March 14, 2005

MEMORANDUM TO: Joseph G. Giitter, Chief
Special Projects Branch
Division of Fuel Cycle Safety
and Safeguards
Office of Nuclear Material Safety
and Safeguards

THRU: Stewart Magruder, Chief /RA/
Mixed Oxide Facility Licensing Section
Special Projects Branch
Division of Fuel Cycle Safety
and Safeguards, NMSS

FROM: David Brown, Sr. Project Manager /RA/
Mixed Oxide Facility Licensing Section
Special Projects Branch
Division of Fuel Cycle Safety
and Safeguards, NMSS

SUBJECT: FEBRUARY 1-2, 2005, IN-OFFICE REVIEW SUMMARY: DUKE COGEMA STONE & WEBSTER CONSTRUCTION AUTHORIZATION REQUEST SUPPORTING DOCUMENTATION FOR CRITICALITY CODE VALIDATION

On February 1-2, 2005, U.S. Nuclear Regulatory Commission (NRC) staff (Christopher Tripp and Stewart Magruder) conducted an in-office review at Duke Cogema Stone & Webster (DCS) Headquarters in Charlotte, NC. The purpose of the visit was to review documents prepared by DCS in response to thirteen follow-up items identified by staff in the draft Final Safety Evaluation Report. For each of the thirteen draft FSER follow-up items, the staff had concluded that it had reasonable assurance that the conclusions DCS made were conservative, based mostly on staff's independent evaluation, but that DCS had not adequately demonstrated this to be the case. Therefore, this in-office review was conducted before final issuance of the FSER so that findings with regard to DCS' response to these items could be made as part of the construction authorization review. By letter dated February 28, 2005, DCS provided a summary of the results of its analysis. As summarized in the attached In-Office Review Summary, the thirteen follow-up items are considered resolved.

Docket No. 70-3098

Attachment: In-Office Review Summary of the DCS Criticality Validation Report Supplement

cc: P. Hastings, DCS
L. Zeller, BREDL
G. Carroll, GANE
J. Conway, DNFSB
D. Curran, GANE
D. Silverman, DCS
J. Johnson, DOE
H. Porter, SCDHEC

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BACKGROUND

On February 1-2, 2005, U.S. Nuclear Regulatory Commission (NRC) staff (Christopher Tripp and Stewart Magruder) conducted an in-office review at Duke Cogema Stone & Webster (DCS) Headquarters in Charlotte, NC. The purpose of the visit was to review documents prepared by DCS in response to thirteen follow-up items identified by staff in the draft Final Safety Evaluation Report. For each of the thirteen draft FSER follow-up items, the staff had concluded that it had reasonable assurance that the conclusions DCS made were conservative, based mostly on staff's independent evaluation, but that DCS had not adequately demonstrated this to be the case. Therefore, this in-office review was conducted before final issuance of the FSER so that findings with regard to DCS' response to these items could be made as part of the construction authorization review. By letter dated February 28, 2005, DCS DCS provided a summary of the results of its analysis. As summarized in the attached In-Office Review Summary, the thirteen follow-up items are considered resolved.

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In-Office Review Summary of the DCS
Criticality Validation Report Supplement
February 1-2, 2005

On February 1-2, 2005, U.S. Nuclear Regulatory Commission (NRC) staff (Christopher Tripp and Stewart Magruder) conducted an in-office review at Duke Cogema Stone & Webster (DCS) Headquarters in Charlotte, NC. The purpose of the visit was to review documents prepared by DCS in response to thirteen follow-up items identified by staff in the draft Final Safety Evaluation Report. For each of the thirteen draft FSER follow-up items, the staff had concluded that it had reasonable assurance that the conclusions DCS made were conservative, based mostly on staff's independent evaluation, but that DCS had not adequately demonstrated this to be the case. Therefore, this in-office review was conducted before final issuance of the FSER so that findings with regard to DCS' response to these items could be made as part of the construction authorization review. By letter dated February 28, 2005, DCS provided a summary of the results of its analysis. As summarized below, the thirteen follow-up items are considered resolved.

During the in-office review, staff reviewed a supplement to the DCS Criticality Validation Report previously submitted to NRC (ADAMS Accession Nos. ML031960150 and ML032890134), as well as supporting references. The supplement is DCS report no. DCS01 ZJJ DS CALC H 35075 A, "MFFF Validation Report Supplemental Information," dated January 31, 2005. Staff reviewed the report and selected references and found that, in each case, the applicant had adequately documented justification for its assumptions.

The draft FSER page numbers containing the original follow-up item, and a brief description of the item resolved by the applicant's supplemental report are summarized below.

1. Draft FSER p. 6.0-6. DCS modeled an infinite cylinder containing a PuO_2-water mixture at five different H/X ratios, assuming four fissile media with different plutonium isotopic vectors. The isotopic vectors included both the bounding reference isotopics used in criticality calculations (96wt% ^{239}Pu, 4wt% ^{240}Pu) and three different combinations of on-spec material, including the combination determined to be the most reactive by the NRC staff (94wt% ^{239}Pu, 5wt% ^{240}Pu, 1wt% ^{241}Pu). This combination contains the minimum ^{240}Pu and maximum ^{241}Pu content, and is expected to be conservative based on the relative values of the cross sections. DCS's calculations concluded that the bounding reference case was as reactive or more reactive than the three combinations of on-spec material across the entire spectrum of H/X values. Therefore, the staff concludes that DCS has demonstrated that the bounding reference case is conservative.

2. Draft FSER p. 6.0-17. DCS modeled three different configurations containing colemanite concrete as a neutron absorber. The three cases considered (two fissile solution tanks and a drip tray) correspond to actual process calculations. The applicant varied the boron content in the concrete to determine the k_{eff} sensitivity to boron number density, and concluded that a 50% reduction the boron density would produce only an -1% Δk_{eff} for these three cases. These cases correspond to thicknesses and arrangements of the colemanite concrete reflector described in table entitled "Definition of AOA(1)" in Section 6.1.3.5.1.1 of the FSER. Therefore, the staff concludes that even a very large error in the ^{10}B cross section will not be sufficient to significantly affect the

code bias.

3. Draft FSER p. 6.0-18. DCS modeled two different configurations containing cadmium sheets as neutron absorbers. The cases considered (slab tanks) correspond to actual process calculations. The applicant performed two series of calculations, in which it: (1) maintained the cadmium sheet thickness but varied the cadmium density, and (2) maintained the cadmium density but varied the cadmium sheet thickness. For both applications, the two methods yielded nearly identical results and showed that a 60% decrease in the Cd density would be required to produce an -1% Δk_{eff} for these cases. These cases correspond to thicknesses and arrangements of the cadmium reflector described in table entitled "Definition of AOA(1)" in Section 6.1.3.5.1.1 of the FSER. Therefore, the staff concludes that even a very large error in the Cd cross section will not be sufficient to significantly affect the code bias.

4. Draft FSER p. 6.0-19. DCS performed a statistical analysis of the benchmark k_{eff} values as a function of ^{240}Pu content, using the ORNL code USLSTATS. Using the results from the confidence band technique generated by USLSTATS, the applicant determined the functional form of both the calculated k_{eff} and its uncertainty, k(x) and w(x), as a function of ^{240}Pu content. The applicant then used this information to extend the trend, including allowance for uncertainty, down to 4wt% ^{240}Pu content, and showed that the originally determined Upper Subcritical Limit (USL) was still valid. Therefore, the staff concludes that the definition of AOA(2) may be extended down to 4wt% ^{240}Pu content without the need for additional margin.

5. Draft FSER p. 6.0-22. DCS modeled 83 different PuO_2-water mixtures ranging from 0 to 0.999 weight fraction of water, for 20 different values of powder density ranging from theoretical density down to 5% of theoretical density. For each density value, the powder and water density were both scaled by the same "density factor" to maintain a constant H/X ratio. K_{inf} values were chosen for the comparison because there is a strong correlation between density, neutron leakage, and energy for a finite system. K_{inf} values were used to isolate the direct effect of density on k_{eff}, in the absence of leakage. When k_{inf} was plotted on a three-dimensional graph as a function of both water content and density, k_{inf} appeared to be totally independent of density. As further demonstration, the residuals $(k_{eff} - k_{REF})/k_{REF}$ were plotted on a Q-Q (quantile-quantile) plot and observed to be normally distributed, such that the variation can be inferred to be due only to Monte Carlo statistical fluctuation. The neutron spectra causing fission for cases with the same water fraction were also found to be identical. Therefore, the staff concludes that variations in powder density have an insignificant effect on the bias and may be ignored for the purpose of choosing validation benchmarks.

6. Draft FSER p. 6.0-23. DCS performed a statistical evaluation of the benchmark k_{eff} values as a function of ^{240}Pu content, using the ORNL code USLSTATS. This was done for the PU-COMP-MIXED-001 and -002 benchmark experiments in AOA(3), which covered the range in ^{240}Pu content from -2-18wt%. Therefore, no extrapolation was needed, and this analysis showed that the originally determined USL was still valid. Therefore, the staff concludes that the definition of AOA(3) adequately covers cases down to 4wt% ^{240}Pu content.

7. Draft FSER p. 6.0-24. DCS compared the neutron spectra causing fission for the two groups of benchmarks in AOA(3) (the 24 Pu-metal benchmarks and the 25 PuO_2-polystyrene benchmarks). The spectra corresponding to Pu-metal benchmarks were graphed in red and the spectra corresponding to Pu-powder benchmarks in blue. When these were overlaid, there was significant overlap across the entire neutron energy spectrum (i.e., fission fraction as a function of the energy of average lethargy causing fission, or EALF). In addition, the applicant plotted the maximum, minimum, and average fission fraction within each energy group for each of the two classes of benchmarks. In addition to considering the spectra using the 238-group structure, the applicant also collapsed the data into 30 energy groups to obtain better statistics within each group. These analyses all showed that, on an energy group by energy group basis, the spread in the fission fraction within either the metal or powder benchmark set was at least as great as the difference between the average values for each benchmark set. Therefore, the staff concludes that the difference between these two sets is smaller than or comparable to the variation within each set, and that there is sufficient overlap in the spectra that they may be combined for validation purposes.

8. Draft FSER p. 6.0-24. DCS compared the macroscopic cross sections for dominant reactions that contribute to reactivity of a PuO_2-water system in the high-energy range. The nuclides considered were ^{239}Pu, ^{240}Pu, ^{16}O, and ^{1}H. The reactions evaluated were fission (n,f), radiative capture (n,γ), elastic scattering (n,n), and neutron knockout (n,2n). Three different fissile media were considered, corresponding to different PuO_2 densities and moderation conditions. It is not necessary to consider higher values of moderation because this demonstration is limited to the high energy (defined as 100 keV to 10 MeV) range. Based on a comparison of the kinematics for the neutron energy loss in elastic scattering, it was determined that elastic scattering is only an important contribution from ^{16}O and ^{1}H. The microscopic cross sections for these nuclide-reaction pairs were multiplied by appropriate number densities to determine the macroscopic cross sections. This showed that in the highest energy range, ^{239}Pu(n,f) dominated all other reactions by at least an order of magnitude. In addition, the relative ranking of nuclide-reaction pairs was consistent with the ranking of sensitivity coefficients determined by the NRC staff using TSUNAMI. Therefore, the staff concludes that ^{239}Pu fission is the dominant reaction for AOA(3) systems in the high energy limit.

9. Draft FSER p. 6.0-27. DCS performed a statistical analysis of the benchmark k_{eff} values as a function of ^{240}Pu content, using the ORNL code USLSTATS. Using the results from the confidence band technique generated by USLSTATS, the applicant determined the functional form of both the calculated k_{eff} and its uncertainty, k(x) and w(x), as a function of ^{240}Pu content. The applicant then used this information to extend the trend, including allowance for uncertainty, down to 4wt% ^{240}Pu content, and showed that the originally determined Upper Subcritical Limit (USL) was still valid. Therefore, the staff concludes that the definition of AOA(4) may be extended down to 4wt% ^{240}Pu content without the need for additional margin.

10. Draft FSER p. 6.0-30. DCS performed a series of sensitivity calculations to determine the effect of depleted uranium (DU) reflectors on the calculated k_{eff}. The first series of runs consisted of spheres containing MOX powder with 0, 1, 3, and 5wt% water content, surrounded by spherical shells of depleted uranium of varying thicknesses. The results

of these calculations showed that the presence of DU results in a significant increase in the system reactivity up to ~20 cm thickness, but beyond that the system k_{eff} is nearly constant. A reduction of 67% in the DU cross sections would thus be required to have a significant effect on the system k_{eff}.

DCS then performed a series of sensitivity calculations applicable to the ball milling operation in the MOX process. This series consisted of a heterogeneous fissile region containing a spherical core of PuO_2 and water surrounded by a spherical shell of depleted UO_2 and water. This arrangement was reflected by a shell containing 500 kg of DU, the same mass as in the ball milling operation. These results showed that, unlike the homogeneous case, there was only a Δk_{eff} of ~5% in going from 2 to 6 cm of DU. The staff reviewed the calculation for the ball milling operation, DCS01 NBX CG CAL H 05629D, "Criticality Safety of Ball Milling Units NBX and NBY", which demonstrated that the heterogeneous two-zone configuration was more reactive than the homogeneous case, and thus was used to determine criticality safety limits for this operation. DCS also performed a calculation in which a DU packing fraction of ~74% (corresponding to a hexagonal close-package array) was used instead of 100%. This is because the DU balls will not realistically form a contiguous shell around the fissile material. This calculation showed there was an ~2% conservatism from assuming the DU formed a uniform shell.

DCS also provided a comparison of the fission spectra for the bare, water-reflected, and DU-reflected calculations and showed that the spectra were nearly identical, except with regard to the small contribution under the thermal peak. The fact that systems covered under AOA(4) will have a significant quantity of DU mixed in with the fissile medium (78% DU for the master blend), and that the spectra are nearly identical, show that the DU cross sections are well-represented by MOX benchmarks applicable to AOA(4). The staff believes that the presence of ^{238}U and the similarity in the spectra is responsible for the high degree of correlation evidenced in its TSUNAMI calculations, even though k_{eff} exhibits significant sensitivity to the presence of DU reflectors of up to 20 cm thickness.

The staff concluded from the analysis provided by the applicant that: (1) it would take a 2/3 error in the DU cross sections to produce a significant effect on k_{eff}; (2) the heterogeneous case is bounding and is used as the basis for criticality safety limits; (3) the heterogeneous case is much less sensitive to the presence of DU than the homogeneous case; (4) the highest-Pu MOX applications still have 78% DU in the fissile medium; and (5) there is considerable overlap between the spectra of bare, water-reflected, and DU-reflected cases covered by AOA(4). Therefore, based on the staff's review of additional analysis prepared by the applicant, the staff has reasonable assurance that design applications containing depleted uranium with no greater worth in k_{eff} than a 60 cm external reflector are within the scope of AOA(4).

11. Draft FSER p. 6.0-32. DCS performed a statistical analysis of the benchmark k_{eff} values as a function of ^{240}Pu content, using the ORNL code USLSTATS. Using the results from the confidence band technique generated by USLSTATS, the applicant determined the functional form of both the calculated k_{eff} and its uncertainty, k(x) and w(x), as a function of ^{240}Pu content, performing this analysis for the Group II benchmarks in AOA(5). The benchmarks in Group I covered the range in ^{240}Pu content from -2-18wt%, while those

in Group II required a slight extrapolation down to 4wt% ^{240}Pu content. The applicant then used this information to extend the trend, including allowance for uncertainty, down to 4wt% ^{240}Pu content, and showed that the originally determined Upper Subcritical Limit (USL) was still valid. Therefore, the staff concludes that the definition of AOA(5) may be extended down to 4wt% ^{240}Pu content without the need for additional margin.

12. Draft FSER p. 6.0-33. DCS modeled PuO_2-water and PuO_2F_2 -water mixtures at six different H/X ratios to cover the full range in moderation covered by AOA(5) (H/X = 30 - 210). For each modeled configuration, DCS performed sensitivity studies in which the O_2 and F_2 in the fissile medium was removed and the change in k_{eff} determined. The applicant used the CIGALES V2.0 code to derive the number densities of the solutions. The staff examined the report entitled Sec/T/03.023, "Density of Actinides Nitric Solutions and their Mixtures: Uranium (VI), Uranium (IV), Plutonium (IV), Plutonium (III), Americium (III) and Thorium (IV)," and determined that the report demonstrated good agreement between the code's predictions and experimental measurements.

    The results showed that the largest change in k_{eff} occurred for PuO_2F_2 at low H/X, consistent with the results of staff's calculations. The largest change was a Δk_{eff} of ~1.6%, demonstrating that the presence or absence of oxygen and fluorine in the fissile medium has a small effect on the calculated k_{eff}. Removal of all the oxygen and fluorine represents a condition which greatly exceeds the effect of the worst credible error in the material cross sections. Therefore, the staff concludes that PuO_2 benchmarks may be used to validate PuO_2F_2 design applications in the parametric range covered by AOA(5).

13. Draft FSER p. 6.0-35. DCS modeled three different configurations containing borated concrete and cadmium as neutron absorbers. The three cases considered (an annular tank with borated concrete inside and outside, and a slab tank and precipitator with cadmium sheets) corresponds to actual process calculations. The applicant varied the boron and cadmium content in increments of 5% from 95% to 0% of their nominal values. These nominal values correspond to the thicknesses and arrangements of the absorbers in the table entitled "Definition of AOA(5)" in Section 6.1.3.5.1.5 of the FSER. The applicant concluded that a 40% reduction in the boron content would be required to produce an ~1% Δk_{eff}. In addition, a 70% and 55% reduction in the cadmium density for the precipitator and slab tank respectively would be required for a noticeable change in k_{eff}. Therefore, the staff concludes that even a very large error in the ^{10}B and Cd cross sections will not be sufficient to significantly affect the code bias.