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RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Topical Reports

Korea Hydro & Nuclear Power Co., LTD

Docket No. PROJ 0782

RAI No.:	**7-8567**
SRP Section:	**TR Realistic Evaluation Methodology for LBLOCA of the APR1400**
Application Section:	**Topical Report APR1400-F-A-TR-12004 Realistic Evaluation Methodology for Large-Break LOCA of the APR1400**
Date of RAI Issue:	**04/07/2016**

Question No. APR1400-4

10 CFR 50.46(a) states that the evaluation model for calculating the emergency core cooling system performance must adequately account for uncertainty in the calculated results. Section 15.0.2 of the standard review plan (NUREG-0800) states the uncertainty analysis must address all important sources of code uncertainty, including the mathematical models in the code and user modeling.

The phenomena identification and ranking table for the APR1400 large break loss of coolant accident identifies the cold leg to containment flow path as being a significant parameter during the refill and reflood phases. The friction and form losses associated with the cold leg to containment flow path are not included in the uncertainty parameters. This has caused NRC staff to question whether the treatment of uncertainty of these significant parameters is suitably conservative. NRC staff requests that KHNP justify their treatment of uncertainty associated with the cold leg to containment flow path in the refill and reflood phases.

10 CFR 50.46(a) states that the evaluation model for calculating the emergency core cooling system performance must adequately account for uncertainty in the calculated results. Section 15.0.2 of the standard review plan (NUREG-0800) states that the major sources of uncertainty must be addressed consistent with the results of the accident sequence identification process. In the development of the phenomena identification and ranking table (PIRT) for analysis of the APR1400 large break loss of coolant accident, [ ]TS phenomena or processes were ranked as important. The topical report identifies [ ]TS uncertainty parameters to be sampled. NRC staff is questioning whether the selection of uncertainty parameters adequately addresses the important phenomena identified in the PIRT. NRC staff requests the following additional information:

1. Explain how the sampled uncertainty parameters (identified in Table 5-1 of the topical report) were selected.

2. Explain how all the important phenomena identified in the PIRT are covered by the selected uncertainty parameters.

Response

1)

Attachment 1 describes the entire process to determine the [ ]^{TS} uncertainty parameters out of the [ ]^{TS} phenomena/processes derived from the APR1400 PIRT. As described in the material, the phenomena already considered by [ ]^{TS}, are not considered as uncertainty parameters. The APR1400 PIRT in the topical report contains some errors mostly related to the definition of time periods and will be revised.

2)

The explanation and justification of the parameters are described in the topical report and these are summarized in Table 1below. Among the [ ]^{TS} phenomena/processes in the APR1400 PIRT, two phenomena are not mentioned in the topical report. One is the [ ]^{TS} The [ ]^{TS} It has been found that the APR1400 PIRT contains errors as to the time period definitions, and the revision to the APR1400 PIRT is shown in Attachment 2. The missing or insufficient rationale of the PIRT is reinforced in accordance with the revised PIRT. As described in the response to Question 1 above), the phenomena [ ]^{TS} are not considered as uncertainty parameters.

(1) Phenomena treated by other uncertainty parameters

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Table 1. Description of each process/phenomena in the topical report (1/3)

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Table 1. Description of each process/phenomena in the topical report (2/3)

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Table 1. Description of each process/phenomena in the topical report (3/3)

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Table 2. Phenomena treated conservatively in CAREM

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Table 3. Modified APR1400 PIRT treated by biases

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Figure 1. The conventional noding diagram of UGS [ ]TS

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Figure 2. The most conservative noding diagram of UGS [ ]TS

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Figure 3. The effect of the noding sensitivity

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Figure 4. The effect of radiation heat transfer to surfaces on PCT

Reference

[1] Presentation Material, “PIRT to Uncertainty Parameter,” presented at the face to face meeting with NRC, 2016. 1. 12 ~ 2016. 1. 15. (Modifications are made in accordance to the reference [2]), Attachment 1.

[2] Presentation Material, “APR1400 PIRT revision,” Attachment 2.

Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

Topical report (APR1400-F-A-TR-12004) will be revised as Attachments 3 and 4.

There is no impact on Technical or Environment Report.

PIRT to Uncertainty Parameter

- Contents
  1. KNGR PIRT
  2. APR1400 PIRT
  3. Uncertainty parameter selection
     - General guide line
     - Uncertainty parameter selection from PIRT
     - Ranges of the parameters
     - Phenomena treated by bias
  4. Audit issues related with PIRT

PIRT to Uncertainty Parameter

- KNGR LBLOCA PIRT (WFO861702, 2001)
  - Former APR1400, KNGR (Korea Next Generation Reactor)
    - Developed by KINS/INEEL
    - Internationally recognized panel members: Dr. Brent E. Boyack (LANL), Dr. Bub-Dong Chung (KAERI), Dr. Lawrence E. Hochreiter (PSU), Dr. Jose N. Reyes (OSU), Mr. Gary E. Wilson (INEEL)
    - Time period definition

      1: Blowdown (break ~ lower plenum begins to refill)

      2: Refill (~ mixture level approaches the core inlet)

      3: Reflood (~ initial core quenched)

      4: long-term cooling period (~ stable core quenched)

PIRT to Uncertainty Parameter

- KNGR LBLOCA PIRT (WFO861702, 2001)
  - Constitutes of
    - PIRT KNGR LBLOCA (main body)
    - Description of process/phenomena used in the PIRT (Appendix A)
    - Importance Ranking, Knowledge-Level and Rationales LBLOCA PIRT for the KNGR (Appendix B)
    - Summary of KNGR RELAP5 LBLOCA Sensitivity Calculations (Appendix C)
    - TRAC-M Simulations of LBLOCA in the KNGR (Appendix D)
    - Curriculum Vitae for KNGR PIRT panel (Appendix E)

PIRT to Uncertainty Parameter

- KNGR LBLOCA PIRT (WFO861702, 2001)
  - KNGR LBLOCA PIRT table
- APR1400 PIRT

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PIRT to Uncertainty Parameter

- Adjustment of rankings modified

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PIRT to Uncertainty Parameter

- Adjustment of rankings modified

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PIRT to Uncertainty Parameter

- APR1400 LBLOCA PIRT (as described in Appendix A of the ToR)

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PIRT to Uncertainty Parameter

- APR1400 LBLOCA PIRT (Appendix A of Topical Report)

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APR1400 LBLAPR PIRT (1/3)

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APR1400 LBLAPR PIRT (2/3)

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APR1400 LBLAPR PIRT (3/3)

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PIRT to Uncertainty Quantification

- General guideline

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PIRT to Code Parameters (1/7)

APR1400 LBLOCA PIRT (ToR)

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PIRT to Code Parameters (2/7)

➢ APR1400 LBLOCA PIRT (ToR)

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PIRT to Code Parameters (3/7)

➢ APR1400 LBLOCA PIRT (ToR)

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PIRT to Code Parameters (4/7)

➢ APR1400 LBLOCA PIRT (ToR)

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PIRT to Code Parameters (5/7)

➢ APR1400 LBLOCA PIRT (ToR)

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PIRT to Code Parameters (6/7)

➢ APR1400 LBLOCA PIRT (ToR)

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PIRT to Code Parameters (7/7)

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Final Uncertainty Parameter Selection

- Total [ ]TS phenomena → [ ]TS uncertainty parameter
- In addition to the parameters selected from PIRT,
  - Uncertainty in the initial and boundary conditions of the plant need to be considered.
  - [

    ]TS
  - Uncertainty ranges of parameters are determined based on the experimental database, code assessment, design data, etc.
  - Distribution of the uncertainty parameter is assumed as either normal or uniform. (Uniform is used when the knowledge level is low for conservatism.)

Final Uncertainty Parameter Selection

- As a results,
  - Total [ ]TS uncertainty parameters are selected for the SRS calculation of the plant
  - Bias evaluation performed for the high (reflood) PCT cases and added
  - Uncertainty from all PIRT phenomena/process are considered in the final calculation of the safety parameters, i.e., PCT, PLO, …

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Distributions and Ranges of the Uncertainty Parameters (1/2)

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Distributions and Ranges of the Uncertainty Parameters (2/2)

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Thank you for your attention

APR1400 LBLOCA PIRT Revision

2016. 3.

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Acronyms

APR1400	Advanced Power Reactor 1400
CCF	Counter Current Flow
CHF	Critical Heat Flux
CL	Cold Leg
DC	Downcomer
DVI	Direct Vessel Injection
ECC	Emergency Core Coolant
FD	Fluidic Device
HL	Hot Leg
IR	Importance Ranking
KL	Knowledge Level
LP	Lower Plenum
PCT	Peak Cladding Temperature
PZR	Pressurizer
NC	Non-condensible
RCS	Reactor Coolant System
SG	Steam Generator
SIP	Safety Injection Pump
SIT	Safety Injection Tank
SIT-FD	Safety Injection Tank with Fluidic Device
UP	Upper Plenum

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Knowledge Level

Knowledge-Level (KL)	Meaning
5	Fully Known. Small uncertainty.
4	Known. Moderate uncertainty.
3	Partially Known. Large uncertainty.
2	Very Limited Knowledge. Uncertainty cannot be characterized.
1	Totally Unknown.

Importance Ranking

Importance Ranking (IR)	Meaning
5	Highest of the high in importance
4	High importance
3	Moderate importance
2	Low importance
1	Lowest of the low in importance

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The considered scenario is a double-ended guillotine break at a RCP discharge leg (i.e., a cold leg), with assumptions of the loss-of-offsite power and a single failure. The assumed single failure is the loss of one emergency diesel generator (i.e., one SIP failure); however, only two of the four SIPs are conservatively assumed to be available.

Reflecting the design finalization of APR1400 and the new experimental findings afterwards, ~~slight~~ modifications were made to the PIRT as described in Appendix A. Determined PIRT for APR1400 is shown in Table 3-2. Each phenomenon or process is ranked in five importance levels. Levels of importance are as follows:

5: highest degree of the high

4: high influence on safety criteria

3: moderate influence on safety criteria

2: low influence on (or important to) safety criteria

1: lowest of the low in importance

"NA" in Table 3-2 means the process or phenomenon is not active or present.

In contrast to the original idea of the ranking in CSAU, no limitation on the number of uncertainty parameters is necessary, in principle, in the distribution-free statistical approach. The original idea of the ranking in CSAU was to reduce the number of parameters as many as practicable. Thus, the importance of the ranking is whether the phenomena or processes are selected or not, rather than the ranking level itself when using the distribution-free statistical approach. Table 3-2 lists all the selected phenomena or processes with their rankings. [

]^{TS}. Selected, important phenomena or processes need to be addressed in terms of uncertainty parameters, biases, or conservatisms.

3.4 Frozen Code Selection (Step 4)

RELAP5/MOD3.3/K, which is a modified version of RELAP5/MOD3.3, and CONTEMPT4/MOD5 codes were selected to calculate system thermal-hydraulics and the containment back pressure calculations, respectively.

RELAP5/MOD3.3 is one of the most advanced best-estimate safety analysis codes to date. It was developed by USNRC and RELAP5/MOD3.3 (patch 03) is its latest version. Code manuals are introduced in the following section. The code has been widely applied to analyze system transients of pressurized water reactors, including the postulated LBLOCA. The film boiling heat transfer model of the reflood package of RELAP5/MOD3.3 was modified based on independent assessment calculations against FLECHT-SEASET data. The modified version was named RELAP5/MOD3.3/K. Details on the modifications including the circumvention of code failures caused by the injection of cold nitrogen gas from SIT-FD are described in Appendix B.

CONTEMPT4/MOD5 is a containment analysis code, especially used for calculating the containment backpressures in the case of a LOCA. This code includes the fan and spray cooling system models and passive heat sink models which are essential to the calculation of containment backpressures of a LOCA. It also facilitates table input of the mass and energy release of primary

Table 3-1 Definition of Time Periods

Period (Number)*)	Starts at	Ends at
Blowdown (1)	Break initiation	Initiation of SIT injection
Refill (2)	End of blowdown	Initiation of core recovery (~~liquid~~ mixture level at the bottom of the fuel rods)
Early Reflood (3)	End of refill	End of SIT injection
Late Reflood (4)	End of SIT injection	Stable core quench

*) The numbers indicated in parentheses are used as indices in the PIRT table to denote each phase in that table.

Table 3-2 Phenomena Identification and Ranking Table (1/3)

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Table 3-2 Phenomena Identification and Ranking Table (2/3)

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Table 3-2 Phenomena Identification and Ranking Table (3/3)

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observed in scaled facilities become atypical to those occurring in the full-scale power plant. Therefore, the observations cannot be directly applied to full-scale power plants. As there is no one code parameter that characterizes the ECC bypass phenomenon, it is necessary to evaluate the ECC bypass as a separate bias.

Except for these ~~three~~ four processes or phenomena of "flashing," "vessel stored energy release," "boiling in the downcomer," and "non-condensable gas effect," ~~13~~ 12 among16 important processes or phenomena of the downcomer identified in Table 3-2 are treated in the evaluation of scale bias in Section 4.2.3.

Vessel Stored Energy Release and Boiling in the Downcomer

If enough cooling water is not supplied, the downcomer water would lose its subcooling and begin to boil. This is especially true in the late reflood period where SIPs only provide the emergency core cooling water. Therefore in order to describe the uncertainty of downcomer boiling, we need to consider the amount of ECCW supply and the wall stored energy. The SIP injection flow rate is treated as one of the plant parameters in Section 5.1.5. Wall stored energy can be described by material properties such as the heat capacity and conductivity. The material properties of the reactor vessel wall are dependent on the system design of the power plant. Therefore, the uncertainties of the material properties are described in Section 5.1.6.

[ ]^{TS}.

Direct Vessel Injection Jet Flow

DVI jet impingement produces dispersed droplets and affects the ECC bypass. This phenomenon is an attributor to the ECC bypass. Code parameter relevant to this phenomenon is not determined, and the effect is evaluated as a scale bias in Section 4.2.3.

Flashing

~~This phenomenon is an attributor to the ECC bypass. Code parameter relevant to this phenomenon is not determined and the effect is evaluated as a scale bias in Section 4.2.3.~~ As described in Section 4.2.2.1.2, the uncertainty of the flashing phenomenon is replaced by the uncertainties of the break flow model and system pressure.

Level

This phenomenon is an attributor to the ECC bypass. Code parameter relevant to this phenomenon is not determined and the effect is evaluated as a scale bias in Section 4.2.3.

Entrainment and De-entrainment

These processes are attributors to ECC bypass. Code parameters relevant to these processes are not determined and the effects are evaluated as a scale bias in Section 4.2.3.

Multidimensional Flow, Condensation, Countercurrent Flow, and Bulk Mixing

These processes or phenomena are attributors to ECC bypass. Code parameters relevant to these are not determined and the effects are evaluated as a scale bias in Section 4.2.3.

Single- and Two-phase Pressure Drop

This phenomenon is an attributor to ECC bypass. Code parameter relevant to this phenomenon is not determined and the effect is evaluated as a scale bias in Section 4.2.3.

Water temperature of the in-containment refueling water storage tank (IRWST) is dependent on the IRWST design of the NPP. Therefore, the uncertainty of the IRWST water temperature is treated as a plant input parameter, and is discussed in Step 11.

4.2.3 Determination of the Code Parameters and Their Variations for Scale Bias (Step 8.3)

As discussed in NUREG-1230 [19], the downcomer, lower plenum, and upper plenum of the test facilities which are designed according to "power-to-volume" scaling, are known as the components that can cause bias due to scale distortions. These distortions may affect phenomena such as ECC bypass, multidimensional flow, entrainment, de-entrainment, and steam binding. The phenomena resulting from these distortions of the test facilities may not be representative of a full-scale plant response.

As discussed previously in Section 4.2.2, the uncertainties of the following phenomena are evaluated as separate biases.

Reactor Vessel Core Region

- CCF at top nozzles

Reactor Pressure Vessel Downcomer

- direct vessel injection jet flow
- ~~flashing~~
- level
- entrainment and de-entrainment
- multidimensional flow
- condensation
- counter-current flow
- bulk mixing
- single- and two-phase pressure drop
- cold leg-downcomer flow
- downcomer-lower plenum flow
- DVI-downcomer flow

Reactor Pressure Vessel Lower Plenum

- level
- multidimensional flow
- entrainment or sweep-out
- bulk mixing
- lower plenum-core flow

and Uncertainty" by B. Boyack et al. 1989 [3] were referenced. Sections 3.1 and 3.2 explain the modification of the four temporal periods and subsequent adjustment of the ranking, respectively.

3.1 Definition of Time Phases

The LBLOCA scenario of APR1400 is divided into four temporal periods. The definitions of each period are described in Table 4. The periods are termed blowdown (1), refill (2), early reflood (3), and late reflood (4). The numbers indicated in parentheses are used as indices in the PIRT to denote each period.

(1) The blowdown period starts when the break occurs and ends when SIT injection initiates.

(2) The refill period ends when the ~~liquid~~ mixture level in the vessel lower plenum approaches the core inlet and remains full thereafter.

(3) The early reflood period ends when SITs are emptied.

(4) The late reflood period continues after SITs are emptied.

3.2 Adjustment of the Rankings

It is necessary to adjust the relative importance of phenomena or processes after modifying the definition of temporal periods. In addition, finalization of the APR1400 design and the findings of the experiments and code simulations, which have been performed after the development of KNGR PIRT, need to be reflected.

The same ranking scale used for the relative importance of phenomena or processes of KNGR PIRT, described in Table 2, is used for APR1400 PIRT. It should be ensured that the phenomena or processes of [ ]TS are considered in the calculation. For these phenomena or processes, relevant uncertainty parameters were identified and their uncertainties were reflected in plant calculations in principle. In cases where the identification of uncertainty parameters was not probable, [ ]TS Relevant uncertainty parameters for [ ]TS were not identified. As described in Table 2, [ ]TS allow modeling of the phenomena or processes with inaccuracy or moderate accuracy. As the RELAP5 code has best-estimate features, those phenomena or processes [ ]TS can be modeled with moderate accuracy if the phenomena or processes are not ignored in the calculation. Modeling of these phenomena or processes includes [ ]TS, and so on. Phenomena or processes of ranks lower than [ ]TS are paid no attention.

Among the phenomena or processes of KNGR PIRT, those phenomena or processes, of which the importance ranking is equal to or higher than [ ]TS in any temporal period, are considered when adjusting the rankings. This selection criterion was established in order to prevent omitting significantly important phenomena or processes. Phenomena or processes of [ ]TS can be modeled by applying the models and correlations as they are in the code or by the nodalization capability of the RELAP5 code. The uncertainty of all the other phenomena or processes, or the combined effect of not-considered low ranked phenomena or processes can be accounted for in [aaa]TS of this method.

Modifications on KNGR PIRT are described below, item-by-item, along with the rationale. The indices for each time period used in the following tables are "1" for the blowdown, "2" for the refill, "3" for the early reflood, and "4" for the late reflood periods as described earlier.

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4. PIRT for APR1400

APR1400 PIRT is described in Table 5. Findings from further code simulations and experiments performed after the preparation of KNGR PIRT are incorporated. Final features of the APR1400 design are also reflected. [ ]TS phenomena or processes from [ ]TS components are ranked as important. The number of phenomena or processes for each component is as follows:

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Table 3 KNGR PIRT (1/8)

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Table 3 KNGR PIRT (3/8)

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Table 3 KNGR PIRT (4/8)

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Table 3 KNGR PIRT (5/8)

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Table 5 APR1400 PIRT (1/3)

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Table 5 APR1400 PIRT (2/3)

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Table 5 APR1400 PIRT (3/3)

RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Topical Reports

Korea Hydro & Nuclear Power Co., LTD

Docket No. PROJ 0782

RAI No.:	**7-8567**
SRP Section:	**TR Realistic Evaluation Methodology for LBLOCA of the APR1400**
Application Section:	**Topical Report APR1400-F-A-TR-12004 Realistic Evaluation Methodology for Large-Break LOCA of the APR1400**
Date of RAI Issue:	**04/07/2016**

Question No. APR1400-5

10 CFR 50.46(a) states that the evaluation model for calculating the emergency core cooling system performance must adequately account for uncertainty in the calculated results. Section 15.0.2 of the standard review plan (NUREG-0800) states the uncertainty analysis must address all important sources of code uncertainty, including the mathematical models in the code and user modeling, such as nodalization.

Section 4.2.1 of topical report APR1400-F-A-TR-12004, Rev. 0 discusses the radial nodalization of the core. The discussion in the topical report does not discuss the assessment of the radial nodalization, which has caused NRC staff to question if the nodalization can capture the multidimensional effects in a realistic or suitably-conservative manner. NRC requests that KHNP provide additional justification for the radial nodalization used in the large break loss of coolant accident analyses.

Response

In CAREM, the core is [ ]TS as shown in Figure 4-1 of the topical report. In order to model the harsh conditions [ ]TS Appendix C and D of the topical report describes the code assessment results against SETs and IETs. The core nodalizations of the SETs and IETs are modeled [ ]TS, thus are consistent with those of the APR1400 plant and RELAP5 predicts the cladding temperature of those tests well.

Multidimensional flows can be broadly characterized by two phenomena. First, high vapor velocities and liquid entrainment occur in the hot power region of the core. The entrained liquid from the core is carried into the upper plenum and entrained liquid is de-entrained by structures of the upper plenum and forming a two phase pool. The liquid from the pool can reenter the low power region of the core due to the low vapor velocities in those regions. Second is the transverse flow between the channels by the difference in the core power between the hot and low powered region.

The first phenomenon of multidimensional flow was evaluated in response to RAI 399-8510 (response to the question number 15.06.05-9 has been submitted in May). Evaluation results show [ ]TS

Therefore, current nodalization, [ ]TS, is applicable to the analysis of LBLOCA of APR1400.

The second phenomenon of multidimensional flow is [ ]TS As mentioned above, [ ]TS is considered for APR1400 as follows.

[

]TS

[

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Consequently, [ ]TS nodalization is applicable to APR1400 LBLOCA analysis.

Impact on DCD

There is no impact on the DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

Topical report (APR1400-F-A-TR-12004) will be revised as attached markup.

There is no impact on Technical or Environment Report.

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Hot Assembly Power

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Hot Pin Power Peaking Factor

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The technical specifications of the SKN 3 and 4 prescribe the LHGR limit as one of the limiting conditions for operation. The LHGR limit is defined as the product of Fq and the core average LHGR. The average LHGR at rated power is 5.602 kW/ft. The Fq corresponding to the LHGR limit 13.6 kW/ft is 2.428 (i.e., 13.6 kW/ft divided by 5.602 kW/ft). Therefore the range of Fq is extended to the limit of the technical specification of 2.428. The distribution function of Fq is conservatively assumed to be uniform.

- Parameter; hot pin power peaking factor (Fq)

  Distribution function; uniform

  Mean value; 2.184

  Minimum value; 1.940

  Maximum value; 2.428

5.1.2 Reactivity Feedback Related Parameters

Void Reactivity

The negative reactivity of the moderator rapidly reduces reactor power during the transient. Because the RELAP5/MOD3.3/K models the moderator density reactivity which corresponds to the void reactivity, it is necessary to treat the uncertainty of the moderator density reactivity. The moderator density reactivity is dependent on the moderator temperature coefficients (MTC); MTC involves various core parameters. This means that there is no one code parameter that characterizes the moderator density reactivity. Therefore, the uncertainty of the moderator density reactivity is treated conservatively. The core design provides two conservative moderator density reactivity curves for the LOCA analysis as shown in Figure 4-4. [