August 27, 2004

Ms. Leah R. Morrell
Licensing Officer
BWX Technologies, Inc.
Nuclear Products Division
P.O. Box 785
Lynchburg, Virginia 24505-0785

SUBJECT: BWX TECHNOLOGIES, INC., AMENDMENT 108 - REVISED RESTRICTIVE MARGIN OF SUBCRITICALITY (TAC L31783)

Dear Ms. Morrell:

We have reviewed your letter, dated October 9, 2003, and your supplemental information dated April 13, August 13, and August 19, 2004, related to your license amendment request to revise Chapter 4 of BWX Technologies', Inc., (BWXT) license. You requested a change to Chapter 4 of your License so that you may manufacture new [redacted] designs. The results of our review are presented in the enclosed safety evaluation report (SER). As discussed with you and other BWXT staff on August 26, 2004, our conclusion is that your proposed subcriticality margin for [redacted] is acceptable based on the inclusion of the License Condition discussed below. You agreed to this License Condition on August 26, 2004. Pursuant to Part 70 of Title 10 of the Code of Federal Regulations, Materials License SNM-42 is hereby amended to include the revised Chapter 4 of your License. Accordingly, Safety Condition S-1 has been revised to include the dates of all submittals. Also, the following License Condition is included in the License:

S-17 Notwithstanding the commitments in Section 4.2.3 of the License Application, (1) a 0.94 Limiting Condition of Operation and a 0.96 Safety Limit (equivalent to a limit of 0.975 when combined with a bias term of 0.015) shall only apply to systems involving [redacted] in which the [redacted] is the reactivity driver of the system; and (2) [redacted] designs subsequent to [redacted] shall meet the 0.92 Limiting Condition of Operation and 0.95 Safety Limit.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

"Systems involving [redacted]" shall be deemed to include only workstations containing one or more machined and assembled [redacted] by themselves or in conjunction with other components that are not [redacted]. This shall apply to clad areas only.

This license condition does not preclude BWXT from submitting a license amendment request to change the margins of subcriticality for [redacted] designs subsequent to the [redacted] design. That license amendment request should provide sufficient information for Nuclear Regulatory Commission (NRC) to find that the request complies with the requirements of 10 CFR 70.61(d).

All other license conditions shall remain the same. This letter closes NRC review activities on this action for TAC L31783.

Enclosed are copies of the revised Materials License SNM-42 and the Safety Evaluation Report (SER) which includes the Categorical Exclusion determination that this action did not require an environmental assessment.

If you have any questions regarding this matter, please contact Billy Gleaves of my staff at (301) 415-5848 or via e-mail to bcg@nrc.gov.

This letter contains sensitive, unclassified information, and is therefore deemed Official Use Only and will not be placed in the Public Document Room nor the Publicly Available Records component of the NRC's ADAMS document system.

Sincerely,

/RA/

Gary S. Janosko, Chief
Fuel Cycle Facilities Branch
Division of Fuel Cycle Safety
and Safeguards
Office of Nuclear Material Safety
and Safeguards

Docket 70-27
License SNM-42
Amendment 108

Enclosures: 1. Materials License SNM-42
2. Safety Evaluation Report

[redacted]

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Docket 70-27
License SNM-42
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DATE	08/26/04	08/26/04	08/27/04

DOCKET: 70-27

LICENSEE: BWX Technologies, Inc.
Nuclear Products Division
Lynchburg, VA

SUBJECT: SAFETY EVALUATION REPORT: REQUEST TO MODIFY CHAPTER 4 OF THE LICENSE APPLICATION TO USE REVISED MARGINS OF SUBCRITICALITY

BACKGROUND:

On October 9, 2003, BWX Technologies, Inc. (BWXT) submitted an amendment request to modify Chapter 4, Nuclear Criticality Safety, of its License Application to increase its k-effective limits for the new [redacted] fuel design, as well as all future [redacted] designs. This would result in a less restrictive margin of subcriticality for safety in accordance with 10 CFR 70.61(d). On April 5, 2004, the Nuclear Regulatory Commission (NRC) issued a request for additional information (RAI), which BWXT responded to on April 13, 2004. Based on faxed questions from NRC, BWXT responded, in kind, with supplemental information dated August 13 and August 19, 2004. During this time frame, multiple communications by telephone also took place. The NRC review of this amendment request is discussed below.

DISCUSSION:

This amendment is needed to allow BWXT to manufacture the new [redacted] design. The [redacted] is in the process of designing new core designs with longer lifetimes, that will decrease the costs associated with refueling [redacted]

[redacted]

Enclosure 2

There was no Integrated Safety Analysis (ISA) Summary submitted with this amendment request, because the changes were deemed to not involve new facilities or processes. In addition, BWXT stated that the new fuel type did not introduce any new accident sequences.

BWXT Submittal

License Application Section 4.2.3 currently states:

> The Safety Limit is set below the Failure Limit value as an added margin of safety. The k-effective for the Safety Limit shall not exceed 0.97 for low enriched (uranium enriched ≤ 10 weight percent in U-235) systems and shall not exceed 0.95 for high enriched (uranium enriched > 10 weight percent in U-235) systems.
>
> The Limiting Condition of Operation (LCO) value is set such that any single failure (contingency) in the controlled parameter will not exceed the Safety Limit for that parameter. Also, the k-effective value for the LCO shall not exceed 0.94 for low enriched systems and shall not exceed 0.92 for high enriched systems without pre-approval of the NRC.

This amendment request would revise License Application Section 4.2.3 to state:

> The Safety Limit is set below the Failure Limit value as an added margin of safety. The k-effective for the Safety Limit shall not exceed:
>
> - 0.97 for low-enriched systems (uranium enriched ≤ 10 weight percent in U-235),
> - 0.975 for systems involving [redacted] and for [redacted] designs subsequent to [redacted], and
> - 0.95 for all other high enriched systems (uranium enriched >10 weight percent in U-235).
>
> For [redacted] designs subsequent to [redacted], a validation study will be performed to ensure an adequate calculational bias and margin of subcriticality.
>
> The LCO value is set such that any single failure (contingency) in the controlled parameter will not exceed the Safety Limit for that parameter. Also, the k-effective value for the LCO shall not exceed:
>
> - 0.94 for low-enriched systems (uranium enriched ≤ 10 weight percent in U-235),
> - 0.94 for systems involving [redacted] and for [redacted] designs subsequent to [redacted], and
> - 0.92 for all other high-enriched systems (uranium enriched > 10 weight percent in U-235).

BWXT justified the changes to the k-effective limits based on: (1) the design of the new fuel is known; (2) the sensitivity of the new fuel's calculated k-effective to changes in its controlled parameters is known; and (3) the SCALE 4.4 computer package can adequately calculate the k-effective of the new fuel. The materials submitted included a validation report for the [redacted] calculations. The validation methodology consisted of selecting experiments using a "spectral agreement" method to compare candidate experiments to the normal and credible abnormal conditions of the [redacted], calculating k-effective for the 578 experiments thus chosen, performing statistical analyses to trend the data and determine whether the data was normally distributed, quantifying the calculational margin (which includes the bias and bias uncertainty), and determining the upper subcritical limit (USL) and the area of applicability (AOA) over which the USL is appropriate.

NRC Review:

Historically, the NRC has required a greater margin of subcriticality for safety for operations involving high-enriched uranium (HEU) than for those involving low-enriched uranium (LEU). This is due to the fact that the k-effective of systems involving HEU is more sensitive to changes in the underlying system parameters and cross section data than systems involving LEU. The margin of subcriticality (MoS) is an allowance for any unknown errors that may bias the result of calculations, beyond those accounted for in the calculational margin. The reason that MoS is required is that the critical experiments chosen will, in general, exhibit different geometric forms, material compositions, and neutron spectra from actual design calculations, and the effect of these differences is difficult to quantify. Calculational margin is determined by calculating the bias (average k-effective) and bias uncertainty for experiments with similar geometric forms, material compositions, and neutron spectra to actual design calculations. Justifying a smaller MoS requires a higher level of assurance that all sources of uncertainty and bias have been taken into account in the calculational margin. Therefore, to make this determination, the NRC staff had to evaluate the degree of similarity between the 578 critical experiments chosen and anticipated normal and credible abnormal condition calculations for the [redacted].

Selection of Critical Experiments

The NRC staff reviewed the applicability of the 578 selected critical experiments to determine whether: (1) they were appropriate for validation of [redacted] calculations; and (2) they were sufficiently similar to those calculations to support a reduced MoS. Determination of the USL involves both determination of the calculational margin (i.e., statistical calculation of the bias and bias uncertainty) and selection of an appropriate MoS. Selection of the MoS depends in part on the confidence one has in the calculational margin and on the sensitivity of k-effective to changes in the system. Because of this, performing an adequate validation is necessary but not sufficient to support the chosen MoS.

The NRC staff noted that the 578 critical experiments consisted of many different types of systems with differing geometric forms and material compositions. Among them were 124 critical experiments that consisted of fully-flooded and water-reflected arrays of [redacted] nearly identical in geometric forms, material compositions, and neutron energy spectra to those of the [redacted]. The remaining 454 critical experiments included many different configurations whose applicability to the [redacted] was not readily apparent. Because of the observed differences between these two groups of experiments, they are discussed separately below.

[redacted] Experiments

The NRC staff evaluated the 124 [redacted] experiments to determine whether they were appropriate for validation and sufficiently similar to the [redacted] to support a reduced MoS. The April 13, 2004, RAI response contained both a detailed description of these experiments and a tabulated comparison of the important parameters (geometric, material, and neutron spectrum) of these experiments to those of the [redacted]. The staff evaluated these experiments and concluded that they were applicable for a validation of calculations involving [redacted]. The 124 experiments were most applicable to the fully-flooded condition of an [redacted] or [redacted]. Although these experiments were performed using a somewhat different [redacted] type from the [redacted], the geometry and material composition (e.g., ^{235}U and poison loading) was very close to that of the [redacted]. Some parametric differences between experiments and design calculations are inevitable, so to compare the 124 experiments to the [redacted] calculations, the staff used the screening criteria in Table 2.3 of NUREG/CR-6698, "Guide for Validation of Nuclear Criticality Safety Calculational Methodology." The screening criterion for each parameter is expressed as a range of that parameter within which critical experiments should fall in order to be considered applicable to a given design calculation. NUREG/CR-6698 states that: "These values are derived by a number of experienced criticality safety specialists and are necessarily conservative in order for a consensus to be obtained." Due to the screening criteria's conservative nature, if the chosen experiments and design calculations agree within the screening criteria, there is a high degree of confidence that the experiments are applicable. However, if they do not agree within the screening criteria, the experiments' applicability must be further evaluated.

With regard to most of the parameters considered, the 124 experiments were within the screening criteria appropriate for fully-flooded [redacted]. The 124 experiments did have a somewhat lower moderator-to-fuel (H/X) ratio than the fully-flooded [redacted], but the 124 [redacted] experiments and the fully-flooded [redacted] are both in the thermal energy range (defined as 0-1 eV in NUREG/CR-6698), and thus these experiments meet the screening criterion for the neutron spectrum according to Table 2.3 of NUREG/CR-6698. This screening criterion specifies that the neutron energy spectrum of selected experiments should cover the same energy range (0-1 eV = thermal, 1 eV - 100 keV = intermediate, and 100 keV - 20 MeV = fast) as that of the design application being validated. Because H/X and neutron energy are strongly correlated and both measure the degree of thermalization of the system, the staff considers agreement with regard to the energy spectrum to be sufficient.

In addition, as explained below, the analysis of all 578 experiments showed that there was an overall decreasing trend in k-effective with increasing energy of average lethargy causing fission (ECALCF). Thus, although the fully-flooded [redacted] is somewhat outside the range of the experimental data, it is on the low-ECALCF side of the data where the calculated k-effective is increasing, so that the bias in this range is bounded by the overall constant bias. Therefore, the staff considers these experiments appropriate for validating calculations involving a fully-flooded [redacted].

The [redacted] models evaluated in the criticality evaluation (NCSA 2003-104) considered three different types of moderation conditions: (1) dry conditions, in which there was no water in the vicinity of the [redacted]; (2) normal conditions, in which a close-fitting, thin film of water was presumed to exist on the [redacted] surface; and (3) moderated conditions, in which, in addition to the water film, varying levels of interstitial moderation (IM) from 1% up to 100% (fully-flooded conditions) were assumed. Both single unit and infinite planar array calculations were performed.

In addition to being the most similar to the 124 [redacted] experiments, the fully-flooded case was also the most reactive, and thus bounds all the other conditions considered. The dry condition is not a safety or regulatory concern because the dry [redacted] has been shown to be highly subcritical (k-effective $\ll$ 1). Applicability of the 124 [redacted] experiments to cover the intermediate moderation cases (normal and 1-100% IM cases) is discussed in the paragraphs below.

BWXT used ECALCF as the independent parameter for determining trends in the bias. Only the ECALCF parameter was used because the disparate nature of the complete set of 578 critical experiments made it difficult to define parameters that applied consistently across the entire set of experiments. Trending of k-effective for all 578 experiments showed that there was a decreasing trend in the bias with increasing ECALCF. The 124 most applicable [redacted] experiments cover a narrow range in ECALCF. Because of the staff's questions over the applicability of the remaining 454 [redacted] experiments (discussed in the following section), the staff used the USLSTATS statistical analysis program to calculate the USL as a function of ECALCF for just the 124 [redacted] experiments. The USL is determined from the following equation:

$$USL(x) = k(x) - \Delta k_m - W$$

where k(x) is the linear fit to the data (bias $\beta(x) = 1-k(x)$), Δk_m is the MoS (chosen by BWXT to be 0.025), and W represents the uncertainty in the linear fit. USLSTATS computes a constant value of W applied over the range in ECALCF covered by the critical experiments. This value represents the maximum value of a curvilinear function w(x) evaluated over the range covered by the critical experiments. Replacing W by w(x) in the equation above allows extrapolation of the USL beyond the range covered by the critical experiments.

BWXT divided the experiments into four groups, corresponding to the subsets of experiments considered applicable to validating the dry, normal, 1% IM, and 100% IM (fully-flooded) cases. For each of the four groups, BWXT calculated the calculational margin as 0.0145, 0.0131, 0.0131, and 0.0138, respectively. For simplicity, BWXT chose to use a constant calculational margin of 0.015 for all calculations involving [redacted]. This results in a conservative USL, using the above equation, of 1-0.015-0.025 = 0.96. In Figure 1, the staff graphs the equation USL(x) with curvilinear w(x) as a function of ECALCF for the 124 [redacted] experiments, and also the constant USL of 0.96 determined by BWXT (for all 578 experiments), along with the actual k-effective values for several [redacted] calculations. The experiments, being critical, are all above the USL curves, and the actual [redacted] calculations, which are required to be subcritical, are all below the curves. The range in which USL(x) exceeds the constant USL of 0.96 is the range over which the 124 [redacted] experiments are sufficient to support BWXT's USL of 0.96.

[redacted]

Figure 1. Comparison of 124 [redacted] experiments to [redacted] abnormal cases

This figure shows that over the range of approximately 0 - 0.8 eV, USL(x) bounds the constant BWXT USL of 0.96. The reason for this is that the entire set of 578 critical experiments had calculated k-effective values much lower than those of the 124 [redacted] experiments. Thus, the inclusion of all 578 experiments biases the USL low compared to the USL determined for just the [redacted] experiments. The staff concludes that the BWXT USL determined on the basis of all 578 experiments is adequately bounding in the range of 0 - 0.8 eV.

The ECALCF value for the dry [redacted] case was 2260 eV, but as mentioned above, this system is highly subcritical (with k-effective $\ll$ 1) and therefore is not a concern. Biases in k-effective are typically on the order of several percent, not tens of percent. For the normal and 1% IM cases, ECALCF is outside the bounds of the 124 [redacted] experiments (1.17 and 0.64 eV respectively), although the 1 - 100% IM cases are still within the screening criteria in Table 2.3 of NUREG/CR-6698. The normal case is slightly outside this screening range. Because they are within or very close to the conservative screening criteria, they are suitable for validation, although the bias in this region must still be determined through extrapolating the experimental data. Even though these cases are outside the range of the data, the k-effective of all the cases is significantly less than that of a fully-flooded [redacted]. K-effective has a local maximum around 1% IM for the infinite planar-array case due to interference between single unit reactivity and interaction between units (i.e., the portion of k-effective due to a single unit increases due to increasing reflection with increasing IM, and the portion due to the interaction between [redacted] decreases due to increasing isolation with increasing IM), but this is less than the k-effective of a fully-flooded [redacted].

The figure shows the normal, 1% IM, and 100% IM (fully flooded) cases along with the BWXT USL and USL(x) based on the 124 [redacted] experiments. With increasing ECALCF, the [redacted] k-effective is dropping off faster than USL(x), and thus the calculated k-effective for a [redacted] under all moderation conditions is less than the USL determined by extrapolating the bias applicable to the 124 [redacted] experiments. The staff concludes that the BWXT USL determined on the basis of all 578 experiments is thus also adequately bounding in the range of > 0.8 eV.

This analysis conclusively shows that the USL calculated for the 124 [redacted] experiments is sufficient to bound the BWXT USL of 0.96 for [redacted] and [redacted] with 1 - 100% IM. In addition, the k-effective for dryer conditions (i.e., dry and normal conditions) is sufficiently low that these cases are unquestionably subcritical.

[redacted] Experiments

The 454 remaining [redacted] experiments include a wide variety of geometric forms and material compositions. Although they span the range in ECALCF from dry to fully flooded [redacted] and [redacted], there is considerable question as to whether they are sufficiently similar to allow any meaningful conclusions to be drawn. BWXT therefore used a "spectral agreement" method to justify the applicability of these experiments by quantifying the degree of similarity in the fission spectra between the experiments and the [redacted]. BWXT stated that experiments whose spectral agreement parameter exceeded 0.8 could be considered applicable for the purposes of validation. However, there was no technical basis provided for why 0.8 represented an acceptable cutoff value. To illustrate the effect of changing the cutoff value, BWXT reevaluated the 184 critical experiments chosen as representative of the 1% IM case. BWXT determined that changing the cutoff value from [redacted] reduced the number of experiments from 184 to 148. By contrast, the spectral agreement parameter associated with the 124 [redacted] experiments was in the range of 0.89 - 0.93. In addition, there are other materials present and other reactions taking place beyond ^{235}U fission (i.e., ^{235}U fission, ^{238}U absorption, ^{1}H scattering, and other absorption) that can have a substantial effect on the system k-effective. Because k-effective is sensitive to more than ^{235}U fission, an error in the cross sections for other nuclides and/or reactions can also affect the bias. Therefore, chosen experiments should test the validity of the cross section data for all important (in terms of the impact on k-effective) nuclides and reactions. In its August 19, 2004, RAI response, BWXT stated that: "The other criticals do not have all of the unique materials that are in the [redacted]. *Those are only found in the 124 criticals.*" Based on this statement and on knowledge of the factors known to contribute to the k-effective sensitivity, the staff does not have reasonable assurance that any level of spectral agreement constitutes a sufficient test to demonstrate benchmark applicability.

However, as shown in the previous section, the 454 additional critical experiments are not necessary to demonstrate an adequate USL across the entire range in ECALCF covered by the [redacted] calculations. The staff was not able to conclude that these 454 experiments are applicable to a validation of [redacted] calculations, and because these experiments were shown to be not necessary to make a regulatory conclusion, the staff did not make any further evaluation of these experiments or the spectral agreement method.

<u>Adequacy of the MoS</u>

In addition to evaluating selected benchmark experiments and determination of an adequate calculational bias, there must be a separate determination of the adequacy of the proposed reduction in the MoS. Both the BWXT and NRC evaluations discussed in the previous section assumed an MoS of 0.025. This represents a significant reduction in what has been accepted historically for HEU systems. A larger margin has historically been required because the k-effective of systems involving HEU is more sensitive to changes in the underlying system parameters and cross section data than systems involving LEU. Therefore, the staff evaluated the adequacy of the 0.025 MoS by considering the following: (1) the degree of similarity between the chosen critical experiments and [redacted] design calculations; and (2) the degree of conservatism inherent in [redacted] design calculations. The role of the similarity of critical experiments to design calculations has been discussed above. The amount of conservatism in design calculations is relevant because if all calculations have a consistent degree of conservatism in k-effective, then regardless of the calculated value of k-effective, the actual k-effective of the system may be well below license limits. A calculated value of k-effective above the license limits is not a safety concern if this represents a grossly conservative condition that goes beyond normal or credible abnormal conditions.

The 124 [redacted] experiments have geometric forms and material compositions that are nearly identical to those of the [redacted]. The degree of similarity between the critical experiments and design calculations (fully-flooded) is unusually close and thus provides a high degree of confidence that [redacted] calculations below the determined USL will be subcritical. In addition, [redacted] fuel is subject to multiple quality assurance checks throughout the manufacturing process, and the fuel must meet tight specifications for its use in [redacted]. In order for [redacted] to be used in reactors, the configuration must be tightly-controlled, and the neutronic behavior of the fuel must be very well-understood.

In addition to this unusually close benchmark similarity and well-characterized behavior of the fuel, the licensee has provided additional data suggesting that the SCALE 4.4 code package has a net positive bias for these types of experiments (i.e., the code calculates a conservative k-effective value). All of the 124 [redacted] experiments have a calculated k-effective greater than one, which is the experimentally known k-effective. BWXT compared its calculated results for a fully-flooded [redacted] to those performed using [redacted] codes, and also performed a preliminary calculation using MCNP5. SCALE 4.4 calculated a k-effective of 0.9409 ± 0.0010 for the nominal case (i.e., not taking geometric and material tolerances into account) of a fully-flooded [redacted]. The [redacted] code at [redacted] calculated a k-effective of 0.9169 ± 0.0007 for this same case, and MCNP5 calculated a k-effective of 0.9216 ± 0.0020. BWXT has stated that this difference of ~2.4% between the SCALE 4.4 results and the [redacted] results has been observed consistently over the period of development of the [redacted]. BWXT concluded that the SCALE 4.4 code is biased high due to the shortcomings of NITAWL (a cross section processing module within SCALE) in handling the multiple resonance nuclides that must be modeled as part of the [redacted] calculations. NITAWL's inability to handle resonance overlap is a widely-known limitation of the SCALE code. Whether or not this is responsible for the net positive bias, both criticality experiments and alternate codes show that there is a tendency of SCALE to overestimate k-effective for these systems by a predictable amount.

In addition, there is a large amount of conservatism present in [redacted] calculations. There are several different types of [redacted], and the reactivity of these types of [redacted] varies by several percent in k-effective. For the purpose of the criticality evaluation (for both normal and abnormal conditions), only the most reactive [redacted] was used. While this is needed to bound credible conditions for a single unit, the assumption of an infinite planar array of the most reactive [redacted] type is clearly very conservative for the low-moderated array cases. In addition, there is a considerable amount of conservatism in the model for an individual [redacted]. There are tight tolerances on the geometric dimensions and material loadings within a [redacted], and these are conservatively taken into account. BWXT has calculated that there is a 1.9% difference in k-effective between a nominal (i.e., on-specification) [redacted] model and the "tolerance" model (i.e., assuming the worst-case combination of tolerances). The staff reviewed the description of the tolerance model and concluded that dimensional and material loading tolerances were conservatively taken into account. Just taking tolerances into account does not, in and of itself, produce conservatism; an actual [redacted] could be made in this condition (although this is not likely because of the large number of parameters that would all have to be shifted in the most reactive direction). However, the staff determined that in some cases, material loading numbers were modeled even more conservatively than taking tolerances into account would require. In some cases, some materials that would reduce the system reactivity were omitted altogether. Due to the multiple quality assurance overchecks during manufacturing, it is extremely unlikely that such a [redacted] would make it to final machining and assembly. This conservatism in modeling individual [redacted] applies to all calculations involving the [redacted].

There is also a large amount of conservatism in the modeling of individual scenarios. The normal case condition is not a safety or regulatory concern because of the low k-effective limit of 0.94; this is actually less than the abnormal limit of 0.95 previously approved for other HEU. Therefore, the staff focused on the conservatism inherent in abnormal case conditions. In its August 19, 2004, RAI response, BWXT stated that there were two scenarios in which the current abnormal case k-effective limit of 0.95 would be exceeded: (1) a single [redacted] approaching fully-flooded conditions (≥70% IM) without a poison fixture; and (2) an infinite planar array of vertical [redacted] under low-moderated conditions (a few percent IM), without a poison fixture. These cases are discussed separately below.

A poison fixture is required whenever a [redacted] is to be immersed. Equipment is designed to ensure that no more than one [redacted] can be immersed in the same tank at the same time. Water reflection also ensures isolation between the immersed [redacted] and other units, so that the single fully-flooded [redacted] is the bounding scenario in terms of k-effective. Since the fully-flooded case is the most reactive, if the fully-flooded case is subcritical, partially-flooded cases are also subcritical. The NRC staff considers immersion of a [redacted] without the required poison fixture to be very unlikely. The presence or absence of the fixture is readily apparent. The requirement for the poison fixture to be present is also stressed in operator training and is recognized as one of the main criticality controls in the process. With the fixture present, the [redacted] will be very subcritical. Therefore, it is very unlikely that the 0.95 limit will be exceeded during the immersion of a [redacted]. However, even if the upset of immersion of an un-poisoned [redacted] (i.e., one without the poison fixture) occurs, there is a high degree of confidence of subcriticality because this is the case to which the set of 124 [redacted] experiments is most applicable. This system is very thermal, and the fissionable material and absorber cross sections have been measured with a high degree of accuracy in this energy range. Together with the results for the 124 [redacted] experiments, this gives a high degree of confidence in the code's ability to calculate k-effective.

There is another scenario that would be bounded by this model and that is an upset involving an un-poisoned [redacted] being exposed to a source of moderation. During part of the process of manufacturing [redacted], the region in which the poison fixture must be placed is being inspected or otherwise worked on and the fixture cannot be in place. During this time, the addition of liquid water can result in the same upset condition. Although the entire processing area is not considered a moderation control area, the addition of sufficient water to moderate the [redacted] to at least 70% IM would constitute a major operational upset, and as for the immersed [redacted], this configuration would be subcritical.

The alternate, low-moderated (i.e., thin film with up to a few percent IM) array case is not as well-represented by the 124 [redacted] experiments, but contains additional conservatism beyond that in the modeling of the actual [redacted] (i.e., geometric and material conservatism in the tolerance model). The assumption of an infinite planar array of the most reactive [redacted] is conservative. The spacing between the [redacted] and the concrete floor, and between adjacent [redacted], was modeled conservatively. Based on its review of sensitivity studies the staff expects these factors to produce an increase in k-effective of a few percent. However, most significantly, the normal and partial flooding (1 - 100% IM) cases all contain a thin film of water on the [redacted] surfaces. The purpose of including this water film is to bound cases in which a [redacted] has just been removed from an immersion process. Even the normal case (with no additional IM) contains a large amount of liquid water. Sensitivity studies in the criticality evaluation 2003-104 show that k-effective is very sensitive to the thickness of the water film, such that a slight reduction will result in a significant hardening of the neutron spectrum (i.e., shifting of the fission spectrum to higher energies) and a corresponding decrease in k-effective. The liquid film thickness assumed in the calculations was chosen to be conservative. Because it appeared to be excessive in the NRC staff's judgement, the staff compared the assumed thickness to the thickness predicted in several published studies. The behavior of a liquid film on a solid surface is difficult to predict accurately because it depends on several different factors (e.g., surface tension, surface roughness, density, viscosity, speed of withdrawal from liquid). However, the staff observed that the assumed thickness exceeded the thickness predicted by the formulae in three different published studies, by a factor of three or more. The margin in k-effective from this conservative assumption has not been quantified, but taken together, all these conservative assumptions are judged to increase k-effective by at least a few percent.

In addition, the staff does not consider this scenario (an infinite planar array of [redacted] with thin water films on the [redacted] surfaces and low-density moderator between the [redacted]) to represent a realistic upset of the [redacted] storage area. A [redacted] that had been removed from an immersion tank would have the poison fixture installed. Since a limited number of [redacted] can be immersed in a short period of time (including only one [redacted] in the same tank at the same time), it is not reasonable to assume that there would be a large number of un-poisoned and wetted [redacted] stored in one area. This would require multiple upsets of the requirement to have a rod in an immersed [redacted] and would require that multiple [redacted] be immersed and then placed into storage before the water drained or evaporated from the surface of the first [redacted]. Based on the number of tanks available for [redacted] immersion, the restriction to immersing a single [redacted] in any given tank, and the amount of time associated with these operations, the staff considers it reasonable that only ≤ 10 [redacted] with wetted surfaces would be in storage at one time. By contrast, experience with similar storage arrays shows that as the number of elements in each row and column increases, the array k-effective asymptotically approaches that of an infinite array. While BWXT did not evaluate the sensitivity of k-effective to the array size, the staff estimates that about a 10×10 array would be needed to approach the k-effective for the infinite array case. Thus, the staff estimates that the number of available [redacted] with these moderation conditions is approximately an order of magnitude less than what is needed to approach the upset case k-effective.

The only other scenario that could produce a similar configuration would be a firefighting event or another unusual means of introducing moderator into a [redacted] storage area. However, the staff considers the upset condition that is modeled to bound this situation to be highly improbable. Achieving conditions similar to those modeled would require liquid water to accumulate on all surfaces of several [redacted] to the assumed thickness, but for only a low-density mist to be present between the [redacted]. It is difficult to envision how these conditions would arise – [redacted] are not flammable, nor do they preferentially attract water. In its August 19, 2004, RAI response, BWXT stated that it evaluated the full range of IM because the license requires this unless partial flooding can be shown to be not credible or is precluded through the use of moderation control areas. There are credible sources of liquid water in these areas, but due to the number of conservative assumptions, staff considers the actual worst-case k-effective of an upset storage array to be much lower than what is modeled.

In addition to this modeling conservatism, as stated above, use of all 578 critical experiments results in addition of a bias that is not present if just the 124 [redacted] benchmarks are used. BWXT uses a constant bias of 0.015 to bound this (requiring for the upset case that $k_{adj} = k_{calc} + 2\sigma + 0.015 \leq 0.975$). Because the 124 [redacted] experiments do not have this bias, and because there is independent evidence that SCALE 4.4 is biased high, the staff considers the addition of this bias unnecessary. In its August 19, 2004, RAI response, BWXT stated that: "if you include the validation bias (0.015) and modeling conservatism together ([redacted] tolerance is 1.9% in k_{eff}), then it is sufficient to reduce the k_{eff} from 0.975 to below 0.95." Subtracting both the allowance for tolerances and the constant bias term would reduce the limit from 0.975 to 0.975 - 0.019 - 0.015 = 0.941. This is below the previous k-effective license limit of 0.95 for abnormal conditions and is therefore bounded by what was previously adequate subcritical.

Because this additional bias term of 0.015 has been shown to be unnecessary to represent the bias of [redacted] calculations, approving the 0.975 k-effective limit, along with the inclusion of this term, is equivalent to approving an effective k-effective limit of 0.975 - 0.015 = 0.96. That is, the following equations are equivalent:

$$k_{adj} = k_{calc} + 2\sigma + 0.015 \leq 0.975$$

$$k_{calc} + 2\sigma \leq 0.96$$

Because of this, the net reduction in subcritical margin is only from 0.05 to 0.04. The NRC staff considers this more modest reduction in margin acceptable based on the degree of similarity between the 124 [redacted] experiments and the [redacted] calculations, and based on the conservatism in the [redacted] calculations.

Adequacy of MoS for Other Systems

The above considerations only apply to calculations of fully machined and assembled [redacted], under various moderation conditions. The amendment request proposed to modify the license application to state that the higher k-effective limits would apply to "systems involving [redacted] and for [redacted] designs subsequent to [redacted]." In its August 19, 2004, RAI response, BWXT stated that "systems involving [redacted]" means "workstations (racks, carts, tanks, machines, etc.) where normal and accident conditions are calculated for an [redacted] in conjunction with another component that is not an [redacted]. This applies to [redacted] areas only." The examples given were a machined and assembled [redacted] in conjunction with an [redacted] or an [redacted]. However, it stated that the current limits of 0.92 (LCO) and 0.95 (SL) would apply to an [redacted] or [redacted] by itself. Also, the current lower limits would apply to uranium recovery or other [redacted].

The staff considers it appropriate to apply the higher limits to fully machined and assembled [redacted], as well as arrangements of [redacted] in conjunction with [redacted] subcomponents. For the calculation of a completed [redacted] to be valid, each portion of the calculation must be valid. Therefore, the calculation of a subcomponent of an [redacted] in conjunction with a completed [redacted] should present no inherent calculational difficulties. Because [redacted] is the most reactive [redacted] that has been designed to date, when combined with other fissionable materials, the [redacted] will generally be the reactivity driver of the system. (This is true in the cases evaluated in NCSA 2003-104, but it is conceivable this may not be true if future calculations are performed.) In loosely coupled interacting systems (which will include [redacted] and other components that are physically separated), the overall system k-effective is determined almost exclusively by the reactivity driver of the system. Thus, any errors introduced by modeling the less reactive constituents of the system will generally be of secondary importance and will typically not significantly perturb the system k-effective. Thus, using the [redacted] limits for such systems is appropriate as long as the [redacted] is the reactivity driver of the system.

In its August 19, 2004, RAI response, BXWT stated that, for systems involving modeling both HEU and LEU components (for which there are two different sets of k-effective limits), the HEU limits govern. It stated that "this is consistent with the thought process of applying the k_{eff} limits that are associated with the reactivity driver of the system." The staff, for the physics reasons stated above, considers this appropriate for systems involving interacting [redacted] and [redacted] components. The only exception to this would be a strongly coupled interacting system or one in which the [redacted] is not the reactivity driver of the system. An example of the former would be one in which several [redacted] were stacked together in a close-packed arrangement. An example of the latter would be one in which a dry [redacted] was placed adjacent to an immersed [redacted]. In this case, using the principle that the reactivity driver governs, the [redacted] limits should apply.

The proposed words in the license application do not clearly convey the principle of using the limits that apply to the reactivity driver of the system, nor do they limit the term "systems involving [redacted]" to systems involving at least one machined and assembled [redacted] in [redacted] of the facility. Because of this, a license condition is necessary to clearly define what is meant by "systems involving [redacted]," and to specify which sets of limits apply to interacting systems of [redacted] and [redacted] components. Because it is easy to envision cases in which the [redacted] is not the reactivity driver of the system, a license condition limiting the use of the higher k-effective limits to systems involving [redacted] in which the [redacted] is the reactivity driver of the system is necessary. This is not expected to have a significant operational impact, because although there are many different types of fuel and fuel components present in the facility at any given time, the fact that the [redacted] is the most reactive fuel type means that bounding upset cases will generally involve [redacted] rather than other fuel types. The staff also notes that regardless of whether the [redacted] is the reactivity driver of the system or not, part of the process of criticality evaluation includes verifying that the system being evaluated falls within the code's validated area of applicability. Systems driven by components other than [redacted] may not fall within the area of applicability for [redacted] calculations.

In addition, the conclusions upon which this approval is based have been verified only for systems involving [redacted]. No information has been presented with regard to the design or validation of "[redacted] designs subsequent to [redacted]." BWXT's proposed commitment to perform validation studies to ensure an adequate calculational margin and margin of subcriticality for all subsequent [redacted] designs does not provide assurance that critical experiments used to validate these new fuel designs would be of the same quality as those used to validate the [redacted], or that calculations would have the same consistent degrees of conservatism. BWXT did not provide any details concerning the characteristics of the new fuel types or how their validation would be performed. Therefore, because a technical basis has only been demonstrated for the specialized case of the [redacted], a license condition to exclude use of the limits with future fuel types is required.

<u>ENVIRONMENTAL REVIEW</u>:

The staff has determined that the revision of the facility's license is administrative and procedural in nature and may categorically excluded from the requirement to perform an environmental assessment, provided the following criteria are met:

1. There is no significant change in the types or significant increase in the amounts of any effluents that may be released off-site:

The scope of the amendment application does not include any operations that are new or significantly different from those currently authorized and being conducted under the license. Although there may be a minimal increase in non-radiological air and wastewater effluents from the production process, the current air and wastewater pollution control equipment will adequately control these effluents to levels permitted by the Virginia Department of Environmental Quality. No permit changes are necessary for this production.

2. There is no significant increase in individual or cumulative occupational radiation exposure:

This amendment will not result in operations different from those currently authorized under the license; neither does it alter the types, forms, or quantities of SNM permitted. Therefore, individual radiation exposures, will not increase as a result of activities requested by this application.

3. There is no significant construction impact:

The facility structure currently exists. There will be no new construction for the new component production, only the modification of process equipment such as tooling and fixtures.

4. There is no significant increase in the potential for or consequences from radiological accidents:

The risks and potential consequences associated with current operations have been evaluated. These risks and potential consequences are not significantly changed by production of the new component types or the new operating and safety limits. Our evaluations demonstrate that the risks are acceptable and the potential consequences of a radiological accident are unchanged.

Therefore, in accordance with 10 CFR 51.22(c)(11), neither an environmental assessment nor an environmental impact statement is warranted for this action.

CONCLUSION:

The staff has concluded that an effective margin of subcriticality of 0.04 provides a reasonable assurance of subcriticality, based on the following: (1) the unusually close similarity between the 124 [redacted] experiments and [redacted] calculations; (2) the tight tolerances on [redacted] fuel and its well-understood neutronic behavior; (3) the known tendency of SCALE to overestimate k-effective for these systems; and (4) the large degree of modeling conservatism present in [redacted] calculations. This effective margin of subcriticality of 0.04 represents only a modest reduction in margin from what has been previously approved; the staff considers this more than offset by the above considerations. This margin of 0.04 includes both BWXT's proposed margin of subcriticality of 0.025 and the additional bias of 0.015 due to the inclusion of all 578 critical experiments. However, the staff has determined that the 0.015 bias term is unnecessary and hence represents an additional degree of conservatism. BWXT's proposed margin of 0.025, when combined with this additional bias margin of 0.015, provides adequate margin of subcriticality for calculations involving [redacted].

Approving an MoS of 0.025 including this bias term is mathematically equivalent to approving an MoS of 0.04 without it. The staff therefore recommends that BWXT eliminate the use of this bias and demonstrate compliance with an SL of 0.96 for future calculations and revisions to the criticality analysis for the [redacted]. However, for the convenience of the licensee, the use of the current limits along with the additional bias term is considered permissible for the current amendment.

As stated in the previous section, the above considerations have only been confirmed for the specialized case of water-moderated [redacted] and [redacted] calculations. They have not been shown to be valid for calculations involving [redacted] when the [redacted] is not the reactivity driver of the system, or for calculations for other fuel types. Therefore, the following license condition is required:

S-17 Notwithstanding the commitments in Section 4.2.3 of the License Application, (1) a 0.94 Limiting Condition of Operation and a 0.96 Safety Limit (equivalent to a limit of 0.975 when combined with a bias term of 0.015) shall only apply to systems involving [redacted]

[redacted] in which the [redacted] is the reactivity driver of the system; and (2) [redacted] designs subsequent to [redacted] shall meet the 0.92 Limiting Condition of Operation and 0.95 Safety Limit.

"Systems involving [redacted]" shall be deemed to include only workstations containing one or more machined and assembled [redacted] by themselves or in conjunction with other components that are not [redacted]. This shall apply to [redacted] only.

Accordingly, the NRC is not approving use of a Limiting Condition of Operation exceeding 0.92 or a Safety Limit exceeding 0.95 for any [redacted] designs subsequent to [redacted]. In accordance with 10 CFR 70.72(c)(4), exceeding the currently approved 0.92 LCO and 0.95 SL values for [redacted] designs subsequent to [redacted] will require an amendment request and NRC pre-approval.

<u>PRINCIPAL CONTRIBUTORS</u>:

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