U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

9.1.1 CRITICALITY SAFETY OF FRESH AND SPENT FUEL STORAGE AND HANDLING

REVIEW RESPONSIBILITIES

Primary - Organization responsible for the review of criticality safety of fuel outside the reactor

Secondary - Organization responsible for the review of neutron absorbing materials performance

I. AREAS OF REVIEW

This SRP section is applicable to construction permit (CP) and operating license (OL) applications submitted under 10 CFR Part 50 and design certification (DC) and combined license (COL) applications submitted under 10 CFR Part 52. The SRP was originally written for Part 50 license applications. For DC and COL applications submitted under Part 52, the level of information reviewed should be consistent with that of a final safety analysis report (FSAR) information submitted in an OL application. However, verification that the as-built facility conforms to the approved design is performed through the inspections, tests, analyses, and acceptance criteria (ITACC) process.

Nuclear reactor plants include facilities for storage of new and spent fuel. The new fuel storage facility includes the fuel assembly storage racks, the concrete storage vault that contains the storage racks, and the auxiliary components. The spent fuel storage facility includes the spent fuel storage racks, the spent fuel storage pool that contains the storage racks, and the associated equipment storage pits.

The reviewing organization verifies that the storage facilities maintain the new and spent fuel in subcritical arrays during all credible storage conditions, in accordance with General Design Criterion (GDC) 62 and 10 CFR 50.68. The reviewing organization also verifies that the new and spent fuel will remain subcritical during fuel handling, in accordance with GDC 62 and 10 CFR 50.68.

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The specific areas of review are as follows:

1. Fuel assembly design to verify that appropriate fuel assembly data were used.

2. Fuel storage rack design to verify that appropriate fuel storage rack data were used.

3. Evaluation of performance effectiveness of the neutron absorbing materials in the fresh and spent fuel racks.

4. Computational methods and related data to verify that acceptable computational methods and data were used.

5. Computational method validation to verify that the validation study is thorough and uses benchmark critical experiments that are similar to the normal-conditions and abnormal-conditions models and to verify that the neutron distribution coefficient (K(eff)) bias and bias uncertainty values are conservatively determined.

6. Identification of normal conditions to verify that the scope of specified normal conditions is comprehensive.

7. Normal-conditions models to verify that normal conditions are modeled conservatively and that all modeling approximations and assumptions are appropriate.

8. Identification of abnormal conditions to verify that the scope of considered abnormal conditions is comprehensive.

9. Abnormal-conditions models to verify that abnormal conditions are modeled conservatively and that all modeling approximations and assumptions are appropriate.

10. Analysis of normal and credible abnormal conditions to verify that the analysis is complete and logically sound and that assumptions, limits, and controls are clearly stated.

11. Analysis conclusions to verify the applicant's conclusions regarding maintaining subcriticality for all normal and credible abnormal conditions.

12. Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC). For design certification (DC) and combined license (COL) reviews, the staff reviews the applicant's proposed ITAAC associated with the structures, systems, and components (SSCs) related to this SRP section in accordance with SRP Section 14.3, "Inspections, Tests, Analyses, and Acceptance Criteria." The staff recognizes that the review of ITAAC cannot be completed until after the rest of this portion of the application has been reviewed against acceptance criteria contained in this SRP section. Furthermore, the staff reviews the ITAAC to ensure that all SSCs in this area of review are identified and addressed as appropriate in accordance with SRP Section 14.3.

13. COL Action Items and Certification Requirements and Restrictions. For a DC application, the review will also address COL action items and requirements and restrictions (e.g., interface requirements and site parameters).

    For a COL application referencing a DC, a COL applicant must address COL action items (referred to as COL license information in certain DCs) included in the referenced DC. Additionally, a COL applicant must address requirements and restrictions (e.g., interface requirements and site parameters) included in the referenced DC.

Review Interfaces

Other SRP sections interface with this section as follows:

1. The review under SRP Sections 3.2.1 and 3.8.4 includes a review of potential storage rack deformation and relocation because of a safe-shutdown earthquake. The organization responsible for SRP Section 9.1.1 confirms that the criticality safety analysis conservatively considers any impact of storage rack deformation and relocation on K(eff).

2. The review under SRP Section 3.8.4 includes a review of storage rack deformation and relocation because of dropped loads. The organization responsible for SRP Section 9.1.1 confirms that the criticality safety analysis conservatively considers any impact of storage rack deformation and relocation (because of credible dropped loads) on K(eff).

3. If the applicant elects, consistent with 10 CFR 50.68(a), to install and maintain a monitoring system capable of detecting a criticality accident, as described in 10 CFR 70.24, review under SRP Section 12.3-12.4 includes a review of instrumentation important to safety. The organization responsible for Section 9.1.1 confirms that the organization responsible for SRP Section 12.3-12.4 has reviewed the criticality accident detection system.

The specific acceptance criteria and review procedures are contained in the referenced SRP sections.

II. ACCEPTANCE CRITERIA

Requirements

Acceptance criteria are based on meeting the relevant requirements of the following Commission regulations:

1. GDC 62, as it relates to the prevention of criticality by physical systems or processes using geometrically safe configurations.

2. 10 CFR 50.68, as it relates to preventing a criticality accident and to mitigating the radiological consequences of a criticality accident.

3. 10 CFR 52.47(b)(1), which requires that a DC application contain the proposed inspections, tests, analyses, and acceptance criteria (ITAAC) that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, a plant that incorporates the design certification is built and will operate in accordance with the design certification, the provisions of the Atomic Energy Act, and the NRC's regulations.

4. 10 CFR 52.80(a), which requires that a COL application contain the proposed inspections, tests, and analyses, including those applicable to emergency planning, that the licensee shall perform, and the acceptance criteria that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, the facility has been constructed and will operate in conformity with the combined license, the provisions of the Atomic Energy Act, and the NRC's regulations.

SRP Acceptance Criteria

Specific SRP acceptance criteria acceptable to meet the relevant requirements of the NRC's regulations identified above are as follows for the review described in this SRP section. The SRP is not a substitute for the NRC's regulations, and compliance with it is not required. However, an applicant is required to identify differences between the design features, analytical techniques, and procedural measures proposed for its facility and the SRP acceptance criteria and evaluate how the proposed alternatives to the SRP acceptance criteria provide acceptable methods of compliance with the NRC regulations.

1. The criteria for GDC 62 are specified in American National Standards Institute (ANSI)/American Nuclear Society (ANS) 57.1, ANSI/ANS 57.2, and ANSI/ANS 57.3, as they relate to the prevention of criticality accidents in fuel storage and handling.

Technical Rationale

The technical rationale for application of these acceptance criteria to the areas of review addressed by this SRP section is discussed in the following paragraphs:

1. Compliance with GDC 62 requires preventing criticality in the fuel storage and handling system through the use of physical systems or processes, with preference given to the application of geometrically safe configurations.

   One function of the fuel storage facilities is to maintain new and spent fuel in a subcritical array during credible storage conditions. This role requires that designs for fuel storage provide assurance that spacing is adequate to prevent not only criticality during earthquakes or other natural phenomena, but also flooding of dry fresh fuel storage racks with potential moderators. The configuration of new fuel storage must also prevent the insertion of potential moderators into existing spaces. ANSI/ANS 57.1 and ANSI/ANS 57.3 provide guidance acceptable to the staff for meeting the requirements associated with fresh fuel storage and handling. The configuration of spent fuel storage must also prevent the insertion of a fuel assembly anywhere other than in a design location. ANSI/ANS 57.1, ANSI/ANS 57.2, and Regulatory Guide 1.13 provide guidance acceptable to the staff for meeting the requirements associated with spent fuel storage and handling.

   Meeting the requirements of GDC 62 provides assurance that criticality will be prevented in the fuel storage facilities.

2. Compliance with 10 CFR 50.68 requires that the licensee either maintain monitoring systems capable of detecting a criticality accident as described in 10 CFR 70.24, thereby reducing the consequences of a criticality accident, or comply with the requirements specified in 10 CFR 50.68(b), thereby reducing the likelihood that a criticality accident will occur.

III. REVIEW PROCEDURES

The reviewer will select material from the procedures described below, as may be appropriate for a particular case.

These review procedures are based on the identified SRP acceptance criteria. For deviations from these acceptance criteria, the staff should review the applicant's evaluation of how the proposed alternatives provide an acceptable method of complying with the relevant NRC requirements identified in Subsection II.

For applications filed under 10 CFR Part 50, the procedures below are used during the construction permit application review to confirm that the design criteria and bases and the preliminary design meet the acceptance criteria in Subsection II. For the review of the operating license application, the staff will use the review procedures and acceptance criteria to verify that the final design appropriately implements the initial design criteria and bases. The operating license review includes verification that the content and intent of the technical specifications prepared by the applicant are in agreement with the requirements for system testing, minimum performance, and surveillance developed as a result of the staff's review.

1. The reviewer evaluates the information in the safety analysis report (SAR) pertaining to criticality safety of the fresh and spent fuel storage facilities. The staff reviews the facility design criteria, safety evaluation, system description, and layout drawings for the storage vault and racks to verify the following:

   A. Criticality information (including associated assumptions and input parameters) in the SAR should show that the spacing between fuel assemblies in the fresh fuel storage racks is sufficient to maintain the array when fully loaded and flooded with potential moderators (e.g., high-pressure water spray) in a subcritical condition (i.e., K(eff) of less than 0.95). Furthermore, the design of the new fuel storage racks will be such that the K(eff) will not exceed 0.98 if fuel of the highest anticipated reactivity is in place, assuming optimum moderation. Credit may be taken for neutron-absorbing materials.

   B. For dry fresh fuel storage racks, provisions have been made for drainage of the fresh fuel storage vault to prevent the accumulation of a fluid moderator.

   C. For boiling-water reactor pools or for pressurized-water reactor (PWR) pools where no credit for soluble boron is taken, criticality information (including associated assumptions and input parameters) in the SAR must show that the spacing between fuel assemblies in the spent fuel storage racks is sufficient to maintain the array such that, when fully loaded and flooded with full-density unborated water, the K(eff) will not exceed 0.95 for all normal and credible abnormal conditions. Credit may be taken for neutron-absorbing materials. The K(eff) must include allowance for all relevant uncertainties and tolerances.

   D. For PWR pools where partial credit for soluble boron is taken, both of the following criteria must be met:

      i. When the spent fuel storage racks are loaded with fuel of the maximum permissible reactivity and are flooded with full-density unborated water, the maximum K(eff) must be less than 1.0 for all normal and credible abnormal conditions. The K(eff) must include allowance for all relevant uncertainties and tolerances.

      ii. When the spent fuel storage racks are loaded with fuel of the maximum permissible reactivity and are flooded with full-density water borated to a minimum concentration ($C_{B,min}$, measured in parts per million of boron), the maximum K(eff) must be no greater than 0.95 for all normal conditions. Plant technical specifications must incorporate the $C_{B,min}$. The K(eff) must include allowance for all relevant uncertainties and tolerances.

      In evaluation of these criteria, credit may be taken for neutron-absorbing materials other than soluble boron.

Reliance on soluble boron credit should be minimized. Use of soluble boron credit removes defense in depth credited explicitly or implicitly elsewhere in the criticality analyses.

E. When credit is taken for neutron absorbing material, its compatibility and chemical stability in the components wetted by water in the spent fuel pool and in the new fuel vault should be evaluated. The neutron absorbing components typically consist of plates or rods that contain a neutron absorbing element(s) which may, or may not, be dispersed in another composite material. The absorbing materials are usually attached to the rack in plate form, used as cylindrical rod inserts in assembly guide and instrument tube locations, or may be an integral part of the rack structure. During a prolonged exposure to the pool's water, the neutron absorbing material may degrade and release the neutron poison, resulting in some reduction of neutron absorbing properties of the components. The degree of degradation is measured by neutron transmittal methods such as blackness testing or by chemical means.

F. The designs are such that a fuel assembly can only be inserted in the designed locations in the fresh and spent fuel racks.

G. Sharing of a storage facility in multiunit plants does not result in any added potential for increasing the K(eff) of the fresh and spent fuel storage arrays.

2. Subsection I of this SRP section includes a list of areas of review. The reviewer verifies the following for these areas of review:

A. The reviewer verifies that the criticality safety analysis used the appropriate fuel design data.

Fuel design data—including materials, dimensional data, uranium loading, and maximum ^{235}U enrichment—should be provided for all fuel design types that may be stored in the fuel storage racks. The reviewer verifies that the information is complete and that the criticality analysis conservatively considers all fuel design types to be handled or stored.

B. The reviewer evaluates the fuel storage rack design to verify that appropriate fuel storage rack data were used.

Fuel storage rack design data—including materials, dimensional data, spacing between storage racks, materials and dimensions of, and distance to, structures near racks, such as floors and walls, that may provide neutron reflection—should be provided for fresh and spent fuel storage facilities. The reviewer verifies that the data are complete and that the criticality analysis conservatively incorporates fuel storage rack design data.

C. The reviewer evaluates the computational methods and related data employed to verify that acceptable computational methods and data were used. The computational methods used for the criticality analysis should be described in detail, including the computer codes and nuclear data used.

The reviewer verifies that the description is complete and that the methods used are acceptable.

D. The reviewer evaluates the computational method validation to verify that the validation study is thorough and uses benchmark critical experiments that are similar to the normal-conditions and credible abnormal-conditions models and to confirm that the K(eff) bias and bias uncertainty values are properly determined.

A detailed description of the validation study supporting the criticality analysis should be provided. Typically, the validation study involves modeling critical experiments that are similar to one or more of the criticality analysis cases. The critical experiments should be similar to the criticality analysis cases to ensure that it is appropriate to apply the bias and bias uncertainty, calculated from the critical experiments, to the criticality analysis cases. The statistical analysis method used to determine the maximum K(eff) values should be described in sufficient detail to permit verification that the method is appropriate and performed correctly.

The validation study should address the following issues:

i. Computational method used, including the following:

   (1) Computer codes, nuclear data, modeling options, and approximations

ii. Critical experiment similarity to criticality analysis cases, including the following:

   (1) Description of the process and criteria used to select the critical experiments

   (2) List of critical experiments used for each bias determination

iii. Incorporation of critical experiment uncertainties and biases related to the following:

   (1) Measurement of K(eff) and extrapolation or adjustment of physical parameters, such as critical water height, to criticality

   (2) Critical experiment physical description

   (3) Model uncertainties and biases related to assumptions and modeling approximations

iv. Determination of maximum allowable K(eff) values

v. Determination of area of applicability for maximum K(eff) values

The reviewer verifies that the validation study description is complete and that the validation study used acceptable methods and was performed correctly.

E. The reviewer evaluates the identification of normal conditions to verify that the scope of specified normal conditions is comprehensive.

Descriptions should be provided that define normal conditions associated with the storage and handling of fresh and spent fuel. In addition to being used to evaluate the subcriticality of normal conditions, the described normal conditions serve as the basis of initial conditions for evaluating abnormal conditions. The reviewer verifies that the normal-conditions descriptions are comprehensive and that the logic used to envelop one or more classes of normal conditions is sound.

F. The reviewer evaluates the normal-conditions models to verify that normal conditions are modeled correctly and that all modeling approximations and assumptions are appropriate.

The normal-conditions computational models should be described. Such descriptions should include modeling assumptions and approximations; handling of dimensional and material tolerances and uncertainties; omitted materials; selection of computer code input options affecting the results; location of the fuel within the storage racks, including consideration of asymmetric fuel placement; and sensitivity studies performed to support normal-conditions model development. Sensitivity studies typically include center-to-center spacing between stored fuel, spacing between storage racks and other structures providing neutron reflection, asymmetric fuel placement, neutron absorber panel areal loading for poisoned racks, steel side-panel thickness for unpoisoned racks, fuel burnup for burnup credit racks, soluble boron concentration and worth for PWR spent fuel racks, and any other parameters used to justify the normal-conditions computational models. The reviewer verifies that normal-conditions models have been prepared for the full range of normal conditions. The reviewer verifies that normal-conditions models conservatively simulate the actual normal operating conditions and that all assumptions and approximations are appropriate. Where possible, detailed three-dimensional models should be used for criticality analyses.

G. The reviewer evaluates the identification of abnormal conditions to verify that the scope of considered abnormal conditions is comprehensive.

A description should be provided of abnormal conditions to be considered in the criticality analysis and of the process used to identify abnormal conditions. This description should include the credible range of parameter deviation from the normal-conditions model. For example, the consideration of seismic events and dropped loads should include descriptions of the credible rack deformation and/or relocation. The process for identifying abnormal conditions should include consideration of common-mode failures, whereby multiple criticality controls may be lost because of single initiating events such as a facility fire or dropped load.

Fighting fires in and around the dry, fresh fuel storage racks should be identified as an abnormal condition. The range of parameter deviation for this event includes the consideration of optimum moderation by hydrogenous-based fire fighting techniques and moderation by full-density water.

Accidental or erroneous placement of a fuel assembly outside of, but next to, the fuel storage racks should be considered as an abnormal condition.

Abnormal conditions should include consideration of fuel assemblies loaded into storage racks not approved for their storage (e.g., fuel not meeting minimum burnup requirements stored in burnup credit storage racks).

The reviewer verifies that the process used to identify abnormal conditions is sound, that the abnormal-conditions descriptions are comprehensive, and that the logic used to envelop or eliminate from consideration one or more classes of abnormal conditions is sound. The reviewer verifies that required abnormal conditions, such as consideration of optimum moderation in dry, fresh fuel storage racks, are identified as abnormal conditions.

H. The reviewer evaluates the abnormal-conditions models to verify that abnormal conditions are modeled correctly and that all modeling approximations and assumptions are appropriate.

The abnormal-conditions computational models should be described. Such descriptions should include, but are not limited to, modeling assumptions and

approximations, handling of dimensional and material tolerances and uncertainties, omitted materials, selection of computer code input options affecting the results, and sensitivity studies performed to support abnormal-conditions model development. The reviewer verifies that abnormal-conditions models conservatively simulate the actual abnormal conditions and that all assumptions and approximations are appropriate. Where possible, detailed three-dimensional models should be used for criticality analysis.

I. The reviewer evaluates the analysis of normal and credible abnormal conditions to verify that the analysis is complete and logically sound and that assumptions, limits, and controls are clearly stated.

The criticality analysis should present a comprehensive analysis of the subcriticality of the normal and credible abnormal conditions. The analysis should clearly identify all assumptions, limits, and controls credited in the analysis. The reviewer should verify that the analysis of the normal and credible abnormal conditions is complete and logically sound. The reviewer should verify that assumptions are appropriate, that preference was given to geometrically safe controls in ensuring subcriticality, and that limits and controls are appropriate and can be effectively implemented.

J. The reviewer evaluates the analysis conclusions to verify the applicant's conclusions regarding maintaining subcriticality for all normal and credible abnormal conditions.

The criticality analysis should conclude that the fuel will remain subcritical under all normal and credible abnormal conditions. The reviewer should review and concur with the conclusions of the analysis.

3. As required in 10 CFR 50.68, one of the following must occur:

A. Installation and maintenance of a monitoring system capable of detecting a criticality accident, as described in 10 CFR 70.24

B. Compliance with the additional design and analysis requirements specified in 10 CFR 50.68

SRP Section 12.3-12.4 covers criticality detection system review. If the applicant chooses to install and maintain a criticality accident detection system, the SRP Section 9.1.1 reviewer should verify that the review of SRP Section 12.3-12.4 included the criticality accident detection system and that the applicant's conclusion regarding compliance with 10 CFR 70.24 has been reviewed and confirmed.

If the applicant chooses to meet the alternative requirements specified in 10 CFR 50.68, the reviewer should verify that the alternative requirements are or will be met.

4. For review of a DC application, the reviewer should follow the above procedures to verify that the design, including requirements and restrictions (e.g., interface requirements and site parameters), set forth in the final safety analysis report (FSAR) meets the acceptance criteria. DCs have referred to the FSAR as the design control document (DCD). The reviewer should also consider the appropriateness of identified COL action items. The reviewer may identify additional COL action items; however, to ensure these COL action items are addressed during a COL application, they should be added to the DC FSAR.

For review of a COL application, the scope of the review is dependent on whether the COL applicant references a DC, an early site permit (ESP) or other NRC approvals (e.g., manufacturing license, site suitability report or topical report).

5. For review of both DC and COL applications, SRP Section 14.3 should be followed for the review of ITAAC. The review of ITAAC cannot be completed until after the completion of this section.

IV. EVALUATION FINDINGS

The reviewer verifies that the applicant has provided sufficient information and that the review and calculations (if applicable) support conclusions of the following type to be included in the staff's safety evaluation report. The reviewer also states the bases for those conclusions.

The new fuel storage facility includes the fuel assembly storage racks, the concrete storage vault that contains the storage racks, and the auxiliary components. The spent fuel storage facility includes the spent fuel storage racks, the spent fuel storage pool that contains the storage racks, and the associated equipment storage pits. On the basis of the review of the applicant's proposed design criteria, design bases, and safety classification for the fresh and spent fuel storage facilities and the provisions necessary to maintain a subcritical array, the staff concludes that the design of the fresh and spent fuel storage facilities and supporting systems is in conformance with the Commission's regulations in GDC 62 and in 10 CFR 50.68.

This conclusion is based on the following:

1. The applicant has met the requirements of GDC 62 pertaining to criticality because the fuel will remain subcritical under all normal and credible abnormal conditions.

2. The applicant has met the requirements of 10 CFR 50.68 by either (1) installation and maintenance of a monitoring system capable of detecting a criticality accident, as described in 10 CFR 70.24, or (2) compliance with the additional design and analysis requirements specified in 10 CFR 50.68.

For DC and COL reviews, the findings will also summarize the staff's evaluation of requirements and restrictions (e.g., interface requirements and site parameters) and COL action items relevant to this SRP section.

In addition, to the extent that the review is not discussed in other SER sections, the findings will summarize the staff's evaluation of the ITAAC, including design acceptance criteria, as applicable.

V. IMPLEMENTATION

The staff will use this SRP section in performing safety evaluations of DC applications and license applications submitted by applicants pursuant to 10 CFR Part 50 or 10 CFR Part 52. Except when the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the staff will use the method described herein to evaluate conformance with Commission regulations.

The provisions of this SRP section apply to reviews of applications submitted six months or more after the date of issuance of this SRP section, unless superseded by a later revision.

VI. REFERENCES

1. 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," Appendix A, "General Design Criteria for Nuclear Power Plants," General Design Criterion 62, "Prevention of Criticality in Fuel Storage and Handling."

2. 10 CFR 50.68, “Criticality Accident Requirements.”

3. ANSI/ANS 57.1-1992, “Design Requirements for Light Water Reactor Fuel Handling Systems,” reaffirmed 2005.

4. ANSI/ANS 57.2-1983, “Design Requirements for Light Water Reactor Spent Fuel Storage Facilities at Nuclear Power Plants,” withdrawn 1999 (reaffirmation in progress).

5. ANSI/ANS 57.3-1983, “Design Requirements for New Fuel Storage Facilities at Light Water Reactor Plants,” withdrawn 1993 (reaffirmation in progress).

6. Regulatory Guide 1.13, Revision 2, “Spent Fuel Storage Facility Design Basis,” March 2007.