ArevaEPRDCPEm Resource

From:	KOWALSKI David (AREVA) [David.Kowalski@areva.com]
Sent:	Tuesday, July 30, 2013 5:14 PM
To:	Snyder, Amy
Cc:	Chowdhury, Prosanta; ANDERSON Katherine (EXTERNAL AREVA); DELANO Karen (AREVA); LEIGHLITER John (AREVA); ROMINE Judy (AREVA); SHEPHERD Tracey (AREVA); VANCE Brian (AREVA); GUCWA Len (EXTERNAL AREVA); WILLIFORD Dennis (AREVA); HOTTLE Nathan (AREVA); KOWALSKI David (AREVA); NOXON David (AREVA)
Subject:	Reponse to U.S. EPR Design Certification Application RAI No. 532 (6155), FSAR Ch. 19, Supplement 3
Attachments:	RAI 532 Supplement 3 Response US EPR DC - Nonproprietary.pdf; NRC-13-066.pdf

Amy,

AREVA NP Inc. letter NRC:13:066 dated July 30, 2013 (attached) provides technically correct and complete final responses to Questions 19-352, 19-353, 19-354 and 19-355 in RAI 532. AREVA NP Inc. has determined that some of the material contained in the responses is proprietary. An affidavit is enclosed with the letter, as required by 10 CFR 2.390(b), to support the withholding of the proprietary information from public disclosure. Attached is the non-proprietary version of the responses. A proprietary version of the responses will be provided separately.

The following table indicates the respective pages in the response that contain AREVA NP's final response to the subject questions.

Question #	Start Page	End Page
RAI 532 — 19-352	2	52
RAI 532 — 19-353	53	104
RAI 532 — 19-354	105	110
RAI 532 — 19-355	111	114

This concludes the formal AREVA NP response to RAI 532, and there are no questions from this RAI for which AREVA NP has not provided responses.

Sincerely,

David J. Kowalski (for)

Dennis Williford, P.E.
U.S. EPR Design Certification Licensing Manager
AREVA NP Inc.
7207 IBM Drive, Mail Code CLT 2B
Charlotte, NC 28262
Phone: 704-805-2223
Email: Dennis.Williford@areva.com

From: WILLIFORD Dennis (RS/NB)
Sent: Wednesday, June 06, 2012 10:47 AM
To: Getachew.Tesfaye@nrc.gov
Cc: BENNETT Kathy (RS/NB); DELANO Karen (RS/NB); ROMINE Judy (RS/NB); RYAN Tom (RS/NB); NOXON David (RS/NB)

Subject: Response to U.S. EPR Design Certification Application RAI No. 532 (6155), FSAR Ch. 19, Supplement 2

AREVA NP Inc. provided a schedule for a technically correct and complete response to the four questions in RAI No. 532 on January 24, 2012. Supplement 1 sent on February 26, 2012 provided a revised schedule. The schedule for a technically correct and complete response to these four questions has been changed as provided below. This schedule was transmitted to the NRC in AREVA NP letter NRC:12:024 dated May 10, 2012.

Question #	**Response Date**
RAI 532 — 19-352	**July 30, 2013**
RAI 532 — 19-353	**July 30, 2013**
RAI 532 — 19-354	**July 30, 2013**
RAI 532 — 19-355	**July 30, 2013**

Sincerely,
Dennis Williford, P.E.
U.S. EPR Design Certification Licensing Manager
AREVA NP Inc.
7207 IBM Drive, Mail Code CLT 2B
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From: WILLIFORD Dennis (RS/NB)
Sent: Sunday, February 26, 2012 7:52 PM
To: Getachew.Tesfaye@nrc.gov
Cc: BENNETT Kathy (RS/NB); DELANO Karen (RS/NB); ROMINE Judy (RS/NB); RYAN Tom (RS/NB); NOXON David (RS/NB)

Subject: Response to U.S. EPR Design Certification Application RAI No. 532 (6155), FSAR Ch. 19, Supplement 1

AREVA NP Inc. provided a schedule for a technically correct and complete response to the four questions in RAI No. 532 on January 24, 2012. The schedule for a response to these four questions has been changed as provided below. This schedule was transmitted to the NRC in AREVA NP letter NRC:12:008 dated February 21, 2012.

Question #	**Response Date**
RAI 532 — 19-352	**August 30, 2013**
RAI 532 — 19-353	**August 30, 2013**
RAI 532 — 19-354	**August 30, 2013**
RAI 532 — 19-355	**August 30, 2013**

Sincerely,
Dennis Williford, P.E.
U.S. EPR Design Certification Licensing Manager
AREVA NP Inc.

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Charlotte, NC 28262
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From: WILLIFORD Dennis (RS/NB)
Sent: Tuesday, January 24, 2012 4:38 PM
To: Tesfaye, Getachew
Cc: BENNETT Kathy (RS/NB); DELANO Karen (RS/NB); ROMINE Judy (RS/NB); RYAN Tom (RS/NB); NOXON David (RS/NB); tanya.ford@nrc.gov; Michael.Miernicki@nrc.gov

Subject: Response to U.S. EPR Design Certification Application RAI No. 532 (6155), FSAR Ch. 19

Getachew,

Attached please find AREVA NP Inc.'s response to the subject request for additional information (RAI). The attached file, "RAI 532 Response US EPR DC," provides a schedule since a technically correct and complete response to the four questions cannot be provided at this time. The following table indicates the respective pages in the response document, "RAI 532 Response US EPR DC.pdf," that contain AREVA NP's response to the subject questions.

Question #	Start Page	End Page
RAI 532 — 19-352	2	2
RAI 532 — 19-353	3	4
RAI 532 — 19-354	5	5
RAI 532 — 19-355	6	6

A preliminary schedule for a technically correct and complete response to the four questions is provided below. This schedule is being reevaluated and a new supplement with a revised schedule will be transmitted by February 21, 2012.

Question #	Response Date
RAI 532 — 19-352	February 21, 2012
RAI 532 — 19-353	February 21, 2012
RAI 532 — 19-354	February 21, 2012
RAI 532 — 19-355	February 21, 2012

Sincerely,
Dennis Williford, P.E.
U.S. EPR Design Certification Licensing Manager
AREVA NP Inc.

7207 IBM Drive, Mail Code CLT 2B
Charlotte, NC 28262
Phone: 704-805-2223
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From: Tesfaye, Getachew [mailto:Getachew.Tesfaye@nrc.gov]
Sent: Friday, December 16, 2011 10:03 AM
To: ZZ-DL-A-USEPR-DL
Cc: Grady, Anne-Marie; Mrowca, Lynn; Ford, Tanya; Segala, John; ArevaEPRDCPEm Resource

Subject: U.S. EPR Design Certification Application RAI No. 532 (6155), FSAR Ch. 19

Attached please find the subject requests for additional information (RAI). A draft of the RAI was provided to you on November 25, 2011, and discussed with your staff on December 13, 2011. Draft RAI Questions 19-352, 19-354, and 19-355 were modified as a result of that discussion. The schedule we have established for review of your application assumes technically correct and complete responses within 30 days of receipt of RAIs, excluding the time period of **December 24, 2011 thru January 2, 2012, to account for the holiday season** as discussed with AREVA NP Inc. For any RAIs that cannot be answered **within 40 days**, it is expected that a date for receipt of this information will be provided to the staff within the 40-day period so that the staff can assess how this information will impact the published schedule.

Thanks,
Getachew Tesfaye
Sr. Project Manager
NRO/DNRL/NARP
(301) 415-3361

Hearing Identifier: AREVA_EPR_DC_RAIs
Email Number: 4637

Mail Envelope Properties (B13FF3C366E1F64F8CF2CE718C67992216E830)

Subject: Reponse to U.S. EPR Design Certification Application RAI No. 532 (6155), FSAR Ch. 19, Supplement 3
Sent Date: 7/30/2013 5:14:19 PM
Received Date: 7/30/2013 5:14:33 PM
From: KOWALSKI David (AREVA)

Created By: David.Kowalski@areva.com

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Tracking Status: None
"Snyder, Amy" <Amy.Snyder@nrc.gov>
Tracking Status: None

Post Office: FUSLYNCMX03.fdom.ad.corp

Files	**Size**	**Date & Time**
MESSAGE	6817	7/30/2013 5:14:33 PM
RAI 532 Supplement 3 Response US EPR DC - Nonproprietary.pdf	521105	
NRC-13-066.pdf	194713	

Options
Priority: Standard
Return Notification: No
Reply Requested: No
Sensitivity: Normal
Expiration Date:

Recipients Received:

Response to

Request for Additional Information No. 532, Supplement 3

12/16/2011

U. S. EPR Standard Design Certification
AREVA NP Inc.
Docket No. 52-020
SRP Section: 19 - Probabilistic Risk Assessment and Severe Accident Evaluation
Application Section: 19.2

QUESTIONS for PRA Licensing, Operations Support and Maintenance Branch 1 (AP1000/EPR Projects) (SPLA)

Question 19-352:

Follow-up to RAI 457, Question 06.02.02.-81

1. Provide summaries of all changes in the MAAP input model, including
   a. Nodalization
   b. Geometrical input
   c. Error correction
   d. Implication of changes (including correction of errors)
2. Provide a summary of the phenomenological modeling differences between MAAP 4.0.7 and 4.0.6 and their impact on in-vessel accident progression with emphasis on MAAP-based specifications for analysis of various PRA and severe accident issues (e.g., ex-vessel steam explosions, hydrogen generation and distribution in containment, etc.)
3. Indicate which nodalization, coarse or fine, will be the basis for the new results provided in the FSAR.

Response to Question 19-352:

Item 1:

The Revision 005 parameters are developed for use in MAAP4.0.7, and supersede the previous parameter files used with MAAP4.0.6Rev12.2+EPR. The Revision 005 parameters are listed in Table 19-352-1 and their derivations are described in detail in the Revision 005 and subsequent parameter file documentation.

In the previous parameter files, parameters that were used for "testing only" were described and remained in the parameter file. In Revision 005 and subsequent files, these parameters are removed from the parameter file, and from the corresponding documentation. These previous parameters are listed in Table 19-352-2.

Because the previous parameter files were used with MAAP4.0.6Rev12.2+EPR, some parameters became obsolete during the release of MAAP4.0.7. These parameters, which are listed in Table 19-352-3, are removed from Revision 005 and subsequent parameter files and the corresponding documentation. As a note, parameters previously known as AQT1 and AQT2 were re-named FAQT1 and FAQT2, respectively, in MAAP4.0.7.

In the previous parameter files, several parameters were left in the parameter files and documentation, even if they were not used due to either non-applicability to the runs performed, or to the plant design. For the Revision 005 and subsequent parameter files, the parameters are removed from the parameter file and documentation. Table 19-352-4 provides a list of these parameters. However, when a parameter is not given a value in the parameter file, MAAP4 assigns a default value to it. This assignment of a default value may have unintended consequences. Therefore, the MAAP4 default value, which would have been used in runs performed using the Revision 005 and subsequent parameter files, is also listed in Table 19-352-4, including the identification of whether or not the runs performed using this parameter file would be affected by using the default value.

Between parameter file Revisions 004 and 005, the entire parameter file was modified using the latest design information available at that time. Additional information was also added to allow for the implantation of steady state conditions. Additionally, a coarse nodalization version of the containment was created. Overall, the coarse nodalization version of the containment is a collapsed version of the fine nodalization version. Parameters and arrays that were modified between parameter file Revisions 004 and 005 (only considering the fine nodalization model) are listed in Table 19-352-5 and Table 19-352-6, and are described in detail in parameter file supporting documentation. Table 19-352-5 lists all of the changed parameters that were altered less than 10 percent between the two revisions and deemed to have a minimal effect upon the calculated transients. Table 19-352-6 lists all of the changed parameters that were altered by greater than 10 percent between the two revisions and also explains the change. In addition to the parameters listed in Table 19-352-5, the pump data were also updated using the latest design information.

Between parameter file Revisions 004 and 005, the junction data were altered to account for the 80-column issue. Table 19-352-7 outlines the downstream to upstream failure pressure (MAAP4 parameter PFBJ) for parameter file Revision 004 (where values were truncated at the 80 column marker) and the corresponding corrected value used starting in parameter file Revision 005. In addition, the following changes were made to the junction data in parameter file Revision 005:

- Mixing dampers (failure junctions) were consolidated:
  - Junctions [ ] were consolidated with junction [ ] .
  - Junctions [ ] were consolidated with junction 9.
- Convection foils (failure junctions) were consolidated:
  - Junctions [ ] were consolidated with junction [ ] .
  - Junctions [ ] were consolidated with junction [ ] .
  - Junctions [ ] were consolidated with junction [ ] .
  - Junctions [ ] were consolidated with junction [ ] .
- With the mixing dampers and convection foils being consolidated, the “freed-up” junctions were used to represent leakage around the doors. This affects junctions [ ] .
- Junction [ ] from parameter file Revision 004 was replaced with a new junction that represents leakage around the doors.
- Junctions [ ] were new junctions that represent leakage around the doors.
- Junctions [ ] were updated with new values for upstream to downstream failure pressure (MAAP4 parameter PFFJ) and for downstream to upstream failure pressure. In parameter file Revision 004, this value was [ ] . In parameter file Revision 005, this value is [ ] .

Additionally, runs performed with parameter file Revision 004 were calculated using the convection include file which modified junctions [ ].

Between parameter file Revisions 005 and 006, there was a minimal amount of parameters modified. The modified parameters are listed in Table 19-352-8, and are described in detail in the documentation associated with parameter file Revision 006.

There were no parameters modified between parameter file Revisions 006 and 007.

Between parameter file Revisions 007 and 008, some parameters were uncommented (i.e., they were given explicit values and no were no longer used only as the default value) and some parameters were modified. The modified parameters are listed in Table 19-352-9.

Between parameter file Revisions 008 and 009, two parameters were uncommented, and one parameter was modified. The modified parameters are listed in Table 19-352-10.

Between parameter file Revisions 009 and 010, the only difference in the parameter file is that parameter JNGO(1) was reassigned from node number [ ] to node number [ ] (error correction) in the coarse nodalization model.

Note that the values presented in the tables within this response are for the fine nodalization model. This is due to the many differences between the geometric input and pointers between the fine and coarse nodalization. The fine nodalization was chosen, because it was the only model created during the early revisions of the parameter file. There are notes to tables when there is a difference between the fine and coarse nodalization parameter files that are not affected by geometric input and their subsequent pointers.

Table 19-352-1—Parameters that are New for MAAP4.0.7

Parameter	Value
APZBK	
ASBO	
FAQT1 (*was AQT1*	
FAQT2 (*was AQT2*	
FCDPZBK[1]	
FCSI	
FKLOSSACUM	
FKLOSSCRTK	
FLDSG1	
FTCWCHX	
FXCWCHX	
ICNTLTIM	
IDOMEHOT	
IEXFMOD	
ILISTVL	
INECCS	
INFANC	
INSGFW	
IOXIDHT	
IPRJN	
IPRTMLST	
IPSGIN	
JNFWBB	
LHHSM(1)	
LHHSM(2)	
LHHSM(3)	
LHHSM(4)	
LHHSM(5)	
NKPROCACUM	
NKPROCCRTK	
PRBHI	
TMPHSM(1)	
TMPHSM(2)	
TMPHSM(3)	
TMPHSM(4)	
TMPHSM(5)	
ZNPZBK[1]	
ZPZBK[1]	
ZUPDC	

Note to Table 19-352-1:

1. This parameter has been commented out in the coarse nodalization model in parameter file Revision 010.

Table 19-352-2—Parameters that are for Testing Only

CPML	FTEREL	LHML	TOXMP
CPOX	HTBLAD	LHOX	UMLMP
DML	KML	STML	UOXMP
DOX	KOX	STOX	VSCML
FTENUR	LHCNCR	TMLMP	VSCOX

Table 19-352-3—Parameters that are Obsolete

AQT1	AQT2	FSGBEN	HTEXTD	NVP	TGOS

Table 19-352-4—Parameters that are No Longer Specified in the Parameter File

Table 19-352-5—Parameters Modified between Revisions 004 and 005 with Less Than 10% Change

Table 19-352-6—Parameters Modified between Revisions 004 and 005 with Greater Than 10% Change

[

]

[ ]

Table 19-352-7—Junctions Affected by the 80-Column Issue

Table 19-352-8—Parameters Modified between Revisions 005 and 006

Table 19-352-9—Parameters Modified between Revisions 007 and 008

Table 19-352-10—Parameters Modified between Revisions 008 and 009

Item 2:

The NRC has requested a summary of the phenomenological modeling differences between MAAP 4.0.7 and 4.0.6 and their impact on in-vessel accident progression, with emphasis on MAAP-based specifications for analysis of various PRA and severe accident issues (for example, ex-vessel steam explosions and hydrogen generation and distribution in containment). It is AREVA NP's position, as presented at the December 17, 2012 Chapter 19.2 closure meeting with the NRC, that the intent of this request is to obtain a summary of the pertinent differences between the official version of MAAP 4.0.7 and the version of the code used for AREVA NP's November 2007 design certification submittal, MAAP 4.0.6+ Rev. 12. The official version of MAAP 4.0.7 is now considered the version of record for the U.S. EPR Design Certification.

Proprietary information provided by Fauske and Associates, LLC (FAI) regarding the MAAP code is identified in the subsequent sections by borders surrounding the text.

Methodology

The phenomenological modeling differences between MAAP 4.0.7 and MAAP 4.0.6+ Rev. 12 were identified by a comparison of the respective source codes. The purposes and the expected impacts on the code results of the identified changes were obtained from the code modification packages prepared by the code developer. These packages were provided with the 4.0.7 code, and are the primary source of the summary information for this response. Supplemental information was obtained from the MAAP4 User's Manual, which is also provided with the code.

Modeling Differences Conclusions

The phenomenological modeling differences between MAAP 4.0.7 and MAAP 4.0.6+ Rev. 12 were identified. The purpose and the expected impacts on the code results of the identified changes, as reported by the code developer, are summarized in the discussions above. The summaries indicate if the changes are enhancements or correct errors. Also, those changes that directly affect in-vessel accident progression and accident phenomena are noted with the individual summaries. The impacts of these changes were all determined by the code developer to be minor.

Table 19-352-11—Modifications that Directly Impact in-Vessel Accident Progression and Accident Phenomena

Region, Phenomenon or System	Modification Topic	Direct Impact
Core	Exponents in Zr oxidation kinetics equations	In-vessel hydrogen generation
Core	Oxidation energy balance related to partially covered nodes	In-vessel hydrogen generation
Pressurizer	Drainage through the surge line	Time of core damage and in-vessel hydrogen generation
Accumulators	Steam generation from accumulator flow	In-vessel hydrogen generation
Corium oxidation	Oxidation of corium jets	Corium oxidation in the vessel and in the containment, in-vessel hydrogen generation
Vessel failure	Options for extensive vessel failure mechanisms	Time of extensive vessel failure and extent of corium relocation from the vessel to the reactor pit
DCH	Oxidation and de-entrainment	DCH phenomena
Containment	Steel-lined concrete heat sink properties	Corium–concrete interactions
Containment	Heat transfer to melting heat sinks	Pressurization of the containment when there is cooling of molten heat sinks
Containment	Steam generation from small corium mass	Pressurization of the containment when there is a small amount of corium in the pit
Fission products	Heating of the hot legs	Hot leg creep rupture

MAAP 4.0.7 Benchmark Update for Level 1 PRA

The success criteria for the U.S. EPR Level 1 PRA was established based on MAAP4 runs. Additionally, the MAAP4 runs were benchmarked using S-RELAP5. The results of the MAAP4 runs were compared and accepted by the NRC in the SER based in part on the NRC MELCOR calculations that provided similar results. AREVA has since revised the MAAP4 model. Therefore, the following will provide the justification that these enhancements to the model do not have an appreciable impact on the Level 1 MAAP runs; and, thus, the benchmark calculation remains valid.

Five cases were originally run as part of the MAAP4 benchmark and consisted of LOMFW and LOCA cases. The results of the original benchmark showed that MAAP4 qualitatively captures the relevant phenomena needed for simulating these events and identifies the uncertainties in the MAAP4 calculations. Additionally, based on the benchmark, an alternative acceptance limit of 1800°F for the MAAP4 calculation was recommended. It was also recommended that MAAP4 calculations yielding peak cladding temperatures in the range of 1400-1800°F be evaluated qualitatively or by an independent calculation before being accepted.

These same five cases have been re-analyzed with the most recent version of the U.S. EPR MAAP4 parameter files. The results for the peak cladding temperature are presented below in Figure 19-352-1 through Figure 19-352-5. It should be noted that “MAAP SC” refers to the original benchmark case, “MAAP REV 10” refers to the calculation using the most recent parameter file, and the “S-RELAP5-IC” refers to the S-RELAP data that the case is benchmarked against.

Figure 19-352–1—Updated Benchmark Results: LOMFW3c

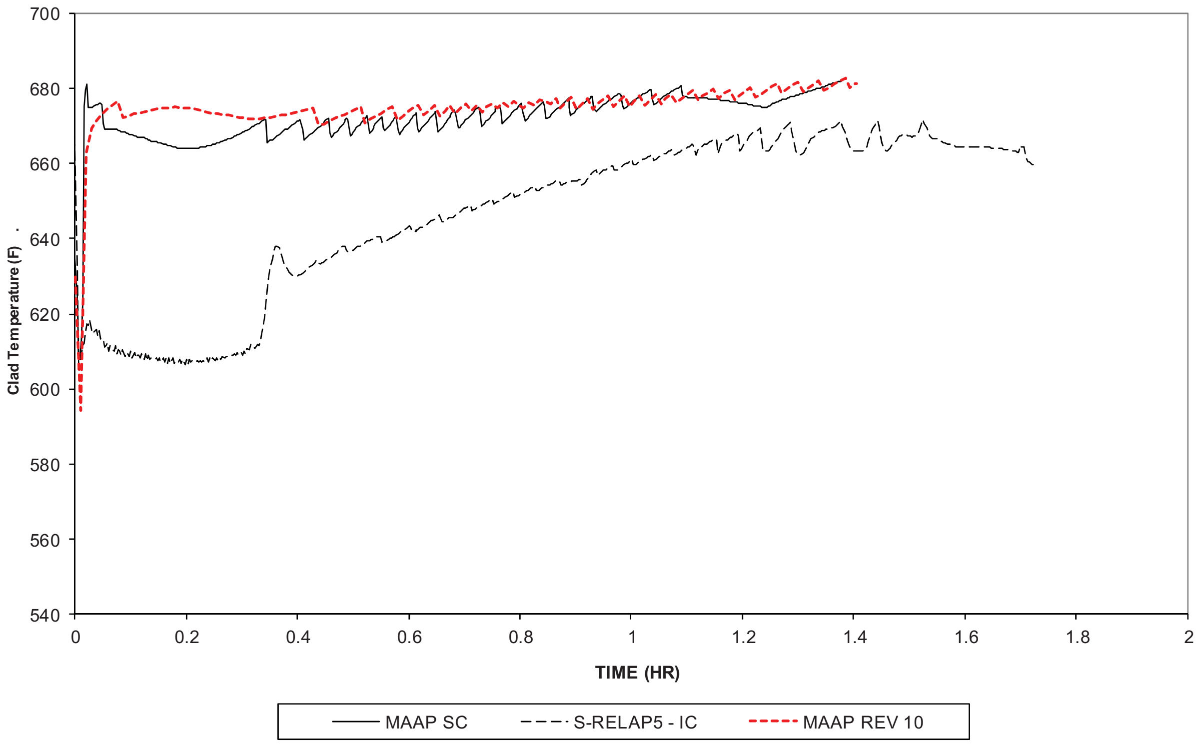


Figure 19-352–2—Updated Benchmark Results: LOMFW4g

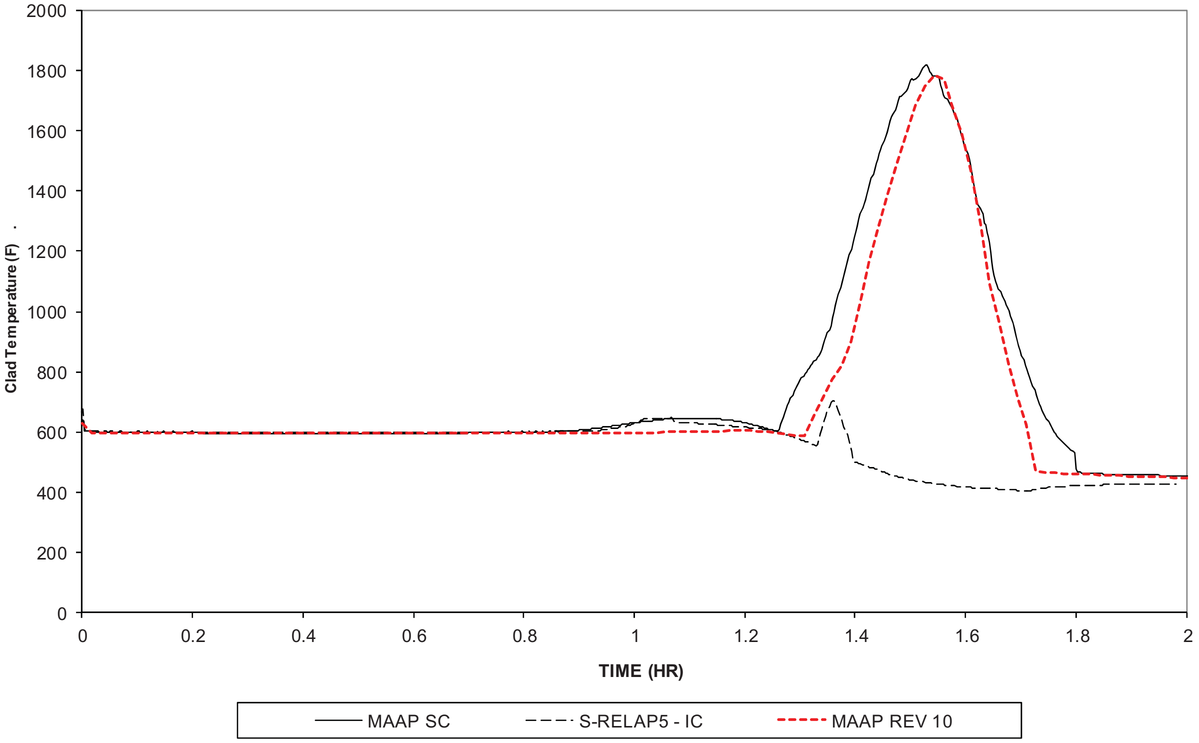


Figure 19-352–3—Updated Benchmark Results: SLOCA12a

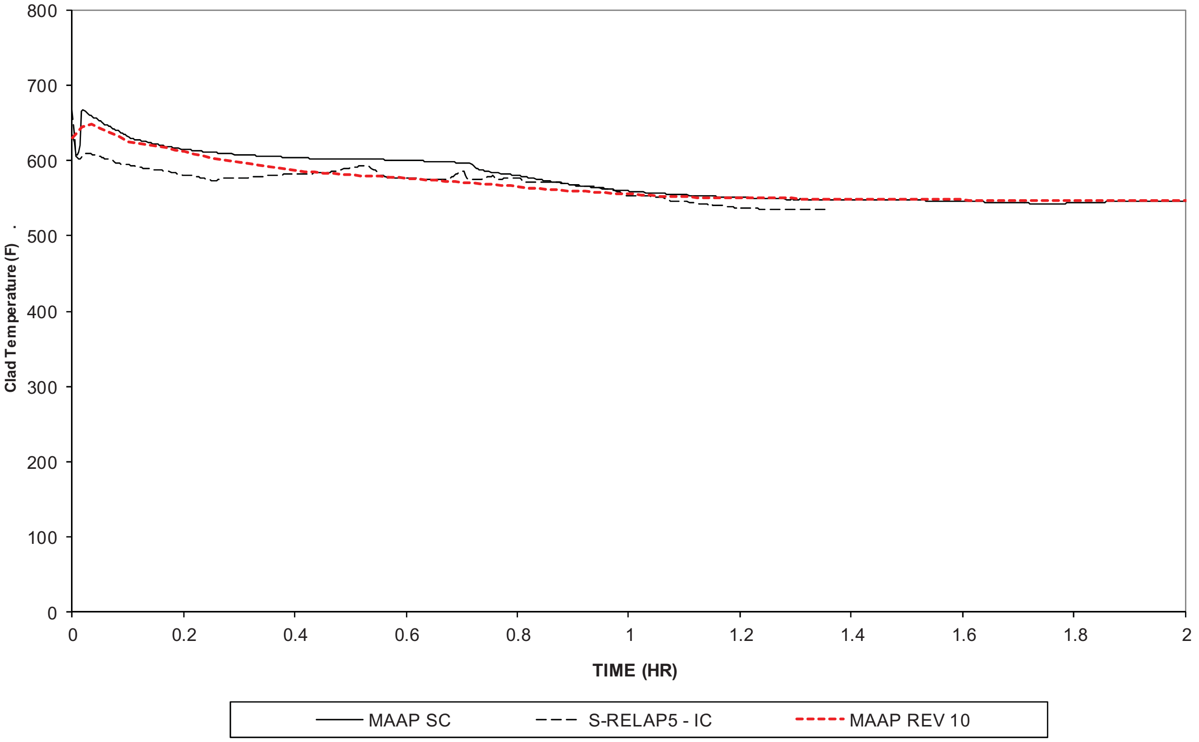


Figure 19-352–4—Updated Benchmark Results: SLOCA13d

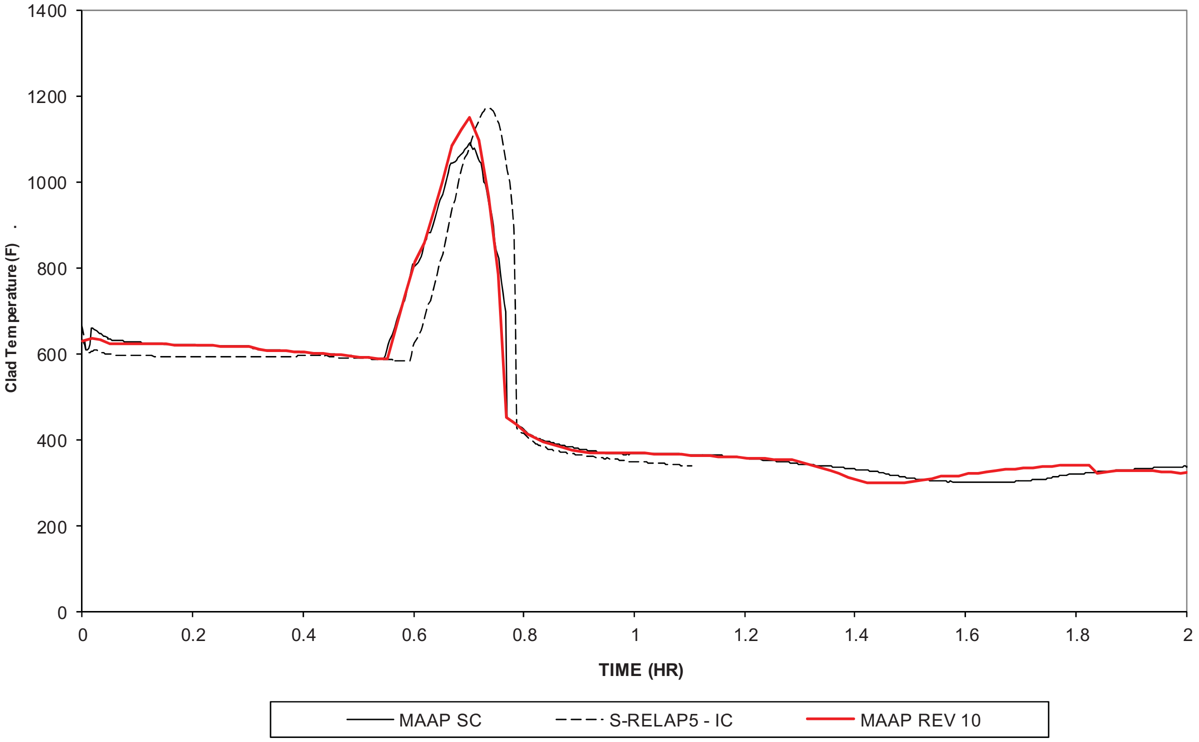
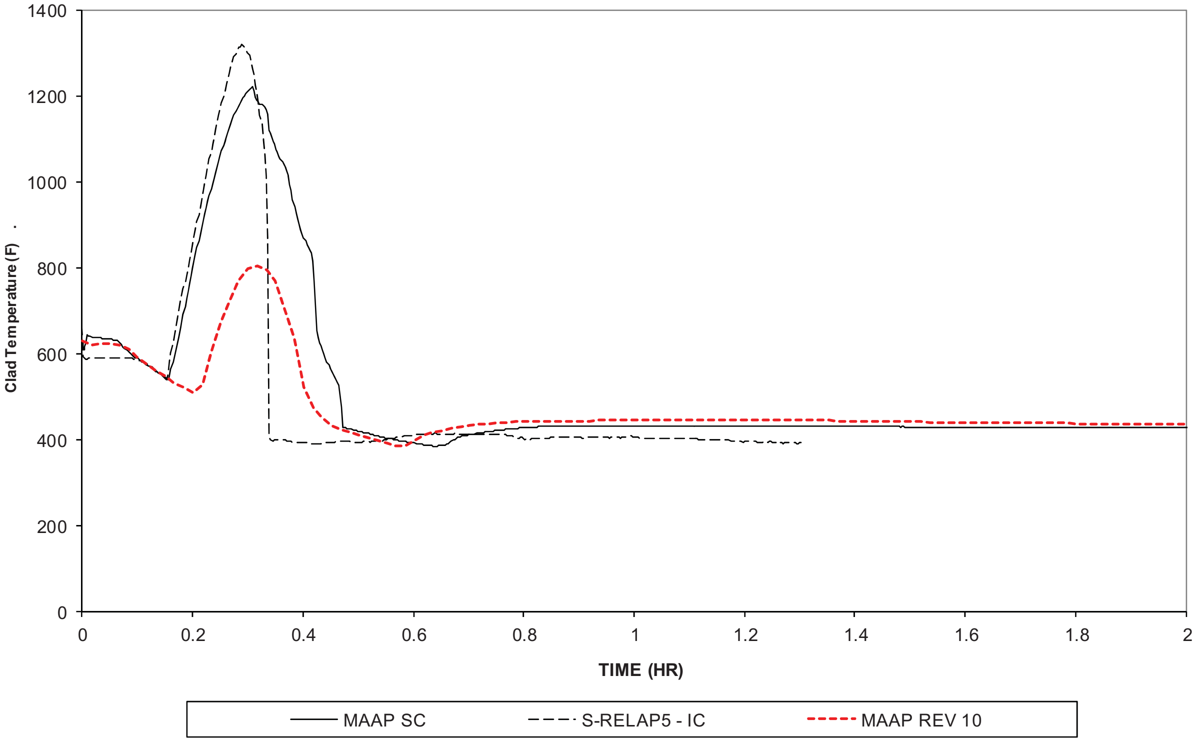


Figure 19-352–5—Updated Benchmark Results: MLOCA16a1



It should be noted that the original “MAAP SC” case for MLOCA16a1 was analyzed with no MHSI available. The S-RELAP5 case that it was being compared with did have one MHSI available; therefore, in the re-analysis of this case (“MAAP Rev 10”) one MHSI was made available. This resulted in more water being available to cool the core and thus provided a large decrease in the peak cladding temperature that was not observed in the previous benchmark (“MAAP SC”).

Based on Figure 19-352-1 through Figure 19-352-5, the resulting peak cladding temperatures were found and are presented in Table 19-352-12 below.

Table 19-352-12—Summary of Peak Cladding Temperatures

In conclusion, the enhancements made to the U.S. EPR MAAP4 parameter file do not adversely change the conclusions that were made in the previous Level 1 PRA benchmark calculation.

MAAP 4.0.7 Update for the Level 2 PRA

The U.S. EPR MAAP4 parameter file has recently been updated. This parameter file represents the base model of the U.S. EPR power plant for severe accident and probabilistic risk assessment (PRA) scenarios. To perform the Level 2 PRA for the U.S. EPR plant, several scenarios are simulated with MAAP4. Upon completion of these scenarios, the output is then used to determine various probabilities that are then integrated into the fault tree analysis software RiskSpectrum, which performs the Level 2 PRA quantification.

This response reconciles the MAAP4 differences seen between the MAAP4 output used in the RiskSpectrum Level 2 PRA model and the current revision of the MAAP4 PRA scenarios. An exhaustive review of the differences between the previously used analysis and the current MAAP4 analysis was performed by the Level 2 PRA team. This review indicated that there were six areas that required further examination. These areas are:

1. Hydrogen Production in Containment.
2. Timing of Creep Rupture.
3. Timing of Vessel Failure for HRA.
4. Pit Pressure at Vessel Failure.
5. Vessel Rocketing and Direct Containment Heating.
6. Rate of Containment Pressurization versus Basemat Ablation.

Hydrogen Production in Containment

Hydrogen phenomenology associated with deflagration, flame acceleration (FA), and deflagration-to-detonation transition (DDT) has been analyzed in the Level 2 PRA. Of all the scenarios discussed in the hydrogen phenomenology; Cases 1.1, 1.1e, and 1.6 are the scenarios whose results from MAAP4 varied from those found previously. Various hydrogen quantities between the two revisions of the MAAP4 output are shown below in Table 19-352-13.

The hydrogen analysis examines the phenomenology of FA and DDT. Specifically, the Level 2 PRA seeks to determine the probability that FA occurs and the overall containment failure probability resulting from FA and DDT. The hydrogen results of the new analysis are different at three general time frames: before vessel failure (Case i), at vessel failure (Case ii), and in the short term after vessel failure (Case iii).

Table 19-352-13—Comparison of Hydrogen Generation

For Case iii (the short term after vessel failure), the previous maximum hydrogen mass in the reactor pit was also higher than in the updated MAAP4 analysis; therefore, what is currently in the RiskSpectrum model is bounding here as well (same as for Case ii).

The containment failure probability at the time of vessel failure from hydrogen deflagration was also examined in the hydrogen phenomenological analysis. For this failure probability the maximum hydrogen in containment was used. Using the previous analysis, with conservatisms added in, the amount of hydrogen found was almost [ ] With the updated MAAP4 results, this value increases. The probabilities of side tear versus base failure used in the MAAP4 model to tune the DCH2 model are not those which are used in the Level 2 PRA phenomenological evaluation at vessel failure. The point estimates which are calculated using the new values are covered by the uncertainty bound in the current Level 2 PRA. In addition, an exhaustive literature search shows that other Level 2 PRAs do not show this same amount of hydrogen generation and it is determined that the current output is on the conservative side.

Timing of Creep Rupture

Phenomenology of creep rupture in relation to the failure of the reactor vessel was performed in the scope of the Level 2 PRA. For Cases 1.1d, 1.1e, and 1.7, it was noticed that while the timing of the predicted creep rupture had not changed significantly, the timing of the reactor vessel failure has changed by ±3000-5000 seconds. The differences are shown below in Table 19-352-14.

[

]

Case 1.7 represents the SS type cases. In both the previous analysis and the updated MAAP4 results, hot leg rupture occurs before steam generator tube ruptures (as there are no steam generator tube ruptures in this case) or vessel failure. The resulting probability derived from the MAAP4 results is 1.0 for both sets of MAAP4 results. Because the value in the model used is unchanged, the current value in the RiskSpectrum is appropriate.

Table 19-352-14—Comparison of Reactor Vessel Failure Times

Timing of Vessel Failure for HRA

A Human Reliability Assessment was performed for the U.S. EPR Level 2 PRA. This HRA uses the timing of vessel failure, in conjunction with other timings, to determine the probability of operators failing to properly enter the Operating Strategies for Severe Accidents (OSSA) before the occurrence of an SGTR or vessel failure. Of concern is the decrease in time between the time at which a specified core exit temperature is reached and vessel failure. Cases 1.1d and 1.1f are used for this purpose; however, only the timing of Case 1.1f shows any appreciable differences. The timings between the previous and updated MAAP4 results of Case 1.1f are shown in Table 19-352-15.

Table 19-352-15—Comparison of Case 1.1f Timings

Pit Pressure at Vessel Failure

Loads at vessel failure are examined in the Level 2 PRA. In particular for this analysis, Case 2.0c is the limiting scenario for non-circumferential breaks, while Case 2.0d is the limiting case for complete circumferential breaks. Both of these scenarios show an increase in the peak reactor pit pressure in the updated MAAP4 results. These are shown in Table 19-352-16.

Table 19-352-16—Comparison of Reactor Pit Peak Pressures

The reactor pit pressure used to calculate the failure probability for a complete circumferential break (from case 2.0d) is of little importance. This is because the vessel failure phenomenology assumes that if a complete circumferential break occurs, the containment fails with a probability of 1.0. Therefore, the value of the reactor pit pressure at the time of vessel failure has no impact on the value of LRF calculated by the RiskSpectrum model.

Vessel Rocketing and Direct Containment Heating

In the scope of the Level 2 PRA an assessment of vessel rocketing and DCH were performed. Case 1.1c is used for the vessel rocketing and the DCH analysis. The updated MAAP4 results show that there is less mass in the lower vessel head before vessel failure and less mass in the corium melt of the reactor pit after reactor vessel failure. The differences are shown in Table 19-352-17.

Table 19-352-17—Comparison of Masses in the Lower Plenum

MAAP Parameter	New (kg)	FSAR Rev. 5 (kg)
MSSPS – mass of steel in the lower plenum at vessel failure	19,668.9	48,400
MCMPS(6) – mass of chromium in the lower plenum at vessel failure	2,886.52	7,832.98
MCMPS(8) – mass of iron in the lower plenum at vessel failure	12,554.7	33,650.8
MCMPS(10) – mass of nickel in the lower plenum at vessel failure	1,876.27	4,932.5

The updated MAAP4 results show a third to a half of the material in the corium melt. This is a result of the change in the MAAP4 `FQP` array parameter, which is the fraction of fission products in the corium melt. The change to `FQP` resulted in less energy in the corium melt, and more in the airborne aerosols. With less decay heat in the melt, the energy (and mass) of the corium pool in the vessel is lower. This lower energy is now below a threshold, whereas the previous analysis was above. Corium temperatures from the previous MAAP4 results were sufficiently high to melt a larger portion of the heavy reflector, adding its material to the corium. In the updated MAAP4 results with the modified decay heat curves, the temperature remains low enough that less of the heavy reflector melts. This consequently results in lower masses in the corium in the lower plenum at vessel failure. These lower masses are favorable in the vessel rocketing and DCH analyses. Therefore, the use of the previous MAAP4 results in the phenomenological evaluation is conservative and bounding.

Rate of Containment Pressurization versus Basemat Ablation

Challenges to the containment in the long-term are analyzed in the Level 2 PRA. When considering the containment, the two most likely modes of failure are from over-pressurization and basemat ablation. The determination of their respective failure probabilities comes from expert judgment based on the results of the MAAP4 analyses, by comparing the relative time between one failure mode and another. The time to containment failure is calculated outside of MAAP4, by determining a containment pressurization rate and a concrete ablation rate. These rates are then extrapolated until the containment pressure reaches the containment failure pressure and the basemat fails from corium ablating the basemat. The amount of time required to reach these failures is compared and expert judgment is applied to determine the relative probabilities of containment failure for each mode.

From the updated MAAP4 results, the rate of containment pressurization increases, while the rate of concrete ablation decreases. This is shown in Table 19-352-18.

Table 19-352-18—Comparison of Rates of Containment Pressurization and Concrete Ablation

[ ]

The increased rate of containment pressurization results from multiple factors. Several parameter changes in the updated parameter file work in combination, resulting in a higher pressurization rate. With this increase in the containment pressurization rate, the number of days required to reach containment overpressure went from [ ]

[

]

Note: These probabilities do not add up to 1.0; this is because there is an additional one percent probability associated with late containment failure due to overpressure considering leak and rupture failure modes.

Impact on Level 2 Conclusion

For the updated MAAP4 results that used the updated parameter file, six items were identified that were different enough to warrant further investigation. For each of these items, the differences were shown, the probable cause for the changes was discussed, and the impact to the Level 2 PRA model of using the values from the previous analysis was dispositioned. The values in the current Level 2 PRA RiskSpectrum model remain applicable.

Item 3

The basis for the new results provided in the FSAR is as follows:

- The coarse nodalization model is used for the relevant scenarios calculation, the Level 2 phenomenological analysis (except for hydrogen generation phenomenology), and the Level 2 source term analysis.
- The fine nodalization model is used for the relevant scenarios calculation, the uncertainty analysis calculation, as well as the Hydrogen Generation Phenomenology used for the Level 2 PRA.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 19-353:

OPEN ITEM

Follow-up to RAI 6, Question 19-79 and RAI 236, Question 19-335

On October 5, 2011, AREVA presented changes in the input data and modeling issues that could affect the nature and sequence of severe accident progression. The changes were significant and affect all MAAP-based analyses that had been provided by AREVA and reviewed by NRC. Therefore, it is requested that AREVA provide results of calculations using the revised/new MAAP inputs for the following accident scenarios:

Station Blackout-Induced Seal LOCA with Containment Isolated [MAAP run St1.1 -5 bar]

Station Blackout-Induced Seal LOCA with Failure of Containment Isolation [MAAP run St1.5]

A. High Pressure SBO with dry MCCI [MAAP run St1.10a]
B. Main Steam Line Break (MSLB) inside Containment
C. Induced-Steam Generator Tube Rupture without Fission Product Scrubbing [MAAP run St2.3]

As a minimum, please provide MAAP-calculated results for the following process variables:

a. Reactor power (for MSLB only)

b. RPV pressure, water level and core exit temperature

c. Steam generator secondary side pressure and level

d. Cumulative hydrogen generation during in-vessel phase and ex-vessel phase (Long-term)

e. Core debris temperature inside the reactor pit and spreading area

f. Containment pressure and temperature

g. Local mole fractions of gases inside various containment compartments

h. Water level in the IRWST, the reactor pit, and the core spreading room

i. Time and location of creep-induced reactor coolant system (RCS) (i.e., hot leg, surge line, and SG tube) failure (specifically for MAAP run St1.10a; present in terms of creep damage parameters or structure temperatures)

j. Predicted source terms at 24 and 48 hours into the accident (specifically for MAAP run St2.3)

These data are requested to be provided in digitized, electronic form (e.g., RPV pressure as a function of time, in columns of an Excel spreadsheet), as well as in plots as a function of time, where appropriate.

Response to Question 19-353:

As requested, the results of the calculations using the revised/new MAAP4 inputs for the following accident scenarios are presented in this RAI response:

- Station Blackout-Induced Seal LOCA with Containment Isolated [MAAP run St1.1-5bar]
- Station Blackout-Induced Seal LOCA with Failure of Containment Isolation MAAP run St1.5]
- High Pressure SBO with dry MCCI [MAAP run St1.10a]
- Main Steam Line Break (MSLB) inside Containment
- Induced-Steam Generator Tube Rupture without Fission Product Scrubbing [MAAP run St2.3]

The data is requested to be provided in digitized, electronic form in an Excel spreadsheet, as well as in plots as a function of time. The following spreadsheets are transmitted containing the requested data:

- MAAP run St1.1-5bar – st1_1_5bar_data.xlsx
- MAAP run St1.5 – st1_5_data.xlsx
- MAAP run St1.10a – st1_10a_data.xlsx
- Main Steam Line Break inside Containment – SLBI_30c_1mf_data.xlsx
- MAAP run St2.3 – st2_3_data.xlsx

Table 19-353-1 lists all of the process variables that were requested as part of the RAI and the respective plot that shows said process variable. The plot reference only lists the final portion of the figure number. For example, when the table lists that the location of RPV pressure for the SLBI case is “74”, this means that this plot is in this response in Figure 19-353-74. Table 19-353-2 lists all of the process variables which were requested and which Excel worksheet includes those process variables.

Two more pieces of data were explicitly requested as part of this RAI:

- The time and location of the creep-induced reactor coolant system failure for MAAP run St1.10a: Unbroken Leg Failed by Creep Rupture at [ ] .
- Predicted source terms at 24 and 48 hours for MAAP run St2.3: Provided in Table 19-353-3.

Also, the local mole fractions of gases (MAAP variables NFSTRB, NFH2RB, NFO2RB, NFN2RB, NFC2RB, and NFCORB), nodes [ ] (for the coarse model, [ ] , respectively for the fine model) represent the reactor pit and the spreading room channel volumes, respectively. Plot data has been omitted for these containment nodes. The reactor pit data is omitted because at the point where MCCI occurs, the node would be extremely hot and any hydrogen that would exist within the volume would be burned. The spreading room channel is omitted because of the use of an artificial stack which does not provide an accurate concentration of hydrogen. The hydrogen concentration for this volume should be identical to that of that spreading room.

Additionally to the plots of compartment water levels (IRWST, Spreading Area and Reactor Pit), an additional plot has been included in order to adjust the water levels with the compartment floor heights). This will make it easier to interpret the data, as the water levels will then have a common datum.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Table 19-353-1—Cross-Reference Table of Requested Process Variable Plot Location

Variable	MAAP	St1.1	St1.5	St1.10a	St2.3	SLBI
Reactor Power	QDECAY[1]	n/a	n/a	n/a	n/a	73
RPV Pressure	PPS	1	19	37	55	74
RPV Water Level	ZWDC	2	20	38	56	75
Core Exit Temperature	TCOROUT[2]	3	21	39	57	76
Broken SG Pressure	PBS	4	22	40	58	77
Unbroken SG Pressure	PUS	4	22	40	58	77
Broken SG Water Level	ZWBS	5	23	41	59	78
Unbroken SG Water Level	ZWUS	5	23	41	59	78
In-Vessel H_2 Production	MH2CR1	6	24	42	60	79
Ex-Vessel H_2 Production	MH2CBT	6	24	42	60	79
Core Debris Temp (Pit)	TCMB(1)	7	25	43	61	80
Core Debris Temp (SA)	TCMB(2)	7	25	43	61	80
Containment Pressure	PRB(10)[3]	8	26	44	62	81
Containment Temperature	TGRB(10)[3]	9	27	45	63	82
Local Mole Fraction - Steam	NFSTRB[4]	10	28	46	64	83
Local Mole Fraction – H_2	NFH2RB[4]	11	29	47	65	84
Local Mole Fraction – O_2	NFO2RB[4]	12	30	48	66	85
Local Mole Fraction – N_2	NFN2RB[4]	13	31	49	67	86
Local Mole Fraction – CO_2	NFC2RB[4]	14	32	50	68	87
Local Mole Fraction – CO	NFCORB[4]	15	33	51	69	88
IRWST Water Level	ZWRB(2)[5]	16,17	34,35	52,53	70,71	89,90
Reactor Pit Water Level	ZWRB(5)[5]	16,17	34,35	52,53	70,71	89,90
Spreading Area Water Level	ZWRB(1)[5]	16,17	34,35	52,53	70,71	89,90
Broken HL Damage Fraction	FCRPBH	18	36	54	72	91
Unbroken HL Damage Fraction	FCRPUH	18	36	54	72	91
Broken SG Tube Damage Fr	FCRBHT	18	36	54	72	91
Unbroken SG Tube Damage Fr	FCRUHT	18	36	54	72	91
Surge Line Damage Fraction	FCRPSR	18	36	54	72	91

Notes to Table 19-353-1:

1. This process variable is only provided for the MSLB case, as requested
2. In the MSLB case, MAAP variable TCRHOT is provided
3. Node **[ ]** is the location for the coarse model, for the fine model Node **[ ]** is used
4. Nodes **[ ]** are omitted for the coarse model; for the fine model, Nodes **[ ]** are omitted (see explanation in text).

5. Nodes [ ] are used for the coarse model; for the fine model, Nodes [ ] respectively, are used.

Note: The SLBI case uses the fine model; all other cases use the coarse model.

Table 19-353-2—Requested Process Variable Excel Worksheet Location

Variable	MAAP	Worksheet
Reactor Power	QDECAY[1]	d40
RPV Pressure	PPS	d40
RPV Water Level	ZWDC	d40
Core Exit Temperature	TCOROUT[2]	d80
Broken SG Pressure	PBS	d40
Unbroken SG Pressure	PUS	d40
Broken SG Water Level	ZWBS	d40
Unbroken SG Water Level	ZWUS	d40
In-Vessel H_2 Production	MH2CR1	d40
Ex-Vessel H_2 Production	MH2CBT	d40
Core Debris Temp (Pit)	TCMB(1)	d10
Core Debris Temp (SA)	TCMB(2)	d10
Containment Pressure	PRB(10)[3]	d11
Containment Temperature	TGRB(10)[3]	d11
Local Mole Fraction - Steam	NFSTRB[4]	d12
Local Mole Fraction – H_2	NFH2RB[4]	d12
Local Mole Fraction – O_2	NFO2RB[4]	d12
Local Mole Fraction – N_2	NFN2RB[4]	d12
Local Mole Fraction – CO_2	NFC2RB[4]	d12
Local Mole Fraction – CO	NFCORB[4]	d12
IRWST Water Level	ZWRB(2)[5]	d11
Reactor Pit Water Level	ZWRB(5)[5]	d11
Spreading Area Water Level	ZWRB(1)[5]	d11
Broken HL Damage Fraction	FCRPBH	d80
Unbroken HL Damage Fraction	FCRPUH	d80
Broken SG Tube Damage Fr	FCRBHT	d80
Unbroken SG Tube Damage Fr	FCRUHT	d80
Surge Line Damage Fraction	FCRPSR	d80

Notes to Table 19-353-2:

1. This process variable is only provided for the MSLB case, as requested
2. In the MSLB case, MAAP variable TCRHOT is provided

3. Node **[ ]** is the location for the coarse model, for the fine model Node **[ ]** is used
4. Nodes **[ ]** are omitted for the coarse model; for the fine model, Nodes **[ ]** are omitted (see explanation in text).
5. Nodes **[ ]** are used for the coarse model; for the fine model, Nodes **[ ]** respectively, are used.

Additional Note: The SLBI case uses the fine model; all other cases use the coarse model.

Table 19-353-3—Predicted Source Terms at 24 and 48 Hours for MAAP Run St2.3

FREL(n)	Description	24 hours[1]	48 hours[1]
1	Noble Gases	1	
2	CsI + RbI		
3	TeO_2		
4	SrO		
5	$MoO_2 + RuO_2 + TcO_2 + RhO_2$		
6	CsOH + RbOH		
7	BaO		
8	$La_2O_3 + Pr_2O_3 + Nd_2O_3 + Sm_2O_3 + Y_2O_3 + ZrO_2 + NbO_2 + AmO_2 + CmO_2$		
9	$CeO_2 + NpO_2 + PuO_2$		
10	Sb		
11	Te_2		
12	UO_2		

Note to Table 19.353-3:

1. Note that these are the raw values provided as MAAP4 output and may not be equivalent to the post-processed values provided in the PRA Level 2 results for the corresponding run.

Figure 19-353–6—Primary System Pressure (St1.1-5bar)

Figure 19-353–7—Downcomer Water Level (St1.1-5bar)

Figure 19-353–8—Core Exit Temperature (St1.1-5bar)

Figure 19-353–9—Steam Generator Pressure (St1.1-5bar)

Figure 19-353–10—Steam Generator Water Level (St1.1-5bar)

Figure 19-353–11—Cumulative Hydrogen Generation (St1.1-5bar)

Figure 19-353–12—Core Debris Temperature (St1.1-5bar)

Figure 19-353–13—Containment Pressure (St1.1-5bar)

Figure 19-353–14—Containment Temperature (St1.1-5bar)

Figure 19-353–15—Local Mole Fraction – Steam (St1.1-5bar)

Figure 19-353–16—Local Mole Fraction – Hydrogen (St1.1-5bar)

Figure 19-353-17—Local Mole Fraction – Oxygen (St1.1-5bar)

Figure 19-353-18—Local Mole Fraction – Nitrogen (St1.1-5bar)

Figure 19-353-19—Local Mole Fraction – Carbon Dioxide (St1.1-5bar)

Figure 19-353-20—Local Mole Fraction – Carbon Monoxide (St1.1-5bar)

Figure 19-353-21—Compartment Water Level (St1.1-5bar)

Figure 19-353-22—Compartment Water Level (Adjusted) (St1.1-5bar)

Figure 19-353-23—Creep Damage Parameters (St1.1-5bar)

Figure 19-353-24—Primary System Pressure (St1.5)

Figure 19-353-25—Downcomer Water Level (St1.5)

Figure 19-353-26—Core Exit Temperature (St1.5)

Figure 19-353-27—Steam Generator Pressure (St1.5)

Figure 19-353-28—Steam Generator Water Level (St1.5)

Figure 19-353-29—Cumulative Hydrogen Generation (St1.5)

Figure 19-353-30—Core Debris Temperature (St1.5)

Figure 19-353-31—Containment Pressure (St1.5)

Figure 19-353-32—Containment Temperature (St1.5)

Figure 19-353-33—Local Mole Fraction – Steam (St1.5)

Figure 19-353-34—Local Mole Fraction – Hydrogen (St1.5)

Figure 19-353-35—Local Mole Fraction – Oxygen (St1.5)

Figure 19-353-36—Local Mole Fraction – Nitrogen (St1.5)

Figure 19-353-37—Local Mole Fraction – Carbon Dioxide (St1.5)

Figure 19-353-38—Local Mole Fraction – Carbon Monoxide (St1.5)

Figure 19-353-39—Compartment Water Level (St1.5)

Figure 19-353-40—Compartment Water Level (Adjusted) (St1.5)

Figure 19-353-41—Creep Damage Parameters St1.5)

Figure 19-353-42—Primary System Pressure (St1.10a)

Figure 19-353-43—Downcomer Water Level (St1.10a)

Figure 19-353-44—Core Exit Temperature (St1.10a)

Figure 19-353-45—Steam Generator Pressure (St1.10a)

Figure 19-353-46—Steam Generator Water Level (St1.10a)

Figure 19-353-47—Cumulative Hydrogen Generation (St1.10a)

Figure 19-353-48—Core Debris Temperature (St1.10a)

Figure 19-353-49—Containment Pressure (St1.10a)

Figure 19-353-50—Containment Temperature (St1.10a)

Figure 19-353-51—Local Mole Fraction – Steam (St1.10a)

Figure 19-353-52—Local Mole Fraction – Hydrogen (St1.10a)

Figure 19-353-53—Local Mole Fraction – Oxygen (St1.10a)

Figure 19-353-54—Local Mole Fraction – Nitrogen (St1.10a)

Figure 19-353-55—Local Mole Fraction – Carbon Dioxide (St1.10a)

Figure 19-353-56—Local Mole Fraction – Carbon Monoxide (St1.10a)

Figure 19-353-57: Compartment Water Level (St1.10a)

Figure 19-353-58—Compartment Water Level (Adjusted) (St1.10a)

Figure 19-353-59—Creep Damage Parameters (St1.10a)

Figure 19-353-60—Primary System Pressure (St2.3)

Figure 19-353-61—Downcomer Water Level (St2.3)

Figure 19-353-62—Core Exit Temperature (St2.3)

Figure 19-353-63—Steam Generator Pressure (St2.3)

Figure 19-353-64—Steam Generator Water Level (St2.3)

Figure 19-353-65—Cumulative Hydrogen Generation (St2.3)

Figure 19-353-66 Core Debris Temperature (St2.3)

Figure 19-353-67—Containment Pressure (St2.3)

Figure 19-353-68—Containment Temperature (St2.3)

Figure 19-353-69—Local Mole Fraction – Steam (St2.3)

Figure 19-353-70—Local Mole Fraction – Hydrogen (St2.3)

Figure 19-353-71—Local Mole Fraction – Oxygen (St2.3)

Figure 19-353-72—Local Mole Fraction – Nitrogen (St2.3)

Figure 19-353-73—Local Mole Fraction – Carbon Dioxide (St2.3)

Figure 19-353-74—Local Mole Fraction – Carbon Monoxide (St2.3)

Figure 19-353-75—Compartment Water Level (St2.3])

Figure 19-353-76—Compartment Water Level (Adjusted) (St2.3)

Figure 19-353-77—Creep Damage Parameters (St2.3)

Figure 19-353-78—Reactor Power Level (SLBI)

Figure 19-353-79—Primary System Pressure (SLBI)

Figure 19-353-80—Downcomer Water Level (SLBI)

Figure 19-353-81—Core Exit Temperature (SLBI)

Figure 19-353-82—Steam Generator Pressure (SLBI)

Figure 19-353-83—Steam Generator Water Level (SLBI)

Figure 19-353-84—Cumulative Hydrogen Generation (SLBI)

Figure 19-353-85—Core Debris Temperature (SLBI)

Figure 19-353-86—Containment Pressure (SLBI)

Figure 19-353-87—Containment Temperature (SLBI)

Figure 19-353-88—Local Mole Fraction – Steam (SLBI)

Figure 19-353-89—Local Mole Fraction – Hydrogen (SLBI)

Figure 19-353-90—Local Mole Fraction – Oxygen (SLBI)

Figure 19-353-91—Local Mole Fraction – Nitrogen (SLBI)

Figure 19-353-92—Local Mole Fraction – Carbon Dioxide (SLBI)

Figure 19-353-93—Local Mole Fraction – Carbon Monoxide (SLBI)

Figure 19-353-94—Compartment Water Level (SLBI)

Figure 19-353-95—Compartment Water Level (Adjusted) (SLBI)

Figure 19-353-96—Creep Damage Parameters (SLBI)

Question 19-354:

OPEN ITEM

Follow-up to RAI 349, Question 19-334 and RAI 471, Question 6.2.5-21

On October 5, 2011, AREVA presented new analyses that indicated major revisions to the previously analyzed conditions. These changes affect the quantities of hydrogen generated during the in-vessel and the ex-vessel phases of severe accidents, and the specification of conditions that are used in the analysis of severe accident issues (e.g., hydrogen distribution, ex-vessel steam explosion, reactor cavity plug failure, etc.). Therefore, it is requested that AREVA provide new MAAP results that could be used to:

a. Demonstrate the effect of the containment nodalization on potential pocketing and maldistribution of hydrogen in the containment. Provide results for both nodalizations, coarse and fine, for the LOOP-TR scenario.

b. Identify the conditions and timing for the various failure events as they relate to the ex-vessel steam explosions and cavity plug failure. These should include the specification (mass, temperature, composition, and timing) of relocating molten core debris into the lower plenum, reactor pit and transfer canal.

c. Assess changes in the phenomenological events (e.g., induced rupture of the reactor coolant system pressure boundary, hydrogen production, etc.) which could potentially impact the assigned split fractions in the containment event tree. Specifically, please provide changes in top event probabilities that are affected by the new MAAP results, and identify any changes to the core damage end states.

Response to Question 19-354:

Item a:

Figure 19-354-1 and Figure 19-354-2 are plotted to show the hydrogen concentration in order to demonstrate the effect of the containment nodalization on potential pocketing and maldistribution of hydrogen in the containment.

As shown in the figures the first spike in hydrogen concentration occurs in the equipment rooms in conjunction with the opening of the dedicated Severe Accident Depressurization Valve. In the fine nodalization model, the equipment rooms are modeled as six separate rooms (lower, middle and upper for the broken and unbroken loops). However, these rooms are connected by large open junctions and hydrogen in one compartment can disperse quickly to the other compartments. In the coarse nodalization model, the equipment rooms are modeled as two separate rooms (one for the broken and one for the unbroken loop). Therefore the results between the two nodalizations should be very similar, which they are (**[** **]** hydrogen concentration for the coarse nodalization, **[** **]** hydrogen concentration for the fine nodalization).

The second spike in hydrogen concentration occurs when water from the IRWST reaches the molten corium located in the spreading area. The results at this point between the two nodalizations are nearly identical ([ ] hydrogen concentration for the coarse nodalization, [ ] hydrogen concentration for the fine nodalization).

After this point, the phenomenology that is occurring in the spreading area is quite complex and there is potential that during the phase where quenching and re-melting is occurring that there may be deviances in the results simply due to the influence of a difference in calculational timestep. The spreading area is nodalized in the same way in both nodalizations (coarse and fine), therefore, these complex phenomena are driving the differences seen in the figures.

As shown in the figures both of the nodalizations provide very similar overall hydrogen concentration traces and pocketing and hydrogen maldistribution does not occur.

Item b:

The conditions and timing for the various failure events as they relate to the ex-vessel steam explosions and cavity plug failure (mass, temperature, composition, and timing of the relocating molten core debris into the lower plenum, reactor pit and transfer channel) are listed in Table 19-354-1, Table 19-354-2, and Table 19-354-3.

Table 19-354-1 lists the conditions at the time of relocation to the lower plenum. The time listed for each relevant scenario corresponds to the time at which MAAP4 predicts relocation. The listed mass comes from MAAP4 parameter MLTCR (total mass of molten core material in the core), and the value presented is acquired from the plotted timestep before the time listed (as some of the corium has started to transfer to the lower plenum and the value of MLTCR is decreasing). The listed temperature comes from MAAP4 parameter TCMPS (temperature of the total debris bed in the lower plenum), and the value presented is acquired by using the maximum temperature value from within several timesteps after relocation.

Table 19-354-2 lists the conditions at the time of relocation to the reactor pit. The time listed for each relevant scenario corresponds to the time at which MAAP4 predicts the failure of the lower head/vessel failure. The listed mass comes from MAAP4 parameter MCMTPS (mass of corium in the lower head) at the time of vessel failure. The listed temperature, as before, comes from MAAP4 parameter TCMPS, at the time of vessel failure. The composition listed comes from the values of the array MCMPS(i) which corresponds to the mass of each component in the lower plenum (UO_2, Zr, ZrO_2, etc.). These individual components are summed and then the corresponding percentage is calculated for each component. Due to rounding caused by the number of significant digits in the table, some percentages for a specific relevant scenario may sum to either 99.9% or 100.1%.

Table 19-354-3 lists the conditions at the time of relocation to the transfer channel (failure of the melt plug). The time listed for each relevant scenario corresponds to the time at which MAAP4 predicts the failure of the melt plug. The listed mass comes from MAAP4 parameter MCMTB(1) (total mass of corium and eroded concrete in the reactor pit) at the time of melt plug failure. The listed temperature comes from MAAP4 parameter TCMB(1) (average temperature of corium pool in the reactor pit) at the time of melt plug failure.

Item c:

As agreed by the NRC staff at the meeting of December 6th, 2012, this question will be responded to as part of the response to RAI 289.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Table 19-354-1—Conditions at the time of Molten Core Debris Relocation to the Lower Plenum

		LBOP	LLOCA	LOOP-PL	LOOP-SS	LOOP-TR	SLBO	SLOCA
Time	(hr)							
Mass	(kg)							
Temperature	(K)							

Table 19-354-2—Conditions at the time of Molten Core Debris Relocation to the Reactor Pit

		LBOP	LLOCA	LOOP-PL	LOOP-SS	LOOP-TR	SLBO	SLOCA
Time	(hr)							
Mass	(kg)							
Temperature	(K)							
UO_2	(%)							
Zr	(%)							
ZrO_2	(%)							
Cr	(%)							
Cr_2O_3	(%)							
Fe	(%)							
FeO	(%)							
Ni	(%)							
NiO	(%)							

*The LOOP-TR case has a side vessel failure; therefore at the time of relocation to the reactor pit, an additional [ ] kg remains in the vessel. This molten corium eventually relocates to the reactor pit by the time of melt plug failure and is relocated to the transfer channel.

Table 19-354-3—Conditions at the time of Molten Core Debris Relocation to the Transfer Channel

		LBOP	LLOCA	LOOP-PL	LOOP-SS	LOOP-TR	SLBO	SLOCA
Time	(hr)							
Mass	(kg)							
Temperature	(K)							

Figure 19-354-1— LOOP-TR Molar Hydrogen Concentration (Coarse Model)

Figure 19-354-2— LOOP-TR Molar Hydrogen Concentration (Fine Model)

Question 19-355:

Follow-up to RAI 457, Question 06.2.2-81

The new/revised MAAP-calculated results show apparent anomalies in core exit temperature and the relationship between in-vessel hydrogen generations upon accumulator injection for the LOOP-Pl and the LLOCA cases. Therefore, it is requested that AREVA assess the core exit temperature anomalies and the effect of the MAAP metal oxidation and candling models (including their influence on whether accumulator injection quenches the core debris) in the MAAP analyses, and to determine the implications of different core exit temperatures on the planned SAMG implementation.

Response to Question 19-355:

The “new/revised MAAP-calculated results” (Revision 7) LOOP-PL (see Figure 19-355-1) and LLOCA (see Figure 19-355-2) sequences demonstrate that the onset of core metal oxidation resulting in hydrogen generation does not occur until after the accumulator water is depleted. The calculated core exit temperatures exhibit oscillatory behavior with the fine containment model for the LOOP-PL sequence and for the coarse containment model for the LLOCA sequence. This behavior does not appear in the most up-to-date MAAP-calculated results (Revision 10)for these sequences, as shown in Figures 19-355-1 and Figure 19-355-2). :Revision 7 LOOP-PL fine nodalization runs made with reductions in two parameter values to match corrections made for Revision 10 also do not exhibit the oscillatory behavior.” These parameters are:

- the elevation of the base of the cylindrical part of the vessel (MAAP parameter ZRVCYL) and
- a shaping factor that governs the selection of the maximum allowable local time step in the steam generator calculations (MAAP parameter F2FRAC)

Concerning the parameter F2FRAC, it is stated in the MAAP4 Code Structure and Theory manual written by the code developers that these parameters may change depending on the numeric stability of the transients being analyzed.

Both parameters independently resolve the oscillations in the LOOP-PL case, which is consistent with an instability in the calculations stemming from input parameter values causing the oscillations. Similarly, the reduction in the elevation of the cylinder in a Revision 7 LLOCA coarse nodalization run resolves the oscillations in that case. Therefore, this behavior is confirmed to be anomalous and is eliminated in the Revision 10 versions of these sequences. Furthermore, the plots of the calculated core exit temperatures for the other five sequences run with the Revision 10 files that are documented in the U.S. EPR MAAP4 model report were reviewed. They also do not exhibit the oscillatory behavior.

The examination of the Revision 7 LLOCA sequence also shows that there is a more distinct period of hydrogen flow out of the core region after the vessel has failed and the remaining core has dumped to the containment in the fine nodalization case compared to the coarse nodalization case and compared to the corresponding Revision 10 cases. This period of hydrogen flow corresponds to an increase in the total mass of hydrogen in the containment and to a matching distinct period of hydrogen flow into the core region from the containment through the vessel breach. It is likely that the period is more pronounced in the Revision 7 fine nodalization case compared to the other three because of the somewhat later times of first relocation, vessel failure and core dump. It is not the result of anomalous in-vessel core material oxidation or relocation calculations.

Accumulator injection does not quench the core as it undergoes degradation and relocation to the lower plenum in the LOOP-PL and LLOCA sequences. The onset of core metal oxidation resulting in hydrogen generation does not occur until after the accumulator water is depleted.

This calculation does not specifically address the implications of the core exit temperatures on the planned SAMGs as requested in the RAI as the transition from EOPs to the U.S. EPR OSSAs is outside the scope of the U.S. EPR Design Certification Process.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Figure 19-355-1—Core Exit Temperature for the LOOP-PL Case

Figure 19-355-2—Core Exit Temperature for the LLOCA Case

AREVA

July 30, 2013
NRC:13:066

U.S. Nuclear Regulatory Commission
Document Control Desk
11555 Rockville Pike
Rockville, MD 20852

Response to U.S. EPR Design Certification Application RAI No. 532, Supplement 3

Ref. 1: E-mail, Getachew Tesfaye (NRC) to (AREVA NP Inc.), "U.S. EPR Design Certification Application RAI No. 532 (6155), FSAR Ch. 19," December 16, 2011.

Ref. 2: E-mail, Dennis Williford (AREVA NP Inc.) to Getachew Tesfaye (NRC), "Response to U.S. EPR Design Certification Application RAI No. RAI No. 532 (6155), FSAR Ch. 19," January 24, 2012.

Ref. 3: E-mail Dennis Williford (AREVA NP Inc.) to Amy Snyder (NRC), "Response to U.S. EPR Design Certification Application RAI No. 532 (6155), FSAR Ch. 19, Supplement 1," February 26, 2012.

Ref. 4: E-mail, Dennis Williford (AREVA NP Inc.) to Amy Snyder (NRC), "Response to U.S. EPR Design Certification Application RAI No. 532 (6155), FSAR Ch. 19, Supplement 2," June 6, 2012.

In Reference 1, the NRC provided a request for additional information (RAI) regarding the U.S. EPR Design Certification Application. Reference 2 provided a schedule for a complete response to the four questions in RAI No. 532. References 3 and 4 were submitted to provide a revised schedule for the four questions in RAI No. 532.

The enclosure to this letter provides complete final responses to the four questions in RAI No. 532.

AREVA NP Inc. (AREVA NP) considers some of the material contained in the enclosed response to RAI 532 to be proprietary. As required by 10 CFR 2.390(b), an affidavit is included to support the withholding of the information from public disclosure. Proprietary and non-proprietary versions of the enclosure to this letter are provided.

The following table indicates the respective pages in the enclosure that contain AREVA NP's final response to the subject questions.

Question#	Start Page	End Page
RAI 532 — 19-352	2	52
RAI 532 — 19-353	53	104
RAI 532 — 19-354	105	110
RAI 532 — 19-355	111	114

This concludes the formal AREVA NP response to RAI 532, and there are no questions from this RAI for which AREVA NP has not provided responses.

If you have any questions related to this submittal, please contact Len Gucwa by telephone at 434-832-3466, or by e-mail at Len.Gucwa.ext@areva.com.

Sincerely,

Pedro Salas, Director
Regulatory Affairs
AREVA NP Inc.

Enclosures

cc: A.M. Snyder
Docket No. 52-020

AFFIDAVIT

COMMONWEALTH OF VIRGINIA)
) ss.
CITY OF LYNCHBURG)

1. My name is Gayle F. Elliott. I am Manager, Product Licensing, for AREVA NP Inc. (AREVA NP) and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by AREVA NP to determine whether certain AREVA NP information is proprietary. I am familiar with the policies established by AREVA NP to ensure the proper application of these criteria.

3. I am familiar with the AREVA NP information contained in the document titled "Response to U.S. EPR Design Certification Application RAI No. 532, Supplement 3," and referred to herein as "Document." Information contained in this Document has been classified by AREVA NP as proprietary in accordance with the policies established by AREVA NP for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by AREVA NP and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in this Document be withheld from public disclosure. The request for withholding of proprietary information is made in accordance with 10 CFR 2.390. The information for which withholding from disclosure is

requested qualifies under 10 CFR 2.390(a)(4) "Trade secrets and commercial or financial information":

6. The following criteria are customarily applied by AREVA NP to determine whether information should be classified as proprietary:

(a) The information reveals details of AREVA NP's research and development plans and programs or their results.

(b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.

(c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for AREVA NP.

(d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for AREVA NP in product optimization or marketability.

(e) The information is vital to a competitive advantage held by AREVA NP, would be helpful to competitors to AREVA NP, and would likely cause substantial harm to the competitive position of AREVA NP.

The information in the Document is considered proprietary for the reasons set forth in paragraphs 6(c) and 6(d) above.

7. In accordance with AREVA NP's policies governing the protection and control of information, proprietary information contained in this Document has been made available, on a limited basis, to others outside AREVA NP only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. AREVA NP policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

SUBSCRIBED before me this 20th

day of July 2013.

Sherry L. McFaden
NOTARY PUBLIC, COMMONWEALTH OF VIRGINIA
MY COMMISSION EXPIRES: 10/31/2014
Reg.#7079129

SHERRY L. MCFADEN
Notary Public
Commonwealth of Virginia
7079129
My Commission Expires Oct 31, 2014