DUKE COGEMA
STONE & WEBSTER

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01 August 2003
DCS-NRC-000154

Subject: Docket Number 070-03098
Duke Cogema Stone & Webster
Mixed Oxide (MOX) Fuel Fabrication Facility
Response to Request for Additional Information Supplemental Questions (DSER Open Item NCS-04)

References:
1) R. C. Pierson (NRC), *Draft Safety Evaluation Report on Construction of Proposed Mixed Oxide Fuel Fabrication Facility, Revision 1*, Dated 30 April 2003
2) A. Persinko (NRC), *Request For Additional Information - Mixed Oxide (MOX) Fuel Fabrication Facility Nuclear Criticality Safety,* Dated 25 June 2003
3) P.S. Hastings to Document Control Desk (NRC), *Response to Request for Additional Information – MFFF Criticality Validation Report (DSER Open Item NCS-04)*, DCS-NRC-000152, Dated 29 July 2003
4) D. Brown (NRC), *July 24, 2003 Summary Of Phone Call With The Applicant: Resolution Of Open Items In The April 30, 2003 Draft Safety Evaluation Report For The Mixed Oxide (Mox) Fuel Fabrication Facility* (NRC Memorandum), Dated 25 July 2003

As part of the review of Duke Cogema Stone & Webster's (DCS') Mixed Oxide Fuel Fabrication Facility (MFFF) Construction Authorization Request (CAR) documented in the Draft Safety Evaluation Report (Reference 1), NRC Staff identified an open item related to Nuclear Criticality Safety. Reference 2 requested additional information, primarily regarding the MFFF Criticality Validation Report. Reference 3 provided responses to those additional inquiries but, in the interest of providing a timely response, did not incorporate follow-on questions identified in Reference 4. Enclosure 1 of this letter provides responses to the follow-on questions in Reference 4.

Additionally, during the NRC public meeting on criticality safety open items on 31 July 2003, the Staff requested that DCS clarify its use of the term "normal condition" as used in the first sentence to the response of Question 7 of Reference 3.

As was discussed in the meeting, "normal condition" is meant to refer to the normal operating condition as would be expected using all normal plant controls. All normal plant controls include those credited safety controls as well as all un-credited controls. In other words, it includes the expected plant condition with all equipment performing as intended.

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NMSS01

Thus the sentence should be modified to read, "All criticality applications in the design of the MFFF show that the abnormal conditions cases are bounding – by an appreciable equivalent margin in k_{eff} – over the normal operating condition cases."

DCS will show by safety analyses that using (only) credited safety controls, all potential credible criticality events are highly unlikely and that the abnormal safety limits are not violated.

Finally, also during the 31 July 2003 public meeting, the following two minor corrections to the MFFF Validation Report were identified and discussed:

- Part II, page 44: changed AOA(4) EALF to narrow according to the benchmarks (no impact)
- Part III, pages 47-48: corrected transposition (typographical) error in AOA (5) H/PU range (no impact)

Change pages for these two corrections are provided in Enclosure 2 of this letter.

If I can provide any additional information, please feel free to contact me at (704) 373-7820.

Sincerely,

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

Enclosures: (1) Response to DSER Open Item on Nuclear Criticality Safety (25 July 2003 Supplemental Questions)
(2) Change Pages as noted

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Enclosure 1
Response to DSER Open Item On Nuclear Criticality Safety
25 July 2003 Supplemental Questions

NUCLEAR CRITICALITY SAFETY

NCS-4 VALIDATION REPORT
These questions include staff review of the revised Validation Report submitted July 2, 2003. Because the review is ongoing, this list of additional questions is subject to change.

(Q refers to the NRC question; R refers to the DCS response.)

Q 1 Demonstrate that the code is valid for those portions of the AOAs in which the parametric range entitled "Validated AOA" in the Validation Report exceeds the range covered by the chosen benchmark experiments. In particular, justify the following areas:

Q AOA(1): Clarify whether the footnote to Table 5-2 means that AOA(1) is considered validated for all possible applications containing borated concrete and cadmium, or if this is confined to those design applications discussed in the footnote. If considered validated for all applications containing these materials, describe and justify the range of these materials considered within the scope of AOA(1).

R AOA(1) is considered validated for applications confined to those design applications discussed in the footnote, specifically:

1. Cadmium sheet of 0.05 cm thickness (clad in 0.1 cm stainless steel) outside of a slab tank of 4.5-9.5 cm fissile material thickness.
2. Refer to Attachment 5 for justification of validation for borated concrete.
Borated concrete (colmanite concrete) of 15 cm thickness (clad in 0.5 cm stainless steel) inside and outside of an annular tank of 7.0-7.5 cm fissile material thickness, separated from the tank by 1.8-2.0 cm conservatively assumed to be filled with water and having the following characteristics:

Colemanite concrete (density = 1.5055 g/cm^3)

Elements	Number densities [10^{24} at/cm^3]
^{10}B	1.59E-03
^{11}B	7.04E-03
Ca	4.65E-03
Fe	5.01E-04
Si	1.66E-04
H	2.17E-02
Al	1.96E-03
O	3.25E-02

Q AOA(4): Justify including the use of depleted uranium in Table 5-2 of Part II of the Validation Report. Justify the value of the bias chosen for design applications exceeding the maximum EALF value of the benchmarks (1740 eV).

Figure 6-6 of Part II shows a net decrease in k-effective with increasing EALF, and Table 5-2 shows the "Validated AOA" range extending up to 3751 eV.

R The validated range of AOA(4) is based upon the characteristics of the "typical design applications" input to the S/U analysis (listed in Table 3-7 of Part II) which determined the benchmarks (as shown in Tables 3-8 through 3-14). Typical design application AOA 4-2 contains depleted uranium in the reflector as shown in Table 3 of Reference [25] (ORNL/TM-2001/262). Thus, the characteristics of the "typical design applications" include depleted uranium in the reflector and it is included in Table 5-2.

As discussed in Section 5.4 of Part II, the validated range of AOA(4) depends on the typical design applications input to the S/U methodology. The S/U methodology determines benchmarks which meet an acceptability criterion. Thus the characteristics of the "typical design applications" establish the acceptability of the benchmarks. In the case of AOA(4), the design application characteristics for EALF went up to 3751. Thus, the range of EALF extends to 3751 regardless of the actual characteristics of the benchmarks. However, as discussed in the NRC public meeting on 31 July 2003, DCS agrees to modify the "Validated AOA" range of EALF to agree with the range of the benchmarks. This is expected to have no impact since as shown in Table 5-2 of Part II, the anticipated range of actual design applications is within the range of EALF of the benchmarks.

Q <u>AOA(5)</u>: Justify including the use of borated concrete and cadmium in Table 5-2 of Part III of the Validation Report. Footnote 2 to this table states that the analysis in Part I is applicable to design applications covered by AOA(5), but does not justify this. Demonstrate that this analysis is applicable to AOA(5). Describe and justify the range of these materials considered within the scope of AOA(5). In addition, the parametric range of H/Pu values appears to be incorrect. The benchmark experiments shown in the tables of Attachment 4 and Figure 6-6 show benchmark data going up to H/Pu = 210, not 858 as claimed in Table 5-2. Address this apparent inconsistency.

R The range of borated concrete and cadmium reflector materials in the scope of AOA(5) in Part III is the same as for the borated concrete and cadmium reflector materials in the scope of AOA(1) in part I. In particular, these are as follows:

[1.] Cadmium sheet of 0.05 cm thickness (clad in 0.1 cm stainless steel) outside of a slab tank of 4.5-9.5 cm fissile material thickness.
[2] Refer to Attachment 5 for justification of validation for borated concrete.
Borated concrete (colmanite concrete) of 15 cm thickness (clad in 0.5 cm stainless steel) inside and outside of an annular tank of 7.0-7.5 cm fissile material thickness, separated from the tank by 1.8-2.0 cm conservatively assumed to be filled with water and having the following characteristics:

Colemanite concrete (density = 1.5055 g/cm^3)

Elements	Number densities [10^{24} at/cm^3]
^{10}B	1.59E-03
^{11}B	7.04E-03
Ca	4.65E-03
Fe	5.01E-04
Si	1.66E-04
H	2.17E-02
Al	1.96E-03
O	3.25E-02

As shown in Attachment 5 in Part I (for borated concrete) and Attachment 6 in Part I (for cadmium), the influence of these reflector materials on the bias in the fissile material is not significant. The loading of the boron in the borated concrete and the thickness of the cadmium sheet is the same in applications involving AOA(5) as it is for applications involving AOA(1). Thus, it would be expected that the influence of these reflector materials on applications involving AOA(5) would be similarly negligible.

Additionally, the bias determined for AOA(5) depends, in part, on benchmarks involving Pu nitrate. Since this is the subject of AOA(1), the justification of the impact of the borated concrete and cadmium for Pu nitrate is applicable to AOA(5) also.

It should also be mentioned that, in the bounding range of AOA(5) (H/Pu 30 to 50), there is significant margin (over 2%) between the fissile material assumed (PuO_2F_2) and that actually occurring (Pu oxalate) which would make any small, credible changes in bias, insignificant.

As for the parametric range of H/Pu for Group b shown in Table 5-2 going up to 858, this is a transposition error. As noted in the table, it was based in the data in Table 5-1. However that is in error also. The corrected tables are shown below (these corrections correspond to change pages [i.e., for Part II, pages 47-48] provided elsewhere in this letter). As noted in the question, this changes the maximum range of H/Pu=210. Note that this is not significant since the limiting H/Pu of AOA(5) materials is from 30 to 50, far below the maximum range (210).

Table 5-1 Critical Experiments Selected for AOA(5)

Experiment of AOA 5 *	H/Pu	EALF [eV]	Reflector and Geometrical form	^{240}Pu [wt. %]	Description
PU-COMP-MIXED-001	5 to 49.6	1.548 to 175000	Bare rectangular parallelepipeds	2.2 to 18.35	PuO_2–polystyrene compacts
PU-COMP-MIXED-002	0.04 to 49.6	0.685 to 4900	Plexiglas-reflected rectangular parallelepipeds	2.2 to 18.35	PuO_2–polystyrene compacts
PU-SOL-THERM-001	87-205	0.35-0.135	Water reflected sphere	4.67	11.5" Diameter sphere
PU-SOL-THERM-008	85-88	0.55-0.52	Concrete reflected and concrete /Cd reflected sphere	4.67	14" Diameter sphere
PU-SOL-THERM-014	210	0.17	Unreflected array of cylinders	4.23	Interacting cylinders in air with 115.1 g Pu/l
PU-SOL-THERM-015	155	0.24	Unreflected array of cylinders	4.23	Interacting cylinders in air with 152.5 g Pu/l
PU-SOL-THERM-016	155-210	0.24-0.17	Unreflected array of cylinders	4.23	Interacting cylinders in air with 152.5 and 115.1 g Pu/l
PU-SOL-THERM-017	210	0.17	Unreflected array of cylinders	4.23	Interacting cylinders in air with 115.1 g Pu/l

* From (Nuclear Energy Agency 1999)

Table 5-2 AOA (5) – Comparison of Key Parameters and Definition of Validated AOA

Parameter	Design application	Benchmarks	Validated AOA
Geometric shape	Parallelepipeds Arrays of cylinders Spheres	a) Parallelepipeds[1] b) Arrays of cylinders	Parallelepipeds Arrays of cylinders Spheres
Absorber/ reflector	Water, Cd, Borated concrete	a) Plexiglas, air b) Air/ water	Water, Cd, Borated concrete[2]
Chemical form	Pu compounds in water and precipitated oxalates	a) PuO_2-polystyrene mixture b) Pu-nitrate solution	PuO_2F_2 solution
Isotopic composition	4 wt. % ^{240}Pu	a) 2.2 to 18.35 wt. % ^{240}Pu b) 4.23 to 4.67 wt.% ^{240}Pu	4 wt. % ^{240}Pu
H/Pu	30 to 50	a) 0.04 to 49.6 b) 85 to 210	a) 30 to 50 b) 85 to 210
EALF [eV]	0.7 to 4.69	a) 0.685 to 4900 b) 0.135 to 0.551	a) 0.685 to 4900 b) 0.135 to 0.551

1 a) refers to Group 1 b) refers to Group 2
2 Justification for borated and cadmium-containing reflectors provided in Part 1 is applicable here.

Q 2 Describe how the bias and uncertainty in the bias will be extrapolated for design applications that fall outside the range of parameters covered by the benchmark experiments, including those within the range labeled "Validated AOA" but outside the range labeled "Benchmark" in the applicable tables.

R As noted in the 13 June 2003 letter (DCS-NRC-000144), where parameter values fall outside the validated area of applicability, DCS committed to identifying additional margin, referred to as AOA margin, in the associated calculations or NCSEs, consistent with the approach described in NUREG 6698. The required margin is typically quantified by extrapolating observed trends in the bias as a function of the parameter.

The only place where parameters fall outside the range of parameters covered by the benchmark experiments, but within the range labeled "Validated AOA" essentially, is in Part II for AOA(4). As described in Section 5.4 of Part II, the AOA is defined by the range of the parameters of the design applications used as input to the S/U technique. These parameters are shown in Table 3-3 of Part II and Table 3-7 of Part II. However, as discussed in the NRC public meeting on 31 July 2003, DCS agrees to modify the "Validated AOA" range of EALF to agree with the range of the benchmarks. This is expected to have no impact since as shown in Table 5-2 of Part II, the anticipated range of actual design applications is within the range of EALF of the benchmarks. To the extent that actual design applications fall outside the validated range, additional AOA margin will be employed consistent with guidance provided in ANSI/ANS-8.1 or further calculations performed as committed to in Section 7.1.1.

Q 3 Tables 3-4 through 3-6 and 3-8 through 3-14 of Part II of the Validation Report contain a list of the c_k values exceeding 0.8 for each design application. This does not contain all c_k values determined using the sensitivity/uncertainty analysis. However, Reference 25 (ORNL/TM-2001/262), Appendix B, contains a complete list of c_k and E_{sum} values for design applications compared to all the candidate experiments. Many of these show a very low level of correlation between certain design applications and those benchmarks included in AOA(3) or AOA(4). Justify including benchmarks that have been shown to be inapplicable to portions of each AOA in the validation.

R As noted in the response to the question 2-D in the RAIs received on 25 June 2003, the range of "typical design applications" used to define AOA(3) and AOA(4) in Part II are all similar in their fissile material form and thus are relevant to this respective AOA. For instance, the three design applications used in AOA(3), (i.e., AOA 3-1, AOA 3-2, and AOA 3-3) are all PuO_2 powder with varying density and water content. Thus, the three typical design applications determine the validated range for AOA (3). Three design applications are indeed different and are intended to span the range of parameters typical of PuO_2 powder. Thus it is not unexpected that there is some variation in benchmark experiments selected by the S/U method. Correspondingly, it is therefore not surprising that, for a particular design application input to the S/U method, experiments not meeting the selection criteria c_k=0.8, but selected by another typical design application, would have a c_k less than 0.8.

This variation in benchmark experiments used as input to the S/U methodology, and the corresponding differences in the selection criteria c_k, is similar to the variation in physical characteristics that occurs when benchmarks are selected in the traditional manner based upon the experiment characteristics. For example, NUREG-6698, section 2.2, discusses the selection of benchmark experiments to be "representative of the types of materials, conditions, and operating parameters found in the actual operations to be modeled." This approach to selecting parameters for benchmarks is also similar to that recommended in other works such as LA-12683.

In the case of the typical design applications used by ORNL as input to the S/U methodology, while the fissile material, moderating material, and reflector material used in the "typical design application" are identical to that found in MFFF calculations, the density, PuO_2 content (in the case of AOA (4)), and water content varied among the applications. This produced a range of parameters which, nevertheless, closely matched typical bounding criticality calculations not unlike that found when selecting experiments whose characteristics had ranges which cover the ranges found in the calculations.

In the traditional case, it is normal to use the full set of benchmark experiments to characterize the bias of the code over the range of benchmark experiments selected. NUREG-6698, section 2.4, discusses analyzing the data thus obtained.

For each AOA, the design applications selected for the S/U analysis do not differ significantly in terms of the traditional basis for defining the AOA. The key parameters characterizing the system are highly similar for each design application. For example, the fissile material is similar differing only in terms of density, moderator content, and reflector materials. That the S/U technique identifies differences in apparent applicability of the resulting benchmark experiments is more reflective of the sensitivity of the S/U method than an indicator that certain benchmarks are inapplicable. For example, the fact that similar materials, geometries, and code options are employed provides a means of benchmarking the large scale potential sources of bias which may arise from potential systematic sources of error, such as coding errors in geometry tracking. These systematic errors can be revealed even for benchmark experiments seemingly unrelated to the design application. This is the reason for the variations in c_k.

For each of the sets of the included benchmarks, one or more typical design applications show high correlation to the included benchmarks. The typical design applications are highly similar to each other and to actual calculations. Thus, included benchmarks for each of these similar design applications is appropriate.

Q 4 Provide the following information for each design application (e.g., AOA 3-1) used in the sensitivity/uncertainty analysis for Part II of the Validation Report: (1) the atom densities for the fissile material; (2) the dimensions of the different geometric regions; and (3) the composition and thickness of any reflecting materials.

R For each design application (e.g., AOA 3-1) used in the sensitivity/uncertainty analysis for Part II of the Validation Report, the following information is provided as part of the output files (echoes the input files) included with the response to the data request for item 1 of Part 2 in the response to the RAIs dated 25 June 2003: (1) the atom densities for the fissile material; (2) the dimensions of the different geometric regions; and (3) the composition and thickness of any reflecting materials.

Q 5 A comparison of Tables 5-1 and 5-2 of Part II of the Validation Report with the description of the design applications (e.g., AOA 3-1) shows that the design applications cover only portions of the "Validated AOA", in terms of H/(U+Pu) and EALF. Given the large variation in the c_k values across this range, demonstrate that the design applications chosen are sufficient to show the code is validated across the entire range.

R As noted in the response to question 2 above and as described in Section 5.4 of Part II, the AOA for Part II is defined by the range of the parameters of the design applications used as input to the S/U technique. The purpose of the S/U technique is to provide justification that benchmarks are appropriate to the selected design applications. The parameters for these design applications are shown in Table 3-3 of Part II and Table 3-7 of Part II. These "typical design applications" were chosen to be very similar to MFFF actual design applications. Thus the, benchmarks selected have been shown to be appropriate by the S/U methodology.

To the extent that actual design applications fall outside this validated range, additional AOA margin will be employed consistent with guidance provided in ANSI/ANS-8.1 or further calculations performed as committed to in Section 7.1.1.

Q 6 Validation Report Part II section 3.6.1 provides justification for using the ck value of 0.8 or higher to determine acceptance of a benchmark for validation of a design application. Provide further justification for using 0.8 vs. 0.9. In particular, provide justification showing that the MOX design applications (PuO2 and MOX powder) are similar enough to the low-enriched uranium systems used in the Generalized Linear Least Squares Methodology analysis to ensure that the results of this analysis can be applied to the MOX design applications.

R As noted in Section 3.6.1 the criteria for determining that the benchmarks are sufficiently similar to design applications is 0.8 or higher.

This information is essentially the same as provided in the report provided by ORNL (ORNL/TM-2001/262) on the work ORNL performed for DCS. Thus the criterion value of c_k=0.8 represents ORNL's recommendation as an acceptance criterion.

Additionally, as noted in Section 3.6.1 and the ORNL report, the selection of the c_k=0.8 criterion was based upon two methods. One was "objectively viewing the sensitivity profiles to determine which systems appear to exhibit similar properties. The systems that exhibited the most similarities were those with a c_k value of 0.8 or higher."

It should be noted that the database of benchmarks ORNL used in their initial research (reference 21) included experiments with enrichments from 2% to 93% over a wide range of H/X values from 0 to 1390. Thus the experiments covered a wide range of energies as would be expected to be represented in Pu in the MFFF.

As noted in the report provided by ORNL (ORNL/TM-2001/262) on the work ORNL performed for DCS, the second method for establishing the criterion was the divergence of the computational bias predicted by the Generalized Linear Least Squares

Methodology (GLLSM) procedure. Through this procedure, the GLLSM code was used to predict the computational bias of a system based on differing sets of experimental benchmarks. First, a large number of critical systems, with a wide range of c_k values, were included in the evaluation, and a bias was computed. Next, systems with c_k values of 0.9 or greater were removed from the experimental set, thus the experiment set included only those experiments with c_k values of 0.89 or lower. No change in the computational bias calculated by GLLSM was observed. A third GLLSM evaluation was performed using only experiments exhibiting a c_k value of 0.79 or lower. In this case, the computational bias computed by GLLSM varied from the previous two calculations by approximately 0.5%. A similarly skewed bias was found when only including systems with a c_k of 0.69 or lower. Thus, it is concluded in Ref. 3 [of ORNL/TM-2001/262], there is a clear break in the behavior of systems at a c_k value of 0.8, and this should be used as the criterion for applicability.

Although it is recognized that ORNL in the development of the S/U methodology applied it to low-enriched systems in the original S/U reference (Reference 21 in Part II), nowhere is it stated that this example only applies to such low-enriched systems.

It is also stated in the ORNL report prepared for DCS (ORNL/TM-2001/262) that "two systems are considered to be similar if the c_k value relating the two systems is 0.8 or higher."

Finally, in the ORNL report prepared for DCS (ORNL/TM-2001/262), the "recommended procedure" is "Count the number of systems with c_k and/or E values greater than 0.8 (approximately 15–20 systems are needed for validation)."

Thus, ORNL concludes that:

1. This S/U study has identified a number critical benchmark experiments that exceed the previously established criterion for applicability to the criticality code validation for AOA 3, PuO_2 powders, and AOA 4, MOX powders, of the proposed MFFF. This criterion is that the correlation coefficient, c_k, meets or exceeds a value of 0.8.
2. For AOA 3, PuO_2 powders, the S/U methods demonstrate that the series of plutonium benchmarks identified by DCS as applicable to the criticality code validation exceed the S/U criteria for the three design systems evaluated. Of the 46 benchmarks identified by DCS, 38 were confirmed by the S/U methods as applicable to the PuO_2 powder systems. In addition to the experiments identified by DCS, *additional plutonium and MOX benchmarks are available that exceed the S/U criterion for this AOA* (emphasis added).
3. For AOA 4, MOX powders, the S/U methods demonstrate that the series of MOX benchmarks identified by DCS as applicable to the criticality code validation exceed the S/U criteria for critical configurations of three of the four compositions studied. These benchmarks *exceed the S/U criterion for subcritical configurations of the fourth composition* (emphasis added). Additional MOX benchmarks included in this

study also demonstrate high correlation coefficients with the design systems from this AOA. Additionally, several plutonium-fueled benchmarks exhibit high correlation coefficients a subset of the MOX design systems studied.

Thus, DCS has accepted ORNL's guidance on the applicability of benchmarks as determined in ORNL/TM-2001/262.

Enclosure 2

MFFF Validation Report Change Pages

Part II, page 44
Part III, pages 47-48

Table 5-2 AOA(4) Comparison of Key Parameters and Definition of Validated AOA

Parameter	Design Application (cf. Table 4-2)	Benchmark	Validated AOA (cf. Table 3-7)
Geometrical shape	Parallelepipeds Spheres	Parallelepipeds Arrays of pins	Parallelepipeds Spheres
Absorber/reflector	Water	Plexiglas	Water Depleted Uranium
Chemical form	MOX powder	MOX and PuO_2 powder in polystyrene Water moderated MOX fuel pins	MOX powder
Pu/(U+Pu) composition	6.3 or 22 wt. %	1.5 to 100 wt.%	6.3 or 22 wt. %
Isotopic composition	4 wt. % ^{240}Pu	2.2 to 11.6 wt. % ^{240}Pu	4 wt. % ^{240}Pu
H/(U+Pu)	1.15 to 1.58	0[1] to 31	0.3 to 1.58
EALF [eV]	0.8 to 175	0.6 to 1740	0.6 to 1740

[1]Moderated arrays of fuel pins

Table 5–1 Critical Experiments Selected for AOA(5)

Experiment of AOA 5 *	H/Pu	EALF [eV]	Reflector and Geometrical form	^{240}Pu [wt. %]	Description
PU-COMP-MIXED-001	5 to 49.6	1.548 to 175000	Bare rectangular parallelepipeds	2.2 to 18.35	PuO_2–polystyrene compacts
PU-COMP-MIXED-002	0.04 to 49.6	0.685 to 4900	Plexiglas-reflected rectangular parallelepipeds	2.2 to 18.35	PuO_2–polystyrene compacts
PU-SOL-THERM-001	87-205	0.35-0.135	Water reflected sphere	4.67	11.5" Diameter sphere
PU-SOL-THERM-008	85-88	0.55-0.52	Concrete reflected and concrete /Cd reflected sphere	4.67	14" Diameter sphere
PU-SOL-THERM-014	210	0.17	Unreflected array of cylinders	4.23	Interacting cylinders in air with 115.1 g Pu/l
PU-SOL-THERM-015	155	0.24	Unreflected array of cylinders	4.23	Interacting cylinders in air with 152.5 g Pu/l
PU-SOL-THERM-016	155-210	0.24-0.17	Unreflected array of cylinders	4.23	Interacting cylinders in air with 152.5 and 115.1 g Pu/l
PU-SOL-THERM-017	210	0.17	Unreflected array of cylinders	4.23	Interacting cylinders in air with 115.1 g Pu/l

* From (Nuclear Energy Agency 1999) [5]

Table 5–2 AOA (5) – Comparison of Key Parameters and Definition of Validated AOA

Parameter	Design application	Benchmarks (cf. Table 5–1)	Validated AOA
Geometric shape	Parallelepipeds Arrays of cylinders Spheres	a) Parallelepipeds[1] b) Arrays of cylinders	Parallelepipeds Arrays of cylinders Spheres
Absorber/ reflector	Water, Cd, Borated concrete	a) Plexiglas, air b) Air/ water	Water, Cd, Borated concrete[2]
Chemical form	Pu compounds in water and precipitated oxalates	a) PuO_2-polystyrene mixture b) Pu-nitrate solution	PuO_2F_2 solution
Isotopic composition	4 wt. % ^{240}Pu	a) 2.2 to 18.35 wt. % ^{240}Pu b) 4.23 to 4.67 wt.% ^{240}Pu	4 wt. % ^{240}Pu
H/Pu	30 to 50	a) 0.04 to 49.6 b) 85 to 210	a) 30 to 50 b) 85 to 210
EALF [eV]	0.7 to 4.69	a) 0.685 to 4900 b) 0.135 to 0.551	a) 0.685 to 4900 b) 0.135 to 0.551

[1] a) refers to Group 1 b) refers to Group 2

[2] Justification for borated and cadmium-containing reflectors provided in Part 1 [15] is applicable here.