specific Studies

In addition to the generic sensitivity studies, AREVA determined that additional plant specific sensitivity studies are required for ONS. These ONS plant-specific SBLOCA sensitivity studies are listed below:

1. CFT Initial Condition for CFT and CLPD Line Break Study
2. RC Pump Two-Phase Degradation Study
3. Steam Generator Fill Logic Study
4. Automatic Feedwater Isolation System (AFIS) Study
5. Number of MSSVs Credited Study

7.1.2.1 CFT Initial Conditions for CFT and CLPD Breaks

Historically, LPI is not credited for CFT line break because of the single failure assumptions. However, a plant modification at the Oconee units allows the cross-tie of LPI lines such that LPI flow will be available to both the intact and the broken CFT lines at low pressures for the CFT line break analyses. This modification adds additional resistance to the LPI injection lines to balance the LPI flows in the event that a CFT line break occurs. The additional LPI line resistance results in a slightly reduced LPI flow rate compared to the LPI flow that would have been delivered before the modification for a CLPD or HPI line break. Consequently, after the intact CFT(s) empties, core cooling must be ensured with reduced LPI and HPI. The choice for the initial CFT conditions differs depending on the timing of the PCT. The CFT line break sensitivity studies performed in Reference [62] indicated that maximum CFT inventory and minimum CFT pressure conditions produce the limiting PCT results

with the cross-tie modification. ONS Mark-B-HTP CFT line break analysis, Section 7.2.3.2.5, predicts PCT during CFT injection and using the maximum CFT inventory and minimum CFT pressure. Thus, the CFT initial conditions for ONS Mark-B-HTP 102% SBLOCA represent appropriate modeling selections for CFT line break analysis.

Conclusions of a sensitivity study considering CFT initial conditions for CLPD breaks are summarized in Revision 0 of Reference [67], Section 5.5. The minimum CFT gas pressure and maximum CFT liquid volume is conservative for those SBLOCA analyses that predict the PCT while the CFT is injecting. The ONS Mark-B-HTP SBLOCA analyses use this modeling selection and the results were reviewed to ensure that the limiting CFT conditions are modeled appropriately.

7.1.2.2 RC Pump Two-Phase Degradation

PSC 2-00 identified that the calculated consequences for some SBLOCAs (in particular a CFT line break and larger CLPD breaks) could be worse if off-site power were available, and the operators tripped the reactor coolant pumps (RCPs) at two minutes after LSCM. When the RCP trip is delayed, the continued forced circulation in the RCS causes more liquid to flow out the break, thereby decreasing the liquid inventory that remains in the reactor vessel. The PSC raised questions regarding the validity of applying the RCP two-phase degradation model listed in the EM to pumps-powered applications for SBLOCA.

Table 9-2 of the SBLOCA volume of the BWNT LOCA EM (Reference [1]) states that the “default curve” (Semiscale) for two-phase head degradation should be used for SBLOCA applications. This is a general use curve that typically falls between the upper bound M1 and lower bound M3-modified curves. This selection was made because the RCP head degradation is of little consequence for SBLOCA transients with RCP trip coincident with LOOP. With off-site power available, the selection of the RCP two-phase head degradation mode can become important to the PCT consequences for larger (Category 5) SBLOCA break sizes. A study on the limiting RCP degradation was performed for Oconee (Reference [68]). The results of the study show that the lower bound M3-modified curve will produce more severe calculated PCT consequences for the CFT line break as well as larger CLPD breaks with a delayed RCP trip. The higher head resulting from the minimum degradation for any B&W-design plant will transport more liquid to the break location. The liquid lost out of the break increases the overall severity for these transients. Therefore, all of the Oconee ROTSG delayed RCP trip SBLOCA analyses used the minimum (M3-modified) head degradation curve. Both Category 5 CLPD break and CFT line breaks were analyzed with a 2-minute RCP trip for the Oconee Units with the ROTSGs installed with Mark-B-HTP full core design.

7.1.2.3 Steam Generator Fill Logic

The secondary level control methods at ONS are dependent on the availability of MFW and can involve filling one or both SGs with either MFW or EFW liquid. SG secondary level control studies were completed considering actual plant-specific options for fill and control of SG with either MFW or EFW and documented in Reference [62] for102% SBLOCA analyses. The results of the sensitivity study concluded that the scenario which models loss of MFW and EFW filling to automatically control to the 50% operating range (OR) in SG-2 only and EFW filling to LSCM level at 20 minutes in SG-2 is appropriate for ONS Mark-B-HTP 102% SBLOCA analyses. SG secondary level control studies for 52% partial power analyses were completed in Reference [10], Section 8.2.3 and the results show that the scenario which models MFW filling to automatically control to both SGs and EFW filling to LSCM level at 20 minutes in SG-2 is appropriate for ONS Mark-B-HTP 52% SBLOCA analyses.

7.1.2.4 AFIS Study

The AFIS (Automatic Feedwater Isolation System) instrumentation automatically terminates MFW and/or EFW in order to limit the effects of a main steam line break accident, which overcools the SG and can lead to unacceptable thermal stresses on the SG tubes and to exceeding containment design pressure. The AFIS logic relies on main steam header pressure and depressurization rate as input signals. The MFW is isolated based on the pressure signal only and the EFW is isolated on receipt of both pressure and depressurization rate signals.

The SBLOCA analyses for ONS have traditionally been evaluated based on boundary conditions that maximize the SG secondary pressure, thus decreasing the potential for heat removal from the primary tube regions. The maximum SG secondary pressure is obtained by considering minimum EFW flow, maximum EFW temperature and delay time, nominal MSSV lift setpoints, no leak paths, SG shell, steam line heat losses and a minimum uncertainty adjusted SG LSCM level setpoint. Maximum SG pressure is generally conservative for SBLOCA PCT predictions, provided that a lower pressure will not deactivate a key component such as EFW and cause the plant to lose the RCS heat removal and pressure control functions for small break sizes. It can be postulated that AFIS may isolate EFW for a case where the EFW availability would be necessary to mitigate the LOCA consequences for a very small LOCA.

A sensitivity study was performed in Revision 2 of Reference [62] to investigate the minimum secondary side pressure that could be achieved for a SBLOCA with credit for maximum EFW flow from two motor-driven EFW pumps and one turbine-driven EFW pump, minimum EFW temperatures, and steam extraction to the turbine driven EFW pump. The results concluded that at 102% power, the secondary side pressure was not low enough and the depressurization rates were not high enough to isolate EFW during the smallest LOCAs that require EFW to mitigate the event.

Although it is unlikely that AFIS will result in an isolation of EFW for SBLOCAs, credit for reasonable operator actions to restart EFW following RCS repressurization after an AFIS actuation is necessary to ensure that the consequences would not become more limiting than the results that were based on maximum secondary SG pressure. The following operator actions to restore EFW are now credited (Reference [19]):

1. If there is a loss of MFW or EFW (via AFIS, for example), the operators will restore EFW if there is a LSCM. The restoration of EFW means that the operators should make sure that at least one EFW pump is operating with an assured suction source and a pump discharge flow path available to at least one SG. EFW flow is verified to be operating or restored for all conditions with a loss of subcooling margin (including an AFIS actuation).

2. Operator action to bypass AFIS before raising the SG level to the LSCM setpoint and ensure continued availability of EFW flow to raise and control the SG level.

The sensitivity study performed in Revision 2 of Reference [62] provides reasonable assurance that it is highly unlikely that AFIS could isolate the EFW flow in the early phase of SBLOCA, which may require long-term SG heat removal. Equally important, the operators are procedurally required to review EFW operation following LSCM within 20 minutes after ESFAS in order to raise the level to the LSCM setpoint. Moreover, in the unlikely event that AFIS isolates EFW, the operator intervention will restore EFW within roughly half an hour. This is a reasonable time period because the break sizes that rely on SG heat removal to mitigate SBLOCA consequences usually do not uncover the core within the first 30 minutes or after (break sizes less than 0.07 ft^2). Therefore, ONS Mark-B-HTP 102% SBLOCA analyses using boundary conditions to maximize the secondary side pressure provide the limiting SBLOCA consequences.

At 52% power, there is a greater potential for reaching the AFIS actuation setpoints because the reduced core power requires less SG heat removal. When the primary to secondary heat transfer is lower, the EFW

condensation increases the secondary side depressurization rate and also the minimum pressure that the secondary side reaches during the EFW fill to the natural circulation or LSCM setpoints. The potential for AFIS to isolate the EFW flow to one or both SGs is the greatest when the EFW flow is maximized (flow from both motor-driven and the turbine-driven EFW pump). However, higher EFW flows increase the primary-to-secondary heat transfer and depressurize the primary side faster than when one EFW pump is credited. Lower RCS pressures increase the HPI flow, shorten the time to get to the CFT discharge pressure, and generally decrease the PCT if it does not all together eliminate core uncovering. Since higher EFW flows are beneficial to the PCT and the operators have actions to restore EFW if AFIS isolates it during a LSCM event, and because the conditions necessary for EFW isolation are unlikely, the AFIS study with maximum EFW flow was not evaluated in the 52% power analysis.

7.1.2.5 Number of MSSVs Credited

A sensitivity study performed in Revision 2 of Reference [62] evaluated the operation of all MSSVs and lowest MSSV bank valve (1065 psia) out of service on the ROTSG 102% SBLOCA results. The analysis showed that one MSSV bank out of service is appropriate for the ROTSG SBLOCA analyses. This is also maintained for ONS Mark-B-HTP full and partial power SBLOCA analyses.

7.2 SBLOCA Analyses

The Oconee full-core Mark-B-HTP fuel design includes HTP spacer grids, HMP spacer grids, M5® cladding, and the FUELGUARD™ inlet debris filter. Additionally, variable Gadolinia weight percent and cycle length of 24 month are considered. Complete SBLOCA break size spectrums for 102% full power and 52% full power were analyzed in Reference [9] and [10], respectively. This section presents the results of the SBLOCA spectrum analyses performed for ONS at 102% power and also 52% power with seven percent steam generator tube plugging in each SG. Two sets of SBLOCA analyses are described in this section:

1. The 102% power with 2 HPI trains without ADV cooldown.

2. The 52% power with 1 HPI train with credit for only one ADV cooldown at 25 minutes after ESFAS.

The base model used in both sets of SBLOCA analyses is described in Section 7.2.1. A general discussion of SBLOCA phenomena and transient progression at full power without ADV cooldown is provided in Section 7.2.2. Section 7.2.3 discusses the interdependencies of the ECCS and EFW systems in mitigating SBLOCAs at full power without ADV cooldown. Section 7.2.4 discusses SBLOCA transient progression at partial power with ADV cooldown. The full power spectrum results are described in Section 7.2.5, and the partial power spectrum results are described in Section 7.2.6. Finally, discussions of SBLOCA EM inputs and changes are discussed in Section 7.2.7.

7.2.1 Base Model – 102% and 52% Full Power

The EM studies (Reference [1]) determined that the most limiting RCS piping SBLOCA break location is in the bottom of the cold leg piping between the reactor vessel inlet nozzle and the HPI nozzle. This location is limiting, because it bypasses the largest amount of HPI flow. Therefore, this break location has been examined for the Oconee SBLOCA break spectrum analysis. Additionally, an HPI line break and a CFT line break were examined as special break cases with unique ECCS flow boundary conditions to ensure that the most limiting case had been determined.

The LOCA AIS for ONS Mark-B-HTP fuel design is summarized in Section 5. For both 102% and 52% full power cases with the ROTSGs, the following modeling choices were made. The high void discharge coefficient method is applied in the break discharge model and the void-dependent core crossflow model was used. The steam generator tube plugging is set to 7% in both loops, with 50% of the EFW wetted region tubes assumed plugged. The pressurizer is attached to the intact loop. The ONS full-core Mark-B-HTP base model has an initial power level of 1.02 times 2568 MWt for full power and 0.52 times 2568 MWt for partial power and an axial power shape with a 1.7 peak at the 10.811-ft elevation. The hot channel contains twelve assemblies with a peak linear heat rate of 17.3 kW/ft. The remaining 165 assemblies are grouped into the average channel. For full power, a moderator temperature coefficient of 0 pcm/F is used, while at partial power, an MTC of +5 pcm/F is used to define the moderator reactivity feedback curve, with a beginning of cycle (BOC) beta-effective of 0.0070. The beginning of life (BOL) initial fuel temperature, BOL oxide thickness, and a range of pin pressures from BOL to EOL pin pressures are used to cover all fuel burnup times.

Gadolinia fuel has lower fuel thermal conductivity and volumetric heat capacities than the UO_2 fuel. The allowed peaking or LHR limits for Gadolinia are reduced to control the LBLOCA PCTs. The reduction in LHR limits for Gadolinia is larger than the volumetric heat capacity differences between Gadolinia and UO_2. Since the LHR limit reduction for Gadolinia is greater than the volumetric heat capacity ratio, the PCTs for Gadolinia rods will be lower, so they are not explicitly included in the SBLOCA analyses.

The plastic weighted heating ramp rate model is applied for the EM pin rupture model. Three supplemental pins are used to facilitate TIL study and examine the effects of rupture on the PCT. The hot channel is set to the pin pressure limit at EOL to maximize the likelihood of cladding rupture and the flow blockage and inside metal-water reaction energy generation. The three supplemental pins use pin pressures consistent with BOL and two pressures roughly uniformly distributed between the BOL and EOL values. Previous sensitivity studies have shown that clad rupture at temperatures less than approximately 1600 F allows increased cooling because of the clad surface area increase. At these temperatures the metal-water reaction is not significant; therefore rupture has a beneficial effect on the rod PCT. Using supplemental rods with lower pin pressures tends to avoid rupture and possibly produce higher PCTs. Use of the supplemental rods ensures that a bounding PCT is predicted despite the overall cladding temperature changes from swelling and rupture as well as metal-water reaction.

The HPI injection data for the ONS full-core Mark-B-HTP SBLOCA analyses are shown in Table 5-3 through Table 5-5. For 102% SBLOCA analyses, separate sets of HPI flows are credited to the broken and intact legs before (based on 1 HPI pump and 2 HPI lines) and after (based on 2 HPI pumps and 4 HPI lines) 10 minutes. For 52% SBLOCA analyses, separate sets of HPI flows to the broken and intact legs are based on 1 HPI pump and 2 HPI lines only. The HPI flows for the 52% full power SBLOCA analysis are the same before and after 10 minutes. HPI flows for the CFT line break do not identify flows for the broken loop since all of the HPI flow injects into the RCS. For 102% power, the flows after 10 minutes are based on an assumed operator action to ensure flow from 2 HPI pumps to 4 HPI lines.

The LPI flow rates applicable to ONS are listed in Table 5-6 for the SBLOCA. The flows are based on the LPI cross-tie modification. The valve opening flow ramp is not modeled for SBLOCA, because the valves will be full open before the RCS pressure reaches the LPI flow pressures with a delay time that includes both the start delay and valve opening delay.

Reactor trip occurs on a low primary system pressure of 1780 psia with a 0.5 second delay before control insertion begins. In cases that assume loss of off-site power (LOOP), LOOP is assumed to occur at the time of reactor trip, causing the reactor coolant pumps to coast down. For cases with off-site power available, the RC pumps are manually tripped two minutes after loss of subcooling margin (LSCM) indication. ESFAS is triggered when the primary system pressure drops below 1515 psia. A 48-second delay time is assumed before HPI flow begins.

For analyses of breaks in the reactor coolant pump discharge piping, including the HPI line breaks, each CFT has an initial liquid inventory of 1085 ft^3 and is pressurized to 565 psia. The initial CFT pressure and liquid inventory used for the CFT line break analyses are discussed in Section 5.12.4 in Reference [19]. The LPI flow is also pressure-dependent, and the LPI pumps are activated by a low-low primary system pressure of 365 psia, with a delay of 74 seconds.

The base analysis assumptions include operator actions as listed in Table 5-14; however, all actions specified in the plant-specific EOPs should be performed to successfully mitigate the consequences of the LOCA.

7.2.2 SBLOCA Transient Progression at 102% Power without ADV Cooldown

The transient progression for SBLOCAs is summarized here to identify the key phenomena and controlling thermal-hydraulic behavior during each phase of the event. Section 7.2.3 further investigates the interdependencies of the ECCS and EFW systems when mitigating a LOCA.

A potentially limiting SBLOCA generally progresses through five phases: (1) subcooled depressurization, (2) reactor coolant pump and loop flow coastdown and natural circulation, (3) loop draining, (4) boiling pot, and (5) refill and long-term cooling. The subcooled depressurization phase begins at the leak initiation. This phase is characterized by the period of time before the RCS begins to saturate and voids begin to form in the RV upper head and hot leg U-bends. During this period, the pressurizer will begin to empty, the RCS will depressurize to the low RCS pressure reactor trip setpoint, and the turbine will trip. With the assumption of a loss of off-site power coincident with reactor trip, the MFW pumps and RC pumps will trip and EFW will be initiated following a 69-second delay.

Following the RCP coastdown, the RCS flow tends to evolve to a natural circulation flow condition. The energy generated by the core is transferred by convection to the steam generators during the flow phase. The continued loss of the RCS liquid inventory allows steam voids to form in the upper reactor vessel head and the upper hot leg U-bends. Natural circulation ends when the U-bend steam void displaces the hot leg mixture levels below the U-bend spillover elevation. Flow is usually interrupted first in the hot leg containing the pressurizer surge line connection, because of the additional flashing of the saturated pressurized liquid that enters during the subcooled depressurization. Near the end of the flow phase, alternating periods of RCS repressurization can cause intermittent spillovers of hot-leg liquid into the steam generator primary region.

With the interruption of the RCS loop flow, the loop-draining phase begins. As the entire RCS approaches saturated conditions, the onset of subcooled and saturated nucleate boiling occurs in the core because of the high decay heat levels and the RCS depressurization. The flashing within the hot legs increases the size of the voids in the U-bends and eventually interrupts RCS flow and decreases the primary-to-secondary heat transfer. For the larger SBLOCAs, the RCS will continue to depressurize as the loops drain. For smaller breaks, however, the reduced heat transfer can interrupt the RCS depressurization; where the volumetric expansion of the RCS, due to continued steam formation, can exceed the volumetric discharge from the break, causing the RCS pressure to temporarily stabilize or even increase.

In the reactor vessel, the steam in the upper head displaces enough liquid to uncover the reactor vessel vent valves (RVVVs), creating a manometric imbalance between the core and the downcomer. The imbalance forces the RVVVs to open and pass steam into the reactor vessel downcomer. The downcomer steam volume grows until the cold leg nozzle is exposed to steam. As soon as the downcomer liquid level decreases below the cold leg nozzle spillunder elevation, a steam venting path develops from the core through the RVVVs to the cold leg break, enhancing the RCS depressurization.

During the loop draining phase, the steam voids that developed in the U-bends can become large enough that the primary liquid level is displaced into the steam generator tube region below the EFW nozzles. If feedwater (MFW or EFW) is injecting through the EFW nozzles, improved primary-to-secondary heat transfer can then be restored through condensation on the tubes wetted by the feedwater. This heat transfer process within a steam generator is referred to as boiler-condenser mode (BCM) cooling. When BCM cooling takes place near the location of the EFW nozzles, it is referred to as high-elevation BCM cooling. If high-elevation BCM occurs, the RCS depressurization rate will be increased. Later in the loop draining phase, a different form of BCM cooling can occur if the RCS tube liquid level decreases below the secondary liquid level. This cooling process is referred to as pool BCM cooling, and will continue if (1) RCS condensation and ECCS injection do not cause the RCS liquid level to increase above the secondary level and, (2) the secondary fluid temperature is maintained below the temperature of the steam on the primary side of the SG tubes. Further, if the secondary liquid level is several feet above the RCP spillover elevation then the condensate formed during this process augment the ECCS flow to the core. For the smaller breaks, the combination of leak flow (with upper-RV venting through the RVVVs), BCM cooling, and HPI cooling will cause the RCS pressure to decrease.

Also during the loop draining phase, the reactor vessel outlet annulus mixture level will decrease to the hot leg nozzle spillunder elevation. If the top of the hot leg nozzles water turns to steam, the steam will flow up the hot leg riser section, and liquid from the hot leg risers will drain back into the vessel. This hot leg draining allows the mixture level in the outlet annulus to remain near the top of the hot leg nozzle until the hot leg liquid level drops into the RV exit nozzle horizontal piping.

After the hot legs empty, another path for the direct venting of steam to the break can be opened if the loop seals in the RCP suction piping are cleared. Depending on the break size, the RCS depressurization can be rapid enough to cause significant flashing in the suction piping, causing the liquid level to decrease below the suction piping spillunder elevation. The loop seals will then be clear, creating another steam relief path, in addition to the path through the RVVVs.

When loop draining ends, the break site void fraction will be based on core steam plus broken loop HPI flow. At that point, the only RCS liquid available for core cooling is the liquid remaining in the reactor vessel and the ECCS flow plus any SG condensate from the intact loops if the loop seal has not cleared. This portion of the transient is defined as the “boiling pot” phase. The increased void fraction at the break will further increase the RCS depressurization rate. The reactor vessel levels will continue to decrease; however, if the ECCS injection plus SG condensate cannot match the reactor vessel liquid loss from flashing, decay heat, and passive metal heat; the break flow allows the RCS to continue to depressurize. Once the CFT or the HPI flow rate exceeds the break discharge rate, the RCS will refill to the break elevation. Before either of these conditions occurs, the mixture levels may descend into the core heated region resulting in a heatup of the fuel cladding in the uncovered portion of the core.

The clad temperature increases calculated for the upper core elevations are conservative because a power shape skewed to the core exit is used. The peak axial power occurs at the 11-ft core elevation.During the period of partial core uncovering, the clad may swell and possibly rupture if the clad temperatures exceed 1300 F. The potential for clad rupture is increased in the SBLOCA analytical model by assuming an initial internal pin pressure typical of fuel assemblies at EOL. If clad rupture is calculated, the use of supplemental pins at various times-in-life show that the fuel pin conditions will be bounded by the calculated PCT at any time-in-life condition.

A SBLOCA transient analysis is normally terminated at some point after the entire core is refilled and the cladding temperatures returned to within a few degrees of RCS saturation temperature. For the level to increase, core inflow (ECCS plus SG condensate) must exceed the liquid loss rate. Continued RCS depressurization permits higher ECCS injection rates that hurries core refill. The additional ECCS flow assures that the core can

be kept covered. Once the core has been completely quenched, the analytical results are checked to ensure a path to long-term cooling is established. For long-term cooling to be assured, the HPI flow and/or LPI flow must match core boiling due to decay heat and wall metal heat plus flashing. When long-term cooling is assured, the LOCA analysis is terminated. The following section further develops the interdependencies of the ECCS and EFW in SBLOCA mitigation strategies.

7.2.3 Interdependencies of ECCS and EFW Used in SBLOCA Mitigation for B&W Plants at 102% Power without ADV Cooldown

AREVA has demonstrated that the B&W-designed plants meet the 10 CFR 50.46 requirements by analyzing the limiting pipe break loss-of-coolant accidents (LOCAs) with an NRC-approved EM. The limiting breaks are generally those that result in the largest bypass of ECCS flow directly out of the break. The break sizes range includes any break that can exceed the makeup system flow up to and including that of a full, double-ended guillotine rupture of the cold leg or hot leg pipe. The mitigation of the break consequences is accomplished by a cooperative effort of makeup flow from high pressure injection (HPI), core flood tanks (CFT) and low pressure injection (LPI), plus ultimate core decay heat removal via emergency feedwater (EFW) and long-term cooling via decay heat coolers with ECCS recirculation from the containment sump. These systems are activated and managed by both automatic trips and controls or manual operator actions identified in the plant emergency operating procedures (EOPs). This section clearly identifies the interrelationship of these systems in successful LOCA mitigation.

The ECCS and EFW interdependencies are break-size dependent. Because of these dependencies, the relationships are best described according to approximate break size ranges. The break spectrum includes pipe break areas of up to twice the hot leg pipe cross-sectional area and less. Within this spectrum there are six categories of breaks. Each provides different challenges to both the ECCS and EFW injection systems. These six categories of breaks are given the following loose characterizations:

1. SBLOCAs which may not interrupt natural circulation.
2. SBLOCAs that may allow the reactor coolant system (RCS) to repressurize in a saturated condition.
3. SBLOCAs that allow the RCS pressure to stabilize initially at approximately the secondary side pressure and then slowly depressurize toward CFT pressure.
4. SBLOCAs that depressurize the RCS to the CFT pressure.
5. SBLOCAs that depressurize the RCS nearly to the containment pressure.
6. LBLOCAs.

The following subsections describe in detail the characteristics of each of the break categories. (While each section identifies a specific break size range, care should be taken in maintaining them as absolute. The HPI flow assumptions, decay heat and critical flow model selected can change the break sizes in the various categories.)

7.2.3.1 Category 1: SBLOCAs too Small to Interrupt Natural Circulation

A LOCA is defined as any break size that is in excess of the makeup system capacity. This minimum break size is not easily defined because it is dependent on break location, makeup and letdown flow rates, the critical flow model used in the analysis, and operator actions that are credited. Accordingly, a variety of break areas can be given as the minimum break size for a LOCA. For Oconee, a calculation was performed to define the minimum break size of 0.00041 ft^2 (Reference [41]). These smaller break sizes are in excess of the makeup system flow delivery and will depressurize slowly and achieve a reactor trip within the first twenty minutes following break opening. After reactor trip, the system will lose core exit subcooling margin (LSCM). The RCPs will be manually

tripped (per the EOPs) within two minutes of LSCM, if they are not lost due to a loss of off-site power (LOOP). These smaller break sizes will not quickly depressurize to the low RCS ESFAS trip pressure. The operators will have time to diagnose the symptoms of a LOCA (predominately LSCM or leakage greater than allowed by Technical Specifications) and may manually activate ESFAS. Once ESFAS is initiated, HPI is actuated and letdown is isolated, such that the net ECCS inflow is increased.

After initiation of ESFAS, the ECCS inflow will be capable of matching liquid break flows for CLPD break sizes in the range of 0.0004 to 0.005 ft^2 depending on break location and number of HPI pumps operating. If the ECCS injection matches break flow, and EFW flow is initiated, either automatically or manually, at a flow rate sufficient to remove the core decay heat not lost through break-HPI cooling; then the RCS will remain in single-phase natural circulation. The single-phase natural circulation flow provides a continuous core-to-steam generator energy transport mechanism that keeps the core from boiling and the RCS pressure coupled to the secondary side pressure. As the system is depressurized with steam generator cooldown via: the atmospheric dump valves, condenser (if available), or steam demand to the EFW pumps; the HPI flow will be throttled to maintain the desired core exit subcooling margin.

These LOCA break sizes are easily mitigated by the combination of HPI and EFW flow. The HPI makes up for break inventory loss, and the EFW provides core decay heat removal and system cooldown. Without HPI, the system inventory loss would cause natural circulation to be interrupted. This interruption in flow would result in initiation of core boiling and RCS repressurization. Without EFW and the steam generator heat transfer, the RCS could repressurize to the pressurizer safety valve open pressure. The steam generator cooldown allows the RCS to be cooled to the conditions at which the decay heat removal system can be initiated.

7.2.3.2 Category 2: SBLOCAs that May Allow RCS Repressurization in a Saturated Condition

If the break liquid discharge is slightly larger than the ECCS inflow, inventory loss causes the RCS to depressurize until the fluid in the hot legs saturates and begins to flash. The steam accumulation in the U-bend region blocks natural circulation and interrupts the steam generator heat removal. For these LOCAs, with break areas ranging from roughly 0.005 to 0.035 ft^2, the steam generator removes core heat during the early portion of the transient, when the decay heat is high to prevent the RCS from repressurizing. When RCS liquid flow ceases, and the energy removal by the steam generator is interrupted, some repressurization can occur due to core boiling. The minimum RCS pressure reached prior to this repressurization determines if the low RCS pressure ESFAS trip is actuated. (If the trip is not achieved automatically, the operator is instructed by the EOPs to activate ESFAS based on the loss of adequate subcooling margin.) The repressurization that occurs accelerates the rate of liquid loss out of the break if the break phase remains liquid only and reduces the HPI inflow if ESFAS has been actuated and the system pressure is not too high. The repressurization is halted when the combination of break-HPI cooling and steam generator heat removal matches or exceeds the core energy addition rate.

The net loss of system liquid inventory causes steam bubbles to form in the hot leg U-bends, which can expand into the steam generator tube region. This expansion is established either by flashing of hot leg liquid during the depressurization periods or by an intermittent steam venting up the hot leg when the break discharge plus HPI condensation cannot offset all the core generated steam. If EFW is flowing when the level descends into the tube region, and the primary pressure is greater than the secondary side pressure, high-elevation BCM will ensue. Condensation on the primary side decreases RCS pressure. If the EFW is off because the secondary side has been refilled to the loss of subcooling margin level (above RCP spillover), then the BCM is delayed until the primary level drops below the secondary side level. The pool BCM reduces RCS pressure before the vessel level has decreased below the bottom of the hot leg nozzle. With either the high-elevation or pool BCM, the core-to-steam generator heat removal mechanism is re-established. The heat transfer condenses RCS steam. This steam sink, in

combination with the break and HPI, reduce the RCS pressure to near that of the secondary side pressure. (It should be noted that if the ESFAS trip setpoint has not been reached or the operators have not manually started HPI, this depressurization will eventually actuate the ESFAS and initiate ECCS flow.) In some cases, the condensate can augment ECCS inflow by keeping the CLPS liquid full, such that liquid displaced by the condensate can flow over the pump into the reactor vessel.

Without any steam generator heat removal, the smallest Category 2 LOCAs could repressurize all the way to the pressurizer safety valve opening pressure, because the break energy removal is unable to relieve all the core-generated energy, through either liquid or steam discharge. At elevated RCS pressures, the HPI system may not be able to provide sufficient (or any) ECCS to make up for the core boiloff rate. With time, the RCS liquid inventory above the top of the core is depleted and the core could uncover and heat up. This evolution, however, does not occur so long as EFW is preserved at a flow rate sufficient to remove the core decay heat, and the secondary side level is controlled to a level (the loss of subcooling margin level) that is above the RCP spillover elevation. In this configuration, a pool BCM is established before the core uncovers. The pool BCM ensures that the RCS pressure can be controlled to a value slightly above the secondary side pressure. At these moderate RCS pressures, the HPI system can generally match core decay heat to prevent core uncovering. Should uncovering occur, HPI will limit the extent that the PCT will increase.

The smaller Category 2 break sizes will not depressurize the RCS below the secondary side pressure for many hours post-LOCA without operator action. The RCS pressure for these break sizes can be decreased via operator-initiated steam generator cooldown. This RCS cooldown could be interrupted if the RCS refills above the top of the tubes, thereby halting the high-elevation boiler condenser mode (BCM). The cooldown can be continued when the RCS refills sufficiently to re-establish single-phase natural circulation, or when the subsequent RCS inventory loss causes the level to drop back into the tube region.

7.2.3.3 Category 3: SBLOCAs that Slowly Depressurize the RCS to CFT Injection Pressure

As the break size increases, the break energy discharge to the reactor building replaces the steam generator as the primary core heat sink. For CLPD breaks in the range of 0.035 to 0.06 ft^2, the break energy discharge exceeds the core decay heat within a few seconds following reactor shutdown. The steam generator heat transfer via EFW is still important for these break sizes, because it can condense RCS steam and augments the break in depressurizing the RCS. The condensate combines with the ECCS flow to help limit the ECCS-to-core-boiloff deficit; EFW also cools the secondary side and limits the magnitude of the reverse heat transfer when the break depressurizes the RCS below the secondary side pressure.

These moderate break sizes limit the RCS depressurization rate. Generally it takes 25 to 60 minutes (depending on break size, decay heat power, and steam generator heat removal) for these break sizes to depressurize the RCS to the CFT pressure. During this time period, the core decay heat boils off the HPI flow that reaches the core and some of the RCS liquid inventory that drains into the reactor vessel. The continuous HPI flow delivery to the vessel is most critical for these break sizes, because the RCS liquid inventory available to augment the ECCS is only capable of providing 5 to 10 minutes of cooling, where core boiloff occurs and the core uncovers. The analyses are terminated once the core is covered and the ECCS flow matches the core decay heat generation. For this break range, this may be with HPI or once the CFT injection begins.

7.2.3.4 Category 4: SBLOCAs that Quickly Depressurize the RCS to the CFT Pressure

Break sizes from 0.06 to 0.25 ft^2 depressurize the RCS to the CFT pressure within five to twenty-five minutes after break opening. The severity of the results somewhat depends on the total HPI flow delivery early during the

transient. The CFT fill pressure is most important in the overall severity of results, because the CFT flow halts the core mixture level decrease and initiates vessel refill. Lower CFT pressures (nominal less operational band and uncertainty) delay the CFT refill which minimizes the core mixture level and maximizes the predicted PCT should core uncovering occur. Once the core level has been recovered and ECCS matches the decay heat generation, the analysis is terminated.

The EFW fill logic and EFW flow rate are less important on these transients because of the larger break size being able to remove the necessary core decay heat. Nonetheless, higher EFW flow rates can be beneficial in accelerating the RCS depressurization rate, holding up slightly more liquid in the hot leg and steam generator tubes, and reducing the steam generator reverse heat transfer.

7.2.3.5 Category 5: SBLOCAs that Depressurize the RCS Nearly to the Containment Pressure

Break sizes greater than 0.25 ft^2 but less than the greatest break size that is in the SBLOCA category (0.50 ft^2 for Mark-B-HTP[1]) are sufficiently large to depressurize the RCS to approximately that of the containment pressure. These breaks are not large enough to reverse core flow, which would cause the cladding to exceed the critical heat flux upon break initiation.

The core is shut down via control rods and cooled during the blowdown transient, which maintains a two-phase mixture that keeps the fuel pin cladding within a few degrees of saturation so long as the mixture level remains above the top of the core. During the rapid depressurization to the CFT injection pressure, some of these break sizes may cause some core uncovering and cladding heatup. For breaks with the RC pumps running for the first two minutes after LSCM, this situation is exacerbated, because the pumps push additional ECCS and RCS liquid to the break site. The duration of the uncovering is short since CFT flow quickly refills the core and quenches the clad temperature.

Depressurization to the LPI initiation pressure occurs within the first two to ten minutes post LOCA, therefore HPI inflow during these first several minutes is of little consequence for core cooling prior to the time of core refill so long as the LPI liquid reaches the vessel. After the CFTs are empty and the core is refilled, however, LPI and HPI flow provide both diversity of makeup injection sites and more than sufficient ECCS flow to match the core boiloff rates. (Note: The dependency on HPI is greater in the event of a CFT line break with limited cross-tied LPI flow reaching the vessel. In this special break configuration, the intact CFT and HPI flow along with the cross-tied LPI flow must be capable of accounting for the necessary core cooling.)

7.2.3.6 Category 6: LBLOCAs

Break sizes greater than the Category 5 SBLOCAs (0.50 ft^2 for the Mark-B-HTP) up to a full double-ended break of any RCS pipe are considered large break LOCAs. These break sizes are of sufficient size to cause the cladding to exceed the critical heat flux upon break initiation.

[1] The EM states that SBLOCAs should not go through DNB during the first few seconds after break opening. A maximum break size for the SBLOCA spectrum of 0.75 ft^2 predicted DNB for the Mark-B-HTP fuel with the BHTP CHF correlation. Break sizes of 0.5 ft^2 and smaller did not go through DNB initially for the Mark-B-HTP fuel. Since the 0.75-ft^2 case did go through DNB initially for the Mark-B-HTP fuel, it is placed in the transition LOCA spectrum and its results are bounded by the LBLOCA. Therefore, the Mark-B-HTP SBLOCA break spectrum is based on break sizes of 0.5 ft^2 and less.

If the break is on the cold leg side of the core, the core flow may reverse during the blowdown phase. Core cooling during the blowdown and refill phases of the LOCA is by high velocity steam or steam plus liquid droplets. The final cladding quench occurs when the core is reflooded by CFT and LPI flow within minutes after break opening. Although not considered as a separate category, the LBLOCA spectrum is divided into two break ranges, up to 2.0 ft^2 and greater than 2.0 ft^2, for the purpose of EM methods. The smaller range is analyzed using the transition LOCA method. These breaks are typically much less limiting than the larger break sizes.

7.2.4 SBLOCA Break Category Transient Progression at 52% Power with ADV Blowdown

The SBLOCAs have traditionally been placed in five categories based on the characteristic of each break as discussed in the previous subsections without credit for ADV blowdown. The ADV blowdown credited at 25 minutes after ESFAS for ONS at 52% full power SBLOCA results in a forced rapid depressurization of the secondary side to a pressure of 315 psia that is modulated thereafter (Section 5.8.4 of Reference [19]). The resulting effect on the transient progression has challenged the previously defined traditional break categories described in Sections 7.2.3.1 through 7.2.3.6 because of the SG heat removal induced by the ADV blowdown.

The SBLOCA spectrum with the ADV blowdown effectively results in the merging of the categories when the operator action to open an ADV is credited at 25 minutes following ESFAS. This merging combines Category 1, Category 2, and smaller sizes of Category 3 breaks into one group, the larger sizes in Category 3 and Category 4 into another, and Category 5 SBLOCA remaining distinct because its PCT consequences occur prior to initiation of the blowdown. This merger results in three distinct characterizations based on the break size, which is consistent with the EM study (BAW-10192P-A [1], Volume II, Appendix A, Section A.7). These three categories are defined as small, intermediate and large SBLOCAs which when combined with the LBLOCA transition and LBLOCA break sizes encompass the entire range of break sizes that must be considered.

With the ADV blowdown, the small SBLOCAs consists of the traditional Category 1, Category 2 and smaller sizes of Category 3 breaks, intermediate SBLOCAs consist of the larger sizes of Category 3 and all of Category 4, and large SBLOCAs consist of the Category 5 breaks. The characteristics for each of these new groups of SBLOCAs are discussed next based on the observed transient progression.

Small SBLOCAs (Break sizes from 0.002 to 0.05 ft^2)

The smallest range of breaks sizes extends from the smallest break that exceeds the normal makeup system capacity to the break sizes that can effectively remove the core decay heat energy within a few minutes after reactor trip. This range of breaks encompasses the full range of the traditional Category 1 and 2 breaks and small sizes of Category 3 breaks. This small break range is approximately 0.002 ft^2 to 0.05 ft^2 at the ONS 52% power level. The smallest to largest break size in this grouping varies by a factor of 25 and encompasses some considerable timing differences in system evolutions going from the minimum to maximum break size. The one key consideration for these breaks is that the rate of ECCS inventory loss is small and none of these breaks could initiate CFT refilling before the ADV blowdown is initiated. The operator action to open the ADV at 25 minutes induces primary-to-secondary heat transfer that in turn depressurizes the RCS to increase the HPI flow and obtain some CFT flow. The combination of the higher HPI flows, SG condensate from the EFW heat removal, along with some CFT discharge for the larger breaks in this group, halt the decrease of the core mixture level. For all the break sizes in this range, the PCT remains at the initial steady state temperature at the time the LOCA was postulated.

The smallest break size that exceeds the makeup flow only has a small net outflow of a few gallons per minute. The break flow plus RCS outflow from letdown and leakage may only exceed the inflow of the normal makeup and RCP seal injection inleakage. Such a small leak of a few gallons per minute will take hours to days to deplete the RCS to the point that the core could have insufficient liquid to keep it continuously covered with a two-phase

mixture capable of removing the core decay heat. For these scenarios, the break cannot remove the core generated energy so the SG provides nearly all the core heat removal via use of the EFW flow. If the EFW flow is inadequate, the RCS will repressurize to the power-operated relief valve (PORV) and pressurizer safety valve lift pressure. While HPI may be initiated, the break flow does not really challenge the HPI delivery rate. The ADV blowdown may not be very effective at depressurizing the RCS for the smallest break sizes because the loop flows could be interrupted and the SG tube levels may not be low enough to achieve boiler condenser cooling. Under these conditions, the RCS pressure will remain significantly above the secondary side pressure that is controlled to 315 psia. Break sizes smaller than roughly 0.02 ft^2 may not reach the CFT pressure before the HPI matches the core decay heat rate and begins to refill the RCS.

As the break size is increased above 0.02 ft^2, the break mass loss will be sufficient to cause the water level inside the SG tubes to drop below the EFW spray elevation and a continuous boiler condenser mode (BCM) of heat transfer is maintained. This SG heat removal augments the break energy relief and allows these break sizes to depressurize below the CFT fill pressure. The credit for the EFW condensate, higher HPI flow, and some CFT flow also keeps the minimum core mixture level high enough so none of these breaks will predict cladding heatup above the initial cladding temperature.

Intermediate SBLOCAs (Break sizes from 0.05 to 0.025 ft^2)

As the CLPD RCS break size gets larger than approximately 0.05 ft^2, the net break flow increases and the break energy relief increases such that the heat removal from the break and the ECCS can match the core decay heat early in the event relative to the small SBLOCAs. There is less reliance on the SG heat removal via EFW flow therefore EFW fill logic and EFW flow rate are less important on these transients because of the larger break size. Nonetheless, higher EFW flow rates and secondary side cooldown can be beneficial in accelerating the RCS depressurization rate, holding up slightly more liquid in the hot leg and steam generator tubes, and reducing the steam generator reverse heat transfer.

Break sizes from 0.05 to 0.25 ft^2 will depressurize the RCS to the CFT pressure within approximately five to twenty-five minutes after break opening. For this break range, the rate of ECCS inventory loss is large enough that all of these breaks could initiate CFT refilling before the ADV blowdown is initiated. These intermediate SBLOCAs produce the most severe PCT for the spectrum of SBLOCAs. The severity of the results somewhat depends on the total HPI flow delivery early during the transient with CLPD breaks limiting the amount of flow that can reach the core. The CFT fill pressure is most important in the overall severity of results, because the CFT flow injects directly into the reactor vessel downcomer instead of bypassing out of CLPD breaks, so it halts the core mixture level decrease and initiates vessel refill.

With higher RCS inventory loss rates the HPI flow capacity and flow split is insufficient so severe core uncovering occurs. For these break sizes, EFW, HPI, and CFT work together to mitigate the consequences of the LOCA. The effects of EFW heat removal help to depressurize the RCS. These break sizes will not keep the CLPS piping full, so the condensate from the high-elevation BCM cooling will not drain into the reactor vessel and augment the HPI in supplying core boil-off.

For the smaller break sizes in the intermediate SBLOCAs (break sizes between approximately 0.05 ft^2 and 0.06 ft^2), initiation of ADV blowdown halts further increase of cladding heatup. For the larger break sizes in the intermediate SBLOCAs (break sizes larger than 0.06 ft^2), use of the ADV blowdown has no effect on PCT as PCT occurs prior to the ADV blowdown being initiated.

The PCT results for the larger break sizes in the intermediate SBLOCAs (from 0.06 ft^2 to 0.25 ft^2) at 52 % full power with the ADV cooldown at 25 minutes are no different than the traditional Category 4 breaks without ADV cooldown.

Large SBLOCAs (Break sizes from 0.25 to 0.5 ft^2)

These break sizes remove all the core decay heat via the break so secondary side depressurization has little to no effect on the event. The HPI, CFT, and longer-term LPI flows manage the RCS inventory loss and refill the system to limit the duration and magnitude of the core uncovering period. The rate of RCS liquid inventory loss is severe for these cases so core uncovering is predicted, but its uncovering period is short and the CFT flow refills the core and abates the core heatup. Flow from one HPI train, CFT and LPI train (using cross-tied LPI flow for a CFT break) provided sufficient ECCS flow to prevent significant core heatup.

The PCT results for the large SBLOCAs (break sizes larger than 0.25 ft^2) at 52% full power with the ADV blowdown at 25 minutes are no different than the traditional Category 5 breaks without ADV blowdown.

7.2.5 Break Spectrum Analysis at 102% Power

The following subsections describe the results of the analyzed SBLOCA spectrum at 102% power based on the characteristics of each of the break categories identified in Section 7.2.3.1 through Section 7.2.3.5. The entire break spectrum was analyzed to ensure that the limiting case was appropriately determined for the Mark-B-HTP fuel design with the ROTSGs.

A total of 17 separate break sizes have been analyzed for ONS Mark-B-HTP full core SBLOCA analyses. The 0.01, 0.04, 0.07, 0.1, 0.125, 0.15, 0.175, 0.2, 0.3, 0.4, 0.5 ft^2 CLPD breaks with LOOP and the 0.3, 0.4, 0.5 ft^2 CLPD break with 2-minute RCP trip were analyzed as part of the CLPD Mark-B-HTP SBLOCA full spectrum. Also, a 0.02464 ft^2 HPI line break with LOOP and the 0.44 ft^2 CFT line breaks (with LOOP and 2-minute RCP trip) were also analyzed. The break sizes were chosen to ensure that the limiting case was appropriately determined considering all categories of SBLOCAs discussed in Section 7.2.3.

The results of the 102% full-core Mark-B-HTP analyses are summarized in Table 7-1 through Table 7-4, and shown in Figure 7-1 through Figure 7-26. These analyses used the base model described in Section 7.2.1 with the indicated break areas. A detailed compilation of PCTs versus break size can be seen in Table 3-8 and Figure 3-7.

7.2.5.1 Category 1 Breaks

The minimum SBLOCA break size required to be explicitly analyzed as part of the BWNT LOCA EM is the 0.01 ft^2 break. Break sizes smaller than 0.01 ft^2 typically do not even interrupt natural circulation. These break sizes are more reliant on EFW flow to remove a significant fraction of the core decay heat and maintain the RCS near the secondary side pressure until the HPI is capable of matching and exceeding the core decay heat energy addition. The core remains continuously covered so long as adequate SG heat removal maintains the RCS near the secondary side pressure.

The Category 1 breaks are not analyzed herein since this category represents breaks smaller than 0.01 ft^2. Further, this category does not represent the most limiting break size. The modeling changes made for this analysis, full core of Mark-B-HTP, inclusion of gadolinia fuel rods, increase in SGTP, to name a few, will not significantly impact the transient such that the limiting PCT would occur in this category. There is sufficient ECCS to maintain this category of breaks continuously covered until the decay heat is absorbed by the ECCS and the transient enters the long-term core cooling phase. The HPI flow, SG heat removal condensate, and residual RCS liquid provide adequate core cooling. Moreover, the continuous SG heat removal via EFW preservation and level control effectively controls the RCS pressure and ensures that adequate ECCS flow is delivered throughout the transient.

These smaller break sizes will also allow for more time for operators to take corrective operator actions, such as initiating flow from the second HPI pump and initiation of EFW flow to the second SG and/or operator initiated SG depressurization.

7.2.5.2 Category 2 Breaks

Break sizes analyzed in this category include 0.01 ft^2 CLPD break and a break in the HPI line with an area of 0.02464 ft^2. The Category 2 break sizes present a greater challenge than the Category 1 breaks to the HPI system to replace lost liquid inventory to ensure the mixture level does not drop below the top of the core. While both EFW and HPI are important, the duration of the period in which EFW flow is needed is shorter than that for the Category 1 break sizes.

For 0.01 ft^2 CLPD break, the subcooled RCS depressurization ends as the hot regions saturate and void accumulation in the hot leg U-bends interrupt flow. After flow interruption, primary to secondary heat transfer is minimized and this loss of heat removal results in RCS repressurization because the break volumetric discharge is insufficient to relieve the steam production due to core boiling. The HPI flow delivered by 10 minutes following ESFAS ensured that the core remained covered during the entire transient. Continuous availability of EFW flow removes the decay heat from the primary side that is not removed via the break. This ensured a slow and continuous RCS depressurization that allowed for an increase in the ECCS inflow as the transient progressed. Although the break flow is slightly higher during the portions of transient where RCS pressure is higher, there is sufficient mixture level remaining above the top of the core to ensure that the core will remain continuously cooled for the duration of the transient. The peak cladding temperature remained at the maximum initial cladding temperature. Additionally, this break size category remains non-limiting in terms of peak clad temperature.

For the HPI line break, 0.02464 ft^2 HPI flow was not available until the second HPI pump started at approximately 10 minutes into the transient because the pressure remained elevated above the injection pressure for the first HPI pump. Although HPI flow was delayed sufficient ECCS was available to ensure the core remained covered and the core mixture level is greater than 7 feet above the top of the core. The peak cladding temperature remained at the maximum initial cladding temperature such that the HPI line break represents a non-limiting break size with respect to the full spectrum analyzed herein.

7.2.5.3 Category 3 Breaks

One break size was analyzed in Category 3, the 0.04 ft^2 CLPD break. The break is dependent on early SG heat removal and continuous HPI flow to mitigate the event. The break energy discharge is more capable of replacing the SG as the primary core heat sink. The EFW heat transfer is still important because it condenses RCS steam and augments the break in depressurizing the RCS when decay heat is high. The condensate also combines with the ECCS flow to help limit the ECCS-to-core boiloff deficit. With the break aiding in core energy removal, shortly after the second HPI pumps begins injecting ECCS core power matchup is achieved. The core remains continuously covered and the PCTs remain at the maximum initial cladding temperature.

The results of the representative break for this category, 0.04 ft^2, indicate that breaks in Category 3 remain non-limiting with respect to the full spectrum analyzed herein.

7.2.5.4 Category 4 Breaks

The break sizes in Category 4 are between 0.06 ft^2 and 0.25 ft^2. This break range typically produces the limiting break scenario for ONS, therefore several cases were analyzed. The break sizes that were analyzed are 0.07, 0.1, 0.125, 0.15, 0.175 and 0.2 ft^2, and are dependent on CFT pressure to initiate vessel refill. The Category 4 breaks cause the RCS to depressurize continuously and achieve CFT injection earlier in the transient than the larger

Category 3 break sizes. The RCS pressure drops below the secondary pressure and initiates reverse heat transfer starting between 2 to 10 minutes after break initiation for breaks in this category. The higher RCS depressurization rates lead to additional flashing and passive metal heat addition. Consequently, the minimum core mixture levels drop below the top of the heated core for the Category 4 breaks greater than or equal to roughly 0.10 ft^2. The uncovered cladding segments increase in temperature until the HPI flow and CFT injection exceed core boiloff and flashing mass losses and begin to refill the core. ECCS core power match up for these cases occurs around 10 minutes into the transient. The most limiting break size for the full core Mark-B-HTP 100% SBLOCA spectrum is the 0.15 ft^2 CLPD with LOOP.

The 0.15 ft^2 CLPD case resulted in the limiting PCT of 1597.5 F. The maximum local oxidation was less than 1.0 percent of the cladding thickness and the whole core hydrogen generation was less than 0.04 percent of the entire core for this category of breaks.

7.2.5.5 Category 5 Breaks

Category 5 break sizes analyzed include breaks in the RCP discharge piping with break areas between 0.25 ft^2 and 0.50 ft^2 with either RCP trip concurrent with low RCS pressure trip based on an assumed loss of offsite power (LOOP) or operator initiated RCP trip two minutes after loss of subcooling margin with offsite power available. It also includes a 0.44 ft^2 CFT line breaks with LOOP and 2 minute RCP trip.

Category 5 breaks are highly dependent on CFT plus HPI/LPI to match core boilloff rate and RCS inventory lost out the break. These break sizes depressurize to the CFT fill pressure within the first several minutes after break opening. The flashing and boiling contributions decrease the RV inventory sufficiently to uncover the core. The rapid depressurization for the large CLPD breaks leads to high CFT discharge rates that quickly refill the core and limit the cladding temperature increase. Since HPI/LPI and CFT injection are important in the transient consequences for this break category, the magnitude of available HPI and CFT initial conditions also play a role in the PCT timing. When the PCT is predicted while the CFT's are injecting, a more limiting PCT is obtained considering a minimum injection rate produced by a maximum initial CFT liquid volume. However, after the CFT's have emptied, the limiting PCT is predicted when the minimum CFT initial volume is modeled because the overall RCS liquid inventory is lower during the time of core uncovering. Category 5 breaks use a maximum CFT inventory combined with minimum CFT pressure.

For breaks higher than 0.3 ft^2, PSC 2-00 (Reference [46]) identified that worse consequences are expected if the RCP's were allowed to remain in operation for to 2 minutes following LSCM. With the RCP's in operation, the RVVV's remain closed and the core steam is circulated through the loops with the remaining RCS liquid that is not lost out of the break. The circulation improves primary to secondary heat transfer and keeps the RCS well mixed until the pumps are tripped. After the RCP trip, the RCS flow coasts down and the break flow transitions to steam only. The RCS operation significantly decreases the RV downcomer liquid inventory and leaves the SG tubes nearly void of liquid. With the reduction of the total inventory, the ECCS is significantly challenged to maintain adequate heat removal in the core region. The results indicate that breaks in Category 5 remain non-limiting with respect to the full spectrum analyzed herein.

7.2.5.5.1 Category 6 Breaks

These breaks are considered LBLOCAs as discussed in Section 7.2.3.6.

7.2.6 Break Spectrum Analysis at 52% Power

The following subsections describe the results of the analyzed SBLOCA spectrum at the 52% full power. The full spectrum of breaks consisted of a number of break sizes analyzed at the CLPD and HPI locations. The specific

break areas analyzed at the CLPD location for the partial power spectrum were: 0.01, 0.04, 0.06, 0.07, 0.072, 0.08, 0.10, 0.13, 0.20, and 0.40 ft^2 with LOOP and the 0.4 ft^2 break with 2-minute RCP trip. Also, a 0.02464 ft^2 HPI line break with LOOP was analyzed. In addition, the PCTs for the 0.3 ft^2 and 0.5 ft^2 CLPD breaks with 2-minute RCP trip, as well as the 0.44 ft^2 CFT line breaks with LOOP and 2-minute RCP were estimated; justification for which can be found in Section 5.1 of Reference [10]. The break sizes were chosen to ensure that the limiting case was appropriately determined considering all categories of SBLOCAs discussed in Section 7.2.3.

The results of the 52% full power SBLOCA analyses with a full core of Mark-B-HTP fuel are summarized in Table 7-5 through Table 7-8, and shown in Figure 7-27 through Figure 7-47. A detailed compilation of PCT versus break size can be seen in Table 3-9 and Figure 3-8.

Note that in the discussion and results tables for 52% full power SBLOCA spectrum of analyses is broken into the traditional categories of SBLOCAs described below. This categorization, which was originally established for cases with no credit for ADV blowdown, is retained for consistency with 102% power summaries of results.

7.2.6.1 Category 1 Breaks

The minimum SBLOCA break size required to be explicitly analyzed as part of the BWNT LOCA EM is the 0.01 ft^2 break. Break sizes smaller than 0.01 ft^2 typically do not even interrupt natural circulation. These break sizes are more reliant of EFW flow to remove a significant fraction of the core decay heat and maintain the RCS near the secondary side pressure until the HPI is capable of matching and exceeding the core decay heat energy addition. The core remains continuously covered so long as adequate SG heat removal maintains the RCS near the secondary side pressure.

7.2.6.2 Category 2 Breaks

Breaks analyzed in this category include the 0.01 ft^2 CLPD break and a break in the HPI line with an area of 0.02464 ft^2. The Category 2 break sizes present a greater challenge than the Category 1 breaks to the HPI system to replace lost liquid inventory. Both EFW and HPI are important in this category.

For the 0.01 ft^2 CLPD break, the subcooled RCS depressurization ends as the hot regions saturate and void accumulation in the hot leg U-bends interrupt flow. After flow interruption, primary to secondary heat transfer is minimized and this loss of heat removal results in RCS repressurization because the break volumetric discharge is insufficient to relieve the steam production due to core boiling. The SG level raise to the LSCM setpoint and the ADV opening ensure that the core remains covered. Continuous availability of EFW flow removes the decay heat from the primary side that is not removed via the break. The peak cladding temperature remained at the maximum initial cladding temperature; therefore, this break size category remains non-limiting in terms of peak clad temperature.

For the HPI line break, 0.02464 ft^2, HPI flow is negligible until the ADV opens and subsequently depressurizes the primary side. It is this same action that brings the RCS to the CFT injection pressure, providing a greatly improved ECCS flow capable of recovering the RV liquid inventory. Core uncovering was thus prevented and the peak cladding temperature remained at the maximum initial cladding temperature such that the HPI line break represents a non-limiting break size with respect to the full spectrum analyzed herein.

7.2.6.3 Category 3 Breaks

Two break sizes were analyzed in Category 3, the 0.04 and 0.06 ft^2 CLPD break. This category establishes the transition from preventing clad heatup to undergoing core uncovering. The 0.06 ft^2 CLPD break is the first to experience clad heatup above the initial cladding temperature because the ADV opening occurs during hot

channel core uncovering and therefore provides only partial benefit, whereas the 0.04 ft^2 CLPD break opens the ADV prior to hot channel cladding heatup .

This break category is dependent on early SG heat removal and continuous HPI flow to mitigate the event. Compared to smaller break categories, the break energy discharge is more capable of replacing the SG as the primary core heat sink. However, the EFW heat transfer is still important because it condenses RCS steam and augments the break in depressurizing the RCS when decay heat is high. The condensate also combines with the ECCS flow to help limit the ECCS-to-core boiloff deficit.

7.2.6.4 Category 4 Breaks

The break sizes that were analyzed in this category are 0.07 ft^2, 0.072 ft^2, 0.08 ft^2, 0.10 ft^2, 0.13 ft^2, and 0.20 ft^2. This category establishes a transition from those break sizes which open the ADV prior to reaching the PCT (smaller breaks), to after the PCT has occurred (larger breaks). As a result, the cladding heatup for the smaller Category 4 breaks is greater than observed in Category 3. The larger Category 4 breaks allow the RCS to depressurize continuously and achieve CFT injection earlier in the transient and more quickly after core uncovery, as the break sizes increase. This causes an improved transient response.

The RCS pressure drops below the secondary pressure and initiates reverse heat transfer starting between 2 and 10 minutes after break initiation. The higher RCS depressurization rates lead to additional flashing and passive metal heat addition. The uncovered cladding segments increase in temperature until the HPI flow and CFT injection exceed core boiloff and flashing mass losses and begin to refill the core. The most limiting break size for the full core Mark-B-HTP 52% full power SBLOCA spectrum is the 0.072 ft^2 CLPD with LOOP.

The 0.072 ft^2 CLPD case resulted in the limiting PCT of 1480.2 F. The maximum local oxidation was less than 1.0 percent of the cladding thickness, and the whole core hydrogen generation was less than 0.01 percent of the entire core.

7.2.6.5 Category 5 Breaks

Category 5 break sizes analyzed include breaks in the CLPD with break areas between 0.25 ft^2 and 0.50 ft^2 with either RCP trip concurrent with low RCS pressure trip based on an assumed loss of offsite power (LOOP) or operator initiated RCP trip two minutes after loss of subcooling margin with offsite power available. At 52% full power, break sizes larger than 0.40 ft^2 undergo departure from nucleate boiling within the first two seconds of the transient, and thus cannot be evaluated using the NRC-approved SBLOCA methodology (Reference [1]). For the partial power analyses, such breaks are therefore estimated based on knowledge derived from 102% power analyses.

Category 5 breaks are highly dependent on CFT plus HPI/LPI to match core boiloff rate and RCS inventory lost out the break. These break sizes depressurize to the CFT fill pressure within the first several minutes after break opening. The flashing and boiling contributions decrease the RV inventory sufficiently to uncover the core. The rapid depressurization for the large CLPD breaks leads to high CFT discharge rates that quickly refill the core and limit the cladding temperature increase. LPI injection is initiated for all of these breaks, but not until after the core is recovered.

For breaks larger than 0.3 ft^2, PSC 2-00 (Reference [67]) identified that worse consequences are expected if the RCP's were allowed to remain in operation for 2 minutes following LSCM. With the RCP's in operation, the RVVV's remain closed and the core steam is circulated through the loops with the remaining RCS liquid that is not lost out the break. The forced circulation improves primary to secondary heat transfer and keeps the RCS well mixed until the pumps are tripped. After the RCP trip, the RCS flow coasts down and the break flow transitions to

steam only. As demonstrated in the 0.4 ft^2 CLPD break with 2-minute RCP trip, the continued RCP operation significantly decreases the RV downcomer liquid inventory and leaves the SG tubes nearly void of liquid. In addition, the ECCS is significantly challenged to maintain adequate heat removal in the core region.

7.2.6.6 Category 6 Breaks

These breaks are considered large break LOCAs, therefore, this category of breaks is not discussed in this document.

7.2.7 Discussion of SBLOCA EM Inputs and Changes

Several items affecting generic SBLOCA analysis inputs have been addressed and incorporated in the current analyses consistent with the methodology described in Section 4.0. These changes are consistent with what is included in the BAW-10192P, Rev. 02, Reference [44]. Items related to the energy deposition factor and methods for addressing changes in actinide decay heat for low enrichment fuel are discussed in Sections 7.2.7.1 and 7.2.7.2, respectively. Items related to the CHF predictions for SBLOCA are discussed in Section 7.2.7.3. Discussions of changes incorporated to address PSCs to ensure that the results are in compliance with 10 CFR 50 Appendix K are presented in Section 7.2.7.4.

7.2.7.1 Energy Deposition Factor

The energy deposition factor (EDF) is defined as the energy absorbed (thermal source) in the fuel pellet and clad divided by the energy produced by the pellet (nuclear source).

$$EDF = P_{\text{thermal source}} / P_{\text{nuclear source}}$$

The BWNT LOCA EM specifies a steady-state and transient EDF of 0.973 for SBLOCA analyses. New methods and predictions for the EDFs appropriate for use in LOCA analyses at various times in life have recently been evaluated by AREVA [50]. These calculations do not totally support 0.973 for high burnup, low power fuel or fuel that may be surrounded by higher power fuel. As a result, the LOCA evaluations may use different EDFs. For the ONS SBLOCA analyses a LHR limit of 17.3 kW/ft with a transient EDF of 1.0 was modeled.

7.2.7.2 Actinide DH for Low Enrichment

Section 6.2.4.3 of the LBLOCA section describes how the actinide decay heat changes with enrichment and burnup. SBLOCA analyses performed with the BWNT LOCA EM typically consider batch fuel pin enrichments in the range of 3 to approximately 5 weight percent ($^w/_o$). The more conservative RELAP5 default actinide model (Reference [70]) utilized in the SBLOCA analyses (References [9] and [10]) has been shown to conservatively cover the entire licensed TIL (0 to 62 GWd/mtU) and enrichment (3 to 5 $^w/_o$) range for the hot pin, hot bundle, and average core actinide contributions.

7.2.7.3 CHF Predictions for SBLOCA

The BWNT LOCA EM (Reference [1, Volume II, p. 4-1]) states that a “break is considered to be a small break when the DNB does not occur within the first few seconds after break opening” and concludes that “breaks with cross-sectional areas less than 0.75 ft^2 should not show initial clad DNB.” Previous Mark-B11 fuel LOCA analyses for ONS (Reference [12]), which used the BWC CHF correlation, did not predict DNB for any break sizes of 0.75 ft^2 or less. The Mark-B-HTP fuel, which uses the BHTP CHF correlation implemented into RELAP5/MOD2-B&W, predicted DNB during the first second of the 102% full power Category 5 break sizes

larger than 0.5 ft^2. Therefore, any small break larger than 0.5 ft^2 will be considered a transition LBLOCAs. These break sizes are well bounded by the limiting LBLOCA.

7.2.7.4 Preliminary Safety Concerns

Since the approval of the EM described in BAW-10192P-A (Reference [1]), a number of preliminary safety concerns (PSCs) have been generated. The results of these PSCs have been incorporated into the SBLOCA analyses or dispositioned from the SBLOCA analyses. These include uncertainty adjusted core flood tank parameters (PSC 5-94) and the SBLOCA reactor coolant pump two-phase degradation modeling (PSC 2-00). This section summarizes the SBLOCA PSCs and indicates how they have been dispositioned with respect to the ONS SB LOCA analyses.

PSC 5-94 Uncertainties on CFT and PZR

The EM states that initial inventories and pressures are to be set by nominal operation design levels. The PZR has active methods to control to the nominal value, therefore maintaining a nominal level for analyses is appropriate. However, the CFT does not have an active method for controlling to nominal conditions. PSC 5-94 identified that the CFT initial conditions would affect the transient results as applied to the CRAFT2-based SBLOCA evaluation model. Therefore, the B&W plant large and small break LOCA analyses performed with the RELAP5-based evaluation model evaluate the combination of minimum and maximum CFT initial volumes and pressures for each plant type. A discussion of these studies for the ONS units is presented in Section 7.1.2.1.

PSC 2-00 – SBLOCA Two-Phase RCP Degradation (R5 versus M3)

The EM states that the “default” two phase RCP degradation multiplier should be used for SBLOCAs. It can be taken that the values provided in the RELAP5 topical are the “default” values that would be used. Sensitivity studies show that the results of a SBLOCA with RCPs tripped at loss of off-site power near the time of reactor trip are not affected by the choice in RCP degradation (Reference [57]). However, with RCPs powered until they are manually tripped, the choice of RCP degradation is important. The M3-modified curve was shown to provide limiting results for the SBLOCA with RCPs running (Reference [68]). A discussion of these studies for the Oconee units is presented in Section 7.1.2.2. The NRC was notified that the M3-modified curve would be utilized to reanalyze the limiting SBLOCAs with RCPs running in the resolution of PSC 2-00. Further, this model would be used in future SBLOCA analyses. The NRC has accepted the resolution of this PSC (Reference [33]). For the Oconee ROTSG SBLOCA full power analyses, the 0.3, 0.4, and 0.5-ft^2 CLPD and 0.44-ft^2 CFT line breaks were analyzed with the assumption of LOOP coincident with reactor trip and with off-site power available and the pumps tripped two minutes after LSCM (see Section 7.2.5). The 0.4 ft^2 CLPD line break was analyzed at partial power with the assumption of LOOP coincident with reactor trip and, and with the pumps tripped two minutes after LSCM (see Section 7.2.6).

Table 7-1: Summary of 102% Full Power SBLOCA Category 2 Break Results

PARAMETER	0.01 ft^2 CLPD Break with LOOP	0.02464 ft^2 HPI Break with LOOP
Peak Nuclear LHR (kW/ft)	17.3	17.3
Break Opens (sec)	0.0	0.0
Low RCS Pressure Reactor Rod Insertion Trip (sec) (Note 1)	96.24	40.06
RCP Trip (sec)	95.72	39.56
EFW Flow to SG-1 50% OR, LSCM (sec)	Not Modeled	Not Modeled
EFW Flow to SG-2 Begins to 50% OR (sec)	164.72	108.58
EFW Flow to SG-2 Begins to LSCM (sec)	1295.74	1239.58
ESFAS Low RCS Pressure (HPI) Actuation (sec	187.5	74.2
ESFAS Low-Low RCS Pressure (LPI) Actuation (sec)	> EOT	> EOT
HPI Flow Starts (sec)	235.5	122.22
LPI Flow Starts (sec)	> EOT	> EOT
Hot Legs Drained, Loop A/B (sec) (Note 2)	> EOT / > EOT	> EOT / > EOT
Core Heatup Starts AC/HC (sec) (Note 3)	No Heatup	No Heatup
CFT Injection Starts / Ends (sec)	> EOT / > EOT	> EOT / > EOT
HPI Core Power Match (sec)	3819.46	2103.72
Entire Core Quenched AC/HC (sec) (Note 4)	Core Remains Covered	Core Remains Covered
Transient Analysis Ends (sec)	4800.0	3200.0
Minimum Mixture Level (ft @ sec) (Note 5)	~ 19.4 @ 0-4800	~ 19.2 @ 470
AC PCT (F) [Segment Number]	675.94 [20]	676.09 [20]
PCT Time (sec)	0.0801	1.52
Heated Segments Uncovered (#) (Note 6)	None	None
Maximum Local Oxidation (%)	0.079937	0.079942
Average Oxidation (%)	0.079927	0.079932
HC PCT (F) [Segment Number / Channel Number]	711.92 [19 / 1]	711.92 [19 / 1]
PCT Time (sec)	0.0051	0.0051
Heated Segments Uncovered (#) (Note 6)	None	None
Rupture Time (sec) [Segment Number / Channel Number]	Not Ruptured	Not Ruptured
Maximum Local Oxidation (%) [Channel Number]	0.079948 [5]	0.079964 [5]
Average Oxidation (%) [Channel Number]	0.079937 [5]	0.07995 [5]
Initial Oxide Fraction AC/HC (%)	0.0799167 / 0.0799218	0.0799167 / 0.0799218
Whole Core H_2 Generation (%) (Note 7)	< 0.01	< 0.01

Notes for this table are provided following Table 7-4.

Table 7-2: Summary of 102% Full Power SBLOCA Category 3 Break Results

PARAMETER	0.04 ft^2 CLPD Break with LOOP
Peak Nuclear LHR (kW/ft)	17.3
Break Opens (sec)	0.0
Low RCS Pressure Reactor Rod Insertion Trip (sec) (Note 1)	24.4
RCP Trip (sec)	23.88
EFW Flow to SG-1 50% OR, LSCM (sec)	Not Modeled
EFW Flow to SG-2 Begins to 50% OR (sec)	92.9
EFW Flow to SG-2 Begins to LSCM (sec)	1223.9
ESFAS Low RCS Pressure (HPI) Actuation (sec)	46.88
ESFAS Low-Low RCS Pressure (LPI) Actuation (sec)	> EOT
HPI Flow Starts (sec)	94.9
LPI Flow Starts (sec)	> EOT
Hot Legs Drained, Loop A/B (sec) (Note 2)	> EOT / > EOT
Core Heatup Starts AC/HC (sec) (Note 3)	No Heatup
CFT Injection Starts / Ends (sec)	> EOT / > EOT
HPI Core Power Match (sec)	807.64
Entire Core Quenched AC/HC (sec) (Note 4)	Core Remains Covered
Transient Analysis Ends (sec)	1500.0
Minimum Mixture Level (ft @ sec) (Note 5)	~ 19.1 @ 250-320
AC PCT (F) [Segment Number]	676.37 [20]
PCT Time (sec)	1.66
Heated Segments Uncovered (#) (Note 6)	None
Maximum Local Oxidation (%)	0.079942
Average Oxidation (%)	0.079931
HC PCT (F) [Segment Number / Channel Number]	711.92 [19 / 1]
PCT Time (sec)	0.0051
Heated Segments Uncovered (#) (Note 6)	None
Rupture Time (sec) [Segment Number / Channel Number]	Not Ruptured
Maximum Local Oxidation (%) [Channel Number]	0.079967 [5]
Average Oxidation (%) [Channel Number]	0.079952 [5]
Initial Oxide Fraction AC/HC (%)	0.0799167 / 0.0799218
Whole Core H_2 Generation (%) (Note 7)	< 0.01

Notes for this table are provided following Table 7-4.

Table 7-3: Summary of 102% Full Power SBLOCA Category 4 Break Results

PARAMETER	0.07 ft^2 CLPD Break with LOOP	0.1 ft^2 CLPD Break with LOOP	0.125 ft^2 CLPD Break with LOOP
Peak Nuclear LHR (kW/ft)	17.3	17.3	17.3
Break Opens (sec)	0.0	0.0	0.0
Low RCS Pressure Reactor Rod Insertion Trip (sec) (Note 1)	13.08	8.2	6.04
RCP Trip (sec)	12.56	7.68	5.52
EFW Flow to SG-1 50% OR, LSCM (sec)	Not Modeled	Not Modeled	Not Modeled
EFW Flow to SG-2 Begins to 50% OR (sec)	81.56	76.68	74.52
EFW Flow to SG-2 Begins to LSCM (sec)	1212.58	1207.7	1205.54
ESFAS Low RCS Pressure (HPI) Actuation (sec)	27.18	19.52	16.38
ESFAS Low-Low RCS Pressure (LPI) Actuation (sec)	> EOT	1427.68	1041.9
HPI Flow Starts (sec)	75.18	67.52	64.38
LPI Flow Starts (sec)	> EOT	> EOT	> EOT
Hot Legs Drained, Loop A/B (sec) (Note 2)	641.24 / 954.26	380.04 / 541.84	302.3 / 424.67
Core Heatup Starts AC/HC (sec) (Note 3)	No Heatup	~640 / ~680	~500 / ~520
CFT Injection Starts / Ends (sec)	1472.04 / > EOT	907.22 / > EOT	678.265 / > EOT
HPI Core Power Match (sec)	627.2	619.54	616.39
Entire Core Quenched AC/HC (sec) (Note 4)	Core Remains Covered	~1150 / ~1025	~1000 / ~950
Transient Analysis Ends (sec)	1646.9	1747.4	1560.7
Minimum Mixture Level (ft @ sec) (Note 5)	~ 17.5 @ 1000-1646.9	~ 9.8 @ 780-890	~ 7.6 @ 640
AC PCT (F) [Segment Number]	676.85 [20]	1020.7 [20]	1168.5 [20]
PCT Time (sec)	1.8	911.38	758.19
Heated Segments Uncovered (#) (Note 6)	None	3	6
Maximum Local Oxidation (%)	0.079930	0.081014	0.10844
Average Oxidation (%)	0.079919	0.079975	0.082469
HC PCT (F) [Segment Number / Channel Number]	711.92 [19 / 1]	1288.2 [20 / 5]	1515.4 [20 / 5]
PCT Time (sec)	0.0051	959.76	738.96
Heated Segments Uncovered (#) (Note 6)	None	2	6
Rupture Time (sec) [Segment Number / Channel Number]	Not Ruptured	Not Ruptured	703.015 [20 / 1]
Maximum Local Oxidation (%) [Channel Number]	0.079962 [5]	0.15585 [5]	0.48326 [1]
Average Oxidation (%) [Channel Number]	0.079947 [5]	0.085355 [5]	0.12548 [1]
Initial Oxide Fraction AC/HC (%)	0.0799167 / 0.0799218	0.0799167 / 0.0799218	0.0799167 / 0.0799218
Whole Core H_2 Generation (%) (Note 7)	< 0.01	< 0.01	< 0.02

Notes for this table are provided following Table 7-4.

Table7-3 (cont'd): Summary of 102% Full Power SBLOCA Category 4 Break Results

PARAMETER	0.15 ft^2 CLPD Break with LOOP	0.175 ft^2 CLPD Break with LOOP	0.2 ft^2 CLPD Break with LOOP
Peak Nuclear LHR (kW/ft)	17.3	17.3	17.3
Break Opens (sec)	0.0	0.0	0.0
Low RCS Pressure Reactor Rod Insertion Trip (sec) (Note 1)	4.6	3.48	2.68
RCP Trip (sec)	4.08	2.98	2.18
EFW Flow to SG-1 50% OR, LSCM (sec)	Not Modeled	Not Modeled	Not Modeled
EFW Flow to SG-2 Begins to 50% OR (sec)	73.08	71.98	71.18
EFW Flow to SG-2 Begins to LSCM (sec)	1204.1	> EOT	> EOT
ESFAS Low RCS Pressure (HPI) Actuation (sec)	14.22	12.54	11.4
ESFAS Low-Low RCS Pressure (LPI) Actuation (sec)	807.84	651.38	547.69
HPI Flow Starts (sec)	62.22	60.54	59.4
LPI Flow Starts (sec)	> EOT	> EOT	> EOT
Hot Legs Drained, Loop A/B (sec) (Note 2)	252.14 / 333.16	208.22 / 268.8	184.5 / 222.8
Core Heatup Starts AC/HC (sec) (Note 3)	~400 / ~410	~350 / ~360	~300 / ~300
CFT Injection Starts / Ends (sec)	552.0 / > EOT	458.245 / > EOT	392.8 / > EOT
HPI Core Power Match (sec)	614.24	612.55	611.42
Entire Core Quenched AC/HC (sec) (Note 4)	~875 / ~810	~760 / ~710	~675 / ~650
Transient Analysis Ends (sec)	1303.7	1028.1	935.44
Minimum Mixture Level (ft @ sec) (Note 5)	~ 7.0 @ 530	~ 7.1 @ 460	~ 7.5 @ 400
AC PCT (F) [Segment Number]	1203.3 [20]	1176.8 [20]	1118.4 [20]
PCT Time (sec)	651.6	593.53	525.22
Heated Segments Uncovered (#) (Note 6)	7	7	7
Maximum Local Oxidation (%)	0.11583	0.10856	0.092901
Average Oxidation (%)	0.083313	0.082541	0.080974
HC PCT (F) [Segment Number / Channel Number]	1597.5 [20 / 5]	1565.9 [20 / 5]	1474.1 [20 / 5]
PCT Time (sec)	641.57	557.67	498.86
Heated Segments Uncovered (#) (Note 6)	6	6	6
Rupture Time (sec) [Segment Number / Channel Number]	586.12 [20 / 1] 603.87 [20 / 3]	512.195 [20 / 1] 533.45 [20 / 3]	482.11 [20 / 1]
Maximum Local Oxidation (%) [Channel Number]	0.8842 [1]	0.696 [1]	0.33653 [3]
Average Oxidation (%) [Channel Number]	0.16895 [1]	0.15323 [1]	0.10599 [3]
Initial Oxide Fraction AC/HC (%)	0.0799167 / 0.0799218	0.0799167 / 0.0799218	0.0799167 / 0.0799218
Whole Core H_2 Generation (%) (Note 7)	< 0.04	< 0.03	< 0.02

Notes for this table are provided following Table 7-4.

Table 7-4: Summary of 102% Full Power SBLOCA Category 5 Break Results

PARAMETER	0.3 ft^2 CLPD Break with LOOP	0.4 ft^2 CLPD Break with LOOP	0.5 ft^2 CLPD Break with LOOP
Peak Nuclear LHR (kW/ft)	17.3	17.3	17.3
Break Opens (sec)	0.0	0.0	0.0
Low RCS Pressure Reactor Rod Insertion Trip (sec) (Note 1)	1.12	0.88	0.7621
RCP Trip (sec)	0.62	0.3601	0.2621
EFW Flow to SG-1 50% OR, LSCM (sec)	Not Modeled	Not Modeled	Not Modeled
EFW Flow to SG-2 Begins to 50% OR (sec)	69.62	69.38	69.28
EFW Flow to SG-2 Begins to LSCM (sec)	> EOT	> EOT	> EOT
ESFAS Low RCS Pressure (HPI) Actuation (sec)	8.92	7.76	6.94
ESFAS Low-Low RCS Pressure (LPI) Actuation (sec)	333.38	232.2	172.10
HPI Flow Starts (sec)	56.92	55.76	54.94
LPI Flow Starts (sec)	540.06	347.52	250.41
Hot Legs Drained, Loop A/B (sec) (Note 2)	296.32 / 143.02	210.7/110.26	> EOT / 93.74
Core Heatup Starts AC/HC (sec) (Note 3)	~190 / ~200	~130 / ~130	~100 / ~100
CFT Injection Starts / Ends (sec)	248.24 / > EOT	177.06 / > EOT	133.94 / > EOT
HPI & LPI Core Power Match (sec)	544.54	350.48	255.27
Entire Core Quenched AC/HC (sec) (Note 4)	~380 / ~390	~250 / ~260	~190 / ~210
Transient Analysis Ends (sec)	588.94	381.32	297.19
Minimum Mixture Level (ft @ sec) (Note 5)	~ 8.2 @ 250	8.4 @ ~180	8.1 @ ~140-150
AC PCT (F) [Segment Number]	953.98 [20]	879.26[20]	841.41 [20]
PCT Time (sec)	314.56	214.68	164.02
Heated Segments Uncovered (#) (Note 6)	6	6	7
Maximum Local Oxidation (%)	0.080107	0.079891	0.079886
Average Oxidation (%)	0.079894	0.079880	0.079876
HC PCT (F) [Segment Number / Channel Number]	1310.3 [20 / 5]	1126.3 [20/4,5]	1103.5 [20/3,4,5]
PCT Time (sec)	330.2	214.36	162.93
Heated Segments Uncovered (#) (Note 6)	5	5	5
Rupture Time (sec) [Segment Number / Channel Number]	Not Ruptured	Not Ruptured	Not Ruptured
Maximum Local Oxidation (%) [Channel Number]	0.13390 [5]	0.082416 [3]	0.082209 [1]
Average Oxidation (%) [Channel Number]	0.084664 [5]	0.080095[5]	0.080061 [5]
Initial Oxide Fraction AC/HC (%)	0.0799167 / 0.0799218	0.799167/ 0.0799218	0.799167/ 0.0799218
Whole Core H_2 Generation (%) (Note 7)	< 0.01	< 0.01	< 0.01

Notes for this table are provided following Table 7-4.

Table7-4 (cont'd): Summary of 102% Full Power SBLOCA Category 5 Break Results

PARAMETER	0.3 ft[2] CLPD Break with 2 Minute RCP Trip	0.4 ft[2] CLPD Break with 2 Minute RCP Trip	0.5 ft[2] CLPD Break with 2 Minute RCP Trip
Peak Nuclear LHR (kW/ft)	17.3	17.3	17.3
Break Opens (sec)	0.0	0.0	0.0
Low RCS Pressure Reactor Rod Insertion Trip (sec) (Note 1)	1.12	0.88	0.7621
RCP Trip (sec)	129.38	128.2	126.86
EFW Flow to SG-1 50% OR, LSCM (sec)	Not Modeled	Not Modeled	Not Modeled
EFW Flow to SG-2 Begins to 50% OR (sec)	69.64	69.38	69.28
EFW Flow to SG-2 Begins to LSCM (sec)	> EOT	> EOT	> EOT
ESFAS Low RCS Pressure (HPI) Actuation (sec)	6.32	5.48	4.94
ESFAS Low-Low RCS Pressure (LPI) Actuation (sec)	270	197.46	165.18
HPI Flow Starts (sec)	54.34	53.48	52.94
LPI Flow Starts (sec)	363.66	271.48	239.20
Hot Legs Drained, Loop A/B (sec) (Note 2)	> EOT/ > EOT	> EOT / 227.6	202.07 / 170.97
Core Heatup Starts AC/HC (sec) (Note 3)	No Heatup	~140 / ~160	~150 / ~130
CFT Injection Starts / Ends (sec)	229.34 / > EOT	181.08 / > EOT	153.69 / > EOT
HPI & LPI Core Power Match (sec)	366.84	271.48	239.20
Entire Core Quenched AC/HC (sec) (Note 4)	Core Remains Covered	~290 / ~290	~275 / ~275
Transient Analysis Ends (sec)	451.93	365.74	340.48
Minimum Mixture Level (ft @ sec) (Note 5)	12.5 @ ~230	< 6.9 @ 190-230	< 6.9 @ 150-210
AC PCT (F) [Segment Number]	677.64 [20]	871.87 [20]	868.86 [20]
PCT Time (sec)	0.1601	235.54	209.5
Heated Segments Uncovered (#) (Note 6)	None	> 16	> 16
Maximum Local Oxidation (%)	0.079885	0.079878	0.080093
Average Oxidation (%)	0.079874	0.079867	0.079877
HC PCT (F) [Segment Number / Channel Number]	711.92 [19/1]	1175.9 [20 / 4, 5]	1255.5 [20 / 5]
PCT Time (sec)	0.0051	233.12	210.03
Heated Segments Uncovered (#) (Note 6)	None	> 16	> 16
Rupture Time (sec) [Segment Number / Channel Number]	Not Ruptured	Not Ruptured	Not Ruptured
Maximum Local Oxidation (%) [Channel Number]	0.079931[5]	0.086297 [3]	0.097947 [4]
Average Oxidation (%) [Channel Number]	0.079916 [5]	0.080667 [3]	0.082024 [4]
Initial Oxide Fraction AC/HC (%)	0.0799167/ 0.0799218	0.0799167 / 0.0799218	0.0799167 / 0.0799218
Whole Core H_2 Generation (%) (Note 7)	< 0.01	< 0.01	< 0.01

Notes for this table are provided following Table 7-4.

Table7-4 (cont'd): Summary of 102% Full Power SBLOCA Category 5 Break Results

PARAMETER	0.44 ft^2 CFT Line Break with LOOP	0.44 ft^2 CFT Line Break with 2 Minute RCP Trip
Peak Nuclear LHR (kW/ft)	17.3	17.3
Break Opens (sec)	0.0	0.0
Low RCS Pressure Reactor Rod Insertion Trip (sec) (Note 1)	0.84	0.84
RCP Trip (sec)	0.3201	127.72
EFW Flow to SG-1 50% OR, LSCM (sec)	Not Modeled	Not Modeled
EFW Flow to SG-2 Begins to 50% OR (sec)	69.34	69.34
EFW Flow to SG-2 Begins to LSCM (sec)	> EOT	> EOT
ESFAS Low RCS Pressure (HPI) Actuation (sec)	7.52	5.26
ESFAS Low-Low RCS Pressure (LPI) Actuation (sec)	215.5	183.32
HPI Flow Starts (sec)	55.52	53.28
LPI Flow Starts (sec)	361.16	271.6
Hot Legs Drained, Loop A/B (sec) (Note 2)	> EOT / 99.22	212.44 / 185.52
Core Heatup Starts AC/HC (sec) (Note 3)	No Heatup	~150 / ~160
CFT Injection Starts / Ends (sec)	161.12 / > EOT	170.8 / 318.88
HPI & LPI Core Power Match (sec) [	368.84	275.62
Entire Core Quenched AC/HC (sec) (Note 4)	Core Remains Covered	~250 / ~250
Transient Analysis Ends (sec)	411.06	911.22
Minimum Mixture Level (ft @ sec) (Note 5)	13 @ ~175	< 6.9 @ 160-210
AC PCT (F) [Segment Number]	678.14 [20]	813.21 [20]
PCT Time (sec)	0.1001	241.42
Heated Segments Uncovered (#) (Note 6)	None	> 16
Maximum Local Oxidation (%)	0.079884	0.079869
Average Oxidation (%)	0.079873	0.079858
HC PCT (F) [Segment Number / Channel Number]	711.92 [19 / 1]	1072.8 [20 / 4, 5]
PCT Time (sec)	0.0051	215.86
Heated Segments Uncovered (#) (Note 6)	None	> 16
Rupture Time (sec) [Segment Number / Channel Number]	Not Ruptured	Not Ruptured
Maximum Local Oxidation (%) [Channel Number]	0.079930 [5]	0.080679 [3]
Average Oxidation (%) [Channel Number]	0.079915 [5]	0.079952 [5]
Initial Oxide Fraction AC/HC (%)	0.0799167 / 0.0799218	0.0799167 / 0.0799218
Whole Core H_2 Generation (%) (Note 7)	< 0.01	< 0.01

Notes for this table are provided the following page.

Notes for Tables 7-1 through Table 7-4:

1. Time that control rod insertion begins (i.e. trip time + delay time).
2. The hot legs are drained when they reach an indicated elevation of approximately 22.25 ft above the upper face of the SG lower tube sheet.
3. Core heatup is characterized as the time when cladding temperature begins to rise above the saturation temperature.
4. Core quench is characterized as the time when the temperatures of all superheated cladding nodes reach the saturation temperature of the surrounding liquid.
5. The minimum mixture level is referenced from the bottom of the heated fuel.
6. Number of heated segments uncovered is characterized as the number of superheated fuel nodes in the indicated channels.
7. The whole-core hydrogen generation was calculated using the oxidation increase in the hot assembly and average channel using the methods discussed in Reference [9, Page 155].
8. The abbreviation ">EOT" means that the parameter occurs at a time greater than the End of the Transient.

Table 7-5: Summary of 52% Full Power SBLOCA Category 2 Break Results

Parameter	**0.01 ft^2**	**0.02464 ft^2**
Break Location	CLPD	HPI Line
Peak Nuclear LHR (kW/ft)	17.3	17.3
Break Opens (sec)	0.0	0.0
Low RCS Pressure Reactor Rod Insertion Trip (sec) (Note 1)	102.74	43.06
RCP Trip (sec)	102.22	42.56
EFW Flow to SG-1 50% OR	116.24	56.56
EFW Flow to SG-2 Begins to 50% OR (sec)	116.24	56.56
EFW Flow to SG-2 Begins to LSCM (sec)	1302.24	1242.58
ADV-2 Begins to Open (sec)	1673.10	1577.30
ESFAS Low RCS Pressure (HPI) Actuation (sec)	173.08	77.28
ESFAS Low-Low RCS Pressure (LPI) Actuation (sec)	> EOT	2785.40
HPI Flow Starts (sec)	221.08	125.30
LPI Flow Starts (sec)	> EOT	> EOT
Hot Legs Drained, Loop A/B (sec) (Note 2)	> EOT / > EOT	1407.38 / 1489.54
Core Heatup Starts / Entire Core Quenched (sec) (Note 3)	No Core Uncovering	No Core Uncovering
CFT Injection Starts / Ends (sec)	> EOT / > EOT	2046.54 / > EOT
HPI + LPI Core Power Match (sec)	3378.16	> EOT
Transient Analysis Ends (sec)	3378.2	5000.0
Minimum Mixture Level (ft @ sec) (Note 5)	~ 17.9 @ ~ 600	~ 13.8 @ ~ 2050
AC PCT (F) [Segment Number]	620.9 [20]	620.93 [20]
PCT time (sec)	0.0801	0.1001
Heated Segments (#) (Note 4)	0	0
Maximum Local Oxidation (%)	0.079947	0.079922
Average Oxidation (%)	0.079941	0.079917
HC PCT (F) [Segment/Channel Number]	711.92 [19 / 1]	711.92 [19 / 1]
PCT time (sec)	0.0401	0.0201
Heated Segments (#) (Note 4)	0	0
Rupture Time (sec)	Not Ruptured	Not Ruptured
Maximum Local Oxidation (%)[Channel Number]	0.079967 [5]	0.079952 [5]
Average Oxidation (%)[Channel Number]	0.07995 [5]	0.079937 [5]
Initial Oxide Fraction AC/HC (%)	0.0799167 / 0.0799218	0.0799167 / 0.0799218
Whole Core H_2 Generation (%) (Note 5)	< 0.01	< 0.01

Notes for this table are provided below Table 7-8.

Table 7-6: Summary of 52% Full Power SBLOCA Category 3 Break Results

Parameter	**0.04 ft^2**	**0.06 ft^2**
Break Location	CLPD	CLPD
Peak Nuclear LHR (kW/ft)	17.3	17.3
Break Opens (sec)	0.0	0.0
Low RCS Pressure Reactor Rod Insertion Trip (sec) (Note 1)	26.28	16.90
RCP Trip (sec)	25.76	16.38
EFW Flow to SG-1 50% OR	39.76	30.38
EFW Flow to SG-2 Begins to 50% OR (sec)	39.76	30.38
EFW Flow to SG-2 Begins to LSCM (sec)	1225.78	1216.39
ADV-2 Begins to Open (sec)	1549.34	1533.49
ESFAS Low RCS Pressure (HPI) Actuation (sec)	49.32	33.48
ESFAS Low-Low RCS Pressure (LPI) Actuation (sec)	1850.46	1674.85
HPI Flow Starts (sec)	97.34	81.48
LPI Flow Starts (sec)	> EOT	> EOT
Hot Legs Drained, Loop A/B (sec) (Note 2)	960.06 / 1014.36	636.72 / 705.16
Core Heatup Starts / Entire Core Quenched (sec) (Note 3)	~1500 / ~1650	~1150 / ~1600
CFT Injection Starts / Ends (sec)	1696.76 / > EOT	1383.40 / > EOT
HPI + LPI Core Power Match (sec)	2732.92	2741.94
Transient Analysis Ends (sec)	2732.9	2742.0
Minimum Mixture Level (ft @ sec) (Note 5)	~ 10.1 @ ~ 1560	~ 8.8 @ ~ 1370
AC PCT (F) [Segment Number]	621 [20]	814.59 [20]
PCT time (sec)	1.7	1566.4
Heated Segments (#) (Note 4)	1	4
Maximum Local Oxidation (%)	0.079914	0.079907
Average Oxidation (%)	0.079908	0.079901
HC PCT (F) [Segment/Channel Number]	711.92 [19 / 1]	1401.5 [20 / 5]
PCT time (sec)	0.0201	1562.8
Heated Segments (#) (Note 4)	0	2
Rupture Time (sec)	Not Ruptured	Not Ruptured
Maximum Local Oxidation (%)[Channel Number]	0.079949 [5]	0.22916 [5]
Average Oxidation (%)[Channel Number]	0.079932 [5]	0.090634 [5]
Initial Oxide Fraction AC/HC (%)	0.0799167 / 0.0799218	0.0799167 / 0.0799218
Whole Core H_2 Generation (%) (Note 5)	< 0.01	< 0.01

Notes for this table are provided below Table 7-8.

Table 7-7: Summary of 52% Full Power SBLOCA Category 4 Break Results

Parameter	0.07 ft^2	0.072 ft^2	0.08 ft^2
Break Location	CLPD	CLPD	CLPD
Peak Nuclear LHR (kW/ft)	17.3	17.3	17.3
Break Opens (sec)	0.0	0.0	0.0
Low RCS Pressure Reactor Rod Insertion Trip (sec) (Note 1)	14.14	13.66	11.96
RCP Trip (sec)	13.62	13.14	11.44
EFW Flow to SG-1 50% OR	27.62	27.14	25.44
EFW Flow to SG-2 Begins to 50% OR (sec)	27.62	27.14	25.44
EFW Flow to SG-2 Begins to LSCM (sec)	1213.63	1213.14	1211.45
ADV-2 Begins to Open (sec)	1528.69	1527.89	1525.04
ESFAS Low RCS Pressure (HPI) Actuation (sec)	28.68	27.88	25.02
ESFAS Low-Low RCS Pressure (LPI) Actuation (sec)	1618.30	1601.67	1428.82
HPI Flow Starts (sec)	76.68	75.88	73.02
LPI Flow Starts (sec)	> EOT	> EOT	2376.98
Hot Legs Drained, Loop A/B (sec) (Note 2)	560.58 / 594.24	547.34 / 613.28	513.98 / 554.44
Core Heatup Starts / Entire Core Quenched (sec) (Note 3)	~900 / ~1600	~900 / ~1600	~800 / ~1500
CFT Injection Starts / Ends (sec)	1128.46 / > EOT	1087.38 / > EOT	953.10 / > EOT
HPI + LPI Core Power Match (sec)	2744.16	2752.38	2378.60
Transient Analysis Ends (sec)	2744.2	2752.4	2378.6
Minimum Mixture Level (ft @ sec) (Note 5)	~ 8.7 @ ~ 1120	~ 8.7 @ ~ 1080	~ 8.8 @ ~ 950
AC PCT (F) [Segment Number]	847.27 [20]	842.89 [20]	806.22 [20]
PCT time (sec)	1373.4	1363	1142.7
Heated Segments (#) (Note 4)	4	4	4
Maximum Local Oxidation (%)	0.079905	0.079902	0.079901
Average Oxidation (%)	0.079899	0.079897	0.079896
HC PCT (F) [Segment/Channel Number]	1446.5 [20 / 5]	1480.2 [20 / 5]	1359.1 [20 / 5]
PCT time (sec)	1370.2	1353.6	1113.2
Heated Segments (#) (Note 4)	3	3	2
Rupture Time (sec)	1350.6 [20 / 1]	1306.3 [20 / 1]	Not Ruptured
Maximum Local Oxidation (%)[Channel Number]	0.37222 [5]	0.44094 [5]	0.26054 [4]
Average Oxidation (%)[Channel Number]	0.10094 [5]	0.10534 [5]	0.09262 [5]
Initial Oxide Fraction AC/HC (%)	0.0799167 / 0.0799218	0.0799167 / 0.0799218	0.0799167 / 0.0799218
Whole Core H_2 Generation (%) (Note 5)	< 0.01	< 0.01	< 0.01

Notes for this table are provided below Table 7-8.

Table 7-7 (cont'd): Summary of 52% Full Power SBLOCA Category 4 Break Results

Parameter	**0.10 ft^2**	**0.13 ft^2**	**0.20 ft^2**
Break Location	CLPD	CLPD	CLPD
Peak Nuclear LHR (kW/ft)	17.3	17.3	17.3
Break Opens (sec)	0.0	0.0	0.0
Low RCS Pressure Reactor Rod Insertion Trip (sec) (Note 1)	8.86	6.10	2.70
RCP Trip (sec)	8.34	5.58	2.20
EFW Flow to SG-1 50% OR	22.34	19.60	16.22
EFW Flow to SG-2 Begins to 50% OR (sec)	22.34	19.60	16.22
EFW Flow to SG-2 Begins to LSCM (sec)	1208.36	> EOT	> EOT
ADV-2 Begins to Open (sec)	1519.60	> EOT	> EOT
ESFAS Low RCS Pressure (HPI) Actuation (sec)	19.58	14.48	9.30
ESFAS Low-Low RCS Pressure (LPI) Actuation (sec)	1051.45	759.24	469.02
HPI Flow Starts (sec)	67.58	62.48	57.30
LPI Flow Starts (sec)	1830.04	1202.70	731.58
Hot Legs Drained, Loop A/B (sec) (Note 2)	405.38 / 423.14	323.82 / 323.78	204.16 / 207.16
Core Heatup Starts / Entire Core Quenched (sec) (Note 3)	~600 / ~1100	~450 / ~750	~300 / ~410
CFT Injection Starts / Ends (sec)	722.55 / > EOT	544.89 / > EOT	351.03 / > EOT
HPI + LPI Core Power Match (sec)	1830.92	1204.70	734.42
Transient Analysis Ends (sec)	1830.9	1204.7	735.04
Minimum Mixture Level (ft @ sec) (Note 5)	~ 8.8 @ ~ 720	~ 8.9 @ ~ 540	~ 9.1 @ ~ 360
AC PCT (F) [Segment Number]	767.44 [20]	716.85 [20]	644.14 [20]
PCT time (sec)	892.63	651.17	394.79
Heated Segments (#) (Note 4)	4	4	4
Maximum Local Oxidation (%)	0.079902	0.079902	0.079902
Average Oxidation (%)	0.079896	0.079896	0.079896
HC PCT (F) [Segment/Channel Number]	1288.9 [20 / 5]	1126.4 [20 / 3, 4, 5]	756.89 [21 / 1]
PCT time (sec)	891.51	635.69	387.28
Heated Segments (#) (Note 4)	2	2	2
Rupture Time (sec)	Not Ruptured	Not Ruptured	Not Ruptured
Maximum Local Oxidation (%)[Channel Number]	0.16704 [4]	0.083802 [1]	0.079941 [5]
Average Oxidation (%)[Channel Number]	0.085824 [4]	0.080172 [5]	0.079924 [5]
Initial Oxide Fraction AC/HC (%)	0.0799167 / 0.0799218	0.0799167 / 0.0799218	0.0799167 / 0.0799218
Whole Core H_2 Generation (%) (Note 5)	< 0.01	< 0.01	< 0.01

Notes for this table are provided below Table 7-8.

Table 7-8: Summary of 52% Full Power SBLOCA Category 5 Break Results

Parameter	**0.40 ft^2**	**0.40 ft^2 w/ 2-min RCP trip**
Break Location	CLPD	CLPD
Peak Nuclear LHR (kW/ft)	17.3	17.3
Break Opens (sec)	0.0	0.0
Low RCS Pressure Reactor Rod Insertion Trip (sec) (Note 1)	0.92	0.92
RCP Trip (sec)	0.40	129.66
EFW Flow to SG-1 50% OR	14.42	143.67
EFW Flow to SG-2 Begins to 50% OR (sec)	14.42	143.67
EFW Flow to SG-2 Begins to LSCM (sec)	> EOT	> EOT
ADV-2 Begins to Open (sec)	> EOT	> EOT
ESFAS Low RCS Pressure (HPI) Actuation (sec)	3.82	3.14
ESFAS Low-Low RCS Pressure (LPI) Actuation (sec)	222.95	195.91
HPI Flow Starts (sec)	51.83	51.15
LPI Flow Starts (sec)	306.94	269.93
Hot Legs Drained, Loop A/B (sec) (Note 2)	> EOT / 110.53	> EOT / > EOT
Core Heatup Starts / Entire Core Quenched (sec) (Note 3)	~150 / ~210	~170 / ~230
CFT Injection Starts / Ends (sec)	167.71 / > EOT	177.78 / > EOT
HPI + LPI Core Power Match (sec)	309.68	269.93
Transient Analysis Ends (sec)	343.78	339.70
Minimum Mixture Level (ft @ sec) (Note 5)	~ 9.7 @ ~ 180	< 6.9 @ ~ 190
AC PCT (F) [Segment Number]	621.85 [20]	621.85 [20]
PCT time (sec)	0.1801	0.1801
Heated Segments (#) (Note 4)	4	> 16
Maximum Local Oxidation (%)	0.079894	0.079872
Average Oxidation (%)	0.079888	0.079866
HC PCT (F) [Segment/Channel Number]	711.92 [19 / 1]	1010.0 [20 / 3, 4, 5]
PCT time (sec)	0.0051	219.98
Heated Segments (#) (Note 4)	1	14
Rupture Time (sec)	Not Ruptured	Not Ruptured
Maximum Local Oxidation (%)[Channel Number]	0.079935 [5]	0.080117 [1]
Average Oxidation (%)[Channel Number]	0.079919 [5]	0.079903 [5]
Initial Oxide Fraction AC/HC (%)	0.0799167 / 0.0799218	0.0799167 / 0.0799218
Whole Core H_2 Generation (%) (Note 5)	< 0.01	< 0.01

Notes for this table are provided on the following page.

Notes for Table 7-5 through Table 7-8:

1. This is the time rod insertion begins (i.e. trip time + delay time).
2. Core heatup is characterized as the time when cladding temperature begins to rise above the saturation temperature
3. The minimum mixture level is referenced from the bottom of the heated.
4. The number of heated segments is taken from the number of superheated clad nodes in the indicated channel.
5. The whole-core hydrogen generation for Mk-B-HTP analysis is calculated using the simplified equation from Table 7 of Reference [20].

   $$H_2\% = 0.63 \times \left(AC\%_{oxide}^{average} - AC\%_{oxide}^{initial}\right) + 0.37 \times \left(HC\%_{oxide}^{average} - HC\%_{oxide}^{initial}\right).$$

   The initial oxidation fraction is taken from the zero edit of the run and multiplied by 100 to provide an initial oxidation percentage for both the hot and average channels.

6. EOT denotes End of Transient, and NA denotes Not Applicable/Available/Actuated.

Figure 7-1: Mark-B-HTP SBLOCA at 102% of 2568 MWt: 0.15 ft^2 CLPD, 17.3 kW/ft – Pressure

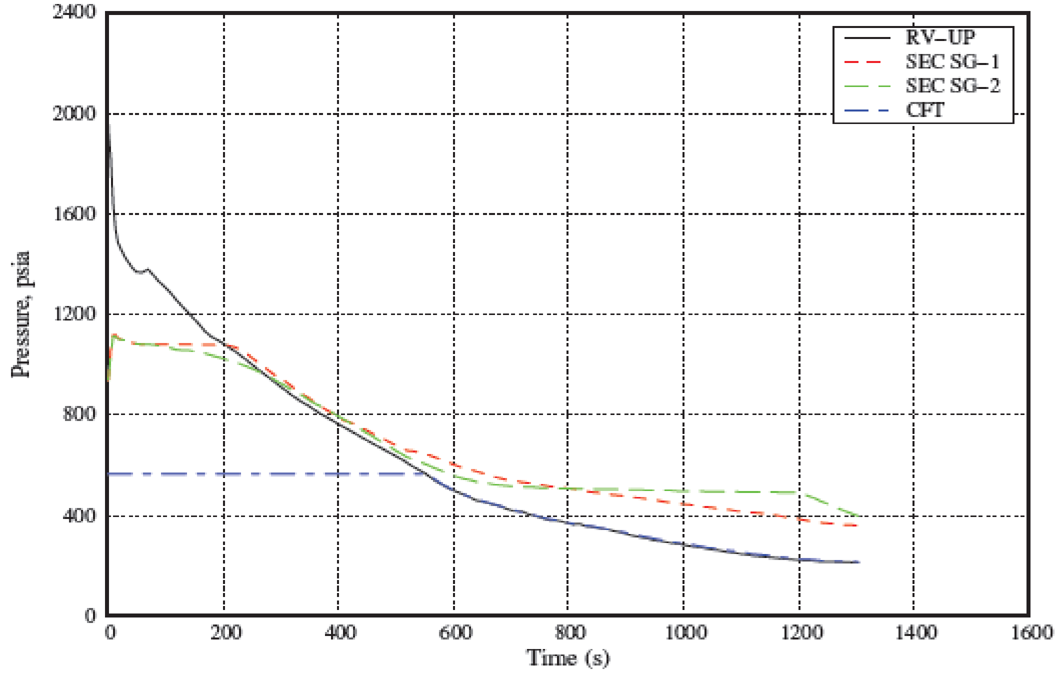


Figure 7-2: Mark-B-HTP SBLOCA at 102% of 2568 MWt: 0.15 ft^2 CLPD, 17.3 kW/ft - Break and ECCS Mass Flow Rates

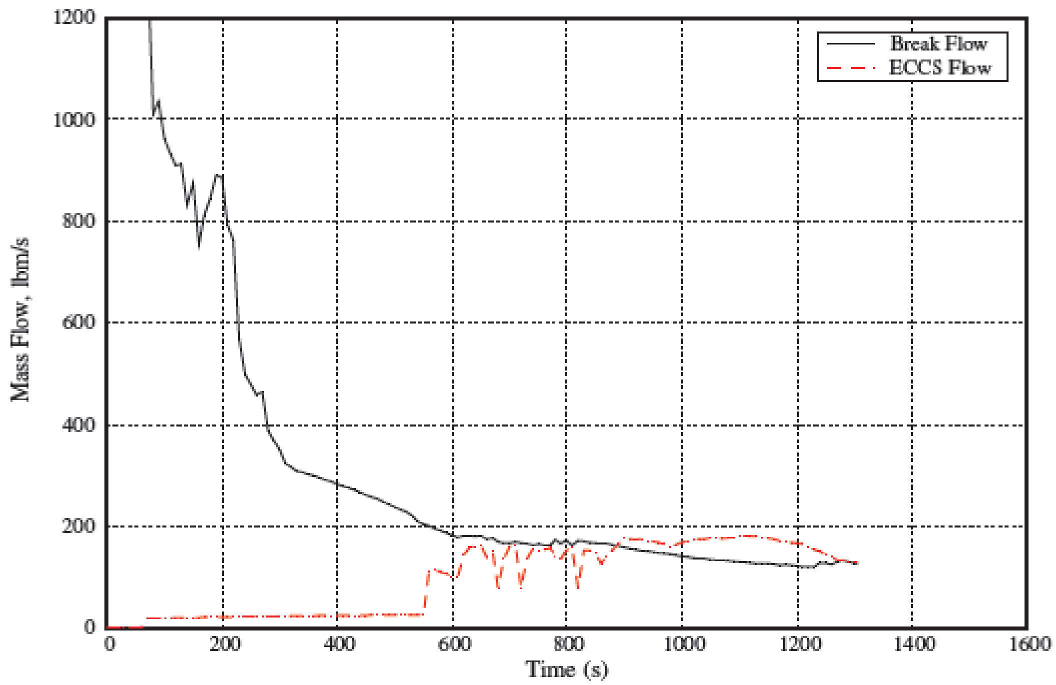


Figure 7-3: Mark-B-HTP SBLOCA at 102% of 2568 MWt: 0.15 ft^2 CLPD, 17.3 kW/ft - RV Collapsed Liquid Level & Hot Channel Mixture Level

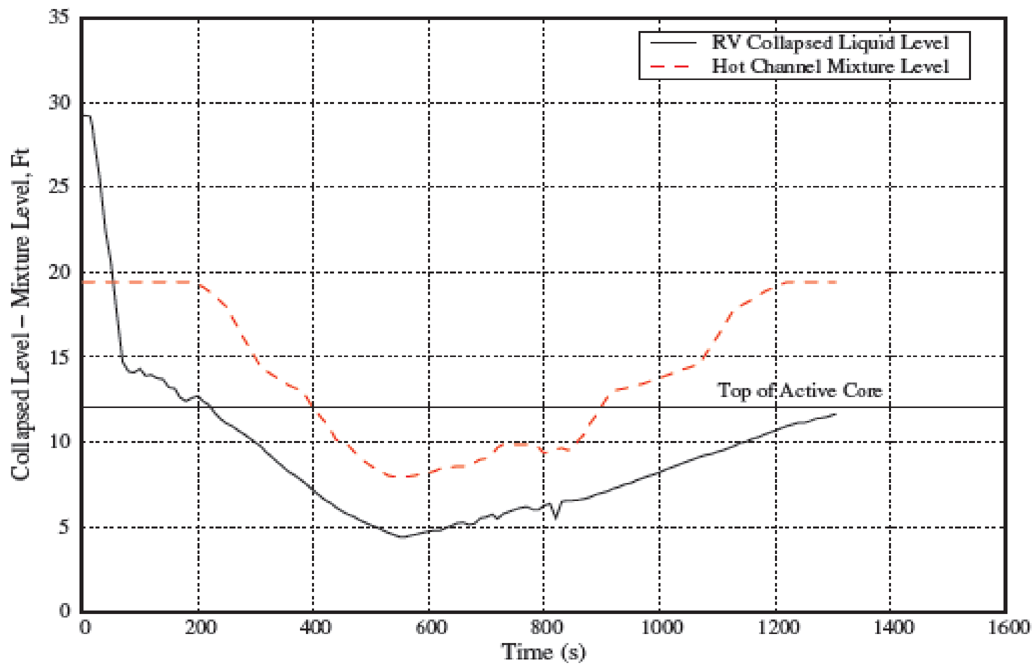


Figure 7-4: Mark-B-HTP SBLOCA at 102% of 2568 MWt: 0.15 ft^2 CLPD, 17.3 kW/ft - Hot Pin Peak Clad Tempature

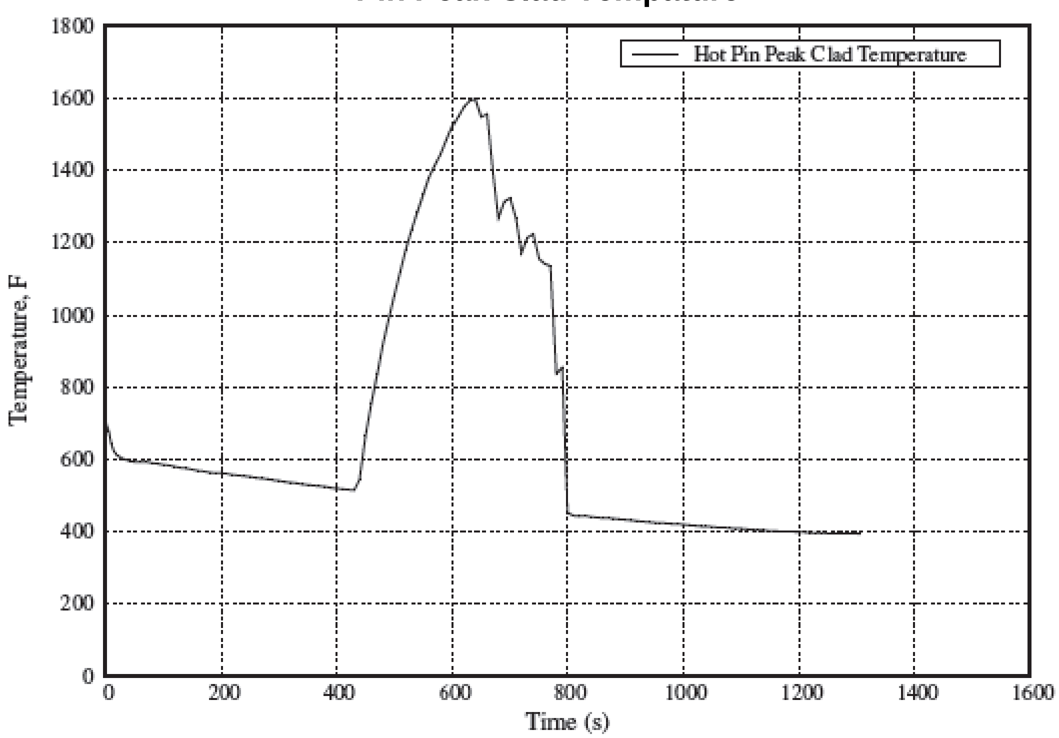


Figure 7-5: Mark-B-HTP SBLOCA at 102% of 2568 MWt: 0.15 ft^2 CLPD, 17.3 kW/ft - Hot Channel Vapor Temperature at Core Exit

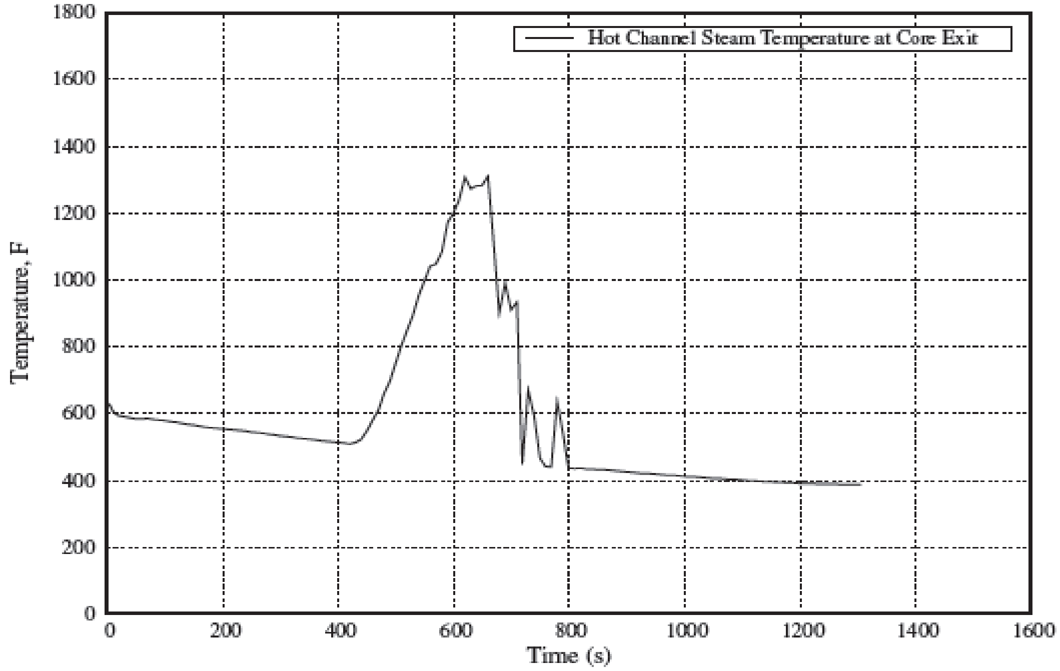


Figure 7-6: Mark-B-HTP SBLOCA at 102% of 2568 MWt: 0.15 ft^2 CLPD, 17.3 kW/ft - HC Heat Transfer Coefficient

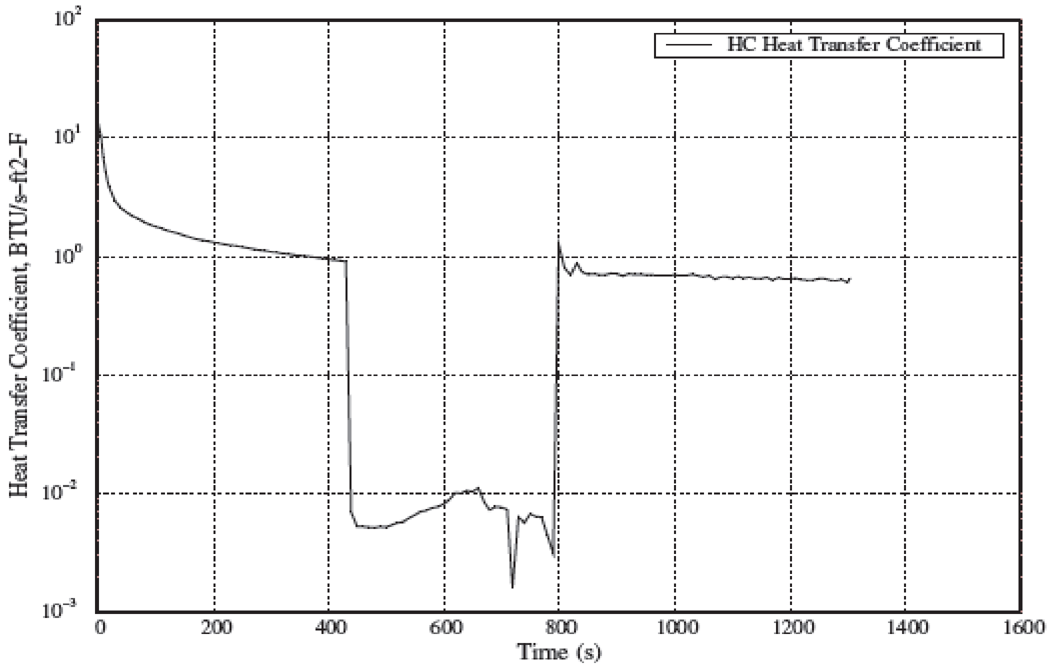


Figure 7-7: Category 2 and 3 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of Primary Pressures, CLPD and HPI (LOOP)

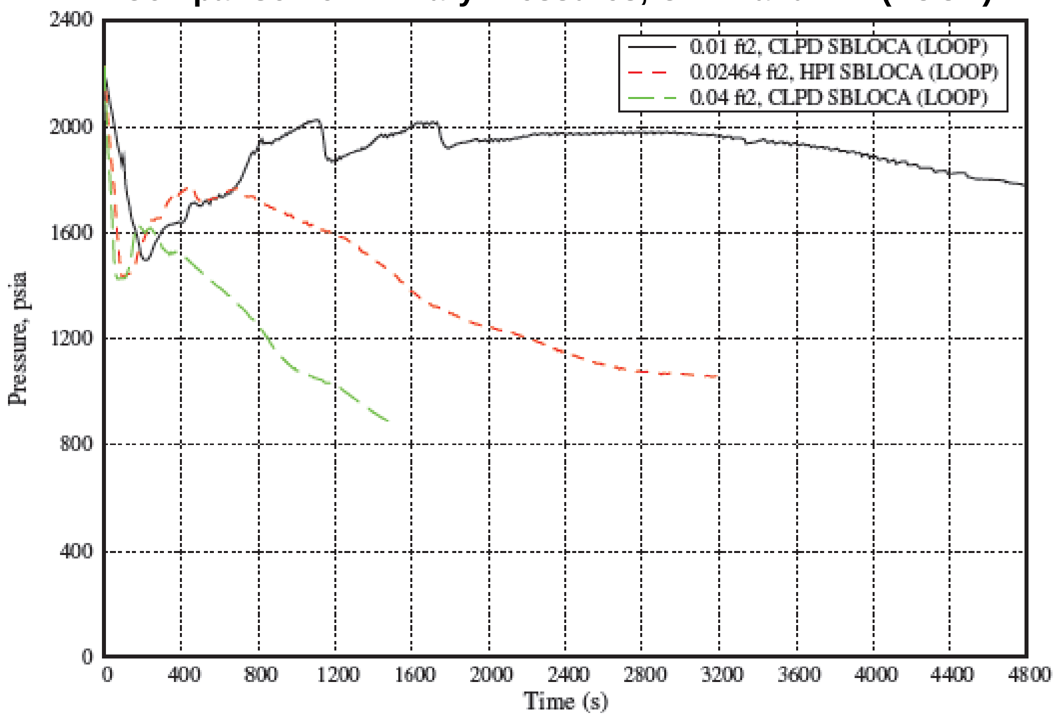


Figure 7-8: Category 4 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of Primary Pressures, CLPD (LOOP)

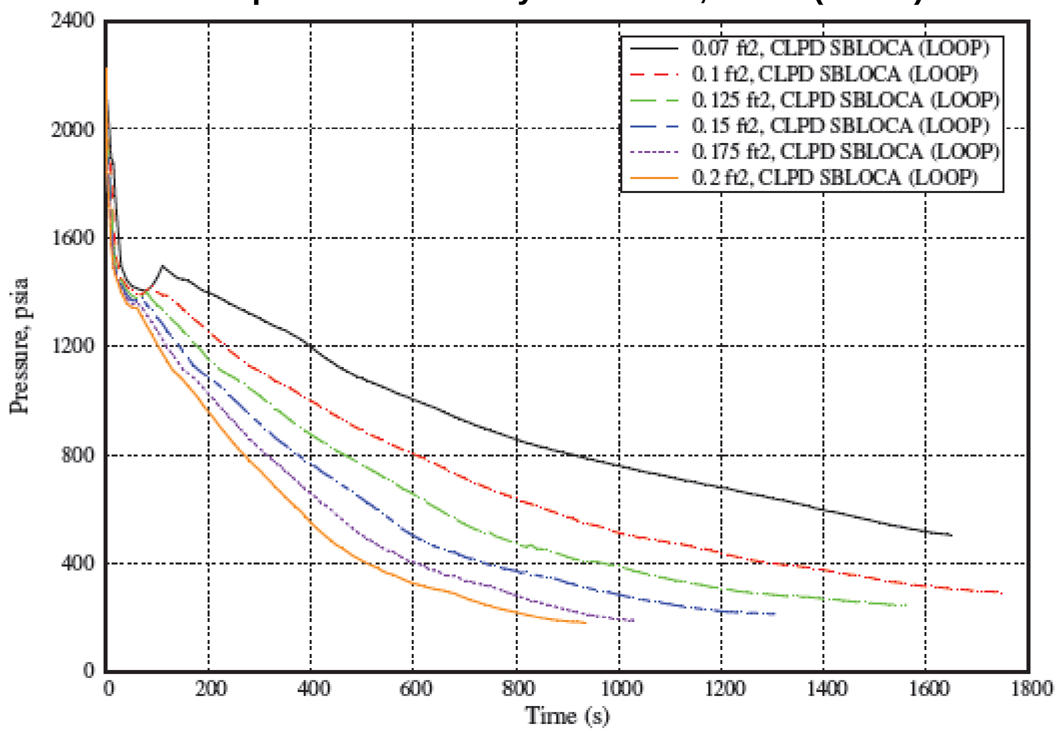


Figure 7-9: Category 5 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of Primary Pressures, CLPD and CFT (LOOP)

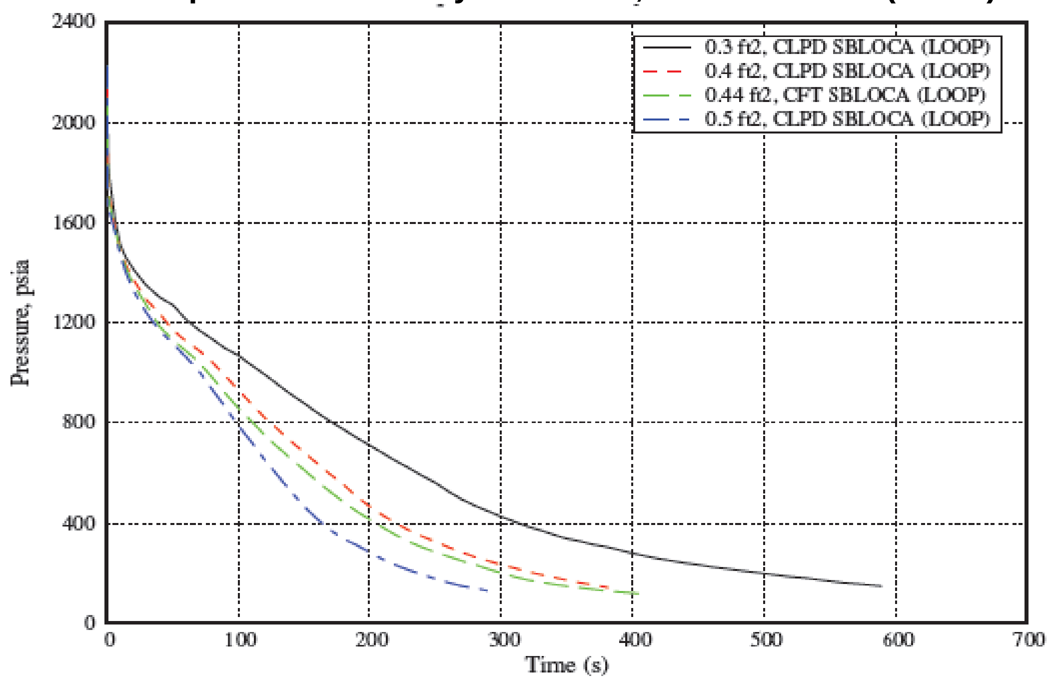


Figure 7-10: Category 5 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of Primary Pressures, CLPD and CFT (2 min RCP Trip)

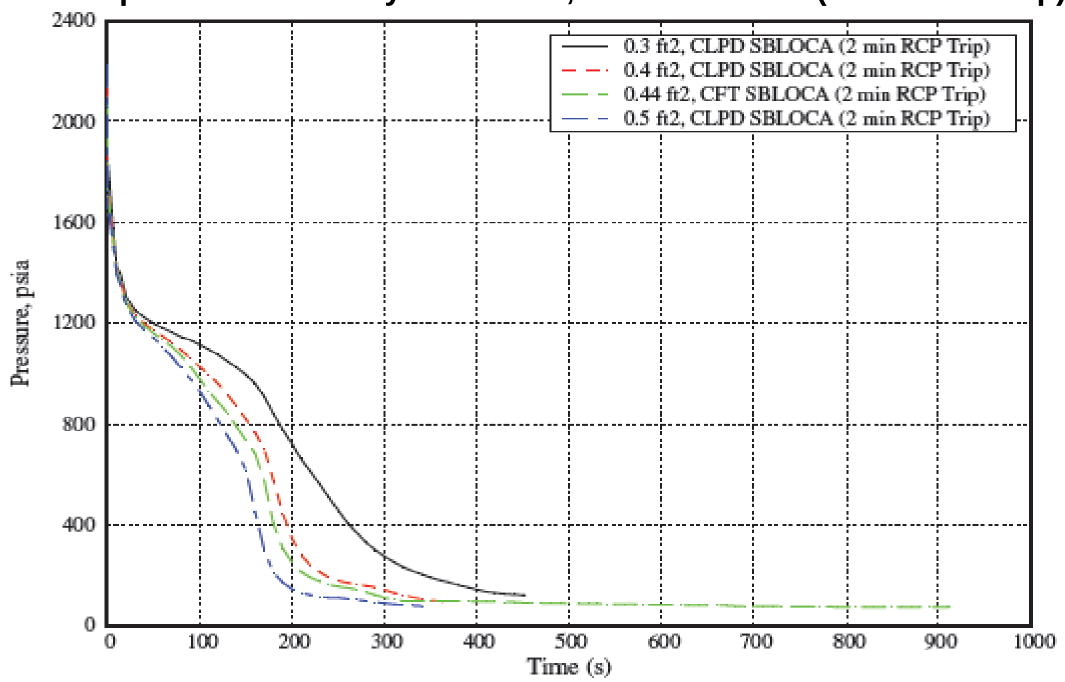


Figure 7-11: Category 2 and 3 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of SG-1 Secondary Pressures, CLPD and HPI (LOOP)

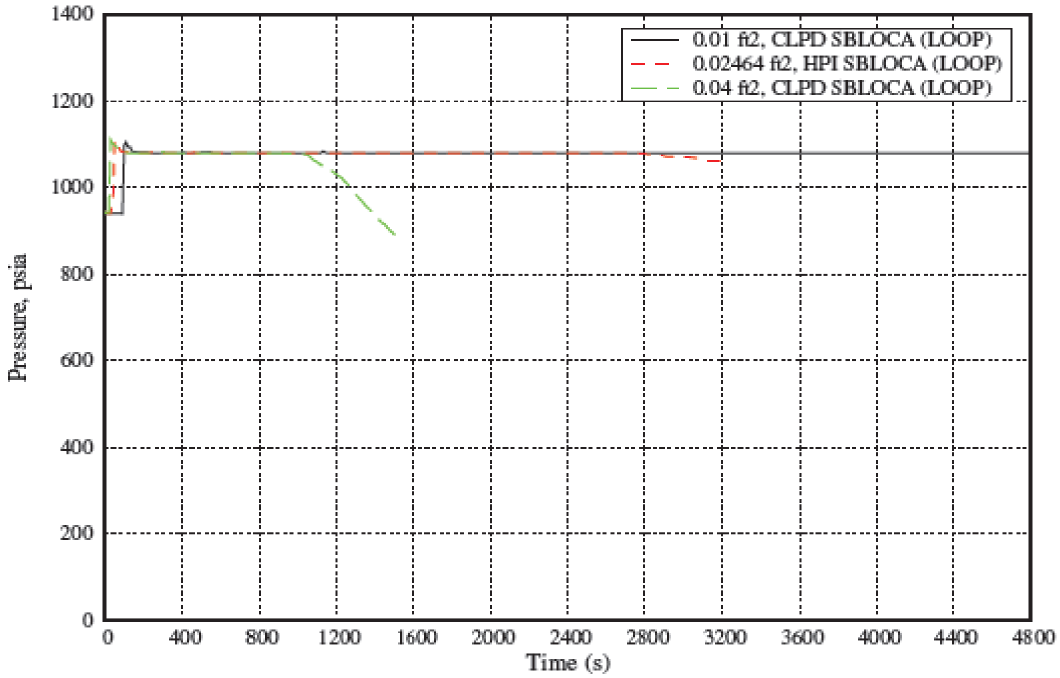


Figure 7-12: Category 4 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of SG-1 Secondary Pressures, CLPD (LOOP)

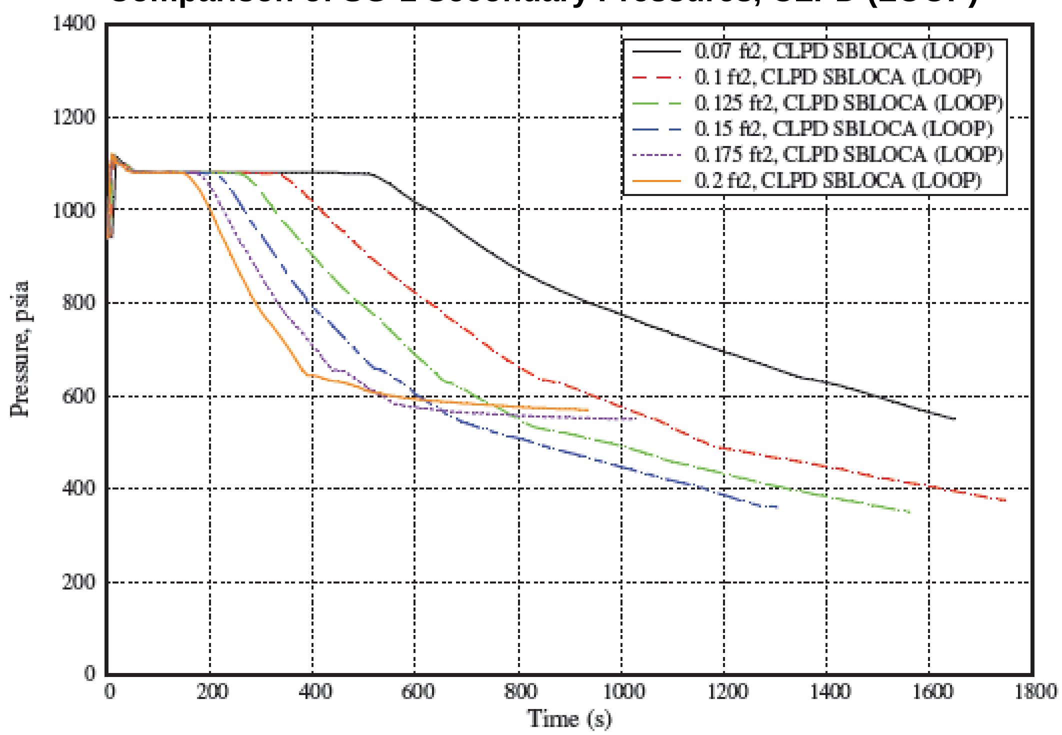


Figure 7-13: Category 5 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of SG-1 Secondary Pressures, CLPD and CFT (LOOP)

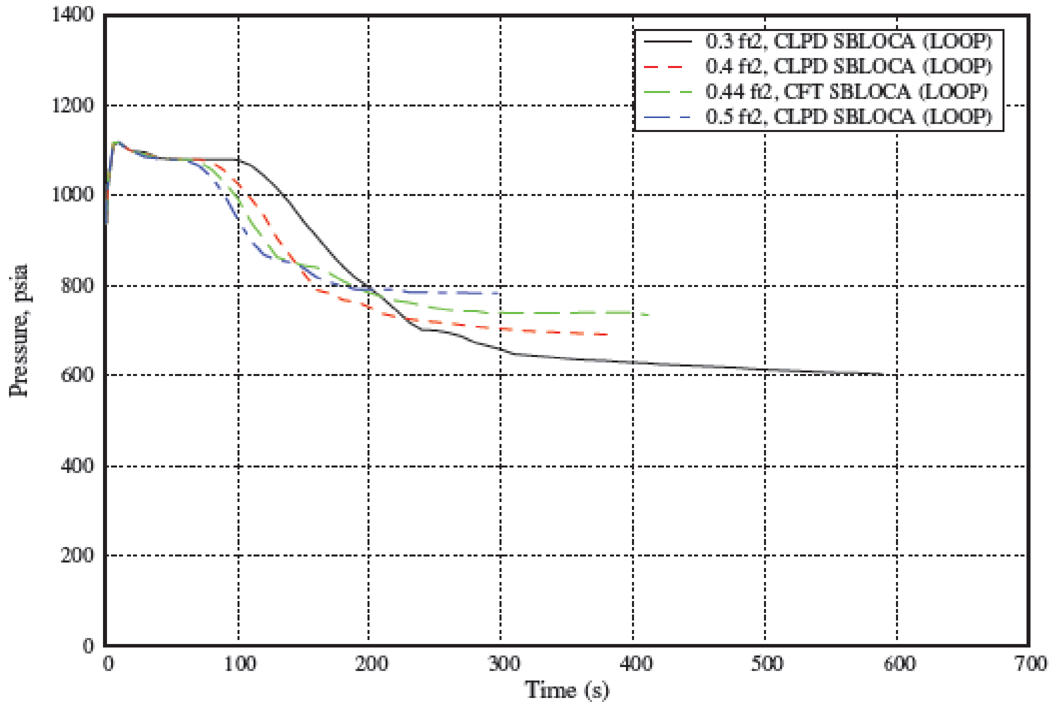


Figure 7-14: Category 5 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of SG-1 Secondary Pressures, CLPD and CFT (2 min RCP Trip)

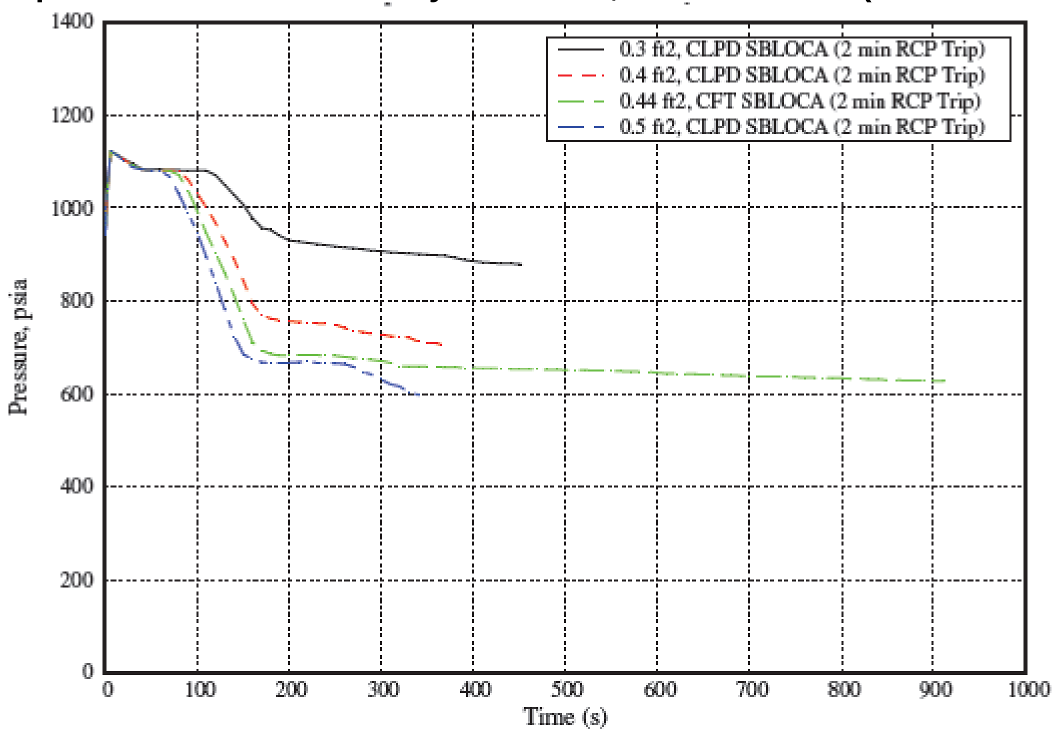


Figure 7-15: Category 2 and 3 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of SG-2 Secondary Pressures, CLPD and HPI (LOOP)

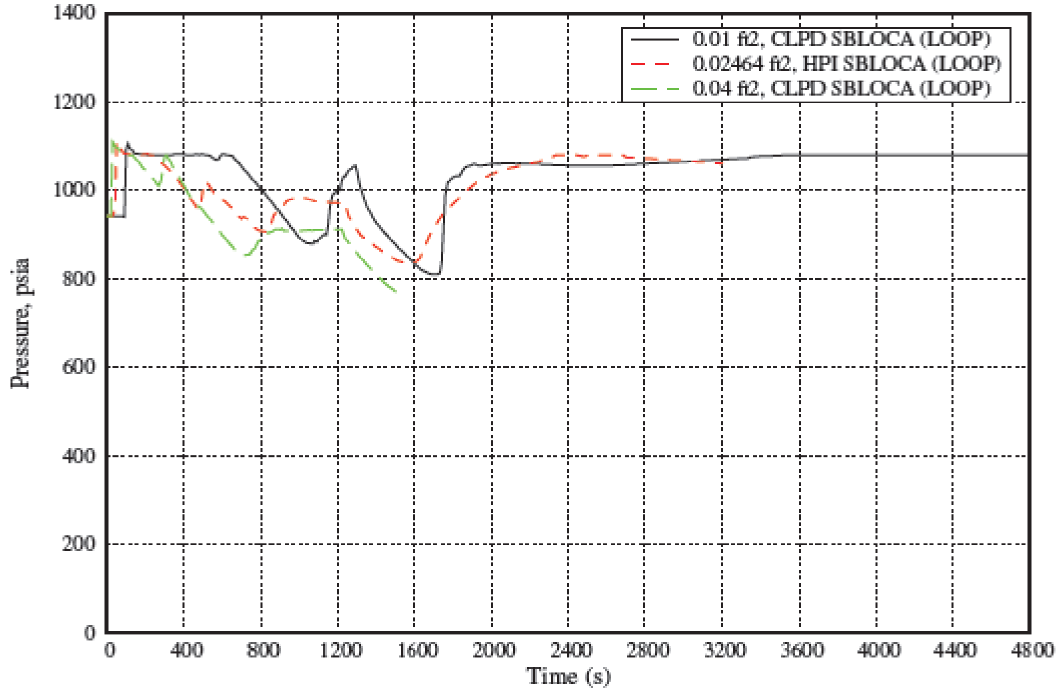


Figure 7-16: Category 4 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of SG-2 Secondary Pressures, CLPD (LOOP)

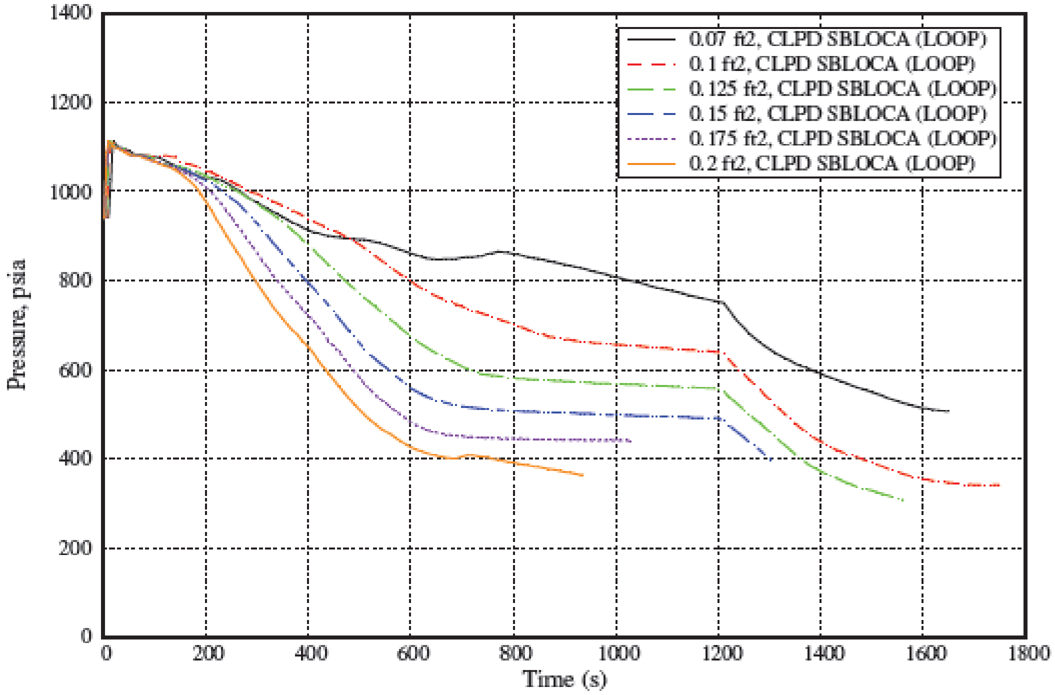


Figure 7-17: Category 5 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of SG-2 Secondary Pressures, CLPD and CFT (LOOP)

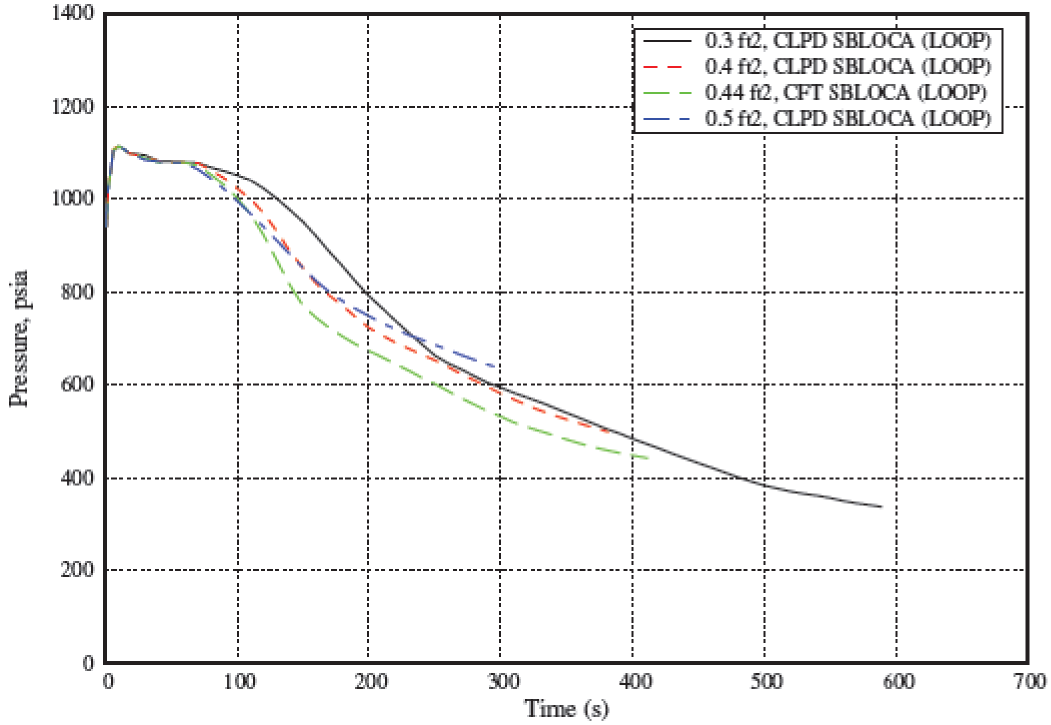


Figure 7-18: Category 5 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of SG-2 Secondary Pressures, CLPD and CFT (2 Min RCP Trip)

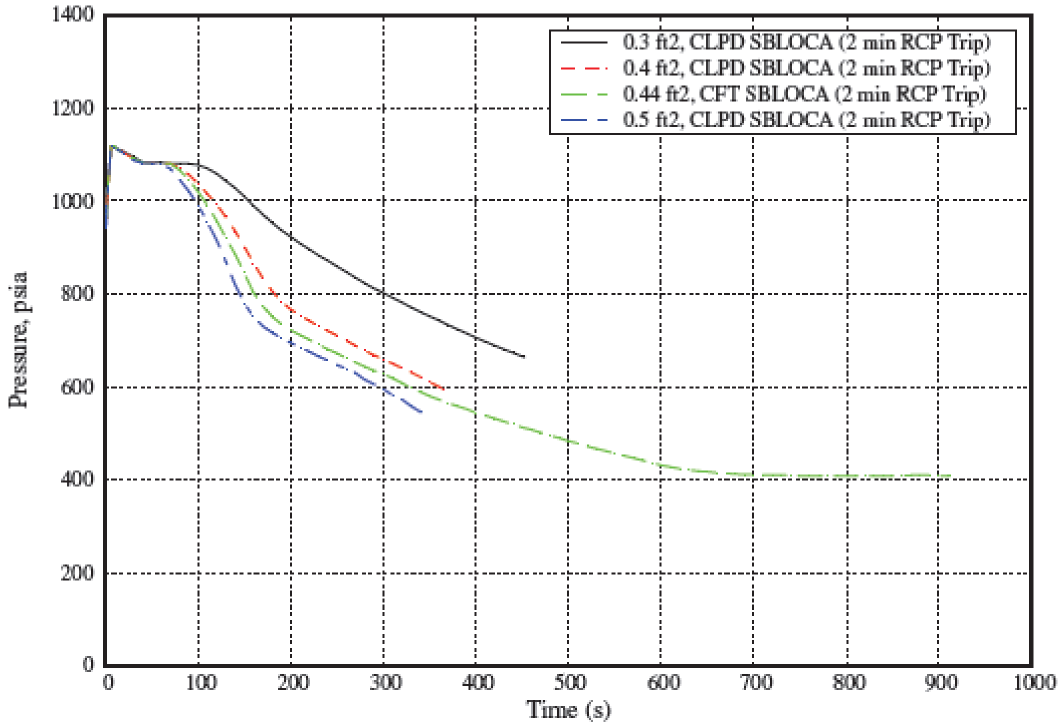


Figure 7-19: Category 2 and 3 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of HC Collapsed Liquid Level, CLPD and HPI (LOOP)

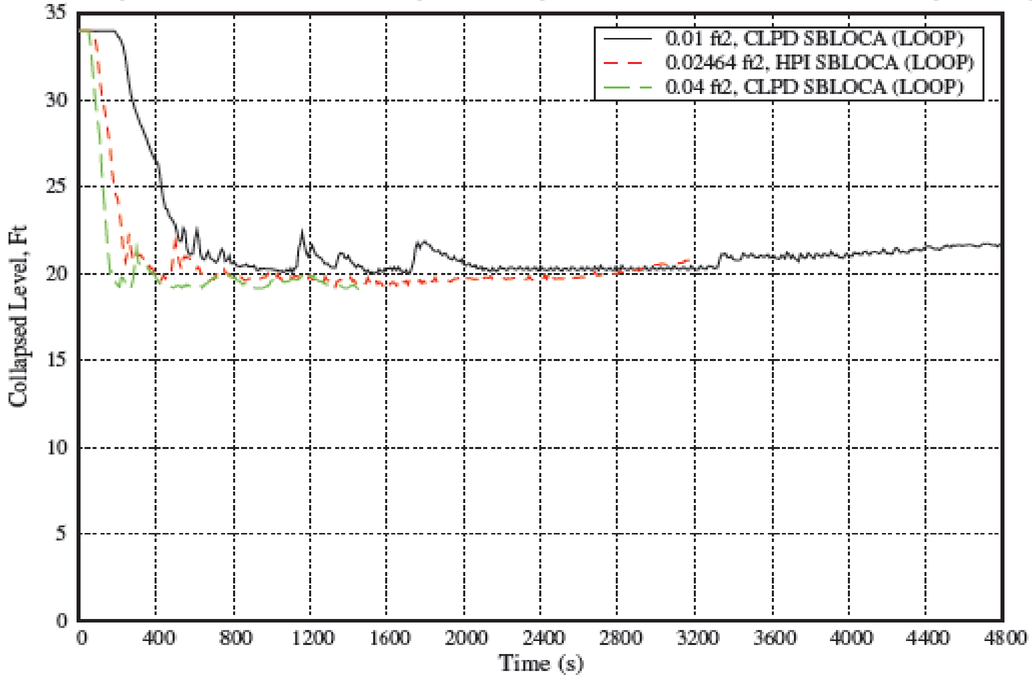


Figure 7-20: Category 4 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of HC Collapsed Liquid Level, CLPD (LOOP)

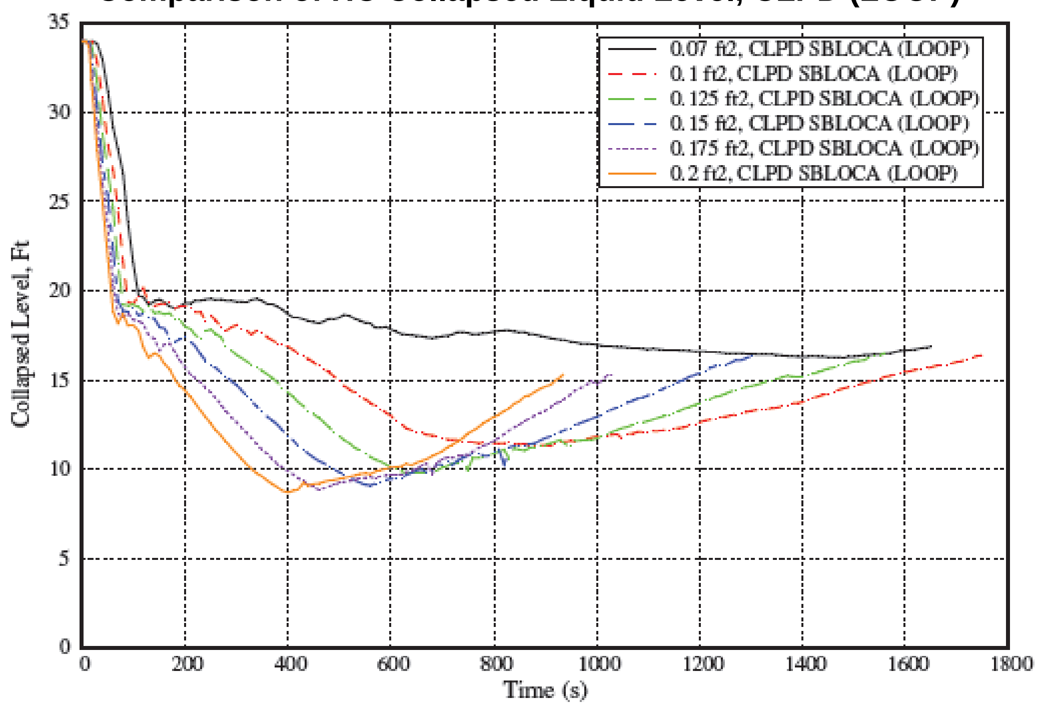


Figure 7-21: Category 5 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of HC Collapsed Liquid Level, CLPD and CFT (LOOP)

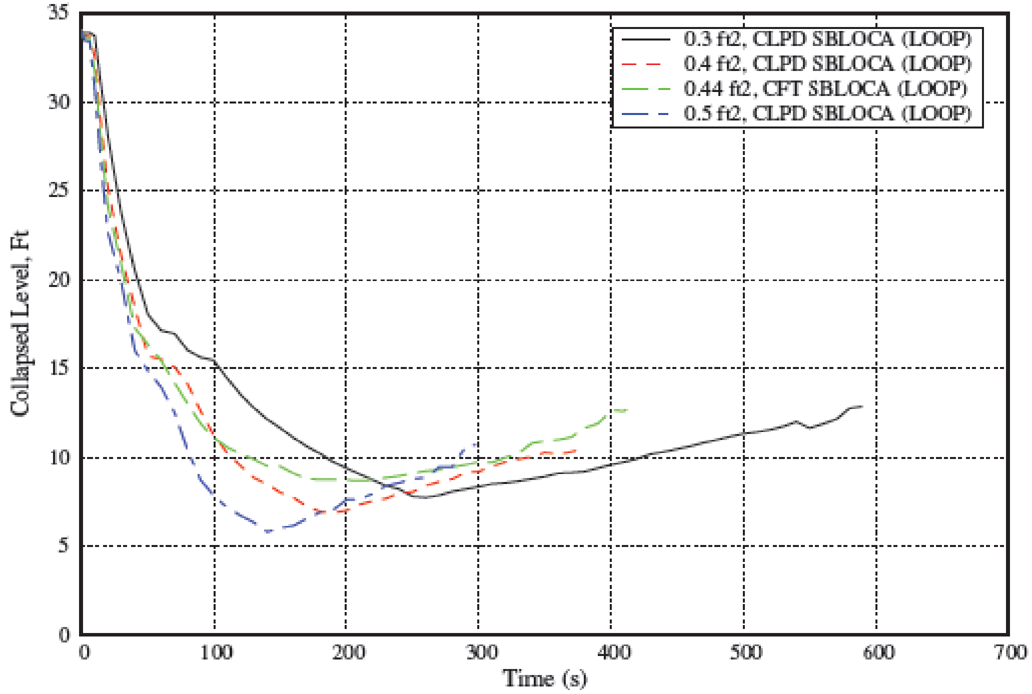


Figure 7-22: Category 5 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of HC Collapsed Liquid Level, CLPD and CFT (2 Min RCP Trip)

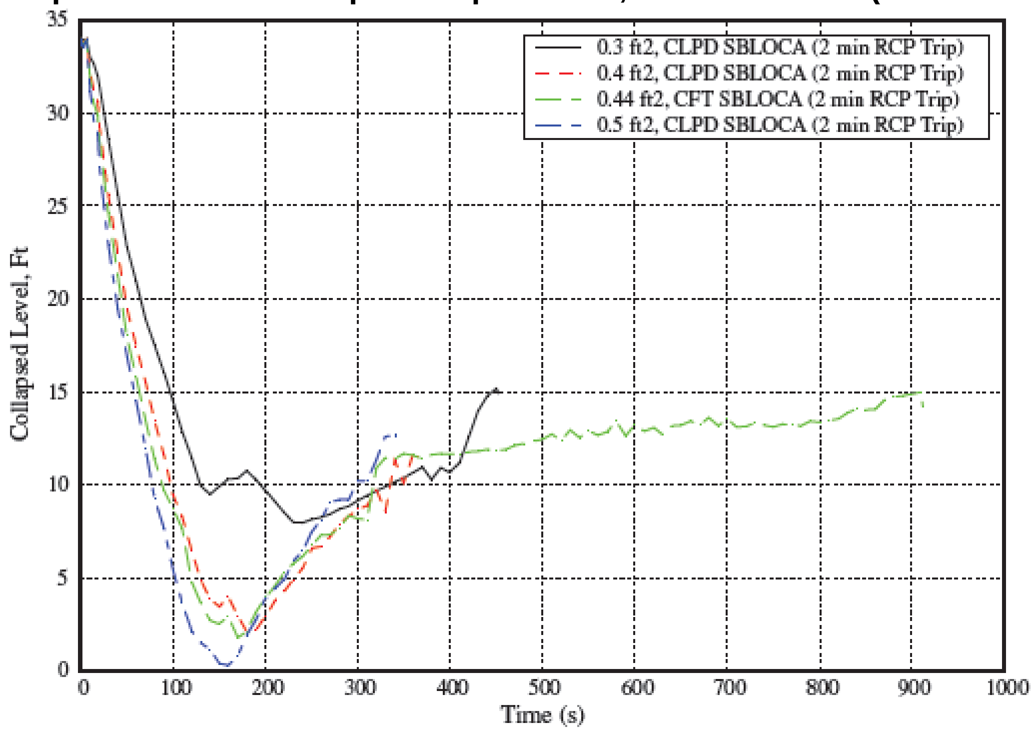


Figure 7-23: Category 2 and 3 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of PCT, CLPD and HPI (LOOP)

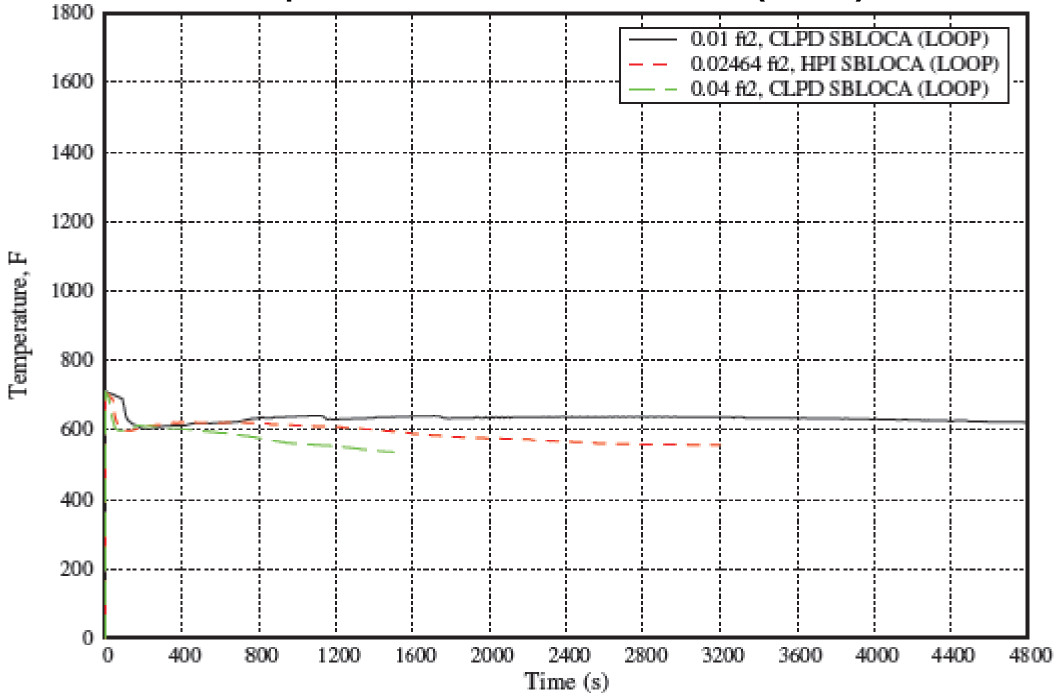


Figure 7-24: Category 4 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of PCT, CLPD (LOOP)

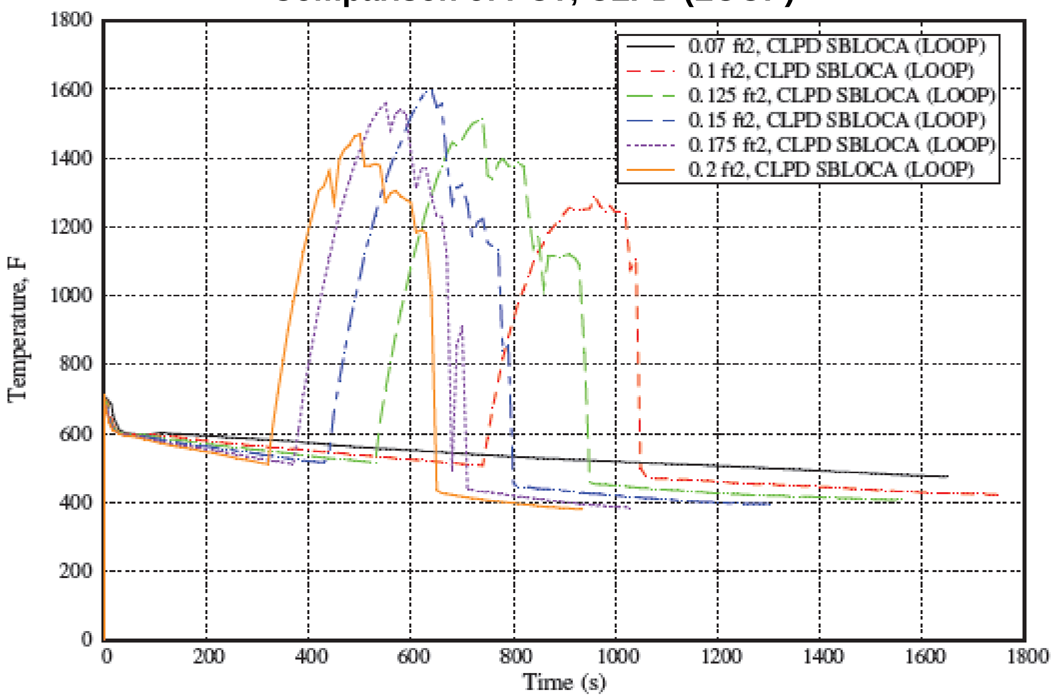


Figure 7-25: Category 5 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of PCT, CLPD and CFT (2 min RCP Trip)

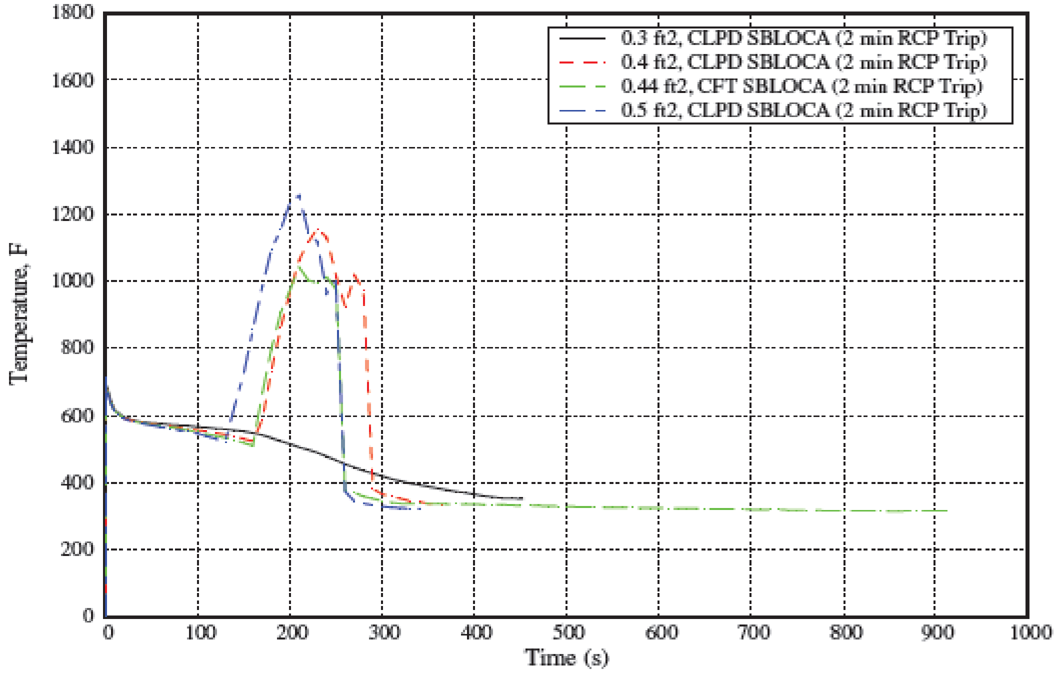


Figure 7-26: Category 5 Breaks, Mark-B-HTP SBLOCA at 102% of 2568 MWt - Comparison of PCT, CLPD and CFT (LOOP)

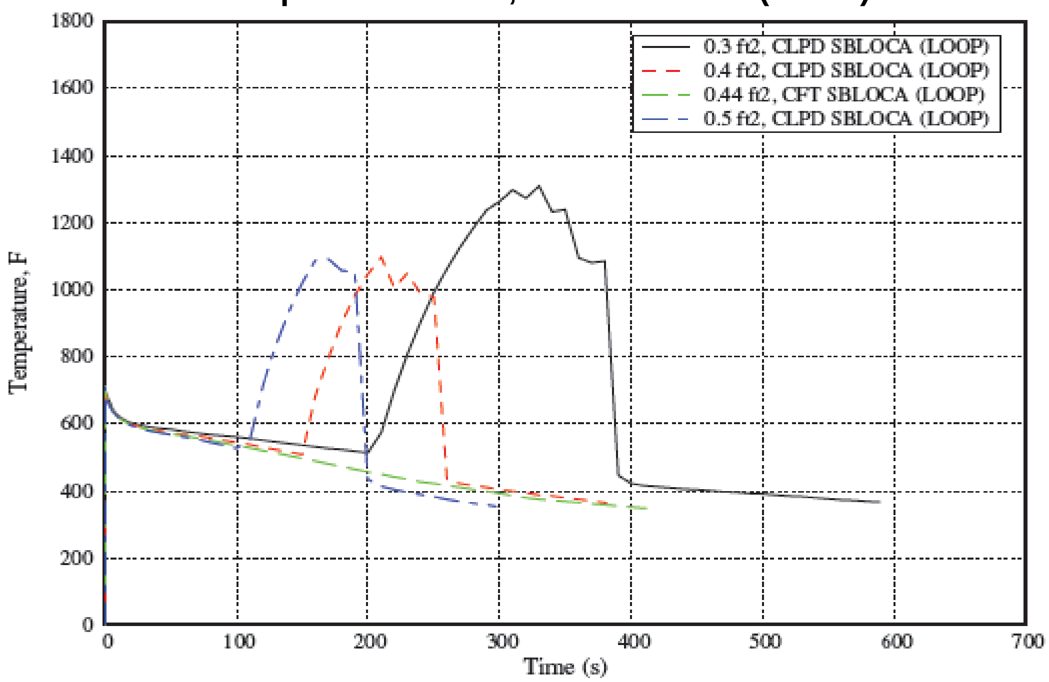


Figure 7-27: Mark-B-HTP SBLOCA at 52% of 2568 MWt: 0.072 ft^2 CLPD, 17.3 kW/ft – Pressure

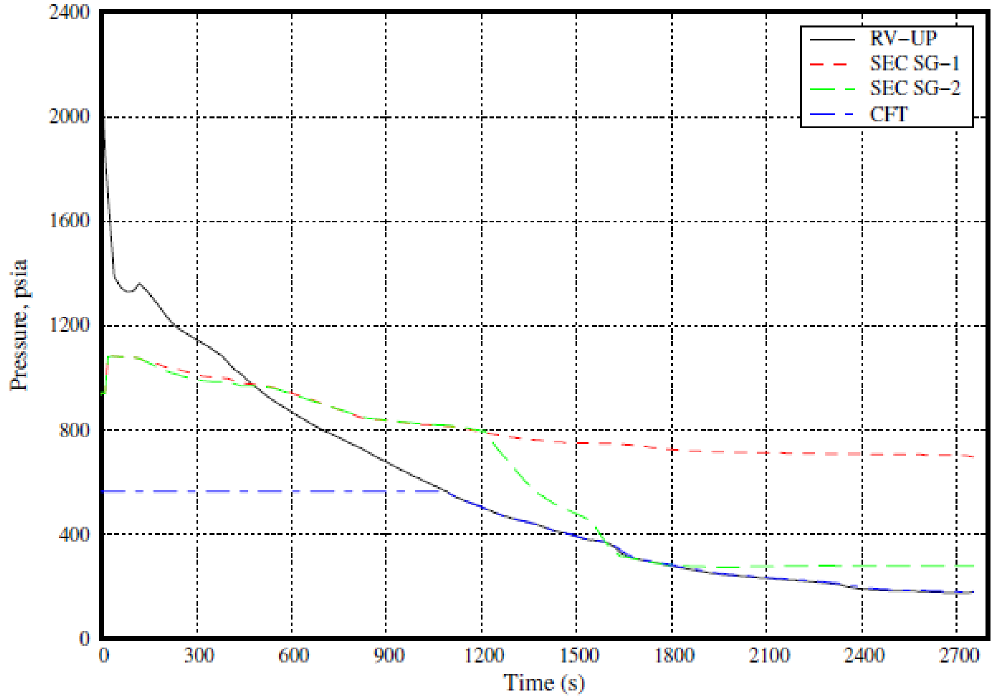


Figure 7-28: Mark-B-HTP SBLOCA at 52% of 2568 MWt: 0.072 ft^2 CLPD, 17.3 kW/ft – Break and ECCS Mass Flow Rates

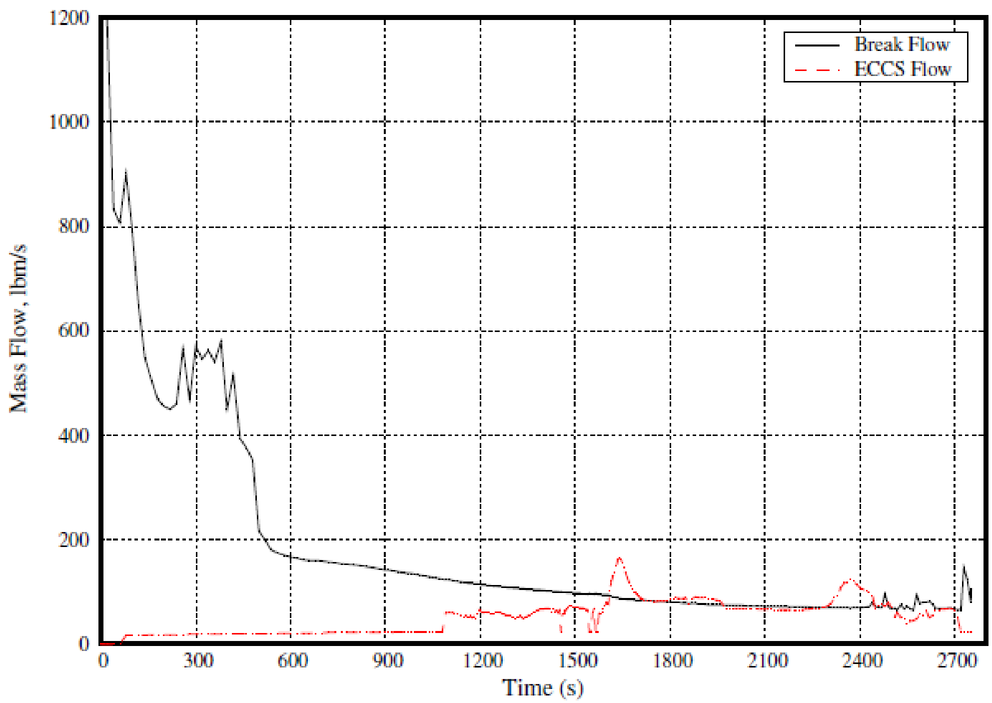


Figure 7-29: Mark-B-HTP SBLOCA at 52% of 2568 MWt: 0.072 ft² CLPD, 17.3 kW/ft – RV Collapsed Liquid Level & Hot Channel Mixture Level

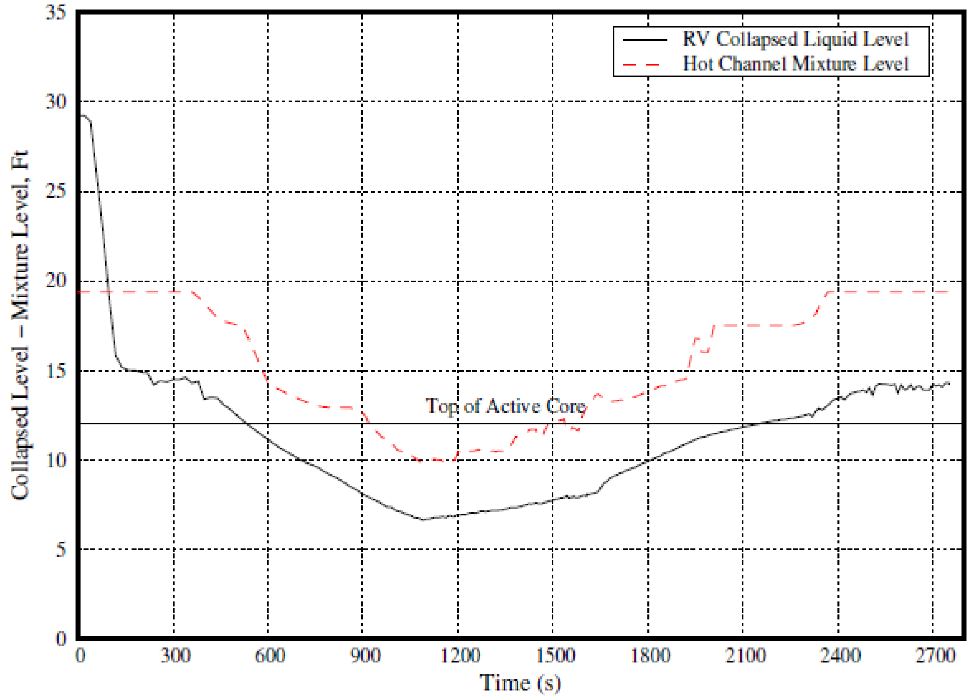


Figure 7-30: Mark-B-HTP SBLOCA at 52% of 2568 MWt: 0.072 ft² CLPD, 17.3 kW/ft – Hot Pin Peak Clad Tempature

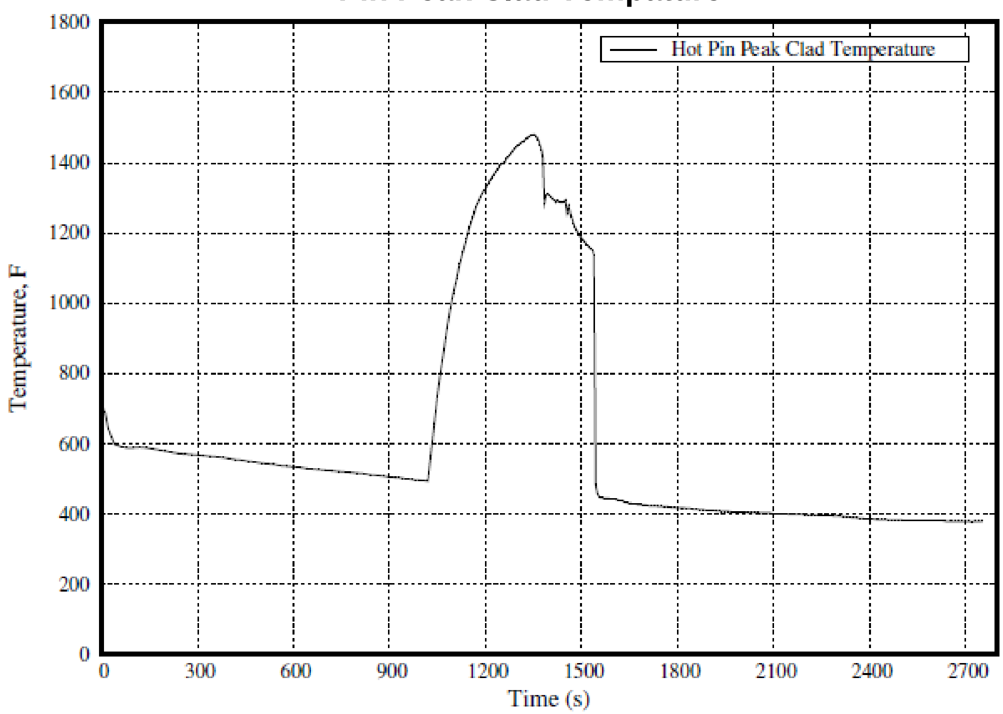


Figure 7-31: Mark-B-HTP SBLOCA at 52% of 2568 MWt: 0.072 ft^2 CLPD, 17.3 kW/ft – Hot Channel Vapor Temperature at Core Exit

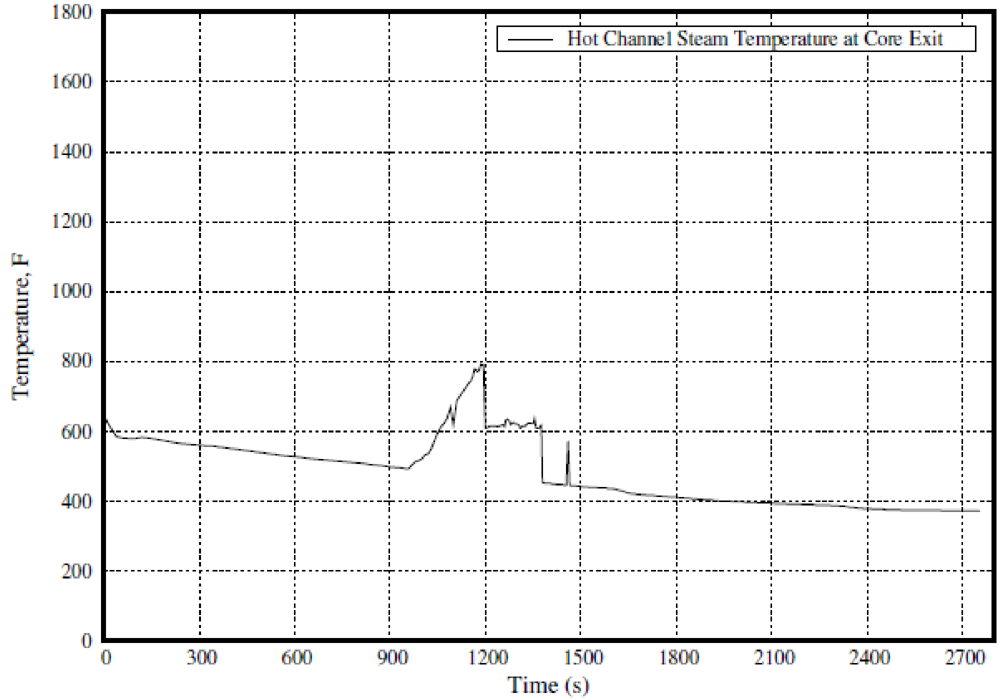


Figure 7-32: Mark-B-HTP SBLOCA at 52% of 2568 MWt: 0.072 ft^2 CLPD, 17.3 kW/ft – HC Heat Transfer Coefficient

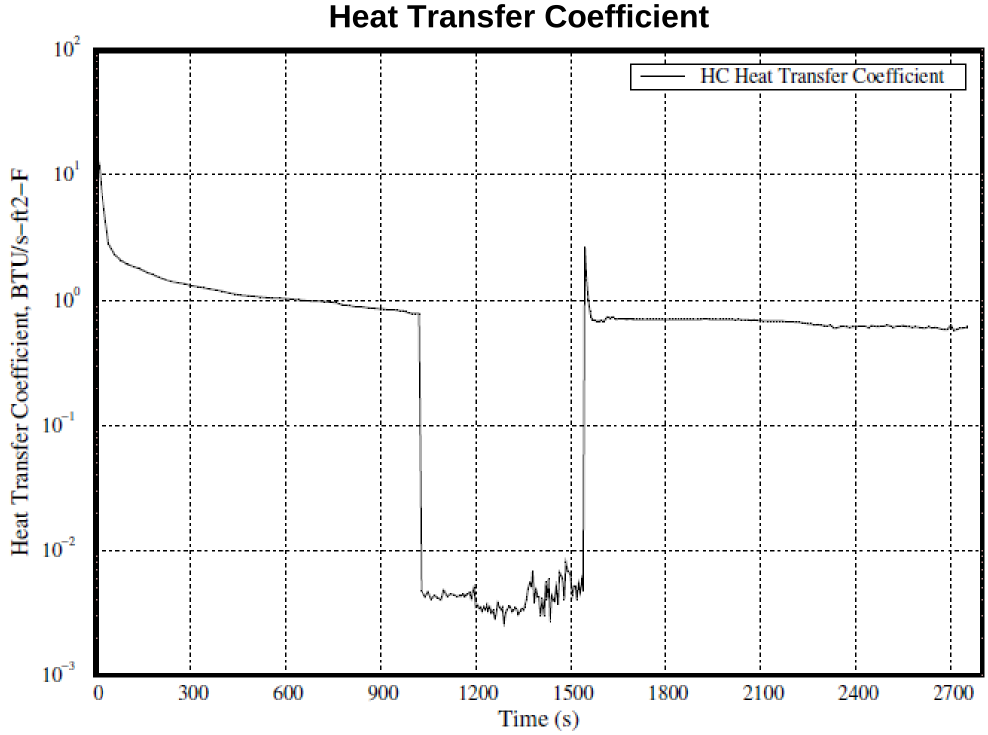


Figure 7-33: Category 2 and 3 Breaks, Mark-B-HTP SBLOCA at 52% of 2568 MWt - Comparison of Primary Pressures, CLPD and HPI (LOOP)

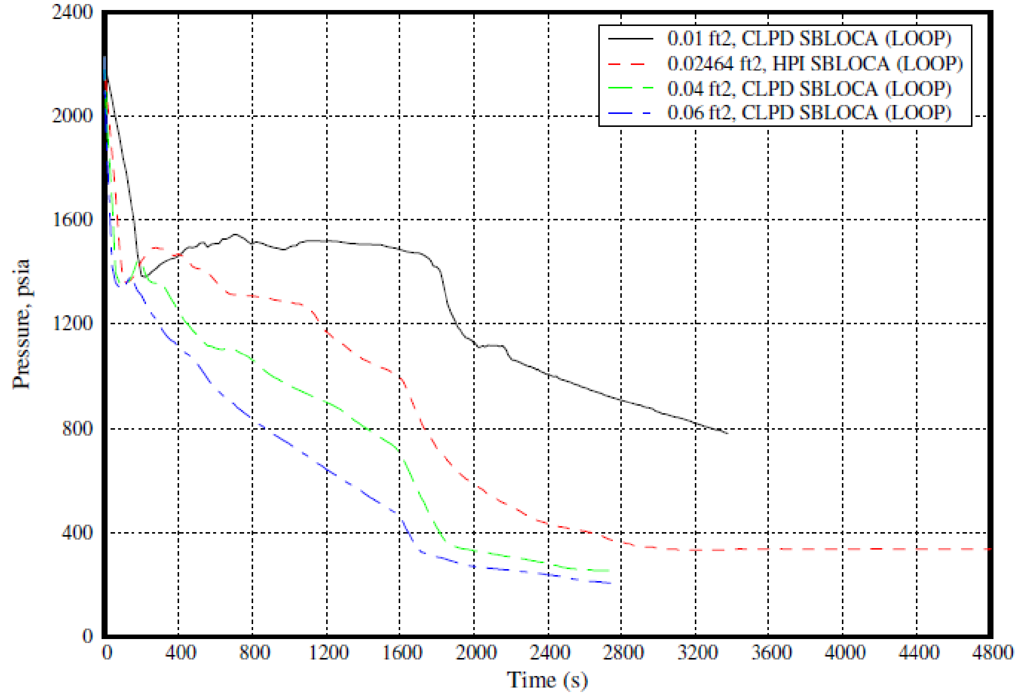


Figure 7-34: Category 4 Breaks, Mark-B-HTP SBLOCA at 52% of 2568 MWt - Comparison of Primary Pressures, CLPD (LOOP)

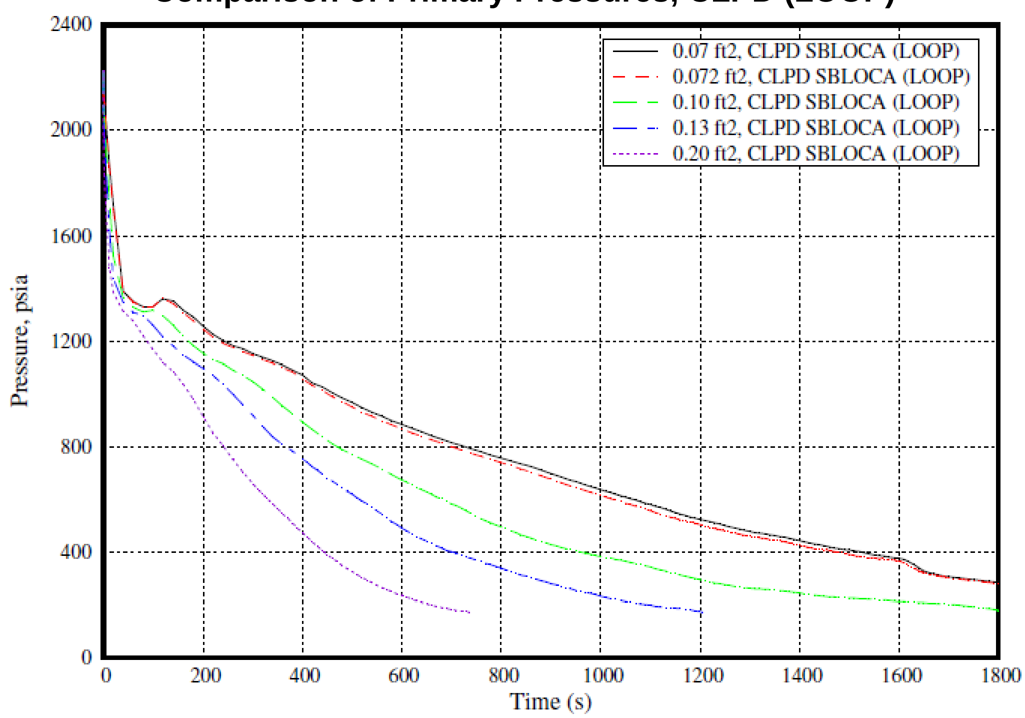


Figure 7-35: Category 5 Breaks, Mark-B-HTP SBLOCA at 52% of 2568 MWt - Comparison of Primary Pressures, CLPD (LOOP & 2 min RCP Trip)

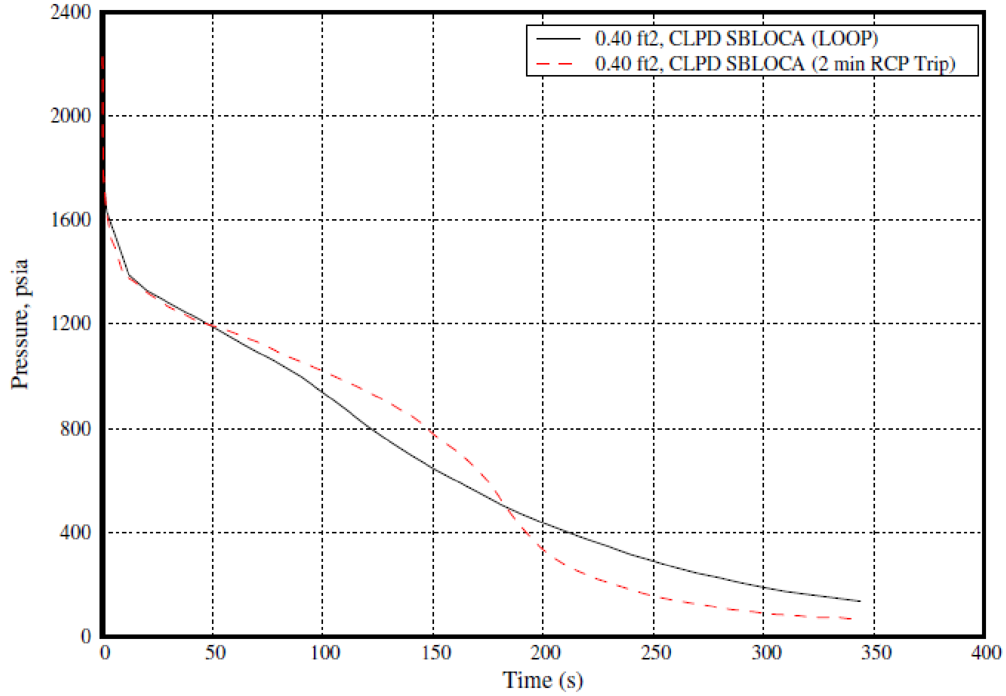


Figure 7-36: Category 2 and 3 Breaks, Mark-B-HTP SBLOCA at 52% of 2568 MWt - Comparison of SG-1 Secondary Pressures, CLPD and HPI (LOOP)

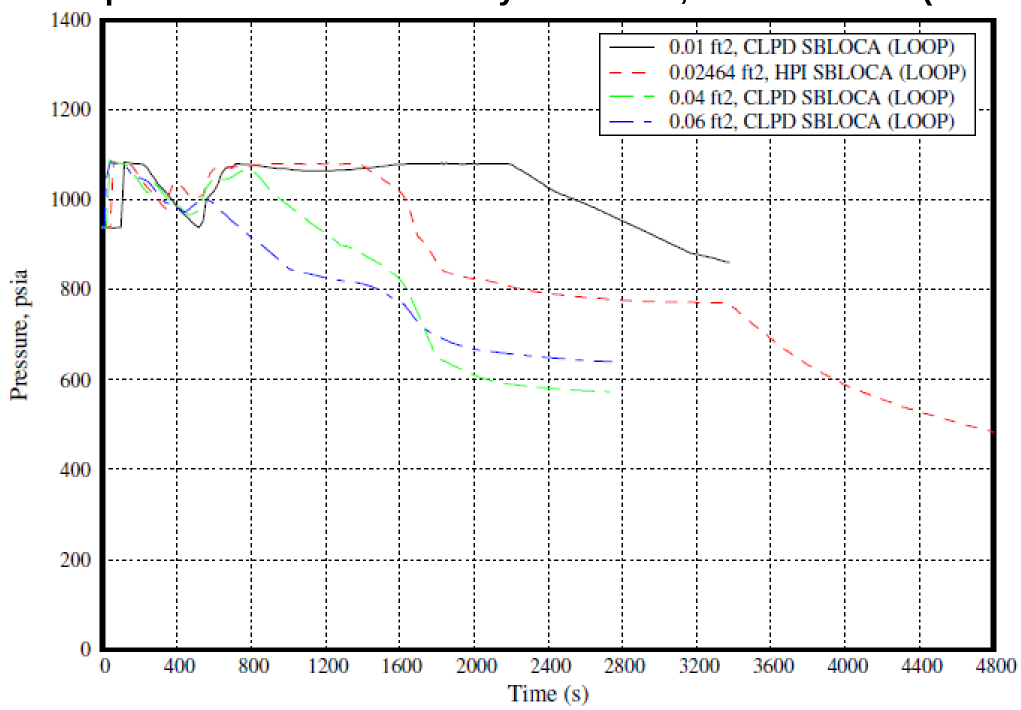


Figure 7-37: Category 4 Breaks, Mark-B-HTP SBLOCA at 52% of 2568 MWt - Comparison of SG-1 Secondary Pressures, CLPD (LOOP)

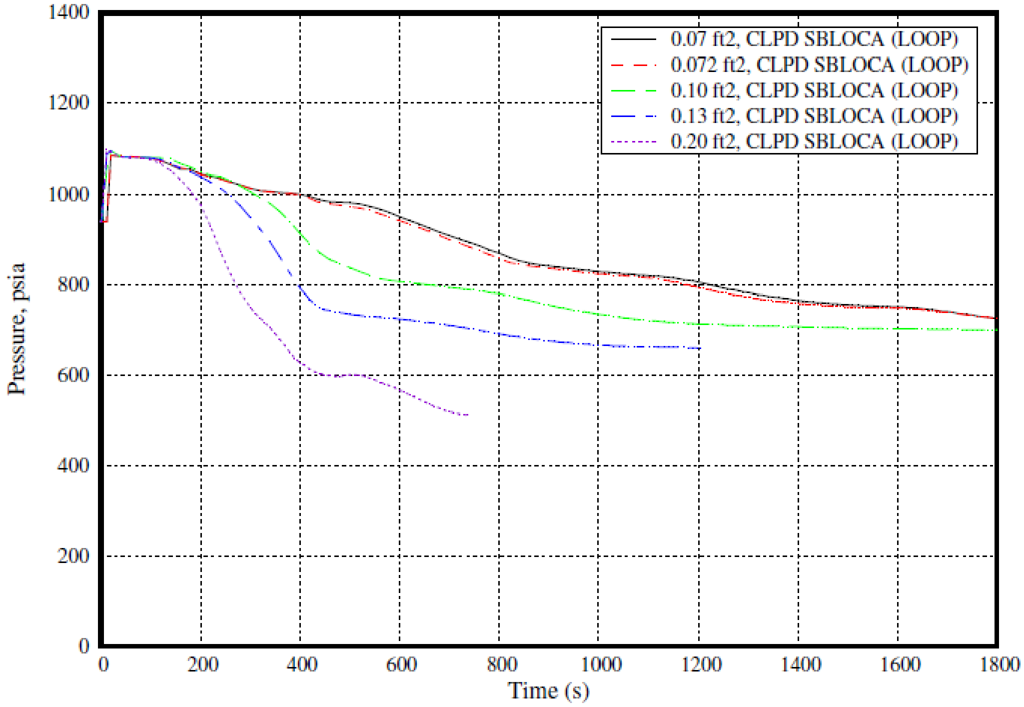


Figure 7-38: Category 5 Breaks, Mark-B-HTP SBLOCA at 52% of 2568 MWt - Comparison of SG-1 Secondary Pressures, CLPD (LOOP & 2 min RCP Trip)

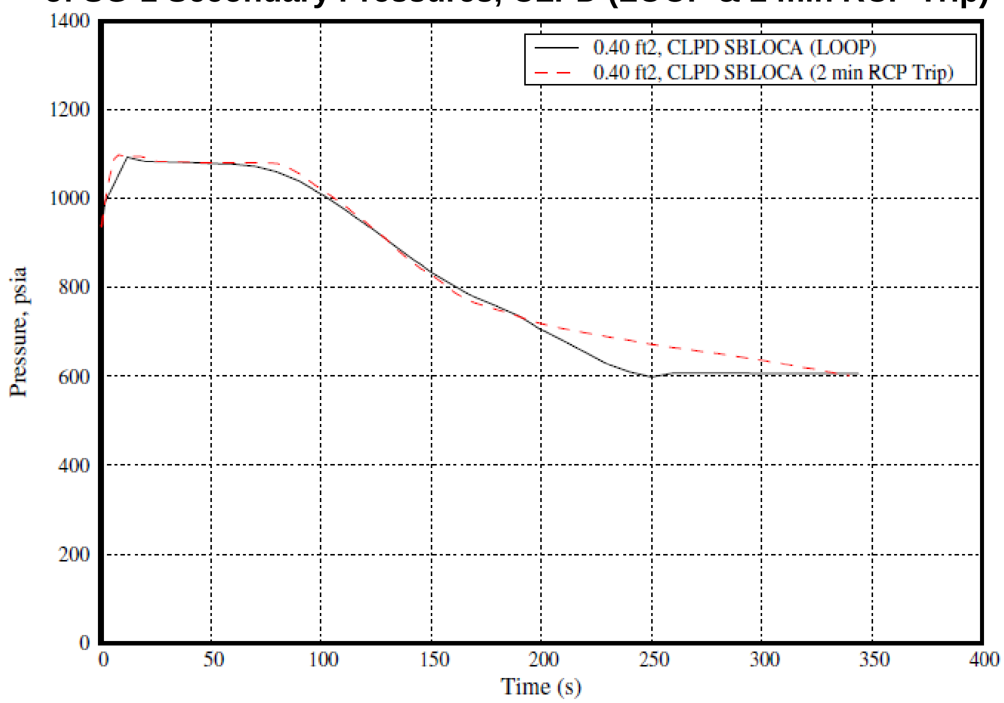


Figure 7-39: Category 2 and 3 Breaks, Mark-B-HTP SBLOCA at 52% of 2568 MWt - Comparison of SG-2 Secondary Pressures, CLPD and HPI (LOOP)

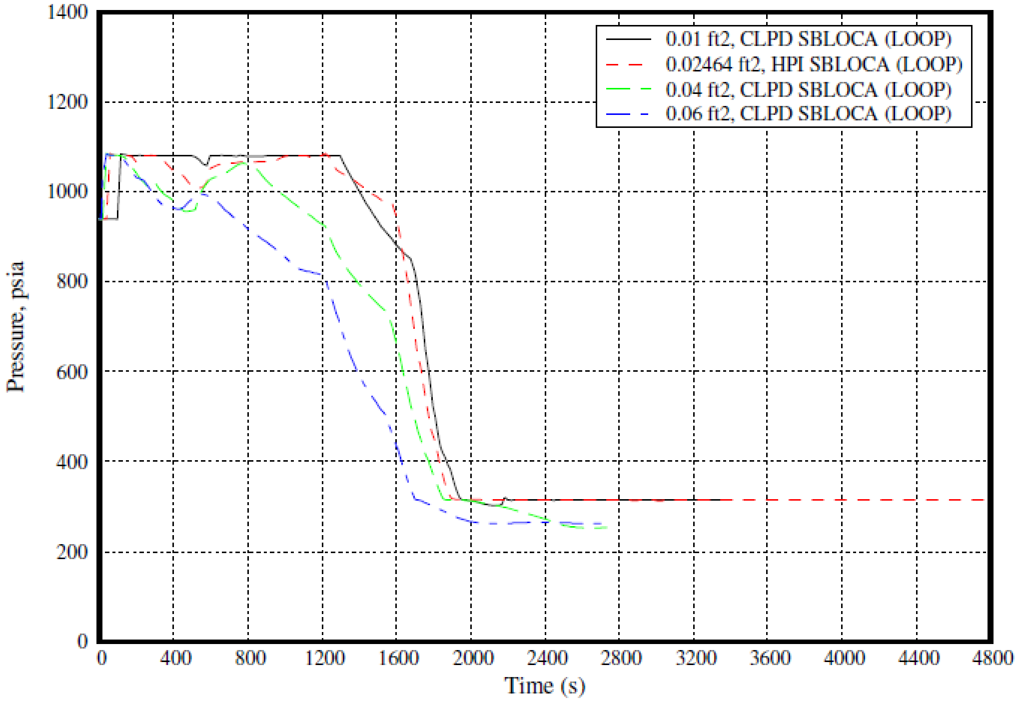


Figure 7-40: Category 4 Breaks, Mark-B-HTP SBLOCA at 52% of 2568 MWt - Comparison of SG-2 Secondary Pressures, CLPD (LOOP)

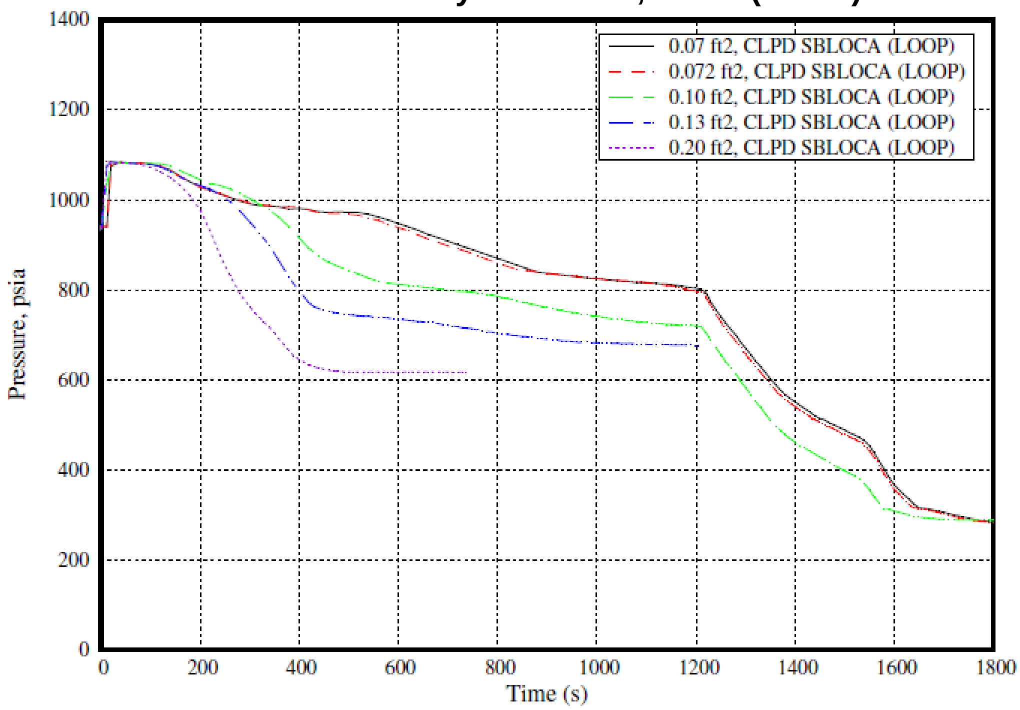


Figure 7-41: Category 5 Breaks, Mark-B-HTP SBLOCA at 52% of 2568 MWt - Comparison of SG-2 Secondary Pressures, CLPD (LOOP & 2 Min RCP Trip)

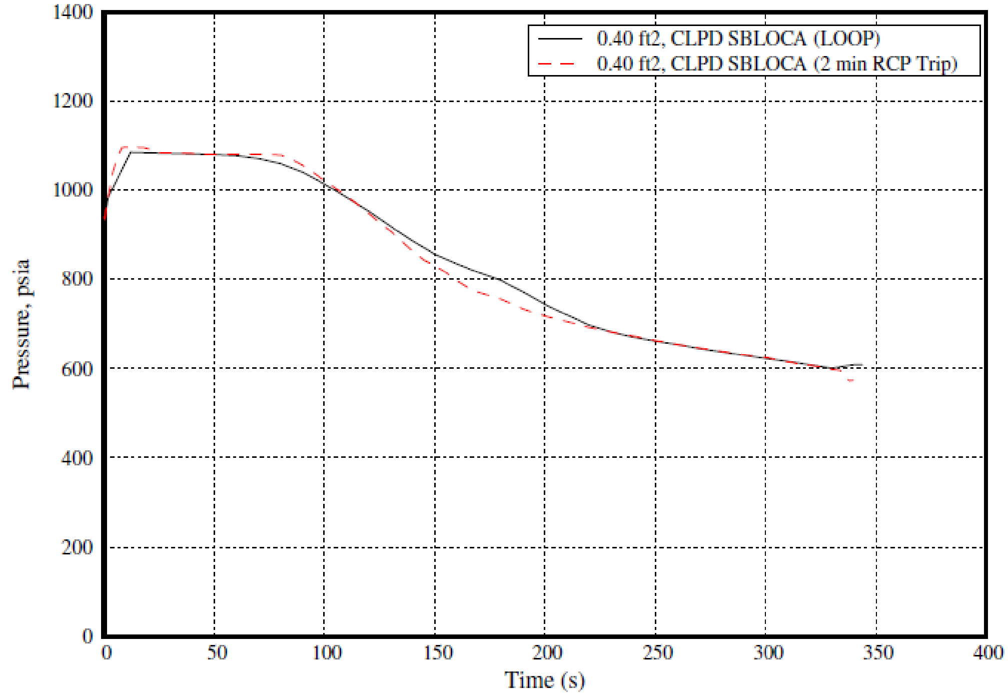


Figure 7-42: Category 2 and 3 Breaks, Mark-B-HTP SBLOCA at 52% of 2568 MWt - Comparison of RV Collapsed Liquid Level, CLPD and HPI (LOOP)

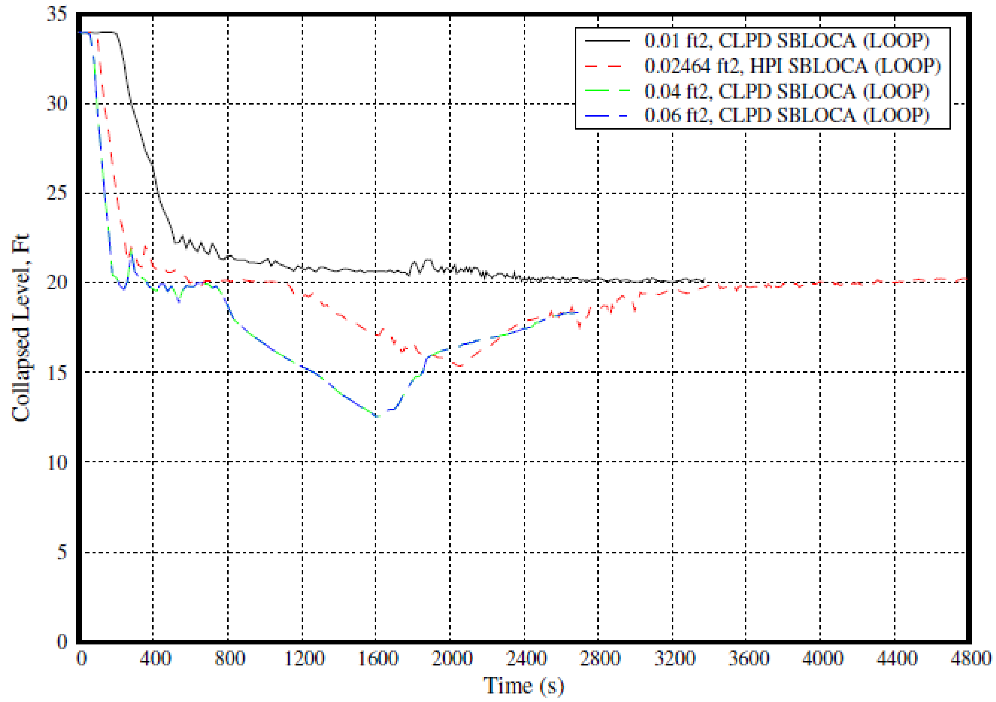


Figure 7-43: Category 4 Breaks, Mark-B-HTP SBLOCA at 52% of 2568 MWt - Comparison of RV Collapsed Liquid Level, CLPD (LOOP)

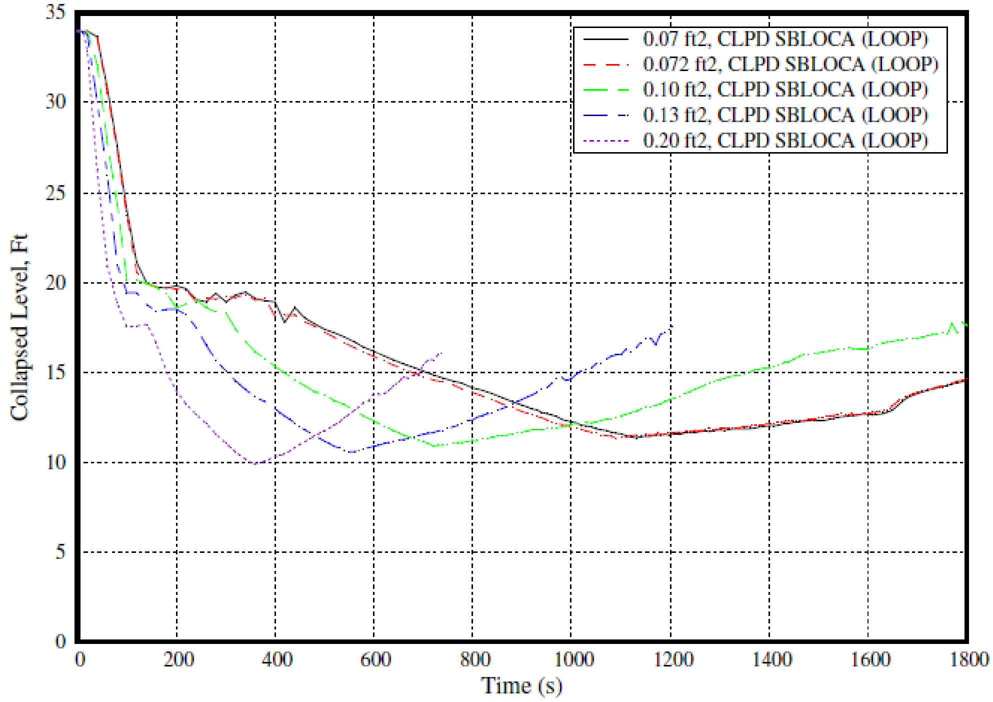


Figure 7-44: Category 5 Breaks, Mark-B-HTP SBLOCA at 52% of 2568 MWt - Comparison of RV Collapsed Liquid Level, CLPD (LOOP & 2 Min RCP Trip)

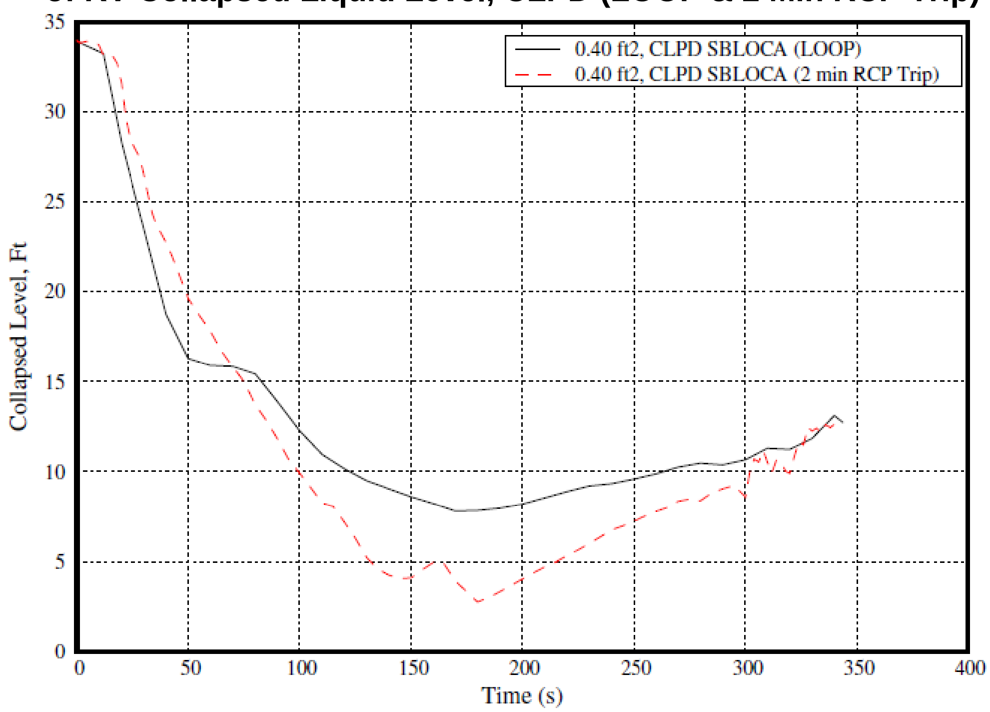


Figure 7-45: Category 2 and 3 Breaks, Mark-B-HTP SBLOCA at 52% of 2568 MWt - Comparison of PCT, CLPD and HPI (LOOP)

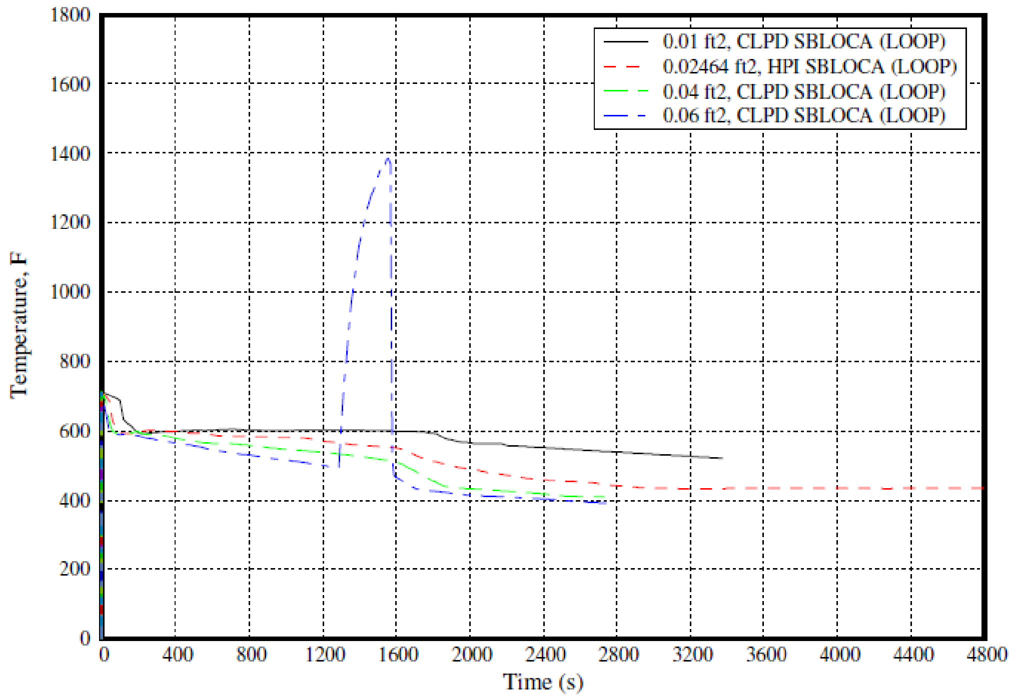


Figure 7-46: Category 4 Breaks, Mark-B-HTP SBLOCA at 52% of 2568 MWt - Comparison of PCT, CLPD (LOOP)

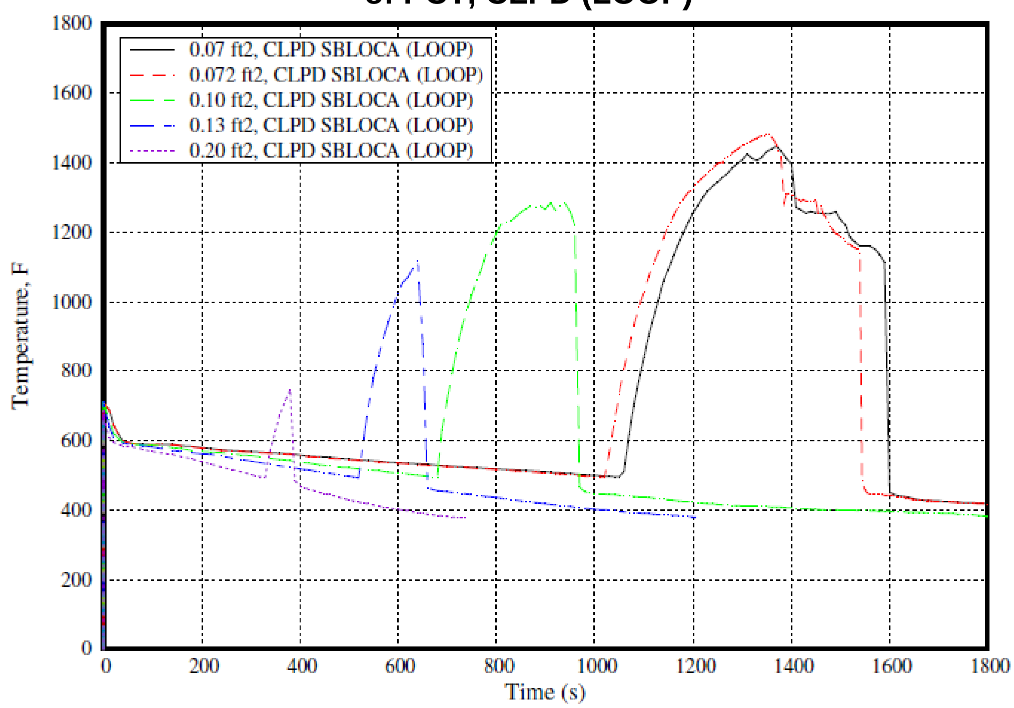
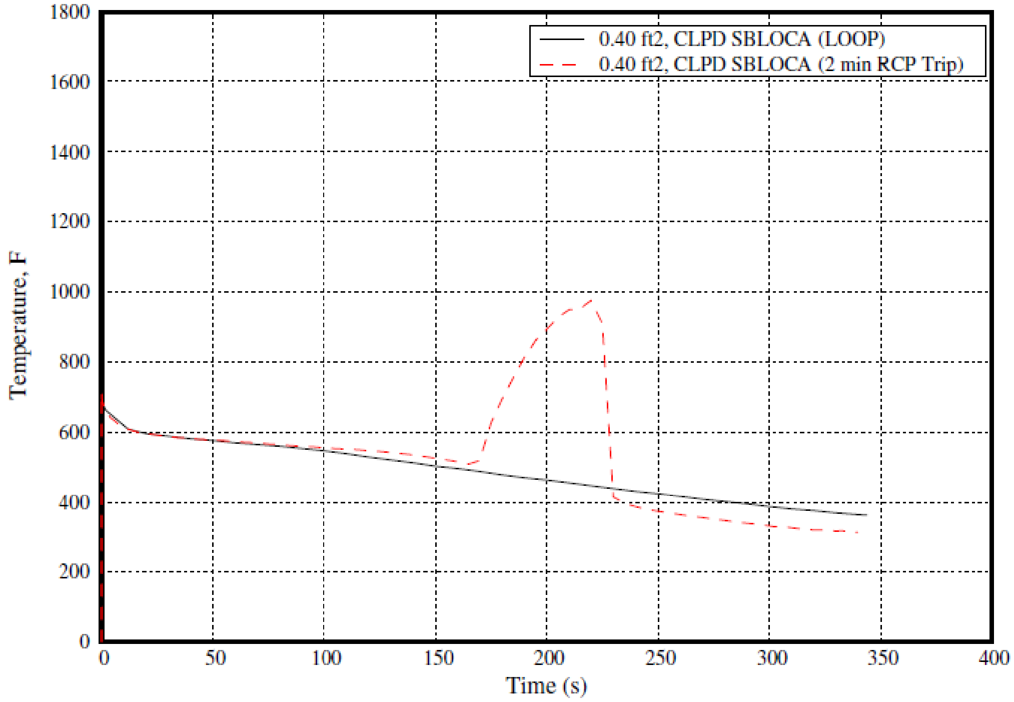


Figure 7-47: Category 5 Breaks, Mark-B-HTP SBLOCA at 52% of 2568 MWt - Comparison of PCT, CLPD (LOOP & 2 Min RCP Trip)



8.0 RELAP5/MOD2-B&W EM SER RESTRICTIONS

The NRC Safety Evaluation Report (SER) on BAW-10192P-A (Reference [1]) contained eleven restrictions related to the use of the RELAP5/MOD2-B&W EM. Compliance with these eleven restrictions, described in Reference [20] and confirmed in References [8], [9] and [10], are summarized in this section. Note that there are no restrictions pertaining to LOCA associated with the use of the M5® cladding material.

1. *The LOCA methodology should include any NRC restrictions placed on the individual codes used in the evaluation model (EM).*

Response: For LBLOCA analyses, the RELAP5/MOD2-B&W (includes BEACH), the REFLOD3B and CONTEMPT codes are utilized. For SBLOCA analyses, only the RELAP5/MOD2-B&W code is utilized. Sections 2.2 through 2.5 of Reference [20] detail the NRC restrictions placed on the codes used in the BWNT LOCA EM. All items were in compliance with the NRC restrictions based on the review performed according to the latest revision of Reference [20].

2. *The guidelines, code options, and prescribed input specified in Tables 9-1 and 9-2 in both Volume I and Volume II of BAW-10192P-A should be used in LBLOCA and SBLOCA evaluation mode applications, respectively.*

Response: Table 9-1 in Volume I (LBLOCA) of BAW-10192P-A is verified via use of Table 4 in Reference [20]. Compliance to the Table 4 restrictions for the LBLOCA analyses is listed in Reference [8]. Table 9-2 in Volume II (SBLOCA) of BAW-10192P-A is verified via use of Table 6 in Reference [20]. Compliance to the Table 6 restriction for the SBLOCA analyses is listed in References [9] and [10]. These tables also include inputs and restrictions placed on the individual codes that make up the BWNT LOCA EM as discussed in detail in Reference [20].

3. *The limiting linear heat rate for LOCA limits is determined by the power level and the product of the axial and radial peaking factors. An appropriate axial peaking factor for use in determining the LOCA limits is one that is representative of the fuel and core design and that may occur over the core lifetime. The radial peaking factor is then set to obtain the limiting linear heat rate. For this demonstration, calculations were performed with the axial peak of 1.7. The general approach is acceptable for demonstrating the LOCA limits methodology. However, as future fuel or designs evolve, the basic approaches that were used to establish these conclusions may change. AREVA must revalidate the acceptability of the evaluation model peaking methods if: (1) significant changes are found in the core elevation at which the minimum core LOCA margin is predicted or (2) the core maneuvering analyses radial and axial peaks that approach the LOCA LHR limits differ appreciably from those used to demonstrate Appendix K compliance.*

Response: This restriction is related only to LBLOCAs. The axial and radial peaks used in the LBLOCA analyses (Reference [8]) were similar with an axial peaking factor of 1.7 for all elevations and linear heat rates analyzed. The restriction states that AREVA must revalidate the acceptability of the evaluation model peaking methods if: (1) significant changes are found in the core elevation at which the minimum core LOCA margin is predicted or (2) the core maneuvering analyses radial and axial peaks that approach the LOCA LHR limit differ appreciably from those used to demonstrate 10 CFR 50 Appendix K compliance.

Several layers of screening criteria needed to show compliance with the BWNT LOCA EM restriction on peaking are detailed in Reference [60]. The effect of the axial peaking factor on the LOCA transient is from two blowdown affects and one reflood effect (Section 3, Reference [60]); CHF timing, elevation of dryout during core flow reversal, and reflood carryout rate. The method described in Reference [60] was based on B9/B10 fuel rod

analyses. It was confirmed in Reference [61] that the method remained applicable to the B11 fuel rod design, which has a different fuel and clad diameters and fuel assembly flow area compared to the B9/B10 fuel rod design. Since very similar trends were seen for both the B9/B10 (BWC CHF correlation) and the B11 (BWCMV correlation), it can be concluded that the CHF correlation does not impact the trend. The CHF timing is set by the initial enthalpy distribution in the channel and local fuel pin power distribution. This is confirmed by the similarities of the comparisons between the BHTP and BWC CHF correlations in a sensitivity study in Reference [59, Revision 04]). Therefore, the methods provided are valid for any current or past Mark-B fuel type (including but not limited to Mark-B4Z, Mark-B8, Mark-B9, Mark-B10, Mark-B11, and Mark-B12), including the Mark-B-HTP, that is ruptured-node limited or has similar ruptured- or unruptured-node PCTs predicted with the BWNT LOCA EM.

Four criteria were developed in Reference [60] to show compliance or to define a LOCA linear heat rate (LHR) limit penalty. These criteria are summarized below.

1) The fuel burnup must be compared to the LOCA LHR limits versus burnup. If the burnup is on the PCT-limited portion of the LOCA limit curve, then proceed to Step 2. If the burnup range is on the pin-pressure-limited portion of the curve, the restriction is met without any other conditions. That is, no axial peaking checks or linear heat rate limit adjustments are needed for pin pressure limited LHRs.

2) If the burnup is on the PCT-limited portion of the curve, then the power distribution analysis LOCA margins must be checked at all core elevations. If there is less than 5% LOCA margin, proceed to Step 3. If there is more than 5% margin, the restriction is met and no further checks are needed because the PCT at the maximum power distribution LHR will be lower than the BWNT LOCA EM PCT.

3) If the burnup is on the PCT-limited portion of the curve and there is less than 5% LOCA margin, then variations in the augmented peaking factor versus the 1.7 axial used in the LOCA analyses must be considered. The axial peak must be 1.65 or greater for 0 to 4 ft power peak elevations, 1.7±0.05 for 4 to 8 ft elevations, and 1.75 or less for 8 to 12 ft elevations. If these axial peaks are in compliance, the restriction is met and no further checks are needed. If they are not met, then proceed to Step 4 for the LOCA LHR limit reductions.

4) If the burnup is on the PCT-limited portion of the curve, there is less than 5% LOCA margin, and the axial peak is not in compliance, then the power distribution analysis must assign a LOCA LHR limit penalty to ensure that the BWNT LOCA EM PCT (based on the given LHR and APR of 1.7) is not under-predicted. The LHR limit penalty compensates for the known deviation between the augmented axial peak and the required peak. The LHR limit reductions, ΔLHR, are core elevation dependent:

$$\Delta LHR_{0\text{ to }4\text{ ft}} = \min\{0.0, [APF_{\text{power distribution analysis augmented peak}} - 1.65) \times 1.5\text{ kW/ft}]\}$$

$$\Delta LHR_{4\text{ to }8\text{ ft}} = \min\{0.0, [1.75 - APF_{\text{power distribution analysis augmented peak}}) \times 4.0\text{ kW/ft}]\} + \min\{0.0, [APF_{\text{power distribution analysis augmented peak}} - 1.65) \times 1.5\text{ kW/ft}\}$$

and

$$\Delta LHR_{8\text{ to }12\text{ ft}} = \min\{0.0, [1.75 - APF_{\text{power distribution analysis augmented peak}}) \times 4.0\text{ kW/ft}]\}$$

4. *The mechanistic ECCS bypass model is acceptable for cold leg transition (0.75 ft^2 to 2.0 ft^2) and hot leg break calculations. The nonmechanistic ECCS bypass model must be used in the large cold leg break ($\geq$ 2.0 ft^2) methodology since the demonstration calculations and sensitivities were run with this model.*

Response: As outlined in BAW-10192P-A Volumes I and II, different bypass models are used for large break and small break analyses. The nonmechanistic ECCS bypass model is used in large break analyses ($\geq$ 2.0 ft^2). The mechanistic ECCS bypass model is used for cold leg transition (0.75 ft^2 to 2.0 ft^2), hot leg, and all smaller sized cold leg breaks. As presented in Sections 4.2 and A.6.3 of Volume II of the EM (Reference [1]), the minimum break size range for cold leg transition breaks is determined based on those breaks that show initial clad DNB. The largest break size that did not undergo DNB was the 0.50 ft^2. Therefore, the analyses of break sizes larger than 0.50 ft^2 up to 2 ft^2 are included in the LBLOCA transition break range.

5. *Time-in-life LOCA limits must be determined with, or shown to be bounded by, a specific application of the NRC-approved evaluation model.*

Response: Time-in-life cases were explicitly examined for the LBLOCA analyses. Conditions appropriate to the specific time in life were used in the hot channel, while the BOL parameters were maintained in the average channel.

Time-in-life calculations for SBLOCA applications, which use a conservative composite set of reactivity parameter bounding for all TILs, are not required unless the fuel pin heatup is sufficient to cause cladding rupture. For the ONS LBLOCA analyses, AREVA used a method to explicitly examine times in life and the likelihood of rupture and its effect on the PCT for each case. The method used three supplemental pins with a plastic weighted heating ramp rate option, BOL fuel temperatures, and BOL initial oxide thicknesses. The hot channel is set to the pin pressure limit at EOL. The three supplemental pins use pin pressures consistent with BOL and two pressures roughly uniformly distributed between the BOL and EOL values. Clad rupture at cladding temperatures less than approximately 1600 F allows increased cooling because of the clad surface area increase. At these temperatures the metal-water reaction is not significant, therefore rupture is a beneficial event that if avoided will produce higher PCTs. For higher cladding temperatures where the metal-water reaction contributes to the peak clad temperature, the pin pressure variation will ensure that clad rupture is obtained at the most limiting time during the transient. To maximize the cladding temperatures, the BOL fuel stored energy and BOL oxide thicknesses are used. While these assertions are based on studies performed with Zr-4 cladding, they are equally applicable to M5® cladding, because the rupture behavior and metal-water reaction are not significantly different between the cladding materials.

A pure TIL calculation (with TIL-specific reactivity inputs, fuel stored energy, pin pressure, and cladding oxide thickness consistent with the TIL that produces the worst rupture time) would be performed if the composite case is judged to be overly conservative. The consistent case would also use the plastic-weighted normalized heating ramp rate to predict the fuel pin swell and rupture performance.

6. *LOCA limits for three pump operation must be established for each class of plants by application of the methodology described in this report. An acceptable approach is to demonstrate that three pump operating is bounded by four pump LHR limits.*

Response: Core power distribution analyses are performed at different core power levels for plant operation with four RCPs and also with three RCPs in operation. At partial power levels, the goal is to maintain the full power LHR limit for all core power levels above 50-percent full power. By preserving the full power LHR limit, the allowable peaking margins are increased in inverse proportion to the power level. The main challenge to maintaining a bounding PCT at the full power LHR limit is related to increases in the moderator temperature coefficient as power level decreases.

The partial power study serves to confirm that the LOCA consequences at full rated power are bounding for partial power conditions. The ONS partial power study was performed in Reference [46] and demonstrated that the LOCA consequences at full rated power are bounding of partial power conditions, considering three and four pump partial power levels and appropriate MTC values. The study concluded that full rated power LBLOCA LHR limits could be utilized at partial power levels without any penalty. These conclusions remain valid for the Mark-B-HTP analyses for the reasons discussed in Section 6.2.3.5.

7. *The limiting ECCS configuration, including minimum versus maximum ECCS, must be determined for each plant or class of plants using this methodology.*

Response: This restriction is primarily related to LBLOCAs and is not applicable to the SBLOCA analyses. The limiting LBLOCA ECCS configuration is a single ECCS train for CLPD breaks. For this application, the minimum containment pressure, derived from a maximum ECCS flow configuration that was applied to the LBLOCA analyses, with minimum ECCS injection. This composite approach conservatively considers the worst containment pressure with the minimum ECCS refill capacity to ensure that LBLOCA calculated consequences are bounding for any combination of available ECCS pumps.

8. *For the small break model, the hot channel radial peaking factor to be used should correspond to that of the hottest rod in the core, and not to the radial peaking factor of the 12 hottest bundles.*

Response: There are twelve assemblies modeled in the hot bundle, and each pin is peaked to the hot pin radial value

9. *The constant discharge coefficient model (discharge coefficient = 1.0) referred to as the "High or Low Break Voiding Normalized Value", should be used for all small break analyses. The model which changes the discharge coefficient as a function of void fraction, i.e. the "Intermediate Break Voiding Normalized Value", should not be used unless the transient is analyzed with both discharge models and the intermediate void method produces the more conservative result.*

Response: This restriction is related only to SBLOCA analyses. A constant discharge coefficient is used for SBLOCA analyses. Verification of this input is performed for each SBLOCA analysis.

10. *For a specific application of the AREVA small break LOCA methodology, the break size which yields the local maximum PCT must be identified. In light of the different behaviors of the local maximum, AREVA should justify its choice of break sizes in each application to assure that either there is no local maximum or the size yielding the maximum local PCT has been found. Break sizes down to 0.01 ft^2 should be considered.*

Response: This restriction is related only to SBLOCA analyses. The SBLOCA break spectrums in Reference [9] and [10] are performed to determine the local maximum PCT. The break sizes analyzed are chosen to ensure that

the local peak has been appropriately defined. The full spectrum of break sizes performed for the Mark-B-HTP fuel covers this requirement.

11. *B&W-designed plants have internal reactor vessel vent valves (RVVVs) that provide a path for core steam venting directly to the cold legs. The BWNT LOCA evaluation model credits the RVVV steam flow with the loop steam venting for LBLOCA analyses. The possibility exists for a cold leg pump suction to clear during blowdown and then reform during reflood before the evaluation model analyses predict average core quench. Since the REFLOD3B code cannot predict this reformation of the loop seal, AREVA is required to run the RELAP5/MOD2-B&W system model until the whole core quench, to confirm that the loop seal does not reform. This demonstration should be performed at least once for each plant type (raised loop and lowered loop) and be judged applicable for all LBLOCA break sizes.*

Response: This restriction is related only to LBLOCA analyses. This verification analysis was performed using the RELAP5 system model for the 177-FA LL plant design in Reference [72]. The results of that analysis confirmed that a loop seal does not reform prior to whole core quench. Since these results were obtained using the 177-FA LL model, it can be concluded that Restriction #11 of the evaluation model is met for the ONS plants.

9.0 REFERENCES

1. AREVA NP Proprietary Topical Report BAW-10192P-A, Revision 0, "BWNT LOCA – BWNT Loss-of-Coolant Accident Evaluation Model for Once-Through Steam Generator Plants", June 1998.
2. AREVA NP Proprietary Topical Report BAW-10227P-A, Rev. 1, "Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel", June 2003.
3. AREVA NP Proprietary Topical Report BAW-10162P-A, Rev. 0, "TACO3 – Fuel Pin Thermal Analysis Code", October 1989.
4. AREVA NP Topical Report BAW-10095-A, Rev. 1, "CONTEMPT – Computer Program for Predicting Containment Pressure-Temperature Response to a LOCA", April 1978.
5. AREVA NP Proprietary Topical Report BAW-10164P-A, Rev. 6, "RELAP5/MOD2-B&W – An Advanced Computer Program for Light Water Reactor LOCA and Non-LOCA Transient Analysis", June 2007.
6. AREVA NP Proprietary Topical Report BAW-10171P-A, Rev. 3, "REFLOD3B – Model for Multinode Core Reflooding Analysis", December 1995.
7. AREVA NP Topical Report BAW-10166P-A, Rev. 5, "BEACH – A Computer Program for Reflood Heat Transfer During LOCA", November 2003.
8. AREVA NP Proprietary Document 32-9131003-000, "Oconee Full Core Mark-B-HTP LBLOCA Analysis," October 2010.
9. AREVA NP Proprietary Document 32-9131352-001, "ONS-2 100% Mark-B-HTP Full Core SBLOCA Analyses," November 2010.
10. AREVA NP Proprietary Document 32-9159803-000, "ONS 50% Partial Power Steam Generator ADV Partial Blowdown SBLOCA Analysis," July 2011.
11. AREVA NP Proprietary Document 32-5015422-00, "Allowed Transient Oxidations Fraction", November 2001.
12. AREVA NP Document 86-5024543-003, "ONS ROTSG LOCA Summary Report", May 2008.
13. AREVA NP Letter FAB10-543, J.W. Davis to T.C. Geer, Subject: "10 CFT 50.46 LOCA Report of EM Error Correction (AREVA CR 2010-4150: EOC SBLOCA Axial Power Shape)", August 2010.
14. AREVA NP Topical Report BAW-2292, Rev. 0, "Framatome Mark-B Fuel Assembly Spacer Grid Deformation in B&W Designed 177 Fuel Assembly Plants", February 1997.
15. NRC Letter from David B. Mathews (NRC) to J. H. Taylor (AREVA NP), Subject: Safety Evaluation of the Babcock & Wilcox Owners Group Submittal Relating to Assumption in the B&W ECCS Analyses (TAC No. M95480), August 1997.
16. AREVA NP Document 51-5006923-01, "PSC 2-98 Transient Evaluation," October 2000.
17. AREVA NP Proprietary Document 51-5066841-01, "GSI-191 Downstream Effects Evaluation for Oconee", April 2006.
18. AREVA NP Topical Report BAW-2374, Rev. 2, "Risk-Informed Assessment of Once-Through Steam Generator Tube Thermal Loads due to Breaks in Reactor Coolant System Upper Hot Leg Large-Bore Piping", December 2006.
19. AREVA NP Document 51-9131004-001, "Oconee Full Core Mark-B-HTP LOCA AIS", March 2011.
20. AREVA NP Proprietary Document 51-5001731-04, "BWNT LOCA EM Limitations & Restrictions", July 2007.
21. AREVA NP Proprietary Document 32-5024295-01, "Oconee ROTSG CFT IC & Cont. Pres. Study", October 2007.
22. AREVA NP Document 32-9154977-000, "ONS 50% Partial Power Mark-B-HTP SBLOCA Model Development," June 2011.
23. AREVA NP Report 47-5022659-00, "Draft 1994 NRC Annual Report", December 2002. *For Information Only*.
24. AREVA NP Report 47-5022658-00, "Draft 1995 NRC Annual Report", December 2002. *For Information Only*.

25. AREVA NP Report 47-5022654-00, “Draft 1998 ECCS Annual Report”, December 2002. *For Information Only*.
26. AREVA NP Report 47-5007106-00, “1999 Draft ECCS Annual Letter”, February 2000. *For Information Only*.
27. Not Used.
28. Not Used.
29. AREVA NP Report 47-5011843-00, “2000 Draft ECCS Annual Letter”, April 2001. *For Information Only*.
30. AREVA NP Report 47-5017330-00, “2001 Draft ECCS Annual Report”, April 2002. *For Information Only*.
31. NRC Letter from H. N. Berkow (NRC) to J. Mallay (AREVA NP), Subject: Evaluation of Framatome ANP Preliminary Safety Concern (PSC) 2-00 Relating to Core Flood Line Break and Operator Action Time (TAC No. MA 9973), Project No. 728, April 2003. See AREVA NP Document 38-5063852-00.
32. AREVA NP Document 86-5044228-00, “B&W LOCA – Two-Phase RCP Degradation”, July 2004.
33. Letter dated January 10, 2005 from R. A. Gramm (USNRC) to J. Holm (AREVA NP), Subject: Request for Amendment of Safety Evaluation for “Report of Preliminary Safety Concern (PSC) 2-00 Related to Core Flood Line Break with 2-minute Operator Action Time” (TAC No. MA 9973). See AREVA NP Document 38-5063854-00.
34. Not Used.
35. Not Used.
36. AREVA NP Document 38-9155506-000, “SBLOCA Data to Support ONS-1, 2 and 3 Full Core Mark B HTP,” (DPND-1553.63-0033, Rev. 6), February 2011.
37. Not Used.
38. Not Used.
39. AREVA NP Proprietary Document 86-9069476-001, “ONS Mixed-Core Mark-B-HTP LOCA Summary Report,” September 2009.
40. AREVA NP Proprietary Document 32-5029696-006, “Mark-B-HTP Fuel Assembly Faulted Component Analysis” March 2011.
41. AREVA NP Proprietary Document 51-5004620-00, “Definition of LOCA for Oconee”, June 1999.
42. Not used.
43. AREVA NP Proprietary Document 32-1232655-01, “Oconee Pump & ECC/Cont Pres Studies”, September 2003.
44. AREVA NP Proprietary Topical Report BAW-10192P, Revision 2, “BWNT LOCA – BWNT Loss-of-Coolant Accident Evaluation Model for Once-Through Steam Generator Plants,” August 2008.
45. AREVA NP Topical Report 43-10184-PA-00, "GDTACO – Urania Gadolinia Thermal Analysis Code," BAW-10184P-A, Revision 0. March 2001.
46. AREVA NP Document 32-1234828-00, "Oconee Partial Power Study," March 1995.
47. AREVA NP Document 32-1232704-02, "Oconee Mk-B11 LOCA Limits," June 1995.
48. AREVA NP Document 32-5025007-02, "ONS ROTSG Mk-B11 LBLOCA Analysis," March 2004.
49. AREVA NP Document 32-5005322-00, "177LL Plant T_{ave} Reduction Analysis," October 1999.
50. AREVA NP Document 32-1267182-06, “Pre and Post LOCA EDFs,” March 2007.
51. AREVA NP Topical Report BAW-10186P-A, Rev. 2, “Extended Burnup Evaluation”, June 2003.
52. AREVA NP Document 32-1266117-02, “New Actinides for LOCA Analyses”, October 2001.
53. AREVA NP Document 51-1203953-02, “R5/M2 B&W Plant LOCA Modeling Guidelines,” June 2003.
54. *Babcock and Wilcox Canada Report No.: BWC-006K-SR-02, Revision 1, “Duke Power Company, Oconee Nuclear Station Units 1, 2, and 3 – Replacement Steam Generators Transient Analysis Stress Report”, August 2003, (Proprietary).
55. Not Used.

56. Schyltz, R. R., Sandervag, O., and Hanson, R. G., “Marviken Power Station Critical Flow Data: A summary of Results and Code Assessment Applications”, Nuclear Safety, Vol. 25, No. 6, November-December 1984.
57. AREVA NP Document 51-5006132-00, “PSC 1-99 Res & Other PCT Changes,” January 2000.
58. AREVA NP Document 32-1232665-00, “Mk-B11 LBLOCA Spectrum Study”, March 1995.
59. AREVA NP Document 32-5024151-05, "CR-3 MARK-B-HTP LBLOCA," August 2003.
60. AREVA NP Document 51-5004541-00, “Radial vs. Axial Core Peaking for LOCA,” June 1999.
61. AREVA NP Document 32-5004379-01, "Duke Mk-B11 LBLOCA" December 2003.
62. AREVA NP Document 32-5025222-03, “ONS 100% 2568 MWt ROTSG SBLOCA,” March 2004.
63. AREVA NP Document 32-1239313-00, “LOCA Fuel Temperature Changes,” October 1995.
64. AREVA NP Document 51-9095650-000, “Post-LOCA Energy Deposition Factor for High Burnup Gad Pins,” December 2008.
65. Not Used.
66. Not Used.
67. AREVA NP Document 51-5009856-01, “Summary of PSC 2-00 Analyses,” August 2001
68. AREVA NP Document 32-1232670-08, “Oconee Mk-B11 SBLOCA Spectrum,” December 2001.
69. Not Used.
70. AREVA NP Document 32-9126518-000, “Decay Heat for LOCA analysis with RELAP5 Default Actinide Model,” February 2010.
71. AREVA NP Document 32-9129893-000, “New SBLOCA Axial Power Shape,” February 2010.
72. AREVA NP Document 32-1266180-00, "RELAP5 Loop Seal Clearing for 177-LL," July 1997.

*References marked by asterisk (*) are maintained and controlled by Duke Energy. Per AREVA NP procedures, use of these references is allowed in safety-grade calculations with the approval of the project manager. The Project Manager’s approval on the signature page authorizes the use of these documents.