Framatome Report ANP-3655NP, Revision 0,
Brunswick MELLLA+ CRDA Assessment with Draft Criteria
(Non-Proprietary)

framatome

Brunswick MELLLA+ CRDA Assessment with Draft Criteria

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Nature of Changes

Item	Section(s) or Page(s)	Description and Justification
1	All	Initial Issue

Contents

This document contains a total of 35 pages.

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Nomenclature

Acronym	Definition
ΔH	deposited enthalpy
AST	alternative source term
BOC	beginning of cycle
BSEP	Brunswick Steam Electric Plant
BWR	boiling water reactor
cal/g	calories per gram
CRDA	control rod drop accident
CWSR	cold work stress relieved
EOC	end-of-cycle
FGR	fission gas release
GWd/MTU	Giga-Watt days per metric ton of uranium
HEX	excess clad hydrogen
LAR	license amendment request
MELLLA+	maximum extended load line limit analysis plus
MPa	Mega-Pascal
MWt	Mega-Watts thermal
NRC	Nuclear Regulatory Commission
PCMI	pellet clad mechanical interaction
PHEX	peak hot excess
ppm	parts per million
RAI	request for additional information
RFI	rod failure increase
RG	regulatory guide
RIA	reactivity initiated accident
RPF	radial peaking factor
SRA	stress relieved and annealed (aka CWSR)
SRP	standard review plan
SSRF	steady state release fraction
TFGR	transient fission gas release
TOTR	total release fraction (SSRF + TFGR)
UFSAR	Updated Final Safety Analysis Report
wppm	parts per million weight percent

1.0 INTRODUCTION

This report has been prepared in response to NRC RAI SNPB-RAI-2 for the Brunswick license amendment request (LAR) maximum extended load line limit analysis plus (MELLLA+). The Brunswick MELLLA+ LAR requests an extension in the minimum core flow to 85% of rated from the current power flow map at rated conditions, currently licensed at 2923 MWt.

The issue being addressed in this report is draft NRC criteria for the BWR Control Rod Drop Accident. SRP4.2 Appendix B (Reference 1) provided interim criteria for new plants in 2007. New draft criteria are provided in Draft Regulatory Guide DG-1327(Reference 3). This item is not part of the current licensing basis for BSEP. However, since the issue represents potential changes to regulatory guidance, the NRC staff Requested Additional Information with respect to the potential impact of the draft criteria for the CRDA. At the time of the RAI, the revised criteria is not finalized nor has the NRC approved a Framatome method to evaluate the CRDA with the revised criteria.

The approach taken in responding to the RAI is to utilize a combination of approved methodologies as well as components of methods that are not yet part of the Framatome NRC approved methodologies.

The content of this report is a response to NRC SNPB-RAI-2 with respect to the potential impact of criteria similar to that provided in SRP4.2 and given in DG-1327. This assessment does not support or propose any changes to the Brunswick plant CRDA licensing basis.

The RAI being answered is not specific to MELLLA+ but this response demonstrates that the new draft criteria can be met for the CRDA analysis for BSEP Units 1 and 2 if the criteria* were to be issued.

* It is anticipated that minor changes will occur in the criteria in response to public comment on DG-1327. No significant changes are anticipated that would alter the conclusion of this response.

2.0 DRAFT FUEL CRITERIA FOR REACTIVITY INITIATED ACCIDENT

Reactivity Initiated Accidents (RIAs) are postulated accidents involving the sudden and rapid insertion of positive reactivity. For Boiling Water Reactors (BWR), the limiting RIA scenario is the Control Rod Drop Accident (CRDA). In support of the BSEP MELLLA+ LAR, evaluations of the BWR CRDA have been performed to address the current BSEP licensing basis using Framatome NRC approved methodology, as summarized in Section 2.1.1.

Draft guidance (Reference 3) for the RIA was published in November, 2016. The draft guidance addressed in this document is described in Section 2.1.2 and the evaluations are subdivided into two primary areas: 1) Fuel Melt, and 2) Fuel Failures.

The potential for cladding failure from fuel melt in the startup range is precluded in this evaluation by demonstrating that the incipient fuel melt temperature is not reached. The evaluation for fuel melt is addressed in Section 2.2 of this report, including impact on core coolability criterion 1 and 2.

Fuel failure assessment against the draft acceptance criteria is the subject of Section 2.3. The fuel failure subsections address various evaluations needed to support the overall fuel failure assessment as summarized below:

- Section 2.3.1: PCMI Cladding Failure Criteria – Addresses failures due to pellet clad mechanical interaction.
- Section 2.3.2: High Temperature Failure Threshold – Addresses potential for high temperature failures, including impact of internal rod pressure.
- Section 2.3.3: Release Fraction Scaling – Addresses the impact of including the transient fission gas release into the isotopic release fractions. This can impact the existing dose assessment. A method of adjusting the number of calculated rod failures is provided to compensate and maintain the current dose assessment basis.
- Section 2.4: Rod Failure Assessment – Combines the results of the previous subsections into a total number of fuel failures using the draft criteria.

This evaluation utilizes a combination of methodologies and analyses to comparatively address the impact of the draft regulatory acceptance criteria for CRDA for BSEP. In addition, significant conservatisms have been included as summarized in Section 2.5 of this report.
The draft criteria differ from that of SRP4.2 Appendix B. In the tabulation of results, the failure criteria of both SRP4.2 and DG-1327 are included.

2.1 *Regulatory Acceptance Criteria*

2.1.1 Current Licensing Basis Criteria

The current Regulatory Guide (RG) 1.77 RIA criterion is that the peak enthalpy must remain below a value of 280 cal/g. As described in Section 15.4.6 of the Updated Final Safety Analysis Report (UFSAR), analyses are performed for each reload cycle to ensure that a peak enthalpy of 280 cal/g is not exceeded. Furthermore, any rods that exceed a value of 170 cal/g are assumed to fail. The number of failed rods for ATRIUM 10XM supported by the Alternative Source Term (AST) CRDA dose assessment for BSEP is 986.

Analyses have been performed using Framatome's NRC approved methodology to support the MELLLA+ LAR and the results from the reload analysis report (Reference 2) are summarized in Table 2-1.

Table 2-1 Summary of CRDA Results with Current Methodology

	Representative Cycle	Criteria
Peak Fuel Enthalpy (cal/g)	180.9	< 280 cal/g*
Number of Failed Rods	182	≤ 986 (Number of rods exceeding 170 cal/g)

2.1.2 Draft NRC Criteria

Reference 3 is a NRC Draft Regulatory Guide intended to replace current regulatory criteria as well as the interim criteria of SRP Section 4.2 (Reference 1). The draft criteria from Reference 3 are summarized Table 2-2. For the PCMI cladding failure criteria, only the low temperature criteria are used in the evaluation. The low temperature PCMI criteria are conservative relative to the high temperature PCMI cladding failure criteria.

* The current regulatory guidance is to limit the peak fuel enthalpy to < 280 cal/g. For the licensing analyses submitted as part of the MELLLA+ LAR, a 230 cal/g limit has been utilized due to the emerging changes to RIA acceptance criteria. The use of the lower enthalpy limit is conservative with respect to the current licensing basis.

Table 2-2 Summary of Draft RIA Acceptance Criteria

Fuel Cladding Failure	Pellet Clad Mechanical Interaction (PCMI)	Figure 2-1	
		Excess Clad Hydrogen, HEX (wppm)	Peak Radial Ave Enthalpy (cal/g)
		$\leq$ 117	150
		> 117	406 – 53.8 ln(HEX)
		Figure 2-2	
		Excess Clad Hydrogen, HEX (wppm)	Peak Radial Ave Enthalpy (cal/g)
		$\leq$ 165	150
		> 165	424 – 53.8 ln(HEX)
	High Cladding Temperature Failure	Figure 2-3	
		Clad Differential Pressure (Mpa)	Peak Radial Ave Enthalpy (cal/g)
		$\Delta P \leq 1.0$	170
		$1.0 > \Delta P < 4.5$	$170-(\Delta P-1.0)*20$
		$\Delta P \geq 4.5$	100
	Fuel Melt	Rod Failure Assumed if fuel temperature anywhere in the pellet exceeds incipient fuel melting conditions.	
Core Coolability		1. Peak radial average fuel enthalpy < 230 cal/g. 2. A limited amount of fuel melt is acceptable provided it is restricted to: (1) fuel centerline region, and (2) less than 10% of pellet volume. For the outer 90% of the pellet volume, peak fuel temperature must remain below incipient fuel melting conditions.	

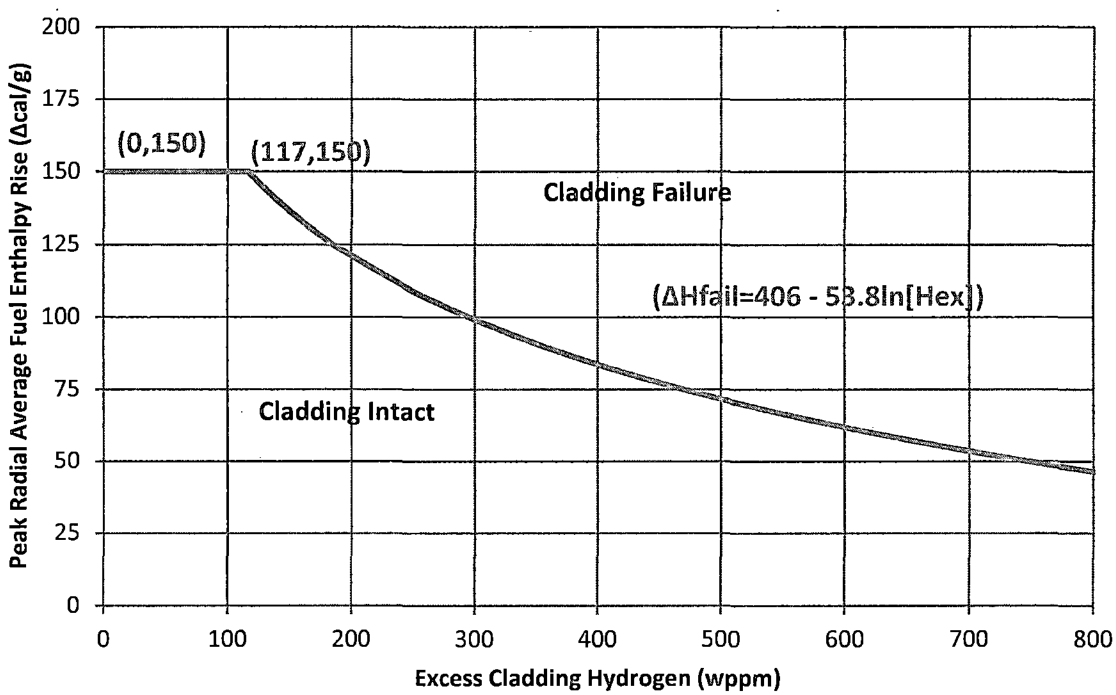

Figure 2-1 PCMI Failure Threshold for SRA Cladding Low Temperature

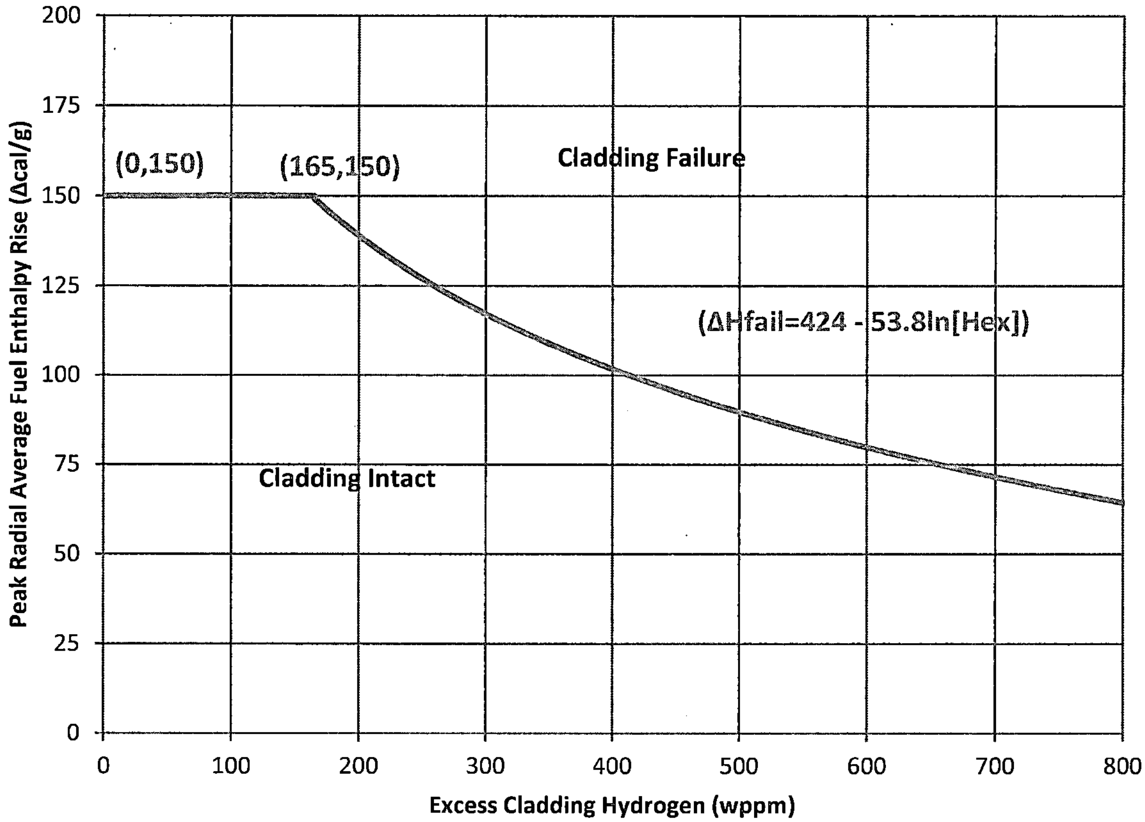

Figure 2-2 PCMI Failure Threshold for SRA Cladding High Temperature

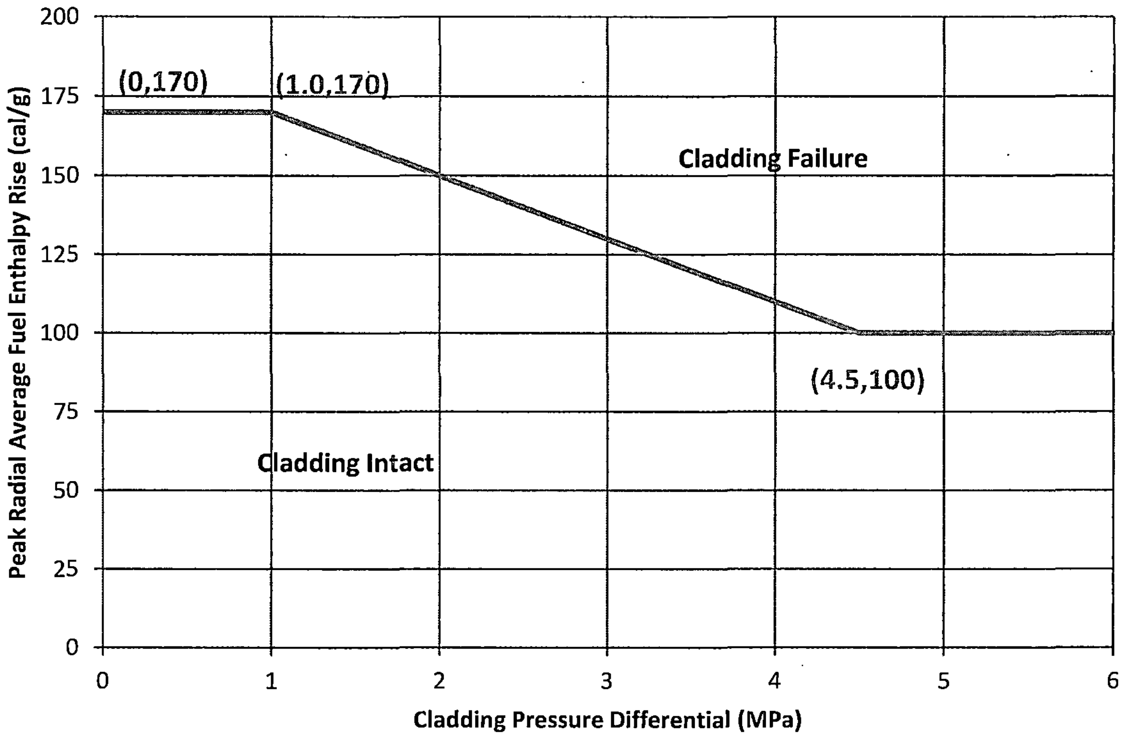

Figure 2-3 High Temperature Cladding Failure Threshold

2.1.3 System Pressure and CPR

The draft regulatory guidance (Reference 3) as well as SRP4.2 (Reference 1) maintain the acceptance criteria for the CRDA with respect to system pressure and CPR. These criteria for the CRDA are summarized in Table 2-3.

Table 2-3 Summary of Pressure and CPR criteria for CRDA Evaluation

System pressure	The maximum reactor coolant system pressure should be limited to the value that will cause stresses to not exceed Emergency Condition (Service Level C), as defined in Section III of the ASME Boiler and Pressure Vessel code
≥ 5% power	Rod failure when heat flux exceeds thermal design limits (critical power ratio)

The impact on system pressure was evaluated in Section 7.8 of Reference 8. The evaluation concluded that there is a local pressure increase in a few assemblies, however there is little change in the core system pressure in either the startup range or the power range. Therefore, the CRDA would not result in a reactor pressure which would cause increased stress to exceed the "Service Level C" ASME Boiler and Pressure Vessel Code.

The CPR response was evaluated in Section 7.7 of Reference 8 at various power levels to demonstrate that the potential number of rod failures would be [ ] The Reference 8 evaluation was performed on a BWR-4 licensed at EPU conditions. This analysis was supplemented in the response to RAI-7 in Reference 10 to address [ ] (Reference 11).

2.2 *Core Coolability*

This section addresses the core coolability criteria 1 and 2 of Table 2-2.

Core coolability criterion 1 is addressed by limiting the peak radial enthalpy to 230 cal/g. The results provided in Table 2-1 demonstrate that this criterion is met for the Brunswick ATRIUM 10XM core.

To address core coolablity criterion 2, a fuel melt curve was established utilizing the RODEX4 methodology (Reference 6). The RODEX4 code was used to establish the steady state pellet radial power profile as a function of exposure. [

]

(Definition of prompt pulse is consistent with SRP Section 4.2 (Reference 1) Appendix B, and is the radial average fuel enthalpy rise at the time corresponding to one pulse width after the peak of the prompt pulse).

[

]

As a consequence of the buildup of fissile plutonium isotopes due to the resonance capture of epithermal neutrons by U238 at the pellet surface, the pellet radial power profile becomes increasingly peaked at relatively high exposures. The temperature versus enthalpy relationship for UO2 is defined in the RODEX4 methodology. Given this relationship, a fuel melt enthalpy is determined. [

] The resulting fuel melt threshold is provided in Figure 2-4.

[ ]

Figure 2-4 Maximum Radial Prompt Average Enthalpy versus Rod Exposure

The current Framatome CRDA methodology (Reference 4) is based on adiabatic conditions. It is well understood that the pellet heats up in a nearly adiabatic condition during the power deposition; therefore variations in the gap thermal conductivity do not have a significant impact on the peak pellet temperature. **[**

] The pellet radial temperature profile peaked at the RODEX4 melting temperature is shown in Figure 2-5.

[

]

Figure 2-5 Radial and Exposure Dependence of the Pellet Temperature Distribution

[

]

The Framatome COTRANSA2 (Reference 7) simulated startup range rod drops with ATRIUM 10XM fuel were evaluated. The enthalpy at the time corresponding to one pulse width after the peak of the prompt pulse was compared to the COTRANSA2 final enthalpy [

]

[

]

2.3 *CRDA Fuel Rod Failure Evaluation*

As discussed in the previous section, maintaining a radial average enthalpy less than [

] The draft RIA criteria evaluated in this report includes rod failure thresholds for pellet clad mechanical interaction and high temperature. The following subsections address these criteria as well as adjustments to the number of calculated rod failures to address the impact of including transient fission gas release within the Brunswick licensing basis.

2.3.1 PCMI Cladding Failure Criteria

The approved methodology for the current licensing basis at Brunswick (Reference 4) is based on a two-dimensional (r-z) geometry in which the core is divided into three zones. The currently approved methodology (XN-NF-80-19) parametrized rod drops such that the deposited enthalpy is a look up function based on static rod worth and peaking factors. Framatome has developed and submitted a new methodology (Reference 8) which is based on the AURORA-B methods which includes a 3D kinetics solution for the rod drop. (The terms XN-NF-80-19 and AURORA-B will be used to identify the methodologies.) The results of the evaluation with the XN-NF-80-19 methodology are provided in Table 2-4 which indicates fuel failures. The AURORA-B results for the same cycle are illustrated in Figure 2-6. (The PCMI failure threshold of Reference 3 was added to the results from the AURORA-B LTR.)

A direct one to one comparison is not straight forward. However, the maximum deposited enthalpy with the XN-NF-80-19 methodology is similar between Brunswick and the sample plant used in the AURORA-B LTR (Reference 8). The results in Figure 2-6 indicate an approximate margin of [ ] is maintained to the PCMI failure thresholds.

Additional comparisons were made between the sample plant core and the Brunswick Unit 1 Cycle 19 core.

Table 2-4 Summary of Sample Plant CRDA Results with XN-NF-80-19 Methodology

		Criteria
Peak Fuel Enthalpy (cal/g)	187.0	< 280 cal/g
Number of Failed Rods	364	< 2000 (Number of rods exceeding 170 cal/g) *

Dropped rod worth:

The MICROBURN-B2 simulator (Reference 5) was used to determine dropped rod worths. A comparison of dropped rod worths at 68F was made between the Brunswick Unit 1 Cycle 19 Core and the Sample Plant. The five highest rod worths above [ ] are provided as a function of time in cycle in Table 2-5 .

Table 2-5 Highest Dropped Rod Worth Comparison

[ ]

The Brunswick cycle has higher dropped rod worths at BOC and PHEX reactivity than the Sample plant. However the Sample plant has a significantly higher EOC rod worths. As the core exposure increases the values of the delayed neutron fraction (β) decreases such that the amount of reactivity insertion to reach prompt criticality decreases. [ ]

* The number of rod failures was conservatively assigned to be all rods in each assembly with a rod that exceeded 170 cal/g.

[

] With consideration of β, the sample plant has a higher insertion of reactivity relative to prompt critical.

Cladding Hydrogen Content:

The high worth BOC rod drops for BRK1-19 occur in interior locations with a combination of fresh and once burned fuel. The approved hydrogen model of Reference 9 was used in the process of establishing the PCMI failure thresholds. The minimum hydrogen dependent failure threshold [

] of each assembly. For the rod drops at peak, the minimum hydrogen dependent failure threshold is [

] away from the dropped rod.

Given that the maximum deposited enthalpy values with the XN-NF-80-19 methodology are similar between the Brunswick cycle and the sample plant, the dropped rod worth's between the plants are similar, and hydrogen dependent cladding failure thresholds are similar it is reasonable to conclude that the Brunswick cycle would not exceed the PCMI failure threshold or that it would only be exceeded by a small amount.

Based on the qualitative comparison of the BSEP analysis to that for the sample plant of Reference 8 it is concluded that for BRK1-19 demonstration cycle [

]

Figure 2-6 Prompt Enthalpy Rise versus Cladding Hydrogen Content with AURORA-B Methodology

2.3.2 High Temperature Failure Threshold

The current approved methodology does not provide a direct method for addressing this failure. The high temperature failure criteria were evaluated in Reference 8 against SRP 4.2 Appendix B criteria and the results are provided in Figure 2-7. No high temperature failures were identified against the SRP 4.2 criteria. An evaluation against the high temperature threshold of DG-1327 was included in Reference 10 and is provided in Figure 2-8. Figure 2-8 provides the maximum enthalpy in the [ ]

The maximum total enthalpy for the drops is slightly more than [ ] cal/g (Table 2-6).

A conservative assumption would be that four assemblies had total enthalpy of [ ] The conservatism of this assumption is supported since the average total enthalpy is less than [ ] cal/g and the results presented in Figure 2-8 indicate no failures.

Table 2-6 Total Deposited Enthalpy for Peak and Average Rod

[ ]

[ ]

[ ]

Figure 2-7 Total Enthalpy versus High Temperature Failure Threshold (SRP4.2 AppB)

[ ]

Figure 2-8 Total Enthalpy versus High Temperature Failure Threshold (DG-1327)

2.3.3 Release Fraction Scaling

The dose consequence for the CRDA determined for rated conditions at Brunswick are summarized in the BSEP UFSAR. The current licensing basis dose evaluation allows 986 ATRIUM 10XM rods to fail. (Within this section the dose scaling is only completed for DG-1327 release terms.)

A component of the draft acceptance criteria is revised release fractions proposed to account for transient fission gas release (TFGR). The transient release terms (from Reference 3) expressed as a fraction are:

Peak Pellet BU < 50 GWd/MTU: $$TFGR = \frac{[(0.26 * \Delta H) - 13]}{100} \geq 0$$

Peak Pellet BU ≥ 50 GWd/MTU: $$TFGR = \frac{[(0.26 * \Delta H) - 5]}{100} \geq 0$$

Where,

TFGR is transient fission gas release (must be ≥ 0)

ΔH fuel enthalpy increase (cal/g)

Three multipliers are established in Reference 3 to be applied to the above TFGR term:

Group	Multiplier	Applied to
Stable long lived isotopes (e.g.,Kr-85)	1.0	Kr-85
Cs-134 and Cs-137	1.414	Alkali Metals
Short-lived radioactive isotopes (i.e., I-131, I-132, I-133, I-135) and xenon and Krypton noble gases except Kr-85 (i.e., Xe-133, Xe-135, Kr-85m, Kr-87, Kr-88)	0.333	Iodine's, nobles, halogens

The transient release term is combined with the existing steady state release fraction to produce revised release fractions for the CRDA.

The steady state release fractions utilized for the BSEP CRDA licensing basis are:

I-131	Kr-85	Other Nobles	Other Halogens	Alkali Metals
0.10	0.10	0.10	0.10	0.12

To account for the inclusion of the TFGR within the release fractions, a conservative approximation of the axial enthalpy shape was utilized to determine the increase in the release for a rod based on the maximum deposited enthalpy and establish modified rod release fractions. The axial enthalpy shape is assumed to be [ ] remainder of the nodes. Based on a review of rod drop evaluations this assumption provides a conservative representation of the total enthalpy deposited in the fuel rod for evaluating the transient fission gas release.

An example of the axial enthalpy distribution for eight rod drops is shown in Figure 2-9. The corresponding TFGR fractions for the eight rod drops based on the deposited enthalpy are given in Figure 2-10. A comparison of the total gas release based on the actual enthalpy to that [ ] for low burnup fuel (< 50GWd/MTU) is provided in Table 2-7.

Table 2-7 Actual TFGR Fraction versus [ ] Basis

[ ]

[ ]

Figure 2-9 Axial Enthalpy Profile for Eight Representative Rod Drops

[ ]

Figure 2-10 Nodal Transient Fission Gas Release Fractions

The total rod release fraction for a given nuclide group can then be reformulated as:

[ ]

Where,

[ ]

Two steady state release fractions are used in the BSEP evaluation: 0.10 for non-Alkali metals and 0.12 for Alkali metals. Since Krypton 85 uses the smaller steady state release fraction in the BSEP licensing basis and Cesium has the largest group multiplier, the TFGR term that will have the largest impact will be either that for Cs (Alkali Metals) or the Krypton 85. [

]

Krypton 85:

Alkali Metals:

The largest RFI occurs from the Alkali metals with a multiplier of 1.414. Therefor the RFI determined based on Alkali metals will be used for all isotopes.

The number of rod failures can be increased by this factor for evaluation with respect to the BSEP current licensing basis. (This term is fuel pin specific based on the enthalpy increase in a specific fuel pin.) For this comparative evaluation, the maximum pin enthalpy increase is assumed for all rods.

The RFI is bundle dependent based on the maximum deposited enthalpy and bundle exposure for this comparative evaluation.

The application of the RFI factors is provided in Section 2.4.

2.4 *Rod Failure Assessment*

From Section 2.3.1 it is determined that it is unlikely there are PCMI failures for this cycle. [ ]

From Section 2.3.2 it is assumed that [ ]

For the release fraction it assumed that half of the failures are below 50 GWd/MT. This is reasonable in that assemblies around the rod include lower exposed assemblies with sufficient reactivity to result in deposited enthalpies of this magnitude. Using the formulation from Section 2.3.3 the following RFIs are tabulated in Table 2-8. (Equivalent modified release fractions are provided in Table 2-10 along with the base release fractions from the BSEP UFSAR.)

Table 2-8 Enthalpy and Exposure Dependent RFI Factors

[ ]

These RFIs are then applied to the assigned rod failures assuming half are below 50 GWd/MT:

Table 2-9 Revised Rod Failure Count

[ ]

The conservative estimate of rod failures is [ ] from PCMI. Assuming that half of the rods have a burnup >50GWd/MT and applying the appropriate release scaling factor an equivalent of [ ] rods fail with respect to the current BSEP CRDA dose consequence evaluation which remains below the allowed 986 ATRIUM 10XM rod failures. The current radiological consequences determined for BSEP are provided in Table 2-11 along with

the fraction of the regulatory limit. The dose consequences for the CRDA are less than 6% of the regulatory limits.

Table 2-10 Enthalpy and Exposure Dependent Total Release Fractions

		I-131	Kr-85	Other Nobles	Other Halogens	Alkali Metals
BSEP UFSAR		0.10	0.10	0.10	0.10	0.12

[ ]

Table 2-11 BSEP CRDA Radiological Consequences

	TEDE Dose (REM) Receptor Location		
	CR	EAB	LPZ
BSEP AST Dose EPU	0.28	0.27	0.22
Allowable TEDE Limit	5	6.3	6.3
Fraction of Limit	0.056	0.043	0.035

2.5 *Summary of Inherent Conservatisms*

The CRDA evaluation with Framatome's current approved methodology and BSEP current licensing basis resulted in an acceptable number of fuel failures (Table 2-1). With the evaluation of the CRDA in consideration of the draft criteria, the number of failures would increase with the currently approved methodology (Reference 4). However with the use of currently submitted methodology (Reference 8), the comparative evaluation does not indicate a significant increase in the number of rod failures.

This comparative evaluation of the rod drop involves numerous conservatisms:

[ ]

The actual dose consequence evaluation contains conservatism in the calculation and in the margin to the regulatory requirement.

2.6 *Conclusion*

This document has addressed the impact of the draft acceptance criteria similar to that of Reference 3 and Reference 1 in the startup range if it were to be implemented during BSEP MELLLA+ operation. In summary, it was found that:

[ ]

It is therefore concluded that continued evaluation of BSEP reload cycles at the proposed MELLLA+ conditions with the currently approved methodology will continue to ensure that the current licensing basis and dose limits are met. Furthermore, based on the results of the evaluations above, it is reasonable to conclude that the BSEP will comply with the proposed new acceptance criteria for the CRDA at MELLLA+ conditions with the implementation of new methodology for evaluating the CRDA.

This response to RAI SPB-RAI-2 for the Brunswick MELLLA+ LAR demonstrates that the new draft criteria can be met for the CRDA analysis for BSEP Units 1 and 2 if the criteria* were to be issued.

* It is anticipated that minor changes will occur in the criteria in response to public comment on DG-1327. No significant changes are anticipated that would alter the conclusion of this response.

3.0 REFERENCES

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