Response to Request for Additional Information (RAI) Questions Regarding EPRI Report 1025203, "Utilization of the EPRI Depletion Benchmarks for Burnup Credit Validation," and EPRI Report 1022909, "Benchmarks for Quantifying Fuel Reactivity Depletion Uncertainty"

1) *For the resulting benchmark model to be applicable, the uncertainty of the benchmark must be established such that a 95/95 confidence assessment can be established on the subsequent criticality calculations. As such the uncertainty in the reactivity of a specific assembly at a specific burnup needs to be determined. The variance of the average of multiple assemblies will be smaller than the variance of a single assembly. The statistics in the proposed approach appears to only derive the uncertainty of the CASMO/SIMULATE code that is applicable to the reactor core average decrement. Clarify how the variance in the reactivity decrement for a specific assembly and burnup can be established to support subsequent criticality benchmark analyses.*

Response:

The statement *"The statistics in the proposed approach appears to only derive the uncertainty of the CASMO/SIMULATE code that is applicable to the reactor core average decrement,"* in the RAI is not accurate as shown in the response below. The final analysis has 191 sub-batch/cycle measured data points (collapsed over each cycle) across the 44 cycles analyzed. Therefore, the data represents the 95/95 confidence limits for the measured Hot Full Power (HFP) PWR fuel reactivity decrement biases derived from PWR reactor data.

These specific issues (and numerous others) identified in the RAI question are addressed directly in the updated statistical analysis provided in Attachment 2. This analyses provides the following information:

- Adds a conservative bias to each individual measured sub-batch reactivity decrement bias to account for the variance of the sub-batch being less than the variance of the individual assemblies within the sub-batch

- Applies individual variances for each measured sub-batch reactivity decrement biases (as a function of sub-batch burnup and sensitivity)

- Treats all measured sub-batch reactivity decrements biases within a cycle as a single value, so within-cycle correlation effects do not adversely influence the variance estimates for the regression fits

- Adds an increased variance to directly-computed variances of the regression fit to account for possible enrichment-dependence of HFP measured reactivity decrement biases

- Tests for normality of final residuals between regression fits and measured reactivity decrement biases – to assure that the regression fit variances can be used directly

- Augments the 95% confidence intervals by the ratio of the two-sided tolerance limit factor to the Student's t-value to arrive at a true 95% confidence limit for the CASMO-5 measured reactivity

decrement biases

Using this conservative approach to assessing the final uncertainty for CASMO-5 measured reactivity decrement biases allows the 95/95 confidence limits to be correctly assigned to the final measured sub-batch reactivities.

Adding additional biases and variances for intra-batch variation in burnup and enrichment dependence makes the final variance estimates applicable to the full range of burnup and enrichments encountered by individual fuel assemblies within any of the specific reactors or core loadings.

2) *Benchmarks have historically been "measurements" with some minor calculation adjustments for clarity or simplification. The approach, as presented in the reviewed documents and revised statistical approach, presents a case to assess the uncertainty of the code methodology based indirectly on core measurements with adjustments to minimize the code difference (error). The "benchmark" is then manufactured from the code using the code's relative uncertainty. Thus, the benchmark is based on the code, not on the measurement. To be based on the measurement, only those measurements (i.e., directly from flux map data) applicable to a benchmark case would be used with the establishment of case-specific absolute variances or errors. Explain why EPRI's reactivity decrement error deduction approach is appropriate given that the benchmark is based on the code rather than direct measurement.*

Response:

By searching the full space of core sub-batch reactivities, the measured flux map data are used directly to find the core reactivity distribution that best predicts measured fission rate distributions. Use of more than 600 measured flux maps allows measurement of the change (bias) in predicted lattice physics code reactivity (here, the CASMO-5 reactivity) that produces the best agreement with measured fission rate distributions for each flux map.

Given the additional assumption that biases in lattice physics code reactivities are expected to be primarily dependent on fuel burnup and enrichment, the large number of individual measurements of the reactivity bias are statistically combined to obtain a reduced-uncertainty estimate of the reactivity bias relative to that which could be obtained from any individual flux map measurement. Correspondingly, the final uncertainties for measured reactivity decrement biases are also smaller that would be obtained from individual flux map measurements.

The measured CASMO-5 bias and CASMO-5 computed reactivity decrements are used to construct measured reactivity decrements for use in the EPRI benchmarks. **When applicants compare their code's predictions to the EPRI benchmarks, they are comparing not to CASMO-5, but to the measured reactivity decrements.** This is why such comparisons are not simply code-to-code comparisons.

Additional tests have been performed to demonstrate that CASMO-5 and SIMULATE-3 do not contribute significantly to the measured reactivity decrements in the EPRI benchmarks. First, one should be able to use any modern lattice code/cross section library and core analysis tool to produce high quality measured reactivity decrement benchmarks that are expected to lie within the range of assigned uncertainties of the EPRI benchmarks. First, in their respective M.S. thesis, Gunow [2,3] and Sykora [2,4] each used full-core multigroup neutron transport calculations to determine reactivity decrement biases for selected flux maps and sub-batches using the BEAVRS benchmark measured reactor data. The BEAVRS data is publicly available and uses data from the first two-cycles [5, 6]. It should be noted that the BEAVRS Benchmark is used by many organizations [7-10] around the world for studying the accuracy of PWR core analysis methods because it may be the only source of publicly available, high-quality, measured reactor data.

Both of these studies showed that the inferred reactivity decrements (see Table 6-2 reproduced here) were nearly the same when using SIMULATE-3 (two-group nodal diffusion calculations) and CASMO-5 (35-group, fine-mesh, transport calculations) to perform the core analysis. Thus, it is unlikely that any of the nodal model approximations have significantly influenced the inferred reactivity decrements of the original EPRI report [1]. These tests rule out any significant influence from core analysis approximations; such as lattice boundary conditions, two-group theory, assembly homogenization, macroscopic depletion, pin power reconstruction, etc.

Sykora's analysis also showed that the burnup perturbation used to perform the k-infinity search in the EPRI methodology produced nearly identical reactivity decrements as using fuel temperature perturbations. This further substantiated the expectation that k-infinity itself dominants changes in core flux distribution, and the method by which the k-infinity perturbation is performed is not very important. Note from Table 6-2 results that the mean reactivity differences and 2-sigma deviations (for nodal diffusion vs. multi-group transport or burnup vs. temperature perturbation) are less than the uncertainty assigned the measured reactivity decrements in the EPRI report [1].

Table 6-2
Reactivity decrement biases computed by burnup and temperature perturbations

Fuel Assembly Reactivity Decrement Biases for BEAVRS Cycle 1 and Cycle 2 (CASMO-5 with ENDF-B/VII)								
Cycle	Enrichment	Cycle Burnup	Fuel Burnup	SIMULATE Bias (burnup pert.) Δk	CASMO Bias (burnup pert.) Δk	CASMO Bias (temp. pert.) Δk	SIMULATE - CASMO Bias (burnup pert.)	Bias Difference (burnup pert. - temp. pert.)
	%	GWd/T	GWd/T	pcm	pcm	pcm	pcm	pcm
1	2.4	2.16	2.44	-215	-251	-182	36	-69
1	2.4	6.49	7.39	66	66	90	0	-24
1	2.4	11.08	12.62	-50	-50	-63	0	13
2	2.4	3.20	18.10	90	119	-30	-29	149
2	2.4	6.52	20.88	-347	-230	-369	-117	139
2	2.4	9.36	23.29	-197	-167	-302	-30	135
1	3.1	2.16	1.87	60	222	198	-162	24
1	3.1	6.49	5.53	0	0	0	0	0
1	3.1	11.08	9.52	14	14	0	0	14
2	3.1	3.20	15.43	432	255	300	177	-45
2	3.1	6.52	19.09	160	72	132	88	-60
2	3.1	9.36	22.17	198	119	65	79	54
2	3.2 / 3.4	3.20	3.29	-328	-242	-243	-86	1
2	3.2 / 3.4	6.52	6.81	-54	0	-61	-54	61
2	3.2 / 3.4	9.36	9.85	-75	0	-62	-75	62
1	3.1 @ 2.4_{min}	2.16	2.15	0	182	66	-182	116
1	3.1 @ 2.4_{min}	6.49	6.46	100	70	0	30	70
1	3.1 @ 2.4_{min}	11.08	11.07	0	14	0	-14	14
			S.D. of Bias	188	152	169	88	67
			Mean Bias	-8	11	-26	-19	36

Another important demonstration of the insensitivity of inferred reactivity decrement biases to the core analysis of methods employed was obtained from studies done by R. D. Harrison in the UK [11, 12]. This very recent analysis followed the EPRI methodology, but used

- **JEF2.2** instead of the **ENDF-B/VII** nuclear data library,
- **WIMS/PANTHER** codes instead of the **CASMO-5/SIMULATE-3** codes of the EPRI report.

These new studies produced reactivity decrement biases and uncertainties (see Harrisons's Table 2 and 3) that are very similar to those of the EPRI study. Differences can be seen to be consistent with the uncertainties assigned to the EPRI benchmark reactivity decrements. The UK study concluded: *"The biases thus found were similar in magnitude to those of the 2014 EPRI study thus reinforcing their conclusion that* ***the corrected reactivities were code independent****."* It is particularly important that two very different cross section libraries lead to such similar results, so that the choice of basic neutronic data libraries does not lead to significantly different results. Taken together, all of the test case comparisons demonstrate that the nuclear data library, lattice code, and core analysis code have no significant influence on measured reactivity decrements. Harrison also concluded that *"This therefore further supports the conclusion of the 2011 EPRI study that the Kopp Memo 5% uncertainty assumption is valid and moreover conservative."*

	PANTHER	Lattice Data	2014 EPRI, CASMO-5	2014 EPRI, SIMULATE-3
Δk mean (pcm)	29.1	21.4	6.0	-27.0
Δk standard deviation (pcm)	170.4	164.4	158.0	171.0

Table 2: Fuel batch reactivity uncertainty comparison

Cycle	Enrichment	BEAVRS Calendar Day	PANTHER Calendar Day	Cycle Burnup	Batch Burnup	Min RMS Batch Burnup	ΔE	Δk PANTHER	Δk Lattice Data
	%			*GWd/tU*	*GWd/tU*	*GWd/tU*	*GWd/tU*	*pcm*	*pcm*
1	2.4	187.0	186.7	2.17	2.40	2.28	-0.113	-23.8	-37.3
1	2.4	368.0	380.1	7.51	8.41	8.52	0.113	-37.3	-22.6
1	2.4	468.0	469.5	11.08	12.44	12.55	0.112	-54.0	-54.9
2	2.4	65.0	61.4	2.11	17.02	17.43	0.410	-272.5	-279.5
2	2.4	156.0	156.6	5.23	19.58	19.50	-0.083	56.4	56.0
2	2.4	266.0	271.8	9.36	23.04	22.95	-0.084	56.8	60.9
1	3.1	187.0	186.7	2.17	1.93	1.84	-0.085	42.7	38.6
1	3.1	368.0	380.1	7.51	6.49	6.32	-0.172	152.3	113.2
1	3.1	468.0	469.5	11.08	9.59	9.33	-0.263	183.7	175.9
2	3.1	65.0	61.4	2.11	14.22	13.78	-0.441	347.4	319.1
2	3.1	156.0	156.6	5.23	17.61	17.29	-0.324	252.8	242.3
2	3.1	266.0	271.8	9.36	22.04	21.83	-0.213	161.4	159.4
2	3.2/3.4	65.0	61.4	2.11	2.25	2.57	0.325	-216.2	-214.9
2	3.2/3.4	156.0	156.6	5.23	5.65	5.98	0.328	-257.7	-264.6
2	3.2/3.4	266.0	271.8	9.36	10.16	10.38	0.219	-174.3	-173.4
1	3.1@2.4min	187.0	186.7	2.17	1.93	1.84	-0.085	42.7	38.6
1	3.1@2.4min	368.0	380.1	7.51	6.49	6.32	-0.172	152.3	113.2
1	3.1@2.4min	468.0	469.5	11.08	9.59	9.42	-0.175	122.6	115.1

Table 3: PANTHER fuel batch reactivity uncertainty

The fact that measured reactivity decrements are not very sensitive to the analytical methods employed provides strong evidence that use of the **EPRI benchmarks should not be viewed as "code-to-code" comparisons, but rather comparisons of an applicant's code predictions with measured burnup reactivity decrements**.

Furthermore, when used by applicants to establish their specific code/application biases and uncertainties, the EPRI benchmarks will provide a stringent test to rapidly uncover any errors in the code or cross sections that lead to significant misprediction of fuel isotopic inventories and/or fuel lattice reactivity. This has been demonstrated by other users when especially ENDF/B-V cross section libraries are used, which showed significant conservatism [13, 14].

References for RAI-2:

1. K. S. Smith et al., "Benchmarks for Quantifying Fuel Reactivity Depletion Uncertainty," Technical Report 1022909, EPRI, Palo Alto, CA, (2011).

2. K. S. Smith et al., "PWR Fuel Reactivity Depletion Uncertainty Quantification – Methods Validation Using BEAVRS Flux Map Data," Technical Report 3002006432 EPRI, Palo Alto, CA, (2015).

3. G.A. Gunow, "LWR Fuel Reactivity Depletion Verification Using 2D Full Core MOC and Flux Map Data," M.S. Thesis, MIT, https://dspace.mit.edu/handle/1721.1/97963, (2014).

4. E. Sykora, "Testing the EPRI Reactivity Depletion Decrement Uncertainty Methods," M.S. Thesis, MIT, pending MIT, dspace.mit.edu/handle assignment, (2015).

5. N. Horelik, B. Herman, B. Forget, and K. Smith. "Benchmark for Evaluation and Validation of Reactor Simulations (BEAVRS), v1.0.1," Proc. Int. Conf. Mathematics and Computational Methods Applied to Nuc. Sci. & Eng., Sun Valley, Idaho, (May 2013).

6. *Benchmark for Evaluation and Validation of Reactor Simulations,* Rev. 1.1.1, MIT Computational Reactor Physics Group (October 31, 2013). Available at the MIT website: http://crpg.mit.edu/pub/beavrs

7. D. J. Kelly III, B. N. Aviles, and B. R. Herman, "*MC21 Analysis of the MIT PWR Benchmark: Hot Zero Power Results,*" Int. Conf. Math. Comp. Meth. Appl. Nucl. Sci. Eng., (CD ROM) Sun Valley, Idaho, USA, May 5—9, 2013.

8. J. Leppanen, R. Mattila, and M. Pusa, "Validation of the Serpent-ARES Code Sequence using the MIT BEAVRS Benchmark – Initial Core at HZP Conditions," Annals of Nuclear Energy, **69**, 212-225, July 2014.

9. B. Collins and A. Godfrey, "Analysis of the BEAVRS Benchmark Using VERA-CS," ANS MC 2015 – Joint International Conference on Mathematics and Computation (M&C), Supercomputing in Nuclear Applications (SNA) and the Monte Carlo (MC) Method, Nashville, TN, April 19—23, 2015, on CD-ROM, American Nuclear Society, LaGrange Park, IL (2015).

10. H. J. Park, H. C. Lee, H. J. Shim, C. H. Kim, “Real Variance Estimation of BEAVRS whole core benchmark in Monte Carlo Eigenvalue Calculations,” Transactions of the Korean Nuclear Society Autumn Meeting, Pyeongchang, Korea, October 2014.

11. R. D. Harrison, et al., “Validation of WIMS/PANTHER PWR Fuel Reactivity Depletion Using the BEAVRS Benchmark Flux Map Data,” PHYSOR 2016, Sun Valley, ID, May 1-5, (2016).

12. R. D. Harrison, et al., “PANTHER Benchmarking of Nuclear Reactor Burnup Data,” Undergraduate Thesis, University of Cambridge, Cambridge, UK, (2015).

13. V. Kucukboyaci, “EPRI depletion benchmark calculations using PARAGON,” Annals of Nuclear Energy, 81, 1-5, 2015.

14. L. Jutier, G. Caplin, A. Mijonnet, “Application of the EPRI Depletion Reactivity Benchmarks,” ICNC 2015, September 2015.

3) Discuss how extrapolation of the EPRI work will be extrapolated to other fuel designs given that the benchmarks contain a limited subset of fuel designs.

Response:

The question of the applicability of the EPRI Depletion Benchmarks has already been addressed in Section 6 of EPRI Report 1025203. Additionally, the NRC requested further clarification on the applicability of the EPRI Depletion Benchmarks, specifically to other fuel designs. In the response to RAI-13 on EPRI Report 1025203, additional information regarding the applicability of the Depletion Benchmark Report and Utilization Report to other fuel designs was expanded. The response provided a comparison of several different PWR fuel designs used in the United States, by comparing the EALF, which is a measure of the energy distribution of the neutron spectrum which has been updated below:

> "All of the fuel designs are very similar and the key parameter that determines the difference is the amount of moderation. Using a spectral index is sufficient for showing the benchmarks are applicable to other fuels. Since all the materials (UO_2, Zircaloy, and water) are the same for all the fuels and the measurements, it is clear that a trend would be due to the relative proportion of these materials which is measured by the spectral index (i.e., EALF).
>
> Some historical figures of merit to show depletion spectrum coverage are H/X and H/U ratios. The fuel to moderator ratio is a spectral index which is easy to determine with publically available data. H/X requires the knowledge of the enrichment which makes this index less useful for fuel with varying enrichment. Conversion between the fuel-to-moderator ratio to H/U is straightforward since the fuel is UO_2. However, the more precise EALF will be emphasized in the revised report and is added to Table 6-3.
>
> Below is the rewritten portion of Section 6 with the newly added tables. Note that the table numbers are 13-x rather than 6-x to prevent confusion with other figures in the response to the RAI. In the revised Utilization Report the Table numbers will be changed to be consistent with Section 6.
>
> *So far the analysis has not addressed the range of applicability for fuel designs. The measured data came from Westinghouse type 17X17 fuel. The benchmarks cover both Standard (Std) and Optimized Fuel Assembly (OFA) fuel designs. This gives the benchmarks a range of depletion spectrum that covers most PWR fuel designs. Table 13-1 shows the fuel design parameters of major PWR fuel designs. Table 13-2 shows the EALF for each fuel type as a function of the burnup over which it is averaged. As can be seen from Tables 13-1 and 13-2, the range of the benchmarks covers the W 15X15, B&W and CE fuel. The Westinghouse 14X14 and 16X16 products will require some extrapolation. As can be seen in Tables 5-2, 5-3, and 5-4, the softer spectrum is slightly more conservatively predicted; so the W 14X14 OFA design is covered. For fuel types that have a harder depletion spectrum, it is recommended to add a bias, based on extrapolation, to cover the impact due to spectral differences. The extrapolation can be done by using the 17x17 and 17x17 OFA cases but this can be supplemented by using the spectral*

differences between the other cases. Table 13-3 shows the average depletion EALF for all the benchmark cases. As can be seen from Table 13-3, there is a significant range of depletion spectra."[1]

[1] Table 13-1 was reformatted from the previously submitted response to put the sequence of assemblies in the same order in both tables from top to bottom.

Table 13-1 Fuel Design Dimensions and Spectra

Fuel Design	Pellet OD (inches)	Clad OD (inches)	Pitch (inches)	Water to Pellet Volume Ratio
W 14X14 Std	0.366	0.422	0.556	1.61
W 14X14 OFA	0.344	0.400	0.556	1.97
W 15X15	0.366	0.422	0.563	1.68
W 16X16	0.323	0.374	0.485	1.53
W 17X17 Std	0.323	0.374	0.496	1.67
W 17x17 OFA	0.309	0.360	0.496	1.93
B&W 15X15	0.369	0.430	0.568	1.66
B&W 17X17	0.323	0.379	0.502	1.70
CE 14X14	0.377	0.440	0.580	1.66
CE 16x16	0.325	0.382	0.506	1.70

Table 13-2 Burnup Averaged Energy of the Average Lethargy Causing Fission (EALF) For Various Fuel Types (4.25 wt% U-235 Case 3 conditions)

	Energy of the Average Lethargy Causing Fission (EALF) (eV)					
	Burnup (GWd/T)					
Fuel	**10**	**20**	**30**	**40**	**50**	**60**
W 14x14	0.849	0.913	0.965	1.011	1.055	1.100
W 14x14 OFA	0.591	0.625	0.652	0.678	0.704	0.734
W 15x15	0.782	0.837	0.882	0.921	0.960	1.000
W 16x16	0.909	0.986	1.050	1.105	1.157	1.209
W 17x17	0.781	0.839	0.887	0.929	0.970	1.011
W 17x17 OFA	0.608	0.646	0.678	0.706	0.734	0.765
B&W 15x15	0.782	0.837	0.882	0.921	0.960	1.000
B&W 17x17	0.745	0.798	0.842	0.880	0.918	0.956
CE 14x14	0.757	0.807	0.848	0.884	0.919	0.957
CE 16x16	0.737	0.789	0.830	0.867	0.903	0.941

Table 13-3 Burnup Averaged Energy of the Average Lethargy Causing Fission (EALF) from the Depletion Analysis of the Benchmark Cases

		Energy of the Average Lethargy Causing Fission (EALF) (eV)					
		Burnup (GWd/T)					
Case	**Lattice Description**	**10**	**20**	**30**	**40**	**50**	**60**
1	**3.25% enrichment depletion**	0.664	0.734	0.796	0.854	0.910	0.965
2	**5.00% enrichment depletion**	0.891	0.943	0.984	1.017	1.048	1.079
3	**4.25% enrichment depletion**	0.781	0.839	0.887	0.929	0.970	1.011
4	**off-nominal pin depletion**	0.608	0.646	0.678	0.706	0.734	0.765
5	**20 WABA depletion**	1.084	1.081	1.086	1.103	1.129	1.160
6	**104 IFBA depletion**	1.006	0.987	0.994	1.013	1.038	1.069
7	**104 IFBA, 20 WABA depletion**	1.381	1.276	1.226	1.212	1.217	1.235
8	**high boron depletion = 1500 ppm**	0.876	0.943	1.001	1.052	1.100	1.148
11	**high power density depletion**	0.877	0.951	1.013	1.066	1.116	1.166

A second valuable reference point is the applicability of the validation analysis performed for criticality codes that support spent fuel pool criticality analyses to the fuel assembly and spent fuel storage rack geometry. The applicant models available fresh fuel benchmark experiments in the criticality code to determine the biases and uncertainties associated with the code, cross-sections and benchmark experiments themselves. In the criticality code validation, benchmark experiments are selected from the International Handbook of Evaluated Criticality Safety Benchmark Experiments [2] that have similar materials and geometric configurations as the system that will be modelled (i.e., the spent fuel storage rack). These benchmark experiments contain a sufficient number of fuel rods to ensure that the

experiment approaches a critical configuration, and are typically placed in a square or hexagonal lattice with a water moderator. However, there are invariably differences between the benchmark experiments contained in the validation and the specific geometry being modelled in the criticality analysis. Typical differences are in the exact material compositions, the size and number of the fuel rods, pitch between fuel rods, location and extent of the surrounding moderator, effect of temperature, just to name a few. One way to address these differences is to compare the energy spectrum of the benchmark experiments to the energy spectrum of the system modelled, which is achieved through determining the EALF (Energy of Average Lethargy causing Fission) of the modeled configurations. Since all of these systems are composed of uranium oxide fuel in a moderator composed of water (either with or without soluble boron), the calculation of the EALF demonstrates that both the benchmarks and the systems modelled are thermal systems (i.e., the part of the neutron spectrum that dominates the production of fission events are neutrons in the thermal energy range).

Therefore, since the benchmark experiments include geometries, materials, configurations, and energy spectrums that are comparable to the fuel assembly and storage rack, even though they are not exact replicas of geometries being analyzed, they provide a good indication of the ability of the code and cross-sections utilized to accurately determine the k_{eff} of the system modelled. Therefore, the comparison of the EALF between different fuel types across the expected burnup range provides a similar comparison showing the applicability of the depletion benchmarks to other PWR fuel designs not explicitly contained in the depletion benchmarks

Subsequently, it can be concluded that the depletion benchmarks are applicable to the range of PWR fuel types containing UO_2 fuel and Zirconium based cladding, within the stipulations contained in the updated portion of Section 6 provided in the previous response to RAI-13 (as updated) on EPRI Report 1025203.

4) *Discuss the range of method applicability with respect to the use of different depletion codes and clarify the general validation procedure outlined in EPRI report 1025203. Specifically, the procedure described in EPRI report 1025203 describes how depletion code validation is to be performed, but does not discuss any of the procedure limitations. For example, the implications of excessive depletion code bias is not addressed. Additionally, how are the 11 calculational benchmarks robust to consideration of different fuel designs that have different physical characteristics? That is, why isn't it necessary to define application-specific calculational benchmarks? The EPRI report 1025203 procedure is also vague with respect to expectations regarding incorporation of biases and uncertainties from EPRI report 1022909 into a user's depletion code validation analysis as part of an overall criticality safety analysis.*

Response:

There are four individual sub-questions contained in the one RAI question, and these are addressed separately:

a) *Discuss the range of method applicability with respect to the use of different depletion codes and clarify the general validation procedure outlined in EPRI report 1025203.*

Section 9.4 of EPRI Report 1022909 [1] already provides a step-by-step description of the end-users application of the experimental reactivity decrements for their individual depletion code. EPRI Report 1025203 [2] follows this process specifically for SCALE 6.1 with the ENDF/B-VII cross-section library, to determine the additional biases and uncertainties that need to be applied in addition to those derived from EPRI Report 1022909. Since publishing EPRI Report 1025203, additional work has been performed that follows this process for other computer codes and cross-section libraries [3-4].

Therefore, as seen from multiple instances, the reactivity benchmarks are applicable to a large range of depletion codes and are limited only by the ability of the individual computer codes to accurately model the depletion benchmark experiments as described in EPRI Report 1022909.

b) *Specifically, the procedure described in EPRI report 1025203 describes how depletion code validation is to be performed, but does not discuss any of the procedure limitations. For example, the implications of excessive depletion code bias is not addressed.*

Following the process described in Section 9.4 of EPRI Report 1022909 allows an individual analyst to gauge the accuracy of their code against the "measured burnup reactivity measurements" in the Depletion Benchmark Report. The fact that the measured reactivity decrements are not very sensitive to the analytical methods employed provides strong evidence that use of the EPRI benchmarks are comparisons of an applicant's code predictions with measured burnup reactivity decrements.

When used by applicants to establish their specific code/application biases and uncertainties, the EPRI benchmarks provide a test to uncover errors in codes and/or cross sections that could lead to significant depletion code bias.

c) *Additionally, how are the 11 calculational benchmarks robust to consideration of different fuel designs that have different physical characteristics? That is, why isn't it necessary to define application-specific calculational benchmarks?*

See the response to RAI-3 on the applicability of the experimental benchmarks to other fuel designs.

d) *The EPRI report 1025203 procedure is also vague with respect to expectations regarding incorporation of biases and uncertainties from EPRI report 1022909 into a user's depletion code validation analysis as part of an overall criticality safety analysis.*

Section 9.4 of EPRI Report 1022909 already provides a description of how the user would incorporate their specific validation analysis into the overall criticality safety analysis:

> "5. Step 4 reactivity decrement tables are differenced from the experimental reactivity decrement tables of Appendix C to construct biases for the user's methodology/tools as a function of lattice type, burnup, and cooling interval.
>
> 6. Reactivity decrement uncertainties are applied (Appendix C Table C-1) for each reactivity decrement of Step 5."
>
> 7. Biases from Step 5 and the uncertainties from Step 6 are combined with biases and uncertainties arising from other portions of the SFP/cask criticality analysis.
>
> (Note: Users have the flexibility to choose different approaches to combining biases and uncertainties. For example: a user might choose to be conservative and apply the largest observed reactivity decrement bias to all cases; independent of lattice type, burnup, cooling interval, or lattice conditions.)"

References for RAI-4

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