REQUEST FOR ADDITIONAL INFORMATION
US-APWR TOPICAL REPORT: LARGE BREAK LOCA CODE APPLICABILITY REPORT, MUAP- 07011-P (R0)

3/15/2010

Mitsubishi Heavy Industries
Docket No. 52-021
SRSB Branch

The following is the second set of NRC requests for additional information (RAIs) based on the review of the Large Break LOCA Code Applicability Topical Report. Pages 1- 3 are follow-up questions (1.1 to 1.12) from previous responses provided in UAP-HF-09173 and UAP-HF-09252. Pages 4 - 19 are new questions (1 to 47).

Question 1.1 (Follow-Up To Question 3.1)

The response to Question 3.1 clarifies the definitions of the three phases during a large break LOCA transient consistent with the CSAU methodology defined in NUREG/CR-5249. Accordingly, correct the description of LBLOCA phases provided in MUAP-07011-P (R0) "Large Break LOCA Code Applicability Report for US-APWR" Section 3.4.1 "LBLOCA PIRT."

Confirm the applicability of the defined phases (blowdown and refilling) as utilized in the Phenomena Identification and Ranking Table (PIRT) presented in MUAP-07011-P Table 3.4-1 "US-APWR PIRT" or adjust the PIRT accordingly. Review all MHI documents that describe phases of large break LOCA and provide a consistent definition of end of blowdown phase.

Question 1.2 (Follow-Up To Question 3.3 and Question 3.15.1)

The response to Question 3.3 describes the occurrence of PCT during the blowdown period and refers to the response to Question 3.15.1 for additional discussion.

The responses to Question 3.3 and Question 3.15.1 do not appear consistent. Also, explain the cause of the blowdown peak, including whether it is due to flooding from the top or from the bottom of the core and identify the cause for the corresponding quench process.

Question 1.3 (Follow-Up To Question 3.6)

The response to Question 3.6 states that the safety injection signal delay is set with conservative margin and therefore pressurizer pressure as a control parameter is not identified as a significant phenomenon in the PIRT.

Describe the relationship between the pressurizer model uncertainty and the actuation of safety injection. In addition, specify the delay in initiation of safety injection and explain how it is determined.

Question 1.4 (Follow-Up To Question 3.7)

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Question 1.5 (Follow-Up To Question 3.10)

The response to Question 3.10 addresses DVI condensation in the downcomer and its ranking in provided in MUAP-07011-P (R0) “Large Break LOCA Code Applicability Report for US-APWR” Table 3.4-1 “US-APWR PIRT.”

Explain the source of oscillations in downcomer level between 40 seconds and 125 seconds and its impact on PCT. In addition, explain how the uncertainty in the prediction of these oscillations is accounted for in the uncertainty estimation of PCT.

Question 1.6 (Follow-Up To Question 3.12.3)

The response to Question 3.12.3 discusses the effect of advanced accumulator test device instrument uncertainty on flow coefficient with variation in cavitation factor. Provide additional information to explain why cavitation factor increases when the system is depressurizing. In addition, explain why there is a larger instrument uncertainty for a larger cavitation factor.

Question 1.7 (Follow-Up To Question 3.12.6)

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Question 1.8 (Follow-Up To Question 3.12.9)

The response to Question 13.12.9 discusses the treatment of the total uncertainty associated with the empirical equations of the advanced accumulator model. Provide additional information explaining whether there a bias in the flow rate correlation and how it is handled.

As per response to Question 3.12.4, the data distribution is not symmetrical on both sides of the line representing the correlation. Describe how this asymmetry is handled in sampling or "S".

Question 1.9 (Follow-Up To Question 3.12.10)

The response to Question 3.12.10 states that the uncertainty in advanced accumulator switching is conservatively accomplished by shortening the duration of the large injection rate, but implementation in ASTRUM is not described.

Provide a description of how switching level uncertainty is implemented in ASTRUM, including quantification of the uncertainty and its basis.

Question 1.10 (Follow-Up To Question 3.13.2)

The response to Question 3.13.2 describes the applicability of the WCOBRA/TRAC(M1.0) flow regimes in modeling the neutron reflector flow channels.

Explain the sudden drop in the measured surface temperatures seen in Figure 3.13-2-2 provided in the response to Question 3.13.2 at approximately 5 s into the transient. Identify the reasons for and the consequences from the code's inability to capture the observed temperature drop in temperatures.

Question 1.11 (Follow-Up To Question 3.15.1)

The response to Question 3.15.1 explains the core flow response during the blowdown period. Provide additional information, which includes plots for pump inlet void fraction, pump flow rates, and break flow rates. In addition, explain the relationship of hot rod PCT (peaks and valleys) and hot assembly channel flow rate.

Question 1.12 (Follow-Up To Question 3.16.4)

The responses to Question 3.16.3 and 3.16.4, pertaining to the parameters used in the uncertainty analyses, are provided by the applicant in a single response. Provide additional information to include a comparative table that lists geometric and operational differences between Westinghouse 4-loop plant and the US-APWR design. Justify the use of the range and distribution of all the uncertainty parameters from the Westinghouse 4-loop plant to US-APWR application in ASTRUM. Explain how the medium and high rank phenomena are covered through parameters considered for uncertainty analyses. In particular, justify the applicability of WCOBRA/TRAC(M1.0) to a taller core and a lower average heat generation rate and evaluate the impact of these changes on the uncertainty ranges of the associated parameters.

The following are the new questions associated with the second set of RAIs in support of the review of the Large Break LOCA Code Applicability Topical Report:

Question 1

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Question 2

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Question 3

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Question 4

As the US-APWR neutron reflector structure surrounds immediately the core periphery, the reflector ring blocks are subjected to high fluence dose rates that cause heat generation in the reflector metal from the irradiation exposure. The coolant flow through the neutron reflector holes cools the reflector ring blocks to minimize void swelling from irradiation of the reflector metal structure under normal operating conditions. As a result of heat deposition and cooling, a certain quasi steady-state temperature field is established within the neutron reflector metal wall volume at normal operating conditions.

As the amount of thermal energy, stored in the neutron reflector metal structure and available for release during a large break LOCA, is determined by this initial steady-state temperature field across the reflector wall, describe the applied approach in calculating the initial temperature field in the reflector metal structure. Provide the obtained results for the initial steady-state temperature field in the neutron reflector metal structure at nominal operating conditions and describe the initialization for the temperature field in the unheated conductors simulating the neutron reflector metal wall in the US-APWR WCOBRA/TRAC(M1.0) model.

Identify possible factors, if any, which can influence the prediction for the initial temperature field in the neutron reflector metal wall. For factors that can lead to higher initial temperature predictions, provide an assessment of the associated temperature effect.

Question 5

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Question 6

Provide description of the nodalization scheme implemented in the input for the unheated conductors representing the neutron reflector metal ring blocks in the US-APWR WCOBRA/TRAC(M1.0) neutron reflector model. Substantiate the applicability of the nodding approach to adequately capture the release of thermal energy from the reflector metal wall governed by thermal conductivity within the structure metal wall and convection heat transfer to the surrounding fluid. In addition, provide the thermal properties data for the neutron reflector material and explain their implementation in the input model. Discuss possible effects of irradiation on the neutron reflector material thermal properties.

Question 7

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Question 8

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Question 9

Table 6.3-5 “Safety Injection System Design Parameters (Sheet 2 of 3)” in MUAP-DC001 Revision 2 “Design Control Document for the US-APWR” describes the advanced accumulator as a vertical cylindrical vessel made of carbon steel with stainless steel cladding. During accumulator discharge and nitrogen gas expansion, heat, initially stored in the accumulator metal wall, is released to the contained gas volume due to heat transfer between the nitrogen gas and the tank wall driven by the gas temperature departure from the initial equilibrium temperature level. In turn, reduction in the tank wall temperature field, upon its propagation to the outer wall surface, will trigger heat transfer between accumulator wall and the ambient containment atmosphere. Heat transfer to the nitrogen volume inside the accumulator affects the gas pressure that drives the accumulator discharge.

The above described effects are compounded by the presence of a flow damper device that retards the advanced accumulator emptying and protracts the time period during which heat transfer between the tank wall and the nitrogen gas takes place. Quantify the effect of heat transfer from the accumulator wall to the nitrogen gas and demonstrate the WCOBRA/TRAC (M1.0) capability to account adequately for this effect in predicting the accumulator discharge performance.

Question 10

Upon reduction in pressure during the accumulator injection, nitrogen gas, initially dissolved in the accumulator liquid, will be released out of the liquid phase. Describe the effects of nitrogen gas release from the accumulator water and how these effects are modeled in WCOBRA/TRAC (M1.0) including validation and treatment of associated uncertainties. In particular, evaluate the effects of out-of-solution nitrogen gas on the performance characteristics of the advanced accumulator flow damper device.

Question 11

Considering cavitation in the advanced accumulator, MUAP-07011-P (R0) “Large Break LOCA Code Applicability Report for US-APWR” in Section 3.5.1.2 “Model Revisions”

defines a cavitation factor, σ_v, in Equation 3.5.1-1 and describes its use in the calculation of the accumulator flow rate flow coefficient, C_v. The flow rate coefficient, C_v, is given as an empirical correlation as a function of the cavitation factor, σ_v. Considering the practical limitations (variance in true vaporization pressure, P_v, and nucleation of the liquid) of predicting inception of cavitation, evaluate the uncertainty of the calculated cavitation factors, σ_v, for both high flow and low flow operating modes of advanced accumulator injection and determine its affect on the uncertainty of the flow coefficient, C_v. In addition, explain how cavitation inception scaling is addressed.

Question 12

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Question 13

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Question 14

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Question 15

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Question 19

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Question 21

Following reactor vessel refill and partial recovery of downcomer coolant inventory by accumulator discharge, direct vessel injection provides safety flow during the core reflood phase and long term cooling.

Describe the WCOBRA/TRAC direct vessel injection modeling approach for the US-APWR, including its validation for the specific direct vessel injection configuration and downcomer characteristics of the US-APWR design. Demonstrate the code capabilities

in predicting the effects of direct vessel injection on downcomer liquid inventory. In particular, address effects related to injection flow distribution, downcomer liquid temperature response, as well as potential for void development in the downcomer region and associated liquid spillover through the break.

Question 22

It is stated in Section 3.3.3 “Refilling Period” of MUAP-07011-P (R0) “Large Break LOCA Code Applicability Report for US-APWR” that the High Head Safety Injection (HHSI) system turns on automatically and injects emergency coolant into the vessel downcomer during the refill period of a large break LOCA. This description of HHSI injection into the vessel during the refill period does not appear consistent with information found in Table 3.3-1 and in Figure 3.3-2, both of which indicate HHSI occurs during the core reflood period. In addition, MUAP-DC001 Revision 2 “Design Control Document for the US-APWR” Section 15.6.5.3.3.1 “Large Break LOCA Analysis Results” states that HHSI begins coolant injection into the vessel during the reflood period.

Explain the sequence of HHSI system operation following a large break LOCA, including delay time between ECCS actuation signal generation and start of vessel injection. In the case of the reference large break LOCA transient calculation, presented in MUAP-DC001 Revision 2 “Design Control Document for the US-APWR” Section 15.6.5.3.3.1 “Large Break LOCA Analysis Results,” ECCS actuation signal is generated at 6 s and start of vessel injection occurs at 124 s, 90 s after the end of the blowdown phase predicted 34 s transient time. Clarify or correct the apparent inconsistency between the information provided in MUAP-07011-P R(0) Section 3.3.3 “Refilling Period” and that found in Table 3.3-1 “Typical Sequence of the LBLOCA of US-APWR” and in Figure 3.3-2 “ECCS Flow Injection Performance during LBLOCA” of the same report as well as in MUAP-DC001 Revision 2 “Design Control Document for the US-APWR” Section 15.6.5.3.3.1 1 “Large Break LOCA Analysis Results”.

Question 23

MUAP-07011-P R(0) “Large Break LOCA Code Applicability Report for US-APWR” Table 3.3-1 “Typical Sequence of the LBLOCA of US-APWR” states that the ECCS actuation signal, or “S” signal, is generated by a containment high pressure condition during the blowdown period. MUAP-DC001 Revision 2 “Design Control Document for the US-APWR” Section 15.6.5.3.3.1 “Large Break LOCA Analysis Results” states that the ECCS signal is generated due to low pressurizer pressure signal in the reference large break LOCA transient calculation.

Present all parameters and related conditions that can lead to S signal actuation following a large break LOCA in the US-APWR design. For each parameter, give the corresponding set point for signal generation along with pertinent causes for delay times and variation ranges, as applicable. Identify any assumptions made with regard to the implementation of the safety actuation signal logic in the US-APWR large break LOCA analysis methodology using WCOBRA/TRAC(M1.0). Include a summary table listing all numerical data for each of the parameters identified. Explain how the information provided in this table relates to the data provided in MUAP-DC001 Revision 2 “Design Control Document for the US-APWR” Table 15.0-4 “Reactor Trip and ESF Actuation Analytical Limits and Time Delays Assumed for Transient Analyses.”

Question 24

Describe the logic for reactor trip, main reactor coolant pump trip, and main steam line isolation following a large break LOCA in the US-APWR design. For each parameter, give the corresponding set point for signal generation along with pertinent causes for delay times and variation ranges, as applicable. Identify any assumptions made with regard to the implementation of the safety actuation signal logic in the US-APWR large break LOCA analysis methodology using WCOBRA/TRAC(M1.0). Identify and substantiate any assumptions with regard to the main coolant pump response following pump trip signal actuation for coolant pumps in both affected and intact loops.

Question 25

A comparison between the list of highly ranked models and phenomena provided in Section 3.4.1 “LBLOCA PIRT” and the information contained in Table 3.4-1 “US-APWR PIRT” of MUAP-07011-P R(0) “Large Break LOCA Code Applicability Report for US-APWR” reveals that not all the highly ranked models and phenomena given in Table 3.4-1 were included in the section text. In particular, not all of the H-ranked items identified in the Phenomena Identification and Ranking Table (PIRT) were included in the Section 3.4.1 “LBLOCA PIRT” list.

Explain how the list of highly ranked models and phenomena provided in MUAP-07011-P R(0) Section 3.4.1 “LBLOCA PIRT” correspond to the ranking in the US-APWR PIRT as documented in Table 3.4-1 “US-APWR PIRT” and substantiate any discrepancies.

Question 26

MUAP-07011-P R(0) “Large Break LOCA Code Applicability Report for US-APWR” Section 3.6.3.3 “Containment Pressure Calculation Model” explains that that the containment pressure used as a boundary condition for WCOBRA/TRAC(M1.0) large break LOCA analyses is calculated with the GOTHIC code in accordance with SRP 6.2.1.5 requirements. Furthermore, MUAP-DC001 Revision 2 “Design Control Document for the US-APWR” Section 6.2.1.5 “Minimum Containment Pressure Analysis for Performance Capability Studies of the Emergency Core Cooling System” describes the GOTHIC analytical model.

SRP 6.2.1.5 refers to RG 1.157 and BTP 6-2 for guidance on an acceptable minimum containment pressure model for ECCS performance evaluation. Prove that the applied single-volume US-APWR GOTHIC containment model yields containment pressure responses that are conservatively low for LOCA analyses across the entire spectrum of ASTRUM run conditions for best-estimate large break LOCA analyses with WCOBRA/TRAC(M1.0). Identify all assumptions and conservative margins used in the representation of the containment volume, associated heat structures, and RWSP water volume initial conditions as well as governing modeling assumptions such as multipliers for heat transfer coefficients for steam condensation on pool water. Quantify the margin of conservatism in the predicted containment pressure responses. If the containment pressure history presented in MUAP-DC001 Revision 2 “Design Control Document for the US-APWR” Figure 6.2.1-80 was applied to all best-estimate large break LOCA analyses, justify that it was conservative assumption for all cases analyzed.

Question 27

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Question 28

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Question 29

MUAP-07011-P R(0) “Large Break LOCA Code Applicability Report for US-APWR” Table 3.6-5 states the control rod drop time as “no drop”. US-APWR DCD application FSAR Section 15.6.5.2.1 “Description of Large Break LOCA” credits reactor trip for core power reduction.

Clarify whether control rods are assumed to insert in the US-APWR best-estimate large break LOCA analyses. Identify the reactivity mechanisms that accomplish reactor shutdown following a large break LOCA. In addition, provide and substantiate the reactivity insertion and feedback coefficients applied in predicting the core power.

Question 30

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Question 31

Table 3.7-1 “Uncertainty Treatment for US-APWR” of MUAP-07011-P R(0) “Large Break LOCA Code Applicability Report for US-APWR” identifies “Core Power” for uncertainty treatment. Describe how reactor core power level is treated in the ASTRUM uncertainty analysis for performing US-APWR best-estimate large break LOCA predictions. Explain treatment of instrument calibration and measurement uncertainty in determining initial power operating conditions.

Question 32

Some of the references cited in the first paragraph of MUAP-07011-P R(0) “Large Break LOCA Code Applicability Report for US-APWR” Section 4.0 “Conclusions” appear to be inconsistent with corresponding titles identified in Section 5.0 “References.” In particular, references to the AP600 design and the AP1000 design appear incorrect. Verify all references in MUAP-07011-P R(0) Section 4.0 “Conclusions” and correct the list of references in Section 5.0 “References” as found appropriate.

Question 33

Section 3.6.1 “Nodalization of Plant Analysis” of MUAP-07011-P R(0) “Large Break LOCA Code Applicability Report for US-APWR” describes the nodalization scheme used for the WCOBRA/TRAC(M1.0) plant model. In addition to the plant nodalization analysis, provide description of the time step controls and numerical convergence criteria used in the WCOBRA/TRAC(M1.0) analyses. Include the results from any sensitivity studies performed to evaluate the effects of time step control and their applicability to the US-APWR design large break LOCA analyses.

Question 34

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Question 35

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Question 36

Table 3.7-2 “Local Model Uncertainty Treatment for US-APWR” of MUAP-07011-P R(0) “Large Break LOCA Code Applicability Report for US-APWR” provides the fuel local parameters that are explicitly treated in the ASTRUM uncertainty analysis. Explain the treatment of fuel manufacturing tolerances in the ASTRUM uncertainty analysis.

Question 37

MUAP-07011-P R(0) “Large Break LOCA Code Applicability Report for US-APWR” does not explicitly address NUREG/CR-5249 CSAU Step 5. Conformance with NUREG/CR-5249 CSAU Step 5 requires that adequate documentation of the frozen code identified in CSAU Step 4 be provided, including, at minimum, a user manual, user guide, developmental assessments reports, and the models and correlations quality evaluation report.

Provide the above-mentioned developmental assessments reports, and the models and correlations quality evaluation report for the frozen version of WCOBRA/TRAC (M1) code.

Question 38

Section 3.6.1 “Nodalization of Plant Analysis” of MUAP-07011-P R(0) “Large Break LOCA Code Applicability Report for US-APWR” describes that the US-APWR nodalization scheme is identical to the one used for the Westinghouse conventional 3- and 4-loop PWR plants as discussed in the WCOBRA/TRAC Code Qualification Document WCAP-12945-P-A.

Identify and justify any differences in the WCOBRA/TRAC (M1.0) US-APWR plant and vessel model noding from that used in the referenced WCAP-12945-P-A report. In addition, describe the noding sensitivity studies performed for the cold leg piping in the vicinity of the break or justify the applicability of the studies performed previously for the conventional 4-loop PWR plants, considering system design and size differences from the US-APWR.

As new safety features in the US-APWR design, describe and present the results from noding sensitivity studies performed for the new advanced accumulator model as well as for the ECC direct vessel injection ports.

Question 39

Conformance with NUREG/CR-5249 CSAU Step 10 requires that the ability of a best-estimate code to scale-up the phenomena and processes observed from a test facility be evaluated on a case-by-case basis. The effects of scaling are not addressed in MUAP-07011-P R(0) “Large Break LOCA Code Applicability Report for US-APWR.”

Considering that the power-to-volume ratio for the US-APWR may differ from the conventional 4-loop PWR as evaluated in either WCAP-12945-P-A or WCAP-16009-P-A, describe the assessment results for the scale-up capability of WCOBRA/TRAC(M1.0) as applicable to the US-APWR. In particular, address scaling and any associated distortion effects with regard to ECC bypass, liquid entrainment, and steam binding in the SG.

Evaluate scaling and dominant distortion effects for in-vessel phenomena resulting from the inclusion of the neutron reflector component in the US-APWR design.

Question 40

Section 3.7 "ASTRUM Methodology Applied to US-APWR" of MUAP-07011-P R(0) “Large Break LOCA Code Applicability Report for US-APWR” does not address the treatment of decay heat.

Describe the ASTRUM uncertainty analysis in the treatment of decay heat modeling in WCOBRA/TRAC (M1.0). In particular, present derivation of any applicable uncertainty ranges, sampling range bounds, type of uncertainty distribution, and any uncertainty dependencies, including such on burnup level.

Question 41

Figure 3.6-18 “Downcomer Liquid Level” in MUAP-07011-P R(0) “Large Break LOCA Code Applicability Report for US-APWR” shows oscillations in the predicted downcomer liquid level during a time period when the reflood PCT occurs at 77 s.

Provide an explanation of the oscillations and their effect on PCT. Include detail plots of downcomer liquid level, core liquid level, core flow, heat transfer coefficient at PCT location, and calculated PCT. Present an evaluation of the effects of the liquid level oscillations on hot spot heat transfer and resultant PCT to ensure that oscillations do not unduly enhance core heat transfer.

Question 42

Comparing the US-APWR design against a conventional 12-ft core 4-loop PWR plant, the ratio of the core thermal power results in value of about 1.30 whereas the ratio of the hot leg area amounts to 1.14. Identify any detrimental effects on the US-APWR core thermal hydraulic response during a large break LOCA that result from this relative deviation in the US-APWR hot leg flow area. In addition, demonstrate that any such

effects associated with processes occurring in the reactor hot legs have been properly accounted for in performing US-APWR best-estimate large break LOCA analyses using WCOBRA/TRAC(M1.0).

Question 43

Appendix A "Thermal Properties of Nuclear Fuel Rods" in MUAP-07011-P R(0) "Large Break LOCA Code Applicability Report for US-APWR" describes the model for computing fuel thermal conductivity. To account for conductivity degradation with fuel burnup, the model uses a correlation by Wiesenack published in 1997, which is based on in-pile temperature data. Furthermore, MUAP-07011-P R(0) explains that the model is identical to the one used in the applicant's FINE fuel design code. A new routine, TCONF, has been implemented in WCOBRA/TRAC(M1.0) to compute the fuel conductivity at 95% of the theoretical density along with a correction factor accounting for the deviation of the actual fuel density from the theoretical value. The thermal conductivity is calculated in subroutines SSTEMP and TEMP by calling subroutine TCONF. In addition, MUAP-07011-P R(0) states that uncertainty of the fuel thermal conductivity has already been partly considered in the uncertainty of stored energy in ASTRUM and claims that the same treatment of the stored energy uncertainty in the ASTRUM methodology is applicable to the US-APWR fuel.

Demonstrate that the fuel properties model used in WCOBRA/TRAC(M1.0) accounts adequately for changes in thermal properties over the fuel burnup range applicable to the US-APWR core design. Provide any additional data in support of the applicability of the model to the US-APWR design. Identify all individual parameters related to the US-APWR fuel design that have been treated in the uncertainty analysis related to the initial stored energy in the US-APWR core. For each parameter, provide and justify the corresponding range, including its lower and upper limits as well as any assumed probability distribution, if such parameters were applied in the uncertainty analysis in the US-APWR best-estimate large break LOCA analyses performed with WCOBRA/TRAC(M1.0).

Question 44

Explain in details how effects associated with initial fuel energy have been accounted for in the modeling of the US-APWR core using WCOBRA/TRAC(M1.0) for best-estimate large break LOCA analyses. Identify and justify any specific assumptions implemented in specifying the core input model. In particular, consider effects associated with core nodalization, presence of different fuel bundles of different burnup in each noding region, fuel cycle, and core loading schemes.

Question 45

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Question 46

When the large break LOCA reference case is run with the core heat flux, the RCP speeds, and the MFW flows all set to zero, the flow in each loop settles to 300 kg/s instead of zero. This is about 6% of the nominal steady state loop flow rate. Explain why the loop flows do not go to zero and assess the effect on the results of the ASTRUM analysis.

Question 47

Was the same seed used to generate the random variables in the ASTRUM analyses presented in MUAP-DC001 Revision 1 “Design Control Document for the US-APWR” and MUAP-DC001 Revision 2 “Design Control Document for the US-APWR”?