WCAP-16996-P/ WCAP-16996-NP Volumes I, II, and III, Revision 0, “Realistic LOCA [loss-off-coolant accident] Evaluation Methodology Applied to the Full Spectrum of Break sizes (FULL SPECTRUM™ LOCA (FSLOCA) Methodology)”

REQUEST FOR ADDITIONAL INFORMATION (RAI)

SECOND SET OF RAI QUESTIONS

RAI Questions 20 through 29

(Revision 0)

ENCLOSURE 1

Table 1: Summary of RAI Questions, Revision 1

Question No.	Subject	Date Issued	Date Responded	Disposition (O/C)[†]	Note
Set 1	**Questions 1 through 19**				
1	WCOBRA/TRAC MOD7A Revision 7				
2	TRAC-PF1/MOD2 Code				
3	Large-break LOCA (LBLOCA) and small-break LOCA (SBLOCA) phenomena identification and ranking tables (PIRTs)				
4	End of blowdown				
5	Gap conductance				
6	Pressurizer response				
7	Long-term cooling and PIRT				
8	SBLOCA boundary and Region-I to Region-II boundary				
9	Worst SBLOCA				
10	Loss-of-offsite power (LOOP) versus reactor coolant pumps (RCPs) operating				
11	LOOP seal behavior				
12	Worst break sampling				
13	Decay heat multiplier/sampling				
14	Number of SBLOCA cases sampled: 93 versus 124				
15	SBLOCA upper limit break size				
16	Long-term cooling restriction				
17	Swelled or two-phase mixture level versus collapsed level				
18	High pressure safety injection (HPSI) curve basis and uncertainty				
19	SBLOCA axial power shape				
Set 2	**Questions 20 through 29**				
20	^{235}U, ^{238}U, and ^{239}Pu decay heat uncertainty fits to ANS 5.1-1979				
21	^{235}U, ^{238}U, and ^{239}Pu decay heat and uncertainty comparison to American Nuclear Society (ANS) 5.1-1979				
22	^{235}U, ^{238}U, and ^{239}Pu decay heat uncertainty comparison to ANS 5.1-1979				
23	Burnup limit in assessing kinetics parameters				
24	Editorial				
25	Utilized codes				
26	Actinides decay heat power				
27	Decay heat in demonstration plant analyses				
28	Decay heat uncertainty distribution				
29	Decay heat sampling approach				

[†] O=Open; C=Closed.

Question 20: ^{235}U, ^{238}U, and ^{239}Pu Decay Heat Uncertainty Fits to ANS 5.1-1979

Decay heat is an important factor in the analysis of postulated LOCAs and ECCS performance evaluation and an accurate assessment of both the decay heat and its uncertainty is necessary. WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 9.2, "Decay Heat Source," explains that WCOBRA/TRAC-TF2 solves the time-dependent decay activity differential equation accounting for ^{235}U thermal, ^{239}Pu thermal, and ^{238}U fast fissions. The energy yield constants are weighted by the appropriate fission rate fractions as a function of initial enrichment and burnup within WCOBRA/TRAC-TF2. Section 9.2 states that the WCOBRA/TRAC-TF2 decay heat model was benchmarked against the ANSI/ANS 5.1-1979 Standard. Results of decay heat for ^{235}U computed by WCOBRA/TRAC-TF2 and using the American Nuclear Standards Institute (ANSI)/ANS 5.1-1979 Standard are presented in Table 9-2, which shows that the difference between the values calculated from both approaches is negligible for decay time up to 10^3 s. The section also states that similar comparisons exist for ^{239}Pu and ^{238}U.

The decay heat uncertainty modeling in WCOBRA/TRAC-TF2 is discussed in WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 9.7, "Decay Heat Uncertainty Evaluation," which explains that WCOBRA/TRAC-TF2 models decay heat uncertainty through the use of pseudo-isotope energy yield augmentation factors generated using a least squares fit to the uncertainty data provided in ANSI/ANS 5.1-1979. The section claims that the results, as provided in Table 9-14, "provide a conservative representation of the standard's quoted uncertainties." Although Table 9-14 presents the computed factors, a description of the uncertainty modeling equations and their implementation in WCOBRA/TRAC-TF2 is not provided. Please provide the equations used in WCOBRA/TRAC-TF2 to compute the decay heat uncertainties for the considered isotopes and explain how the individual uncertainties are used in predicting the overall decay heat uncertainty in plant analyses.

Question 21: ^{235}U, ^{238}U, and ^{239}Pu Decay Heat and Uncertainty Comparison to ANS 5.1-1979

WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 9.7, "Decay Heat Uncertainty Evaluation," in discussing the decay heat uncertainty modeling in WCOBRA/TRAC-TF2, refers to Figures 9-26 to 9-28 for comparison of "predicted decay heat with uncertainties to the standard decay heat plus 2σ uncertainties" for cooling times from 1 s to 10^9 s. Figure 9-26 shows the decay heat for ^{235}U, Figure 9-27 exhibits the decay heat for ^{239}Pu, and Figure 9-28 plots the decay heat for ^{238}U as functions of cooling time after shutdown and each plot identifies three data sets. The first data set is labeled "DH Standard" and the second data set is labeled "DH Standard + 2 Sigma" in all three plots. The third data set is labeled as "DH Fitted" in Figure 9-26 and as "DH Calculated" in Figures 9-27 and 9-28.

Please clarify and address, as needed, the following comments related to Section 9.7 and Figures 9-26 to 9-28.

(1) It is believed that the units for decay heat on the Y-axis in each figure should be "MeV/fission" (MeV/fission=[MeV/s]/[fission/s]). Instead, the decay heat units appear as "MeV/sec/fission".

(2) It appears that Figure 9-26 exhibits the decay heat function $F_i(t,T)$ for thermal fission of ^{235}U, Figure 9-27 plots $F_i(t,T)$ for the thermal fission of ^{239}Pu, and Figure 9-28 shows $F_i(t,T)$ for fast fission of ^{238}U for the infinite irradiation time ($T=10^{13}$ s) in all three plots. However, description for the plotted quantities is not provided in Section 9.7.

(3) Only two data sets (curves) are seen in each of the plots. A third data set (curve) is not distinguishable and using symbols to indicate overlapping curves can be used if appropriate.

Please provide updated plots that represent the WCOBRA/TRAC-TF2 decay heat predictions for ^{235}U, ^{239}Pu, and ^{238}U for decay time from 0.1 s to 10^6 s. In each plot, please show the standard decay heat values $F_i(t,\infty)$ for ^{235}U, ^{239}Pu, and ^{238}U as tabulated in ANSI/ANS 5.1-1979, Tables 4, 5, and 6 representing each value by a symbol with a two-sided Y-error bar corresponding to $\pm 2\sigma$ uncertainty using the uncertainty data in the ANSI/ANS 5.1-1979 tables. The uncertainties in both ANSI/ANS 5.1-1979 and ANSI/ANS 5.1-2005 are currently represented in tabular form for the decay heat functions $f_i(t)$ and $F_i(t, \infty)$ and values for intermediate times are obtained by interpolation. The included figure presents the $F_i(t,\infty)$ ANSI/ANS 5.1-1979 Standard decay heat and uncertainty data for ^{235}U, ^{239}Pu, and ^{238}U. In each figure, plot a curve that shows the "nominal" WCOBRA/TRAC-TF2 decay heat prediction as a continuous function of time and then show two additional curves that represent uncertainties predicted by WCOBRA/TRAC-TF2 and representing the decay heat "upper bound" (nominal plus 2σ) and "lower bound" (nominal minus 2σ). Explain how the code predicts the uncertainties for t < 1 s as no standard data are provided.

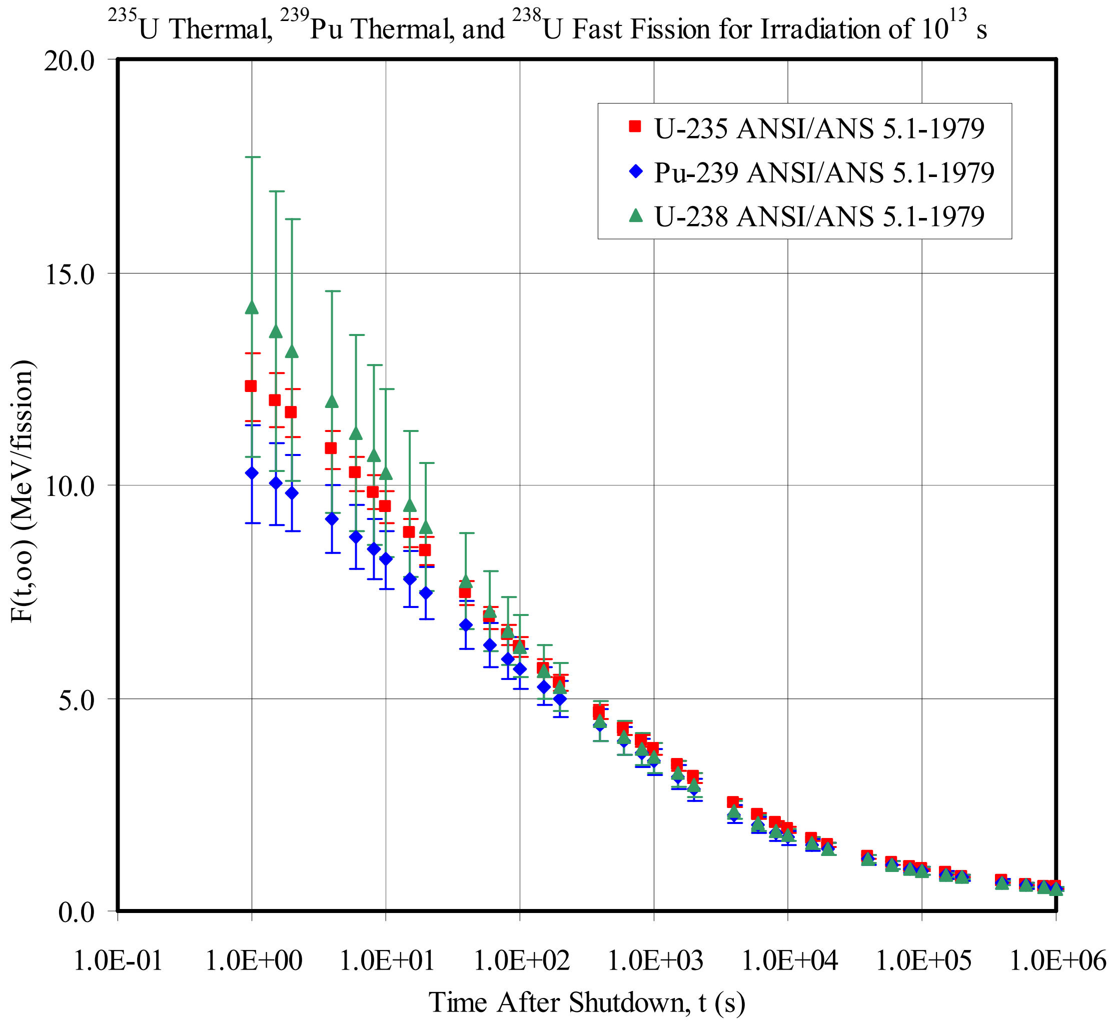

Figure: ANSI/ANS 5.1-1979 Tabular Data for Standard Decay Heat Power and Uncertainty for Thermal Fission of ^{235}U and ^{239}Pu and Fast Fission of ^{238}U for Irradiation of 10^{13} s

Question 22: ^{235}U, ^{238}U, and ^{239}Pu Decay Heat Uncertainty Comparison to ANS 5.1-1979

The determination of decay heat uncertainties is an important area and the modeling of decay heat uncertainty in WCOBRA/TRAC-TF2 is discussed in WCAP-16996-P/ WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 9.7, "Decay Heat Uncertainty Evaluation." WCOBRA/TRAC-TF2 models decay heat uncertainty through the use of pseudo-isotope energy yield augmentation factors generated using a least squares fit to the uncertainty data provided in ANSI/ANS 5.1-1979. The section refers to Figures 9-23 to 9-25 stating that they "illustrate the fit deviation in both energy and decay heat versus cooling time." According to the figure captions, the plots represent "percent fit deviations" for ANSI/ANS 5.1-1979 plus 2σ for ^{235}U, ^{239}Pu, and ^{238}U.

It is seen from Figures 9-23 to 9-25 that the plotted discrepancies exhibit most pronounced deviation during the first 100 s of cooling time. At the same time, approximately 25 percent of the residual decay energy is released in the first 10 s after the fission process ends and about 50 percent is released by 100 s after fission (see I. Gauld, "Validation of ORIGEN-S Decay Heat Predictions for LOCA Analysis," PHYSOR-2006, ANS Topical Meeting on Reactor Physics, Vancouver, BC, Canada, September 10-14, 2006).

Please explain how the quantity labeled "Deviation" and shown along the vertical Y-axis in Figures 9-23 to 9-25 for cooling time from 10^{-1} s to 10^{9} s was computed and define the parameters "energy" and "decay heat" for which the results were plotted. Please provide updated plots that compare the WCOBRA/TRAC-TF2 uncertainty predictions for ^{235}U, ^{239}Pu, and ^{238}U for cooling time from 0.1 s to 10^{6} s. In each plot, please show the uncertainty presented as 1+2σ and computed using the tabulated σ uncertainty percent values provided in ANSI/ANS 5.1-1979, Tables 4, 5, and 6. The included figure presents the ANSI/ANS 5.1-1979 Standard decay heat uncertainty data for ^{235}U, ^{239}Pu, and ^{238}U. In each figure, plot a curve that shows the WCOBRA/TRAC-TF2 decay heat uncertainty prediction as a continuous function of time. Explain how the code predicts the uncertainties for $t < 1$ s as no standard uncertainty data are provided. If the WCOBRA/TRAC-TF2 decay heat uncertainty model underestimates any of the ANSI/ANS 5.1-1979 Standard values, a correction factor needs to be implemented to ensure that the code calculates uncertainties that are not less than the standard values.

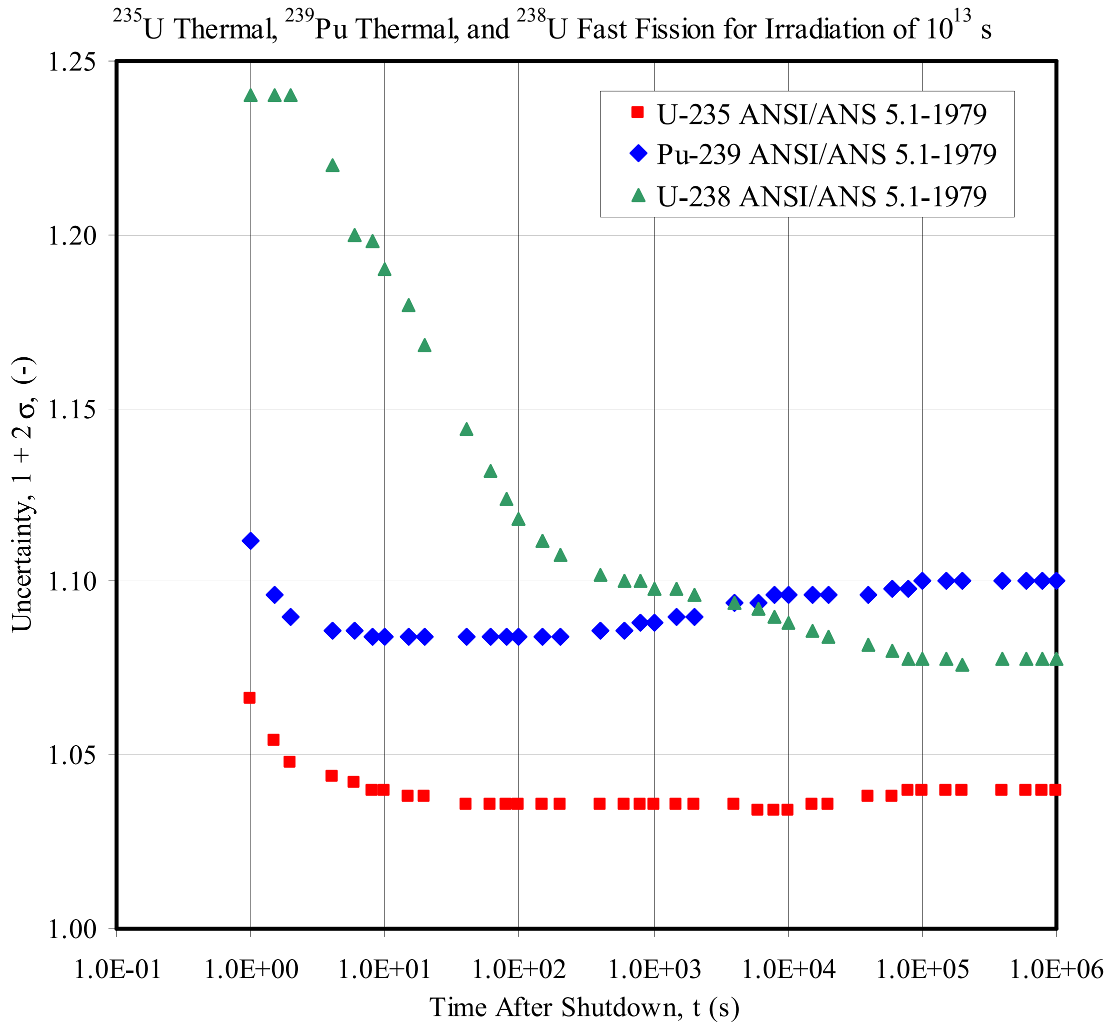

Figure: ANSI/ANS 5.1-1979 Tabular Data for Standard Decay Heat Power Uncertainty for Thermal Fission of ^{235}U and ^{239}Pu and Fast Fission of ^{238}U for Irradiation of 10^{13} s

Question 23: Burnup Limit in Assessing Kinetics Parameters

WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 9, "WCOBRA/TRAC-TF2 Reactor Kinetics and Decay Heat Models," includes Figures 9-1 through 9-3, Figures 9-5 through 9-15, and Figures 9-32 through 9-34 that illustrate the dependence of various important physical parameters on the fuel burnup. With regard to neutron kinetics, WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 9.3, "Fission Heat," states that WCOBRA/TRAC-TF2 explicitly models the burnup and initial enrichment dependence of kinetics data. Such data, generated for typical Westinghouse fuel lattice designs, are presented in Figures 9-5 through 9-14.

In all identified figures, the burnup range is limited to 60 MWD/MTU. Please explain if the application of the FSLOCA methodology is limited by this burnup level. If this is not the case, please show revised plots that cover the entire expected range of fuel burnup levels.

Question 24: Editorial

WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 9.10, "Generalized Energy Deposition Model (GEDM) Validation," refers to Table 9-19 for a comparison **[**

] Table 9-19 is not found in WCAP-16996-P Revision 0. It is believed that the referenced table should be Table 9-18 instead of Table 9-19. Please clarify and correct accordingly.

WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Subsection 9.9.2, "WCOBRA/TRAC-TF2 Fission Energy Accounting," refers to Table 9-18 with regard to the prompt fission energy release, radiative capture release, and average fission neutron energy utilized in the evaluation of the composite prompt energy release per fission. It is believed that the referenced table should be Table 9-17 instead of Table 9-18. Please clarify and correct accordingly.

WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Subsection 9.9.1, "Actinide Decay Power," with regard to physical data for **[** **]** used in calculations performed to evaluate the impact of the total actinide heat source. It is believed that the referenced table should be Table 9-16 instead of Table 9-17. Please clarify and correct accordingly.

Question 25: Utilized Codes

WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 9.2, "Decay Heat Source, explains that WCOBRA/TRAC-TF2 solves the time-dependent decay activity differential equation accounting for ^{235}U and ^{239}Pu thermal fission as well as for ^{238}U fast fission. The energy yield constants are weighted by the appropriate fission rate fractions as a function of initial enrichment and burnup within WCOBRA/TRAC-TF2. It is explained that the fission rate weighting was obtained from detailed physics evaluations of PWR fuel lattice designs and the results from these evaluations are presented in Figure 9-1 for ^{235}U thermal fission and in Figures 9-2 and 9-3 for ^{239}Pu thermal fission and ^{238}U fast fission weightings, respectively. Thus, WCOBRA/TRAC-TF2 solves for the composite decay heat of the reactor of interest using the fission rate fractions derived from specific physics calculations for the fuel lattice design. Please identify the codes

used to perform these calculations, explain if they have been approved by NRC, and provide appropriate references.

WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 9.3, "Fission Heat," states that a series of detailed space/energy calculations have been performed for a typical fresh assembly to quantitatively evaluate fission rate per unit neutron density for water densities that occur during a LOCA transient. Figure 9-4 shows the calculated coolant density dependence of the macroscopic cross section. Please identify the codes used to perform these calculations, explain if they have been approved by NRC, and provide appropriate references. In addition, please identify and explain the values for the physical parameters "KSF," "NSF," and "SIGA" that are used to indentify each of the three curves shown in Figure 9-4. Which of the results was used to model the fission frequency in WCOBRA/TRAC-TF2?

WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Subsection 9.6.2, "GEDM," explains that the DOT code was used as the dimensional particle transport code for the examples presented in this report. Please explain if this code has been approved by NRC and provide appropriate references.

WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Subsection 9.9.1, "Actinide Decay Power," explains that detailed calculations have been performed to evaluate the impact of the total actinide heat source. Please identify the codes used to perform these calculations, explain if they have been approved by NRC, and provide appropriate references.

Question 26: Actinides Decay Heat Power

In treating actinide decay heat power, ANSI/ANS 5.1 explicitly considers only decay heat power from ^{239}U and ^{239}Np. These two actinide isotopes are the dominant actinide decay heat for cooling times for which the standard is routinely applied to calculate decay heat for thermal-hydraulic safety system analyses. This limitation of the standard necessitates consideration of its augmentation with actinide values obtained from other calculations as actinide contribution, with ^{239}U and ^{239}Np excluded, increases from approximately 1 percent of the fission product decay heat power after 1 s up to approximately 10 percent after 10^5 s following shutdown (I.C. Gauld et al., "Proposed Revision of the Decay Heat Standard ANSI/ANS-5.1-2005," ORNL Publication No. 24753, October 2011). WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Subsection 9.9.1, "Actinide Decay Power," presents results from detailed calculations performed to evaluate the impact of the total actinide heat source. As seen from Figures 9-32 and 9-33 **[**

] Please present the analysis results that quantify the impact of **[**

] Identify the assumptions applied in this analysis and show the

results for the predicted actinide power for both cases **[**
] Illustrate the impact from major parameters over their entire range of interest for decay heat predication.

Question 27: Decay Heat in Demonstration Plant Analyses

WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 9, "WCOBRA/TRAC-TF2 Reactor Kinetics and Decay Heat Models," describes the models for heat sources from fission heat, fission product decay heat, and actinide decay heat. However, the section does not show a calculated reactor power curve used in any of the analyses discussed in WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0.

For the demonstration Westinghouse plant (V. C. Summer) examined in WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 31, "Full Spectrum LOCA Demonstration Analysis," please present graphs that show the WCOBRA/TRAC-TF2 predicted total residual power relative to the operating power (total reactor power or local power as appropriate) for the Region I and Region II limiting cases (Run 059 and Run 119). Use logarithmic scales for both the X-axis showing time after shutdown or break occurrence from 0.1 s to 10^6 s and for the Y-axis showing relative power from 10^{-3} to 10^0. In each plot, please show with separate curves the residual fission power from the point kinetics model, the individual decay power contributions accounting for fission product decay power, actinide decay power, and decay power due to neutron capture by fission products during irradiation using the ANSI/ANS 5.1-1979 decay heat model, and the resulting total residual power. Present the "nominal" WCOBRA/TRAC-TF2 decay heat curve along with the upper (nominal plus 2σ) and lower (nominal minus 2σ) bounds in the plots. Please include two tables that document all utilized input parameters to the applied WCOBRA/TRAC-TF2 models to compute the contributing residual powers for both runs as plotted in the presented graphs (e.g., energy per fission). For each appropriate input parameter, please show its identifier, units, numerical or logical value, and the way in which the input value was determined. In the same manner, please document also all relevant uncertainty factors applied for both runs. Please explain if suggestions contained in NRC Information Notice 96-39, "Estimates of Decay Heat Using ANS 5.1 Decay Heat Standard May Vary Significantly," dated July 5, 1996, are of relevance when determining any ANSI/ANS 5.1-1979 Standard input model parameters for WCOBRA/TRAC-TF2.

Question 28: Decay Heat Uncertainty Distribution

As described in WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Subsection 25.2.1.4, "The Effect of Fuel Burnup on Power Distributions," the time-in-cycle impacts the decay heat as a burnup-dependent parameter. Furthermore, Subsection 29.5.1, "Fuel Rod," explains that the decay heat uncertainties, based on the ANSI/ANS 5.1-1979 Standard, "vary with time in cycle as the decay heat contribution from each fissionable isotope changes." Also, Subsection 29.4.1.2, "Reactor Core Power Distributions and Global Uncertainties," states that "uncertainty in decay heat is considered through the application of ANSI/ANS 5.1-1979 Standard (DH, normal distribution)." Table 29-4, "Uncertainty Elements – Power-Related Parameters Defined in Section 29.4.1," describes the decay heat uncertainty distribution as normal and characterizes it with a mean value and a standard deviation σ defined as a function of

burnup and enrichment, σ = f (burnup, enrichment). Please explain the method of calculating the dependency of the standard deviation σ for the decay heat uncertainty distribution on the fuel burnup and enrichment and present results to illustrate the predicted effect on σ over the entire range of expected burnup levels and enrichments.

Tables 31.3-1a and 31.3-2a in WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Section 31.3, "Analysis of Results for Region I," and Table 31.4-1a in Section 31.4, "Analysis of Results for Region II," include the uncertainty attribute "DECAY HT (-)" along with the values used in the documented runs. If this or any other attributes are related to the decay heat uncertainty characterization, please explain their meaning and relationship to the characteristics defined in WCAP-16996-P/ WCAP-16996-NP, Volumes I, II, and III, Revision 0, Table 29-4 to describe the decay heat uncertainty distribution. Also, please explain how "DECAY HT" or any other decay heat related uncertainty attributes are applied in executing the runs and obtaining the WCOBRA/TRAC-TF2 predictions.

Please explain how the ANS 5.1 uncertainties, represented in tabular form in ANSI/ANS 5.1-1979 Tables 1 to 6 for the decay heat functions $f_i(t)$ and $F_i(t, \infty)$, the fission product decay heat power for a pulse and infinite irradiation as a function of time after fission, relate to the decay heat uncertainty distribution parameters and the decay heat related uncertainty attributes considered above. In particular, please explain if dependence of the decay heat uncertainty distribution standard deviation σ or of the decay heat related uncertainty attributes on the cooling time following reactor shutdown is considered in the FSLOCA methodology.

Question 29: Decay Heat Sampling Approach

WCAP-16996-P/WCAP-16996-NP, Volumes I, II and III, Revision 0, Subsection 26.2.2, "V. C. Summer Reference Case and Allowable Plant Operating Conditions," explains that the best-estimate methodology establishes a sampling of the distribution of potential uncertainty contributors, which occur due to changes in plant or model variables. The input values for V. C. Summer and Beaver Valley Unit 1 reference cases considered in Section 26, "WCOBRA/TRAC-TF2 Model of Pilot Plants," are divided in three categories: 1) plant physical description, 2) plant initial operating conditions, and 3) accident boundary conditions. Decay heat is not included in the lists of categorized parameters. The parameters in these categories are sampled once for each run in order to initialize the input values needed to analyze the case.

Decay heat generation is a process that occurs in time and as such it differs from the parameters considered in the above identified categories of input parameters. Decay heat measurement data is characterized by experimental uncertainties. Detailed calculations of decay heat bear the uncertainties that originate from errors in the nuclear data and the yields of individual fission products. As a result, uncertainties are inherent to the decay heat generation process and its quantification at any point in time during the cooling period following reactor shutdown. In this regard, please explain the technique, appropriateness, and applicability of the FSLOCA methodology sampling approach in accounting for uncertainties in the decay heat prediction. This RAI question is related to Question 13.