DUKE COGEMA
STONE & WEBSTER

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DCS-NRC-000164

Subject: Docket Number 070-03098
Duke Cogema Stone & Webster
Mixed Oxide Fuel Fabrication Facility (MFFF), Response to Questions on the Criticality Validation Report – Revision 3 of Part II

References:
1) M. Chatterton (NRC) to J. Giitter (NRC) Memorandum, *November 7, 2003, Summary of Phone Call with the Applicant: Criticality Safety Open Item NCS-4 for the Mixed Oxide Fuel Fabrication Facility,* November 7, 2003
2) C. Tripp (NRC) to J. Giitter (NRC) Memorandum, *December 17-19, 2003, In-Office review Summary: Duke COGEMA Stone & Webster Construction Authorization Request Supporting Documentation for Criticality Code Validation,* January 8, 2003.
3) D. Brown (NRC) to J. Giitter (NRC) Memorandum, *January 13, 2004, Summary of Phone Call: Revisions to November 7, 2003, Questions on Criticality Safety Open Item NCS-4 for the Mixed Oxide Fuel Fabrication Facility,* January 22, 2004

In Reference 1 above, the Nuclear Regulatory Commission (NRC) requested clarifications to information previously provided by Duke, COGEMA, Stone and Webster (DCS). In addition, the NRC conducted an in-office review (Ref. 2) of the supporting documentation associated with the DCS Criticality Code Validation Report Part II. As a result of the in-office review, the NRC issued a revision (Ref. 3) to the requested clarifications originally identified in Reference 1. Enclosure 1 to this letter provides DCS' responses to the revised questions in Reference 3.

As outlined in Reference 3, DCS understands that no response is required for Questions 10, 11, 13, and 17. DCS also understands that a response is required for Questions 1, 6, 8, 12, 18, and part of 16 (the portion of the question on LATTICECELL vs. INFHOMMEDIUM is considered closed). Finally, DCS understands, a response to Questions 2, 3, 4, 5, 7, 9, 14, and 15 are required only if the topic identified in the question supports one of the answers provided for Questions 1, 6, 8, 12, 18 and part of 16. Please note that DCS did not rely on the topics in Question 2, 3, 4, 5, 7, 9, 14, and 15 for the responses to Questions 1, 6, 8, 12, 18 and 16.

With the information provided in Enclosure 1, DCS believes that an adequate justification is presented for inclusion of additional benchmarks for AOA(4) (MOX powder) and determination of the upper safety limit (USL).

PO Box 31847
Charlotte, NC 28231-1847

128 South Tryon Street, FC-12A
Charlotte, NC 28202

M-MSS01

If I can provide any additional information, please feel free to contact me at (704) 373-7820 or Thomas Doering of my staff at (704) 382-2225.

Sincerely,

p:

Peter S. Hastings, P.E.
Manager, Licensing and Safety Analysis

Enclosures: (1) Response to Remaining NRC Questions on: Validation Report for AOA(3) & AOA(4).

xc (with enclosure):
David Alberstein, NNSA/Room 6G0-69
Kenneth L. Ashe, DCS
Thomas W. Doering, DCS
Andrew Persinko, USNRC/HQ
Donald J. Silverman, Esq., DCS
PRA/EDMS: Corresp\Outgoing\NRC\2004 NRC\DCS-NRC-000164

xc (without enclosure):
Marc Arslan, DCS
David A. Ayres, USNRC/RII
L. Ron Barnes, DCS
Timothy S. Barr, NNSA/CH
Jean-Marc Belmont, DCS
Edward J. Brabazon, DCS
James R. Cassidy, DCS
Vincent Chevalier, DCS
Mosi Dayani, NNSA/Clt
Sterling M. Franks, III, NNSA/SR
Joseph G. Giitter, USNRC/HQ
Joseph J. Holonich, USNRC/HQ
James V. Johnson, NNSA/HQ
J. David Nulton, NNSA/HQ
Joseph Olencz, NNSA/HQ
Robert C. Pierson, USNRC/HQ
Luis A. Reyes, USNRC/RII
Brian W. Smith, USNRC/HQ
Phillipe Sordelet, DCS
Thomas E. Touchstone, DCS
Martin J. Virgilio, USNRC/HQ

Response to Remaining NRC Questions on:
Validation Report for AOA3 and AOA4
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Introduction

The following responses are to the questions from the November 7, 2003 meeting between Duke Cogema Stone & Webster and the NRC, Special Projects Section, Special Projects and Inspection Branch Division of Fuel Cycle Safety and Safeguards, NMSS. The meeting was held to review the *"Mixed Oxide Fuel Fabrication Facility Criticality Code Validation Part II, Revision 3, October 2003."* From this meeting, 18 questions were generated by the NRC technical staff. This enclosure responds to the balance of the open NRC questions, on AOA3 and AOA4 validation report.

As noted in the January 22, 2004 memorandum from David Brown to Joseph Giitter of the NRC:

1) Questions 10, 11, 13, and 17 are considered closed and require no additional response. These questions dealt with AOA(3), PuO_2 powder validation.
2) Questions 1, 6, 8, 12, 16, and 18 require a response. Parts of question 16 that deal with any additional technical options used in KENO-VI are addressed. The question of LATTICECELL vs. INFHOMMEDIUM is considered closed.
3) Questions 2, 3, 4, 5, 7, 9, 14, and 15 are addressed only if the responses in item number 2, above, rely on the technical issues noted in these questions.

Discussion

Question 1:

For Revision 3 of the Validation Report, has DCS evaluated the newly included experiments in the September 2003 version of the International Handbook of Evaluated Criticality Safety Benchmark Experiments? If not, why not? If so, state which of these new experiments would be applicable to a validation of PuO_2 or MOX powder systems.

Response:

DCS has reviewed the September 2003 revision of the noted report. It has been noted that the change pages in the report do not list all of the additions; therefore a careful review of each section was performed. There are no additional experiments identified that would be useful to benchmarking AOA(3) or AOA(4).

Question 2:

Describe the difference between parameters that are "logarithmically important" and those that are "non-logarithmically important." Fully justify the extension factors of 5 and 2 on page 24 of the Validation Report for these types of parameters respectively.

The classification of parameters as "logarithmically important" or "non-logarithmically important" appears based on how the data for these parameters are typically displayed, rather than on any intrinsic properties of the parameters. There

are no definitions provided or discussion of how to differentiate between "logarithmically important" and "non-logarithmically important" parameters. The values of the extension factors must be fully justified. The stated justification that there is no discernable trend in the bias as a function of the energy of average lethargy causing fission (EALF) and H/(U+Pu) ratio is not sufficient. The graph of k_{eff} as a function of a particular parameter may not reveal any trend, even when the benchmarks are unrelated. For instance, lack of a trend involving a set of uranium and plutonium benchmarks would not provide any information on the behavior of the bias for a particular subset of plutonium systems.

Response:

The technical topic was not used in responses to other questions. Therefore, as noted in the NRC Memorandum of January 22, 2004, no response is needed to this question. This question is considered closed.

Question 3:

The justification for the screening criteria extension factors relies on the observation that there is no discernable trend in the bias as a function of EALF and H/(U+Pu) in Figures 3-3 and 3-4. Regarding this conclusion, address the following: (1) an apparent trend in k_{elf} at high EALF ($\geq 5x10^4$ eV); and (2) the effect of the fact that the analysis was performed on the entire set of 308 benchmark experiments, even though only 70 have been found applicable to AOA(3) and 59 to AOA(4). Justification that relies on an empirical analysis of data that is not applicable to the AOAs being validated is not conclusive.

Response:

The technical topic was not used in responses to other questions. Therefore, as noted in the NRC Memorandum of January 22, 2004, no response is needed to this question. This question is considered closed.

Question 4:

The methodology in Section 2.5 of NUREG/CR-6698 does not contain any provision for extending the screening criteria without employing an additional margin of subcriticality. Justify including Step 4 in Section 3.6. The methodology described in NUREG/CR- 6698, Section 2.5, states:

> "The analyst needs to consider the overall parametric span and try to ensure that experiments provide a spectrum of critical experiments throughout the range...It may be desirable to include additional critical experiments in the validation. Often experiments within these ranges do not exist or are not readily available. In such cases, a larger margin of subcriticality will be needed."
>
> "Guidance for extrapolation in LA-12683 gives typical extrapolation ranges for the parameters presented in Table 2.3. These values are provided for information. Should extrapolation of critical experiments area of applicability be required,

justification should be documented. Margin will be affected by extrapolation as described in Section 5."

Response:

The technical topic was not used in responses to other questions. Therefore, as noted in the NRC Memorandum of January 22, 2004, no response is needed to this question. This question is considered closed.

Question 5:

Explain the procedure outlined in paragraphs A through D on page 25 of Part II. In particular, clarify whether the discussion about including additional benchmarks meeting one of the four criteria pertains to: (1) experiments identified as being outside the initial screening criteria but within the revised screening criteria; or (2) those experiments still not included after applying the revised screening criteria. Also, for each of the four conditions listed, justify fully why this is an acceptable basis for inclusion and answer the following questions:

A. Explain how a parameter whose value is outside the screening criteria range could be found not to be of primary importance. Presumably, parameters included in the primary screening criteria are those that are considered of primary importance to the determination of the bias and its uncertainty. Therefore, this appears self-contradictory.

B. Explain why a benchmark outside the screening criteria is acceptable as long as it has the same neutron energy range as the application. This appears to elevate the EALF to greater importance than other system parameters, without justification provided. As an example of this, a uranium benchmark could have the same EALF value as a plutonium design application, but would still not have any applicability to plutonium systems.

C. Explain what is meant by "...and its/their inclusion help(s) to reduce gaps between benchmark cases within the range." It would appear that the determination of whether a benchmark experiment is applicable should be independent of whether it is helpful to reducing gaps in the data.

D. Explain why a comparison of fission spectra is sufficient to permit a conclusion that the benchmark is applicable to the subject design applications. The fission spectrum contains only partial information about the overall neutronic behavior of the system. There are other nuclide-reaction pairs that may also affect the bias.

Response:

The technical topic was not used in responses to other questions. Therefore, as noted in the NRC Memorandum of January 22, 2004, no response is needed to this question. This question is considered closed.

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Question 6:

Explain the purpose and usage of the secondary screening criteria. It appears that they were not used in selecting benchmark experiments. If so, what is their purpose?

Response:

As noted in Section 3.6.1, secondary parameters are those which are well modeled by SCALE and which are not expected to have a significant impact on the bias or its uncertainty. The use of primary and secondary parameters allows the analyst to have a list of ascending parameter importance. This guides the analyst in the review of the proposed experiments. Knowing that the historic experiments were not developed explicitly for a unique process but were performed to investigate a range of parameters, the analyst uses an integral as well as a discrete approach to selecting the experiments that test the analytical tools. In reviewing the parameters, DCS implemented a table format, as is demonstrated in the response to questions 18. Each parameter is reviewed and noted if it is applicable.

Question 7:

In Section 3.6.2, fully justify using parameter correlations to expand the allowable range in ^{240}Pu rather than contract the range in ^{239}Pu. Table 2.3 of NUREG/CR-6698 contains the allowed range of ±10% in ^{239}Pu and ±4% in ^{240}Pu. Because they are correlated for Mixed Oxide Fuel Fabrication facility (MFFF) operations (i.e., ^{239}Pu + ^{240}Pu = 1), the screening criteria have been revised to allow a variation of ±10% in ^{240}Pu. This is the least conservative way of reconciling the screening criteria in these two parameters, but justification is not provided. Also, similar arguments are made with regard to correlations between H/(U+Pu) and EALF, but it is not clear how this information is used.

Response:

The technical topic was not used in responses to other questions. Therefore, as noted in the NRC Memorandum of January 22, 2004, no response is needed to this question. This question is considered closed.

Question 8:

The primary screening criteria of Table 3-3 do not include the total Pu content, although this is known to be one of the most important parameters. Justify not including the Pu content in the set of primary parameters.

Response:

The total Pu content (Pu/(Pu+U)) is dependent on the Pu and U isotopic contents. Since only ^{239}Pu and ^{240}Pu comprise the validated isotopic vector of Pu and the remaining material is uranium, the individual parameter ranges specified in Table 3-3 of the validation report defines a parameter range for Pu content. For example, the Pu content can be shown in the following Table 3-3:

Excerpt from Table 3-3 Physical Parameters and Screening Criteria Guidance

Application Parameter	Potential Application Parameter Range	Allowable Screening Criteria Range	Allowable Extension Factor for Screening Criteria Range to AOA Range
Primary Parameters			
Fuel			
Fissile Isotope ^{239}Pu	5 – 10 wt. %	± 2.5 wt. %[a]	± 5 wt. %
	20 – 80 wt. %	± 15 wt. %[a]	---
	80 – 100 wt. %	± 10 wt. %[a]	± 20 wt. %
Fissionable Isotopes ^{240}Pu	0 – 32 wt. %	± 4 wt. %[a]	1 – ^{239}Pu Content
^{238}U	0 – 98 wt. %	± 4 wt. %	Based on $PuO_2 + UO_2 = 100\%$
Pu Content (Pu/Pu+U)	6.3% - 22%	3.8%[b] - 37%[c]	---

[a] Reference Table 2.3, NUREG-6698.

[b] Acceptable variation in ^{239}Pu in the range of 5 – 10% is ± 2.5 wt. %, acceptable variation Pu content can be determined as 6.3%-2.5%=3.8%.

[c] Acceptable variation in ^{239}Pu in the range of 20 - 80% is ± 15 wt %, acceptable variation Pu content can be determined as %. 22%+15%=37%.

Question 9:

Provide the basis for the screening criteria for the 238U wt%. This does not appear to be drawn from NUREG/CR-6698, Table 2.3, and no other reference is provided.

Response:

The technical topic was not used in responses to other questions. Therefore, as noted in the NRC memorandum of January 22, 2004, no response is needed to this question. This question is considered closed.

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Question 10:

Justify including an H/Pu of 0 in the description of design applications for AOA(3). The use of such a low moderation does not appear physically reasonable or consistent with commitments in Construction Authorization Request (CAR) Section 6.3.4.3.2.6. This and the parameters in CAR Tables 6-1 and 6-2 indicate that bounding moderation levels of at least 1wt% H2O are assumed in MFFF operations. This corresponds to an H/Pu of 0.3.

Response:

No further response is needed. This question is considered closed, per NRC memorandum of January 22, 2004.

Question 11:

Given the geometrical and physical differences between anticipated design applications (PuO_2 and MOX powder intimately mixed with water) and Pu metal benchmarks (dry, high-density metal surrounded by water), fully justify their inclusion in the benchmarks for AOA(3) and AOA(4). NUREG/CR-6698, Table 2.3, states that geometry and physical form (i.e., metal, solution, oxide, or compound) should be as close as possible to the system being evaluated.

Response:

No further response is needed. This question is considered closed, per NRC memorandum of January 22, 2004.

Question 12:

Given that only certain experiments have been chosen from some benchmark experiment sets, justify including the chosen benchmarks and excluding the remainder from those benchmark sets (such as for PU-COMP-MIXED-001 in Section 5.1.1).

Response:

This response will provide the rational for why given benchmark experiments have been excluded and in the response to Question 18 the rational for the included benchmarks are given.

Generally, benchmarks are excluded from the validation set for those cases which differ markedly in more than one primary screening criterion or fall well outside the range for a given parameter. In some cases, uniquely applicable cases varying in two or more key parameters are justified on a case-by-case basis. The following table provides justification for the excluded cases within the benchmark experiments selected for AOA(4).

Excluded Benchmark Experiments:

Benchmark	Included	Excluded	Reason
NSE55T5	1–10	None	–
PU-29	1–9	None	–
PU-COMP-MIXED-002	6–22	1–5 23–29	H/X =0.04 is too low H/X = 49.6 is too high
BNWL2129T4	1–19	None	
BNWL2129T3 (Table 3)	none	all	Cases excluded because H/X = 30.6 is too high and EALF is too low
PU-8	1–4	None	–

Question 13:

With regard to the comparison of fission spectra used to justify inclusion of specific benchmark experiment sets, provide information on the design applications used in the comparisons. These apparently differ from the design applications used in Revision 2 (e.g., AOA(3)-1, 3-2, etc.), but there is no information regarding the assumed composition or geometrical configuration. This information is necessary to understand the significance of the spectral comparison.

Response:

No further response is needed. This question is considered closed, per NRC memorandum of January 22, 2004.

Question 14:

Justify the comparison of fission spectra in the fuel region (and the consequent neglect of other materials and reactions) as an acceptance criterion for benchmark selection. There are a large number of nuclides and reactions that may affect the calculated value of k_{eff}, but these are not considered. A benchmark may have a very similar fission spectrum to a given design application but may still not be applicable. An example would be a uranium benchmark with a similar fission spectrum to a plutonium design application.

Response:

The technical topic was not used in responses to other questions. Therefore, as noted in the NRC Memorandum of January 22, 2004, no response is needed to this question. This question is considered closed.

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Question 15:

Describe the standard used to determine satisfactory agreement between the fission spectra of candidate benchmarks and design applications. Many of the comparison figures in Section 5 show considerable disagreement between the candidate benchmark data and that of the design application.

Response:

The technical topic was not used in responses to other questions. Therefore, as noted in the NRC memorandum of January 22, 2004, no response is needed to this question. This question is considered closed.

Question 16:

Describe and justify what code options (in particular, cross-section treatment options) are considered within the scope of Part II of the Validation Report, Revision 3. The previous version of the Validation Report limited the validation to the INFHOMMEDIUM cross section treatment option, in response to an NRC question regarding code options. This material has been removed from Revision 3. Section 5.4 of Revision 2 stated:

> "One qualitative parameter defining the AOA requires special attention. The geometric form of the material is characterized simply based on whether the fissile material is a single contiguous mass or an array of such masses...due to the multigroup energy treatment employed in KENO-VI, the potential for code bias exists as a result of the resonance processing performed in the Material Information Processor (MIP) of SCALE...For single contiguous units or for arrays of large units...the INFHOMMEDIUM treatment is used."

Response:

The code options used in demonstrating that the computational tool is adequate for AOA 4 are noted in Table 1.

Table 1 Validated SCALE 4.4a Code Options

Code Option	Limitation*
Cross Sections	238GROUPNDF5
Resonance Treatment	INFHOMMEDIUM only
Temperature	293 K (Default)
Geometry	All KENO VI Options
Convergence Criteria	<0.0015 Δk_{eff}

* Engineering experience is also applied when selecting the computational Code options. Users are experienced and knowledgeable in Monte Carlo criticality safety codes, including SCALE.

The resonance processing option validated for AOA(3) and AOA(4) is limited to the INFHOMMEDIUM option.

Consistent with general practice in criticality calculations, KENO-VI calculations are performed using strictly analog Monte Carlo transport, and no biasing options are used or validated.

Although certain preliminary calculations employed albedos due to uncertainty of specific peripheral material compositions in the early design, the validated use of the code does not use the albedos parameter. Where albedos were employed in the past, subsequent reanalysis with explicit modeling of peripheral materials has indicated that the use of albedos was conservative. The use of albedos is not included in the validated AOAs.

A potential of introducing a bias, when applied to the benchmark cases, is related to the code convergence options. In general, the analyst is required to ensure appropriate convergence of the Monte Carlo process by inspection of the output file. The primary basis for this assessment is the indicated Monte Carlo uncertainty in the computed reactivity. Additionally, inspection of the convergence history of the problem as a function of generation run is performed. Specific code options governing the convergence behavior of the code are NPG, the number of neutrons per generation, and GEN, the total number of generations run. The total number of histories tracked is the product NPG×GEN. As a guideline, sufficient total histories are executed to obtain a target Monte Carlo uncertainty of $\sigma < 0.0015$, and for the purpose of establishing subcriticality, the computed reactivity plus twice the uncertainty is compared with the USL:

$$k_{eff} + 2\sigma < USL$$

The 0.0015 convergence criterion is well below the typical experimental uncertainty observed in the validation benchmark experiments. From the 'International Handbook of Evaluated Criticality Safety Benchmark Experiments,' a typical value is e.g., 0.0043 to 0.0045 for PCM002; 0.0041 to 0.0030 for Pu-16.

Question 17:

Address the following differences between anticipated design applications and the various sets of benchmark experiments for AOA (3). Explain why systems that are so physically dissimilar in terms of geometric configuration and material composition can be judged to be similar based only upon comparison of the fission spectra. In particular, justify using benchmarks modeled with the LATTICECELL treatment to validate design applications using the INFHOMMEDIUM treatment (NOTE: Each of the cases with LATTICECELL treatment has significantly different geometry from

previously described applications.) PMF003: Benchmark models contain large amounts of interspersed metals and use the LATTICECELL treatment. PMF016: Benchmark models contain large amounts of interspersed metals and use the LATTICECELL treatment. PMF017: Benchmark models contain large amounts of interspersed metals and use the LATTICECELL treatment. PMF033: Benchmark models contain large amounts of metals and have low Pu content. PMF037: Benchmark models contain interspersed water and use the LATTICECELL treatment. BNWL2129T4: Benchmark models contain low Pu content. NSE55T5: Benchmark models contain low Pu content. PU-29: Benchmark models contain low Pu content. 5

Response:

No further response is needed. This question is considered closed, per NRC Memorandum of January 22, 2004.

Question 18:

Address the following differences between anticipated design applications and the various sets of benchmark experiments for AOA(4). Explain why systems that are so physically dissimilar in terms of geometric configuration and material composition can be judged to be similar based only upon comparison of the fission spectra.

PCM002: Benchmark models contain H/(U+Pu) ratio and Pu content outside the screening criteria.

PU-8: Benchmark models contain H/(U+Pu) outside the screening criteria.

Response:

PU-COMP-MIXED-002

PU-COMP-MIXED-002 is a set of 29 experiments that involve 100% plutonium oxide (and no UO_2) that has been mixed with various quantities of polystyrene and compacted into cubes. For PU-COMP-MIXED-002, these cubes are stacked in array configurations with full reflection by Plexiglas. Therefore, Cases 6 through 22, are used to support AOA(4).

Comparison of Parameters with Validation Ranges in Validation Report, Part II, Revision 3

Parameter	AOA(4) Screening Range	Benchmark Set Parameters	Comment
Pu Physical Form	Powder	Powder	In-range
Wt. % ^{239}Pu	86 – 100	86-98	In-range
Wt. % ^{240}Pu	0 – 14[a]	2.2-11.46	In-range
Pu Content (%)	3.8-37[b]	100	Not in-range
Wt. % ^{238}U in U	80-100	N/A	N/A
Wt. % ^{235}U in U	0-20	N/A	N/A
H/(Pu + U)	0.44-3.84	5-15	Not in-range
EALF (ev)	0.022 –100,000	4.14-92.6	In-range

[a] Based on ^{239}Pu content and MFFF assumption of only ^{239}Pu and ^{240}Pu.
[b] Based on ^{239}Pu isotopic composition in NUREG-6698, Table 2.3.

For Cases 6 through 22 the deviating parameters are the H/(U+Pu), which varies from 5 to 15, and the Pu content, which is 100%. The following justification is provided to demonstrate that this experiment set can be used to validate the computational tools for this AOA.

Experiment Set Justification

This set of 17 experiments has been included in AOA(4) because, while the cases do not meet the H/(Pu + U) and wt. % PuO_2 ranges, they are neutronically very similar to AOA(4) design applications. This is illustrated by the similarity of the energy causing fission and the resonance location which are illustrated in Figure 1. Figure 1 gives a comparison of the neutron spectra causing fissions for a typical AOA(4) design application and Case 6.

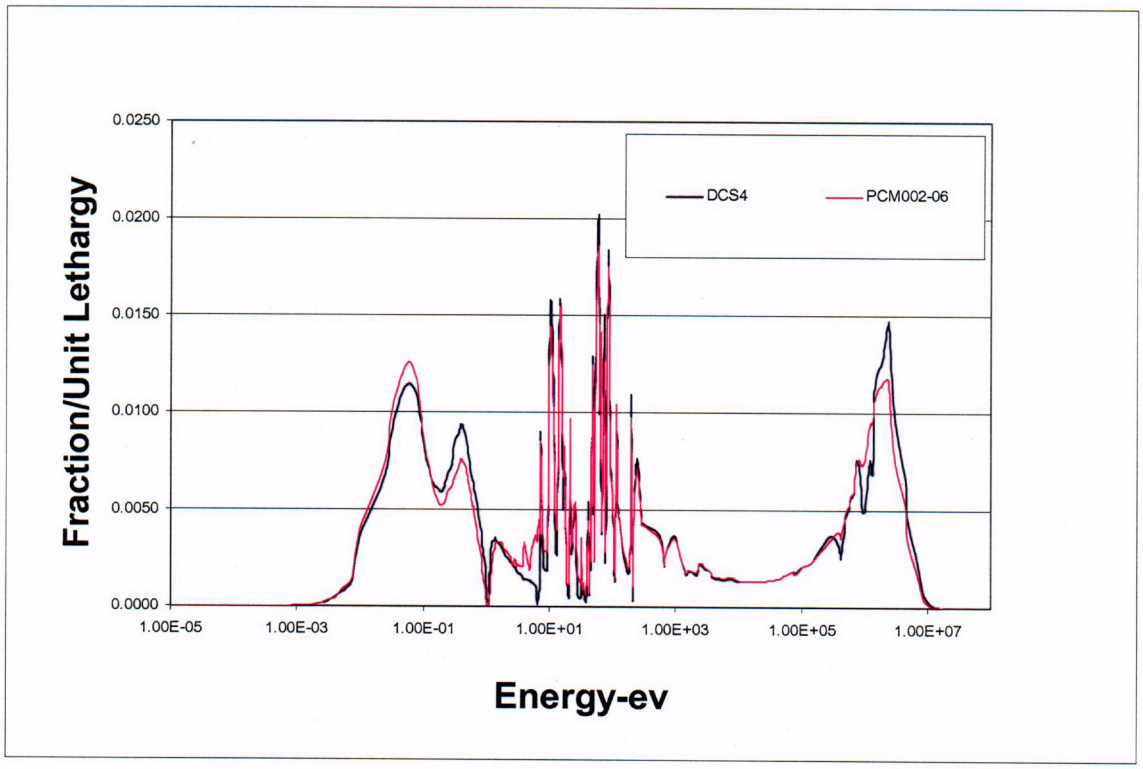

Figure 1. Neutron spectra comparison between PCM002-06 and MFFF typical design application

As seen in Figure 1, in both cases the neutron spectra causing fissions are essentially identical with similar fissions occurring throughout the low, intermediate and high energy ranges providing additional justification for the applicability of this experiment to AOA(4).

Furthermore, the k_{eff} from both the benchmark set as well as the design applications are dominantly based on the ^{239}Pu fissions. To demonstrate this, the 22% Pu content typical design application DCS4, shown in Figure 1, was re-run with the number densities of the uranium set to zero. The k_{eff} only went up 2.18% (from 1.0010 to 1.0228) showing that about 98% of the k_{eff} was the result of ^{239}Pu fissions.

For the PCM002 cases (6-22) selected, a similar analysis shows that the ^{239}Pu fissions are dominant. To illustrate this, depleted uranium oxide was artificially added to the benchmark fuel content such that the Pu content was approximately 22%, similar to that of modeled MFFF primary blend. Shown in the table below is the k_{eff} for the 17 experiments with and without the added depleted uranium.

Comparison of PCM002 with and without Added Uranium

Experiment	100% Pu $k_{eff}+2\delta$	22%Pu/(Pu+U) $k_{eff}+2\delta$	$k_{eff}+2\delta$ Difference
PCM002-06	1.0240	1.0527	-0.0287
PCM002-07	1.0231	1.0445	-0.0214
PCM002-08	1.0222	1.0279	-0.0057
PCM002-09	1.0235	1.0170	0.0065
PCM002-10	1.0337	0.9800	0.0537
PCM002-11	1.0296	0.9820	0.0476
PCM002-12	1.0296	0.9852	0.0444
PCM002-13	1.0273	0.9865	0.0408
PCM002-14	1.0309	0.9909	0.0400
PCM002-15	1.0291	0.9902	0.0389
PCM002-16	1.0262	0.9821	0.0441
PCM002-17	1.0092	0.9581	0.0511
PCM002-18	1.0111	0.9687	0.0424
PCM002-19	1.0101	0.9682	0.0419
PCM002-20	1.0100	0.9693	0.0407
PCM002-21	1.0102	0.9685	0.0417
PCM002-22	1.0157	0.9710	0.0447

As seen, the effect of adding depleted uranium oxide is less than approximately 5%, showing that fissions from ^{239}Pu dominate and thus a comparison of the fission spectra as shown in Figure 1 is appropriate.

The impact of slightly different H/(Pu+U) between that of the benchmarks and that of the desired validation range is indicative mainly of differences in the relative amount of hydrogen. The relative amount of hydrogen affects thermalization which, in turn, affects energy spectra. However, as can be seen in Figure 1, the energy spectra for this set is similar to that of the design applications. Hence, to the extent that differences in neutron moderation have the potential to affect the spectral properties of the problem, no such impact is observed in the important comparison of fission spectra.

As is noted above in the text and demonstrated in Figure 1, the fissile material in this set is plutonium oxide experiments are closely matched to the fissile material in AOA(4). Hydrogen is contained in the polystyrene moderator for this set matching the hydrogen moderator in the AOA(4) MFFF materials.

The presence of a reflector in this set is consistent with the range of configurations analyzed for AOA(4) which includes reflected situations.

In summary, the complete justification for including this experiment set is shown in the following table:

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PCM002: Comparison of Benchmark Parameters vs. Application Parameters:

Parameter	Benchmark Set Parameters	MFFF Application Parameters	Comment
Pu Physical Form	MOX powder (0%U[a])	MOX powder	OK
Wt. % ^{239}Pu	86-98	96	OK
Wt. % ^{240}Pu	2.2-11.46	4	OK
Wt. % ^{238}U in U	N/A	99.7	[a]
Wt. % ^{235}U in U	N/A	0.3	[a]
EALF (ev)	4.14-92.6	0. 28-850	OK[b]
Moderator	Hydrogenous	Hydrogenous	OK
Fuel Temperature	Room temperature	Room temperature	OK
Geometry	Contiguous	Contiguous	OK
Reflector	Hydrogenous	Hydrogenous	OK
H/(Pu+U)	5-15	1.1-1.6	[c]
Pu Content (%)	100	6.3 or 22	[d]
^{239}Pu Fission Spectra	Figure 1	Figure 1	OK
^{239}Pu Fission dominates	>~95% (See Table)	>~98% (See text)	OK

[a] Impact of lack of uranium in the benchmark set is small (<~5%, see text).
[b] EALF below 0.63 and greater than 92.6 will be treated as out of AOA. (EALF greater than 0.63 and less than PCM002 minimum value validated by other benchmarks.) (In the cases where this is not in the range, it will be addressed in the specific calculation.)
[c] Impact of slightly different H/(Pu+U) is indicative mainly in relative amount of hydrogen. Relative amount of hydrogen affects thermalization which affects energy spectra. However, energy spectra for this set are similar to that of the design applications.
[d] Impact of varying Pu content is small (<~5%). See text.

As seen, most parameters are in range. This includes the most important parameters of fissile medium (Pu) and moderator (H). The average energy range of this set (EALF) is also comparable to the range specified in table 4-2 in the validation report. Most fissions come from Pu which is the constituent of this set. Where the parameters are out of range, the neutronic behavior of the benchmark set is similar, as illustrated (Figure 1) by a comparison of the neutron spectra causing fission.

Thus, this experiment set demonstrates that the analytical tools are acceptable over the range being verified; therefore, the experiments are acceptable for this AOA.

Pu-8-1

Pu-8 is a set of four experiments that involve ~8 wt. % plutonium oxide and depleted uranium oxide that has been homogeneously blended with polystyrene, and then compacted into cubes. The plutonium consisted of ~11.5 wt. % ^{240}Pu (~88.5 wt. % ^{239}Pu) and the ^{235}U content of the depleted uranium was ~0.2 wt.%. For all four cases, the resulting H/(Pu + U) atomic ratio of the compacts was 7.33, a value higher than the desired AOA(4) validation range of 3.84. The cubes in each experiment are stacked in array configurations with full reflection by Plexiglas.

Pu-8-1: Comparison of Parameters with Validation Range in Validation Report, Part II, Revision 3:

Parameter	AOA(4) Screening Range	Benchmark Set Parameters	Comment
Pu Physical Form	MOX powder	MOX powder	In-range
Wt. % ^{239}Pu	86 – 100	88.5	In-range
Wt. % ^{240}Pu	0 – 14[a]	11.5	In-range
Wt. % ^{238}U in U	80-100	99.8	In-range
Wt. % ^{235}U in U	0-20	0.2	In-range
Pu Content (%)	3.8-37[b]	8	In-range
H/(Pu + U)	0.44-3.84	7.33	Not in-range
EALF (ev)	0.022 –100,000	0.63	In-range

[a] Based on ^{239}Pu content and MFFF assumption of only ^{239}Pu and ^{240}Pu.
[b] Based on ^{239}Pu isotopic composition in NUREG-6698, Table 2.3.

This experiment set is not completely within the revised screening range for AOA(4) due to the H/(Pu + U) values. The following justification is provided to demonstrate that this experiment set can be used to validate the computational tools for this AOA.

Experiment Set Justification

While this set is not completely within the desired validation range for AOA(4) due to the H/(Pu + U) values, the other parameters are in range. In particular, the Pu content of this set, about 8%, is very close to the bounding Pu content analyzed in the MFFF of 6.3%.

The impact of the H/(Pu+U) value (7.33) as compared to the screening range (3.84) and application values (1.1-1.6) is that the relative amount of hydrogen is greater than that in the design application. An increase in the relative amount of hydrogen affects the neutron spectrum and results in increased thermalization.

However, a comparison of the neutron spectrum causing fission between this benchmark set and a typical AOA(4) design application, involving final 22% MOX blend, (homogenizer/pelletizer with a bounding double amount of additives) shows (Figure 2) similar behavior.

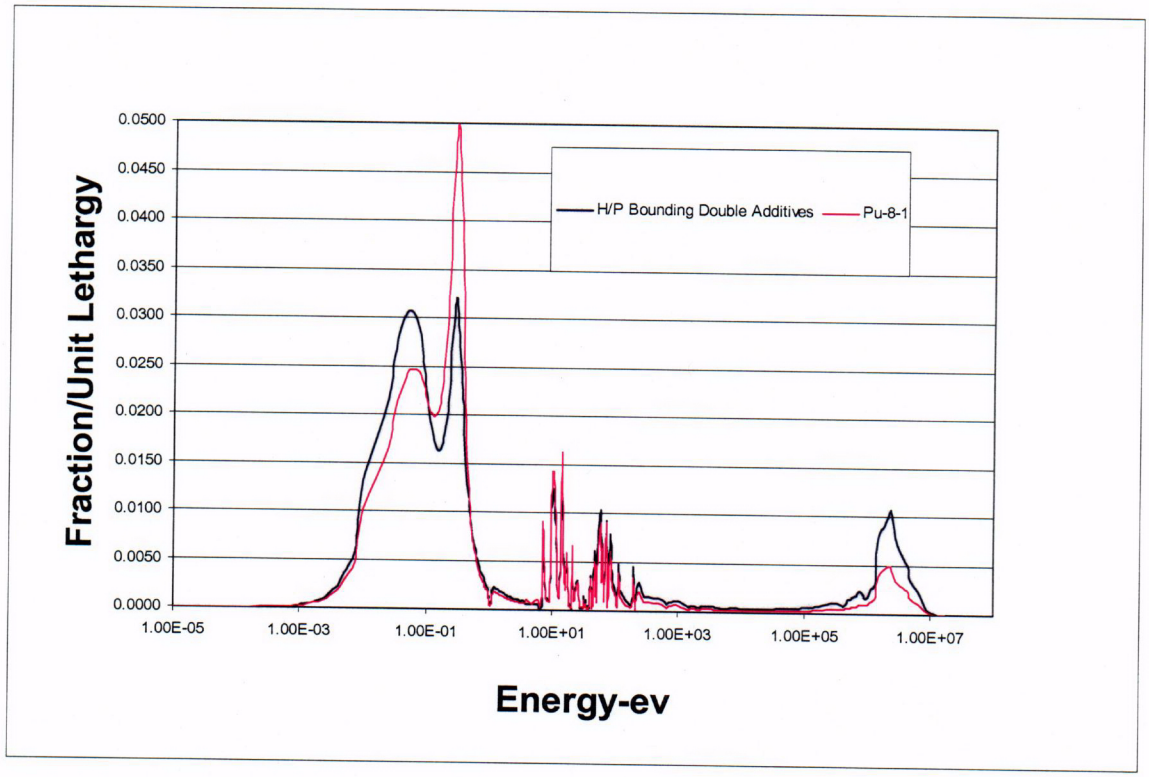

Figure 2. Neutron spectra comparison between Pu-8-1 and MFFF typical design application

As seen in Figure 2, in both cases the neutron spectra causing fissions are essentially identical in shape with similar fissions occurring throughout the low, intermediate and high energy ranges providing additional justification for the applicability of this experiment to AOA(4).

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In summary, the complete justification for including this experiment set can be seen in the following table:

Pu-8-1: Benchmark Parameters Vs. Application Parameters

Parameter	Benchmark Set Parameters	MFFF Application Parameters	Comment
Pu Physical Form	MOX powder	MOX powder	OK
Wt. % ^{239}Pu	88.5	96	OK
Wt. % ^{240}Pu	11.5	4	OK
Wt. % ^{238}U in U	99.8	99.7	OK
Wt. % ^{235}U in U	0.2	0.3	OK
EALF (ev)	0.63	0. 28-850	OK[a]
Moderator	Hydrogenous	Hydrogenous	OK
Fuel Temperature	Room temperature	Room temperature	OK
Geometry	Contiguous	Contiguous	OK
Reflector	Hydrogenous	Hydrogenous	OK
H/(Pu+U)	7.33	1.1-1.6	[b]
Pu Content (%)	8	6.3 and 22	OK
^{239}Pu Fission Spectra	Figure 2	Figure 2	OK

[a] EALF below 0.63 and greater than 92.6 will be treated as out of AOA. (EALF greater than 0.63 and less than 92.6 validated by other benchmarks.

[b] Impact of slightly different H/(Pu+U) is indicative mainly in relative amount of hydrogen. Relative amount of hydrogen affects thermalization which affects energy spectra. However, energy spectra for this set are similar to that of the design applications.

As seen, most parameters are in range. This includes the most important parameters of fissile medium (Pu) and moderator (H). The average energy range of this set (EALF) is also comparable to many applications. Where the parameters are out of range, the neutronic behavior of the benchmark set is similar as illustrated by a comparison of the neutron spectra causing fission.

Thus, this experiment set demonstrates that the analytical tools are acceptable over the range being verified; therefore, the experiments are acceptable for this AOA.