January 6, 2016

MEMORANDUM TO: Donald E. Carlson, Senior Project Manager
Advanced Reactor and Policy Branch
Division of Advanced Reactors and Rulemaking
Office of New Reactors

FROM: Christopher P. Jackson, Chief ***/RA/ (E. Oesterle for)***
Reactor Systems Branch
Division of Safety Systems
Office of Nuclear Reactor Regulation

SUBJECT: STATUS OF SPENT FUEL POOL CRITICALITY SAFETY ANALYSIS REVIEW GUIDANCE

On February 9, 2009, your memorandum (Agencywide Documents Access and Management System (ADAMS) Accession No. ML15005A208) was sent to the Branch Chiefs of the Reactor Systems Branch in the Office of Nuclear Reactor Regulation (NRR) and Reactor Systems, Nuclear Performance and Code Review Branch in the Office of New Reactors (NRO). The purpose of the memorandum was to forward a discussion paper, entitled "Recommendations for Review Guidance on Spent Fuel Pool Criticality Safety Analysis (Revision 1)."

The central theme in the discussion paper relates to development of unified review guidance/methods by the U.S. Nuclear Regulatory Commission (NRC) offices performing review of licensing actions that involve evaluating the nuclear criticality safety (NCS) of spent nuclear fuel (SNF). The discussion paper also included 13 specific areas of concern with the NRR/NRO review guidance/methods. Since the memorandum was issued in 2009, significant evolution has occurred within the aforementioned review guidance/methods. Most of the 13 areas identified have been impacted by the ongoing efforts to update existing NRR/NRO guidance.

The first Atomic Energy Commission (AEC)/NRC regulations governing possession of special nuclear material by licensees were codified in 10 CFR Part 70. Further regulations were developed for transportation of radioactive materials (10 CFR Part 71), dry cask storage (10 CFR Part 72), and long term storage (10 CFR Part 63) in order to address the unique needs of each configuration and the existing state of technical knowledge regarding these configurations. When nuclear power plants began to be licensed, operators requested exemptions from the 10 CFR Part 70 requirements for their spent fuel pools (SFPs) in order to preclude the need to maintain criticality monitoring systems and emergency procedures. The exemptions were granted based on very conservative analyses provided by licensees, which demonstrated significant margin to criticality.

CONTACT: Kent Wood, DSS/SRXB
(302) 415-4120

In subsequent years, many licensees began to utilize combinations of high density racks and fuel characteristics that reduced the margin to criticality relative to their original license requirements. As a result, the NRC decided to codify a new regulation for nuclear fuel storage at nuclear power plants (10 CFR 50.68), based on the operating experience and technical/regulatory knowledge available in 1998. As a result, the regulatory requirements for SFPs allow for best-estimate NCS calculations coupled with a statistical analysis of uncertainties to demonstrate that the regulatory limit is met at a 95 percent probability, 95 percent confidence level.

Due to the different regulatory structure and how applicants chose to address those differences, the review guidance/methods in Nuclear Material Safety and Safeguards and NRR/NRO evolved down different paths. In some respects, a unified review guidance/methodology structure is appealing; however, there is no identified need or safety case requiring unified review guidance/methods. Additionally, implementing a unified review guidance/methodology at this time could impose an undue regulatory burden on licensees without a corresponding substantial safety benefit.

The enclosure to this memo provides an update on the current SFP NCS review guidance status and discusses its relation to each of the 13 items from your 2009 discussion paper.

Enclosure:
Update on SFP Criticality Actions

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Enclosure:
Update on SFP Criticality Actions

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OFFICE	NRR/DSS/SRXB	NRR/DSS/SRXB	NRR/DSS/SRXB/BC
NAME	SKrepel	KWood	CJackson (EOesterle for)
DATE	1/ 6 /2016	1/ 6 /2016	1/ 6 /2016

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To demonstrate compliance with the spent fuel pool (SFP) safety requirements in 10 CFR 50.68, licensees must perform nuclear criticality safety (NCS) analyses that assess the potential reactivity impact from a wide variety of potential storage configurations, manufacturing tolerances, accident scenarios, and methodological uncertainties. As a part of this process, the licensee quantifies the reactivity impact of each consideration, including any applicable statistical treatment in the treatment of uncertainties. The U.S. Nuclear Regulatory Commission (NRC) staff reviews the treatment of each potential reactivity impact, and ensures that the individual evaluations are appropriate. Furthermore, the NRC staff confirms that any positive reactivity impacts are appropriately incorporated in the final reactivity calculation that demonstrates compliance with the regulatory requirements.

Enclosure 2 to the February 6, 2009 memorandum (Agencywide Documents Access and Management System (ADAMS) Accession No. ML15005A208) describes 13 areas that may affect spent nuclear fuel (SNF) reactivity. The memorandum's implication is that additional guidance is necessary to ensure that licensees and applicants avoid under predicting the effective neutron multiplication factor (k_{eff}) in SFP NCS analyses. A potential under prediction of k_{eff} could reduce safety margins and lead to a more lengthy review by the staff and increased number of requests for additional information in order to ensure compliance with 10 CFR 50.68. Since the memorandum was issued, the NRC has taken several actions to strengthen existing guidance for 10 CFR 50.68 reviews.

This enclosure provides an overview of the status of NRC guidance associated with SNF NCS reviews to verify compliance with 10 CFR 50.68, with respect to each of the 13 areas identified in enclosure 2 to the February 9, 2009 memorandum. In the discussion below, the aforementioned enclosure will simply be referred to as "the discussion paper." The "final guidance document" refers to a spent fuel pool (SFP) NCS criticality analysis guidance document, NEI 12-16 (Reference 5), under review by NRC staff, with any limitations or conditions incorporated in the NRC endorsement via a regulatory guide.

1) **Burnup Credit Isotopics** addresses the isotopes that are modeled in the SNF NCS analysis. In a NCS safety analysis that includes irradiated fuel, a methodology needs to be utilized for the modeling of the isotopes and to determine their quantity after irradiation in the operating reactor. The actinides and fission products that are produced during irradiation in an operating reactor are physically present and contribute to the reactivity of the fuel. However, there has historically been some debate over which isotopes to include in the NCS analysis and how to model them. The discussion paper explores several points of that historical debate.

    a) Historically, the NRC has allowed licensees to credit a full set[1] of actinides and fission products to demonstrate compliance with 10 CFR 50.68. At the time of the memorandum, compliance reviews for 10 CFR Parts 63, 71, and 72 were only allowing

[1] A 'full set of actinides and fission products' includes every isotope, except those with a short half-life, that is produced during the fission process and that has a neutron absorption cross section.

credit for a limited number of actinides. The NRC position that disallowed credit of actinides and fission products for these purposes was based on the limited ability to explicitly validate every isotope in the full set at that time. Removal of those isotopes, which function as a poison, from criticality calculations will lead to a conservative, bounding result. However, since the full set is actually present, and credited in reactor safety analysis determinations such as shutdown margin, the NRC's position has historically been, and remain to be, that it is appropriate to consider the full set when determining compliance with 10 CFR 50.68.

b) Historically, modeling the full set of isotopes was difficult; older computer systems and models lacked the ability to track the presence and subsequent nuclear interactions of hundreds of isotopes with a reasonable computing time. In order to credit the full set, several modeling simplifications were required. Two simplifying assumptions mentioned in the discussion paper are reactivity equivalency methods, where the reactivity of a full set is modeled by a smaller set. The first is a method where fresh fuel was used to represent SNF, with the enrichment adjusted to achieve an equivalent reactivity. This was subsequently shown to be non-conservative in some circumstances. The second is to replace fission products, particularly Lumped Fission Products[2], with an amount of boron-10. Neither reactivity equivalency method is currently widely used, and when accepted by the staff, incorporates a significant penalty. The treatment of Lumped Fission Products is addressed in Section 4.d of the current staff guidance on SFP criticality analyses, DSS-ISG-2010-01 (Reference 1), and more detailed guidance will be provided in the final guidance document.

The staff position is: (1) the full set of actinides and fission products is physically present; (2) the reactivity equivalency methods are no longer being accepted without a significant penalty; and (3) the Lumped Fission Products are addressed in existing and future staff guidance for review of NCS analyses. The staff does not plan to take further action at this time regarding credit for actinides and fission products (including Lumped Fission Products). Reactivity equivalency methods are used in some SFP NCS analyses, and have generally been addressed on a case by case basis.

2) **Burnup Credit Validation** refers to the validation of the isotopic number densities predicted by the depletion computer codes. The availability of data on relevant isotopic number density measurements for SNF is limited. Additionally, performing such measurements is difficult, so some of the data that does exist have significant uncertainties. The inability to explicitly validate the number density of every isotope was a contributing reason why the NRC did not grant credit for a full set of actinides and fission products when reviewing for compliance with 10 CFR Parts 63, 71, and 72 at the time that the discussion paper was written.

Since that time, there have been several guidance documents published by both the NRC and industry. Joint efforts between NMSS, NRO, NRR, and the Office of Nuclear Regulatory Research (RES) have resulted in the publishing of NUREG/CR-6979 (Reference 2) and NUREG/CR-7108 (Reference 3). The former document added significantly to existing data

[2] Lumped Fission Products have been in use for decades to collectively represent the reactivity effect of low worth isotopes.

for use in validating the actinides in SNF, and the latter document presents a rigorous methodology for performing validation on actinides and fission products. NUREG/CR-7108 also provides some representative values for typical SFP storage configurations based on the validation methodology. The NRC has used that information to revise SFST-ISG-8 (Reference 4) to allow credit for a larger set of actinides and fission products. More recently, the Electric Power Research Institute (EPRI) has published several topical reports regarding SNF isotopic number density validation. Those are currently under review by the NRC.

The current guidance in DSS-ISG-2010-01 (Reference 1) includes the historical NRC recommendation to use 5% of the reactivity decrement from fresh fuel to the burnup of interest for the depletion uncertainty. This appears to be conservative relative to the proposed EPRI methodology and provides results comparable to what would be obtained using the methods in NUREG/CR-7108. The discussion paper describes the use of commercial reactor restart critical data to develop conclusions on the bias trends for full burnup credit. The use of commercial reactor restart critical data has not been universally accepted as appropriate for burnup credit validation, so this reflects a lack of consensus within the NCS community on the appropriate approach for this part of the SNF NCS analysis.

The staff believes that burnup credit validation is adequately addressed by the current guidance. However, it remains an area of continued work. A guidance document for SFP NCS analysis methodologies, NEI 12-16 (Reference 5), is currently under NRC staff review, and includes discussion regarding burnup credit validation and determination of the depletion uncertainty.

3) **Rodded Burnup Histories** relates to the effect that control rod insertion or removable burnable poison (e.g., wet annular burnable absorbers, or WABAs) have on the accumulated isotopic mix in SNF. Control rod insertion during the irradiation period for fuel typically results in increased plutonium production, which may increase the reactivity of the SNF in the SFP environment. This area is discussed in sections 2.c and 2.d of DSS-ISG-2010-01 (Reference 1), and will be addressed in the final guidance document.

   The staff believes there is currently adequate guidance and does not plan to take further action at this time.

4) **Spatial Burnup Profiles** may refer to either axial or transverse burnup profiles in SNF. Axial burnup profiles have been shown to have a significant impact on the reactivity of SNF, and are addressed in section 3.a of DSS-ISG-2010-01 (Reference 1). The discussion paper indicates that studies of transverse burnup profiles show significant reactivity effects only in small, isolated arrays of fuel bundles, which is typically not the case in SFP analyses. However, transverse (or radial) burnup profiles due to fuel near an inserted control rod may have an impact on the reactivity of SNF and are addressed in section 2.d.ii of DSS-ISG-2010-01. The final guidance document will also address both impacts on the NCS analyses.

   The staff believes there is currently adequate guidance and does not plan to take further action at this time.

5) **Pin Burnup Modeling** covers several different aspects of how individual fuel rods are modeled. This section discusses 10 different aspects of the fuel rod, as listed below.

   a) **Fuel pin radial temperature profile**: The current guidance does not specifically cover this item.
   b) **Radial reaction rate and depletion profiles, including the skin or rim effect**: The current guidance does not specifically cover this item.
   c) **Uniform and granular integral burnable poisons**: Integral burnable absorbers are covered by section 2.c of DSS-ISG-2010-01 (Reference 1).
   d) **Burnable poison coatings**: Burnable poison coatings on the fuel are considered to be integral burnable poisons, which are addressed in item (c), above.
   e) **Fuel pellet-stack thermomechanical changes**: The current guidance does not specifically cover this item.
   f) **Cladding thermomechanical changes**: The current guidance does not specifically cover this item.
   g) **Intra-assembly, inter assembly, and by-pass coolant void distributions (for BWRs)**: The current guidance does not specifically cover this item.
   h) **Grid spacers**: The current guidance does not specifically cover this item.
   i) **Part length rods**: BWR fuel assemblies typically contain part length rods, which are not specifically addressed in DSS-ISG-2010-01. Section 1 does discuss the selection of a limiting fuel assembly design, including variations in axial and radial enrichment distributions. During typical reviews of BWR SFP NCS analyses, this is interpreted to include the axial variations due to part length rods.
   j) **In-core gamma and neutron detector response models in conjunction with (i) and other key effects above**: The current guidance does not specifically cover this item. However, the effect of an instrument filling the instrument tube has been negligible when compared with the bounding use of other inserts.

   The staff initially believed that item (a) would have a minor effect, based on recent analysis comparing pin-wise versus assembly average evaluations in some prior license amendment requests (LARs). However, the staff subsequently found literature that indicates the fuel pin temperature profile could have an appreciable effect on post irradiation reactivity, and other literature that indicates this may already be taken into account by modern depletion codes. More investigation is necessary to determine whether or not any action is required.

   As the staff understands the 'rim effect' in item (b) it deals with the release of volatile fission gases from the fuel pellets. Volatile fission gases are not typically credited in SFP NCS. When they have been the guidance in NUREG/CR-6487, "Containment Analysis for Type B Packages Used to Transport Various Contents," has been followed. NUREG/CR-6487 was written to address fuel in transportation scenarios, but the radionuclide release rates should be similar.

   Items (c), (d) and (i) are covered by existing guidance and the staff plans no further action at this time, other than to ensure that appropriate guidance is also incorporated in the final guidance document.

Items (e) and (f) are related to area #10 identified in the discussion paper, “Actual Fuel Pin Conditions,” which is addressed later in this enclosure.

Section 2.b of DSS-ISG-2010-01 provides guidance on reactor parameters used in the depletion simulations of the SNF used for the SFP NCS analysis. For BWRs, this results in a sensitivity study on void fraction. Those sensitivity studies do not have the specificity mentioned in the discussion paper. However, the most limiting condition has generally been found to be at or near a void fraction of 0%, therefore, use of that void fraction for the bypass and water hole regions are most likely conservative. The staff does not believe any further guidance is necessary at this time.

Fuel assembly grid spacers, item (h), are not modeled in the depletion portion of the analysis, but they are also not typically modeled in the k_{eff} estimation. As a weak local absorber, the grid spacers would have a much smaller effect than the integral and removable burnable absorbers or rodded operation. Furthermore, any potential non-conservatism resulting from the lack of the grid spacers during the depletion would be offset by the conservatism resulting from the lack of the grid spacers in the SFP analysis. While the staff believes the current guidance is adequate, the staff will evaluate whether additional specificity regarding spacer grids is warranted in NEI 12-16 (Reference 5) or any other NRC-endorsed guidance for SFP NCS analyses.

Item (j) is bounded by the current treatment of removable burnable absorbers, and the staff plans no further action at this time.

6) **Spent Fuel Record Accuracy** is essentially the question of how well the licensee knows the burnup of an individual fuel assembly. In the past, some licensees listed a batch average burnup for fuel assemblies rather than the actual individual burnup in plant records. This is not specifically addressed in the current guidance. Spent fuel record accuracy has been discussed in several license amendment requests. In cases where it is not, the staff would expect licensees to take it into account when determining what burnup to use for a particular fuel assembly when determining whether it meets the storage requirements. This is consistent with the staff expectation for licensees to apply any bias and uncertainty in the SFP soluble boron concentration measurements when verifying compliance. The current draft of NEI 12-16 (Reference 5) under review by the NRC includes specific guidance on how to address this issue.

7) **Absorber Plate Granularity** relates to the potential for neutron streaming and self-shielding of permanently installed neutron absorbers in the SFP racks. The efficiency of the neutron absorber, especially considering the potential for self-shielding and streaming, is covered in section 3.b.ii of DSS-ISG-2010-01 (Reference 1). The staff believes the current guidance is adequate and plans no further action at this time, other than to ensure that comparable guidance is incorporated in the final guidance document.

8) **Bundles with Removed Pins** may result in an increase in reactivity in the SFP due to a change in the fuel-moderator ratio. Fuel reconstitution is included in section 3.d of ISG DSS-2010-01 (Reference 1) as a normal condition and in section 3.e as the initial state for an abnormal condition. The staff believes the current guidance is adequate and plans no

9) further action at this time, other than to ensure that comparable guidance is incorporated in the final guidance document.

10) **Cooling Time Am-241 Credit** refers to the crediting of the reactivity decrease due to the decay of Pu-241 to Am-241. Am-241 is a strong neutron absorber, so as the quantity of Am-241 in SNF increases, the reactivity decreases. Published studies such as NUREG/CR-6979 (Reference 2) provide sufficient information to validate the inclusion of Am-241 in SNF NCS analyses. Any such validation would be done consistent with guidance in section 4 of DSS-ISG-2010-01 (Reference 1). The discussion paper does suggest some potential for non-conservative long term effects resulting from existing recommendations. However, there is no reason to believe that spent fuel pools will remain in operation for over 200 years (the applicable time frame provided by one of the references). 10 CFR 50.82(a)(3) makes it clear that the NRC's expectation is for fuel to be stored in the SFP for no longer than 60 years after cessation of power plant operation. Therefore, the staff believes the current guidance is adequate and plans no further action at this time.

11) **Actual Fuel Pin Conditions** are not typically modeled in SFP NCS analyses. As the discussion paper states, "Per existing review guidance, the modeled spent fuel pellet and cladding dimensions and cladding compositions are those of fresh fuel." Consideration of the fuel assembly physical changes due to irradiation, i.e., clad thinning, is not included in the current guidance. However, the staff is aware of the potential for the changes to affect SFP reactivity and the topic has been covered in several LARs. A methodology to address fuel assembly physical changes due to irradiation is included in NEI 12-16 (Reference 5), which is currently under review by the staff. The staff believes the subject is currently being adequately addressed and will be included in the final guidance document.

12) **Monte Carlo Undersampling** can lead to under-predictions of k_{eff} by missing localized effects in the SFP. This is a valid concern that was not included in DSS-ISG-2010-01 (Reference 1). However, the staff has been including consideration of Monte Carlo code undersampling and false convergence in their technical reviews of LARs (e.g., Reference 6). The staff believes the subject is currently being adequately addressed, and intends to include Monte Carlo convergence as a topic in the final guidance document.

13) **Wall Reflection Effects** from the concrete surrounding the SFP may result in non-conservative k_{eff} values due to insufficient modeling of the reflection of neutrons back into the SFP. Section 3.b of DSS-ISG-2010-01 (Reference 1) addresses the rack model and directs the reviewer to ensure the rack model is appropriate. However, the guidance does not specifically call out the wall reflection effect. A recent LAR (Reference 7) regarding a fresh fuel storage vault indicated a strong wall effect for the optimum moderation analysis, but a much lesser effect, if any for the fully moderated analysis. This wall reflection effect was similar to, but not exactly as described in the discussion paper. It is unclear whether those results would be applicable to a fully flooded SFP due to its differing geometry. The staff is using the lesson learned from the fresh fuel storage vault LAR to inform their reviews. Therefore, the staff believes the subject is currently being adequately addressed. While a guidance document cannot cover every possibility, the staff intends to enhance the rack modeling guidance in the final guidance document.

14) **Offsetting Conservatisms** refers to conservative assumptions or modeling methods within a NCS analysis that the NRC staff may credit to offset a non-conservatism elsewhere. The discussion paper indicates some modeling conservatisms that could be analyzed to quantify their reactivity impact. The staff agrees that any conservatism in a NCS analysis credited to offset non-conservatisms elsewhere in the analysis should be appropriately evaluated to verify that the net effect is not non-conservative. However, the staff doubts that quantifying them on a generic basis would provide sufficient benefit to offset the cost investment given the plant specific variations from one analysis to the next. Most conservative modeling assumptions, including the ones mentioned in the discussion paper, are not universally adopted by all licensees. Therefore, the staff plans no further action at this time.

Conclusion

The discussion paper indicated 13 areas where NRC staff guidance on NCS analyses related to 10 CFR 50.68 compliance could potentially benefit from insights based on experiences in NCS analyses for SNF storage in casks as a part of 10 CFR Parts 63, 71, and 72 compliance. Recently, the paper was re-visited to evaluate the current state of NRC guidance for review of 10 CFR 50.68 compliance with respect to the issues identified therein. The staff has determined that most of the concerns have been satisfactorily addressed, but there are six specific issues that warrant further evaluation for inclusion in the guidance document currently under review for SFP NCS analyses, NEI 12-16 (Reference 5). The staff will take action to ensure that each issue is adequately addressed in the final guidance document, or that there is a sound technical basis for excluding an issue. The issues are listed below.

1) Evaluate whether the fuel rod radial temperature aspect is adequately covered by modern depletion codes or if additional guidance is necessary.

2) The methodology provided in the final guidance document to treat uncertainties in crediting the full set of actinides and fission products present in spent fuel should have a sound technical basis that is consistent with the current state of technical knowledge regarding burnup credit validation.

3) The impact of including fuel assembly grid spacers in the depletion simulations done to support the NCS analyses should be evaluated. If there is a potential non-conservative reactivity impact, specific guidance should be included in the final guidance document.

4) The methodology described in NEI 12-16 is being assessed to ensure that it adequately addresses all reasonably expected changes described in item 5 of this enclosure that could affect the reactivity of the fuel in the SFP environment.

5) A section should be included in the final guidance document that addresses Monte Carlo convergence, including the potential for under-prediction of the k_{eff} due to undersampling or false convergence.

6) The discussion on modeling of the SFP racks in the final guidance document should be enhanced to address the potential for increased reactivity due to reflection of neutrons back into the SFP racks from the pool walls.

References

1. NRC Division of Safety Systems Interim Staff Guidance DSS-ISG-2010-01, Rev. 0, “Staff Guidance Regarding the Nuclear Criticality Safety Analysis for Spent Fuel Pools,” October 13, 2011 (ADAMS Accession No. ML110620086).

2. D.E. Mueller, et al., “Evaluation of the French Haut Taux de Combustion (HTC) Critical Experiment Data,” NUREG/CR-6979, ORNL/TM-2007/083, U.S. Nuclear Regulatory Commission, Oak Ridge National Laboratory, September 2008.

3. G. Radulescu, et al., “An Approach for Validating Actinide and Fission Product Burnup Credit Criticality Safety Analyses – Isotopic Composition Predictions,” NUREG/CR-7108, ORNL/TM-2011/509, U.S. Nuclear Regulatory Commission, Oak Ridge National Laboratory, April 2012.

4. SFST-ISG-8, “Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transport and Storage Casks,” revision 3, October 2012 (ADAMS Accession No. ML12261A433).

5. Nuclear Energy Institute document NEI 12-16, “Guidance for Performing Criticality Analyses of Fuel Storage at Light Water Reactor Power Plants,” revision 1, April 2014.

6. Quad Cities Nuclear Power Station, Units 1 and 2, Issuance of Amendments Regarding (TAC Nos. MF2489 and MF2490)(RS-13-148), December 31, 2014 (ADAMS Accession No. ML14346A306).

7. Seabrook Station, Unit 1 – Issuance of Amendment Regarding License Amendment Request Regarding New Fuel Vault (TAC No. MF3283), May 18, 2015 (ADAMS Accession No. ML15118A632).