Spent Fuel Project Office
Interim Staff Guidance - 21
USE OF COMPUTATIONAL MODELING SOFTWARE

Issue:

Given the growing industry need to store spent reactor fuel of increasingly higher burnups and heat loads in dry storage casks, and eventually to transport that same spent fuel in transportation packages, analyzing the performance of casks and other radioactive material packages has become a greater challenge. Finite Element, Finite Difference, and Finite Volume analysis computer codes, defined here as Computational Modeling Software (CMS), are tools used by many licensees to analyze cask and package performance in the structural and thermal disciplines. CMS can be used to determine structural stresses, dynamic impact or drop performance, and thermal performance of cask designs.

The information in this Interim Staff Guidance (ISG) will supplement the guidance provided in the Standard Review Plans (SRPs) for Dry Storage Facilities and Storage and Transportation Cask and Package reviews.

Similar guidance on the use of CMS in the criticality and shielding disciplines can be found in NUREG/CR-5661, “Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages,” and NUREG/CR-6802, “Recommendations for Shielding Evaluations for Transport and Storage Packages.”

Introduction:

This interim staff guidance (ISG) provides the staff’s position on what an acceptable analysis using CMS should include, and what information should be reviewed by the staff when considering a submittal from an applicant using CMS in the design review of a storage cask or transportation package. This ISG applies to both thermal and structural analyses utilizing CMS; however, application of this ISG does not extend to shielding and criticality analyses that rely on CMS since present guidance, mentioned above, sufficiently addresses current issues in these areas.

In general, staff will conduct an audit review of the thermal and structural performance of spent fuel cask and package designs. In the course of these audit reviews, it sometimes becomes necessary for the staff to scrutinize specific parts of analyses that are submitted as part of an application. In these cases, the staff will often need more in-depth information regarding an analysis submitted by an applicant. When cask designs are manufactured and placed into service, for either storage or transportation, these casks behave as systems. In order for the staff to properly scrutinize any one part or feature of a cask system, information about the entire system and the related models may be necessary. This should be kept in mind when considering the types of information that the staff will need to properly complete a review, as outlined in this ISG.

This ISG supplements the information in and is compatible with Regulatory Guides 3.61, "Standard Format and Content for a Topical Safety Analysis Report for a Spent Fuel Dry Storage Cask, and 7.9, "Standard Format and Content of Part 71 Applications for Approval of Packages for Radioactive Material."

Discussion:

As the industry updates the designs of its spent fuel casks and canisters to accommodate spent fuel with higher burnups and higher heat loads, reliance on complex computer simulation increases. The current standard review plans (SRPs) do not provide sufficient detail on what information the staff should review in a SAR and what supporting documentation is needed to adequately describe the specifics of computer modeling of cask or package performance.

Engineering analyses of cask and package performance contain many parameters that can change the results of the analyses if treated inappropriately. In situations where applicant's designs are close to currently accepted temperature or structural limits, the staff must verify the validity of an applicant's analysis model, including the methodology used to create the model, and, in some cases, perform confirmatory analyses. For the staff to conduct an efficient review of cask and package analyses, sufficient detail is necessary on the approach and execution of an applicant's analysis. The information provided should be sufficient to allow the staff to perform confirmatory analyses, should they be necessary.

This ISG will delineate the specific areas that should be addressed by the staff when reviewing cask or package analyses using CMS, including performing confirmatory analyses. The staff should encourage applicants to submit documentation that describes the analytic methods used as well as the validation for those methods. This documentation will enhance the efficiency of staff review, minimize the need for additional information, and provide for a shorter overall review time. Where this type of documentation has been previously submitted by the applicant, the submittal may be made by reference.

Regulatory Basis:

The specific regulations cited below provide the basis for the information discussed in this ISG.

10 CFR 72.24 defines the technical information to be contained in an application for spent fuel storage (site specific license). Specifically 72.24(b), (c)(1), (2), and (3), and (d)(1) and (2).

10 CFR 72.230, subparts (a) and (b) specify the procedures for spent fuel storage cask submittals, and 72.236 subparts (a), (b), (d), (e), (f), (g), and (l) define the design requirements that provide the regulatory basis for spent fuel storage cask submittals and the specific requirements to be satisfied for spent fuel storage cask design approval and fabrication (Certificate of Compliance).

10 CFR 71.31(a)(2) specifies the content of the package evaluation that is required to be included in the application for package approval and 10 CFR 71.31(b) requires that the application include sufficient information to demonstrate that the proposed design satisfies the package standards in effect at the time the application is filed.

10 CFR 71.35(a) defines the requirements for the content of an application and provides reference to the applicable Sections (subparts E and F of 10 CFR Part 71), where specific regulatory standards on demonstrating compliance are delineated for spent fuel transportation.

Technical Review Guidance:

Computational Modeling Software Application

The staff does not endorse the use of any specific type or code vendor of CMS. Any CMS application could be used for analyses of cask or package components; however, for any CMS to demonstrate that a particular cask design satisfies regulatory requirements, adequate validation of that CMS must be demonstrated by the applicant. Descriptions of CMS validations can be contained within a given application or incorporated by reference.

The reviewer should verify that the following information is provided in the SAR or related documentation (such as proprietary calculation packages or benchmark reports):

(1) details of the methodology used to assemble the computational models and the theoretical basis of the program used;

(2) a description of benchmarking against other codes or validation of the CMS against applicable published data or other technically qualified and relevant data that is appropriately documented;

(3) standardized verification problems analyzed using the CMS, including comparison of theoretically predicted results with the results of the CMS; and

(4) release version and applicable platforms.

Once the information described above has been docketed, it need not be submitted with each subsequent application, but can be referred to in subsequent SARs or related documents. If an applicant changes their analysis methodology or changes the type or vendor of the CMS used, the applicant should submit either a revision of previously submitted information or include a clear explanation of the methodology changes, and their effects on the analysis in question, in subsequent SAR submittals.

Modeling Techniques and Practices

Modeling techniques and practices used by applicants may need to be verified to demonstrate adequacy of the model.

- The reviewer should verify that the CMS and the options used by the applicant are appropriate for adequately capturing the behavior of a cask, package, or any components.

Relevant input and results files or an equivalent detailed model description and output should be submitted with the original application.

- Analysis input files should be submitted in an electronic format that would most easily allow the solution to be executed by the staff, should the staff desire to do so. In-depth review of CMS models is most easily done with input files that contain individual commands used to develop the model and apply the various boundary conditions; therefore, a text input file format (versus database format) is preferred.

- Input files should be annotated in a way that clearly demonstrates the process behind building and solving models developed using CMS. A well annotated input file will expedite staff review and preclude the need for further clarification questions by the staff.

- Appropriate electronic media should be used for submitting case and support files. It should be noted that electronic media should be delivered to the appropriate SFPO staff directly, if possible, as electronic media sent to the NRC Document Control Desk may be damaged during security screening.

Computer Model Development

The reviewer should verify that the computer model used for the analysis is adequately described, either in the SAR or in other documentation, is geometrically representative of the cask design being analyzed, has addressed how material and manufacturing uncertainties might affect the analysis, has appropriate boundary conditions, and has no significant analysis errors.

- The reviewer should verify that the model description includes an adequate basis for the selection of parameters and/or components used in the analysis model (e.g., why was a particular element type applied in the analysis model?)

- The reviewer should verify that models sufficiently represent cask or package geometry and that adequate justification is provided for simplifications used. Models created with CMS are often simplified to reduce computer processing time. Models can often omit geometric details or use homogenized or smeared material properties to represent complex geometry or material combinations and still retain analytic accuracy.

- The reviewer should verify that the applicant has discussed how manufacturing and/or assembly tolerances and contact resistances will affect the analyses that have been conducted, if at all, in both the structural and thermal disciplines. The reviewer should also verify that the applicant has described how tolerances and/or contact resistances are accounted for, if applicable, in the cask or package analysis models that are submitted for review.

- The reviewer should verify that the applicant has provided a general discussion of how error, warning, or advisory messages affect the analysis result (if applicable). When processing a computer model developed using CMS, the software will frequently provide error, warning, or advisory messages indicating a possible problem with the model that may or may not be sufficient to terminate processing. If the error/warning function has been disabled during processing, an explanation of why this is appropriate should be

provided.

- The reviewer should verify that, within the specific disciplines, the dimensions and physical units used in the models developed are clearly labeled and mutually consistent. The fundamental units of time, mass, and length should be clearly identified. All other physical units derived must be consistent with the basic units adopted. For example, if the unit of length is the millimeter (mm), time in milliseconds (ms), and mass in gram (g), then, the mechanical force will have units of Newton (N), energy in milliJoule (mJ), and stress in megapascal (MPa). Verify that the input parameters are expressed in the units as assigned. If an applicant chooses not to adopt this uniformity of units, the appropriate conversion must be applied prior to processing input into CMS. Similar assurances must be provided for the output for the analysis solution.

Computer Model Validation

- The reviewer should verify that model validation done with applicable experiments is properly documented and appropriate references are provided.

- The reviewer should ensure that if the applicant takes credit for modeling conservatisms, those conservatisms have been demonstrated through validation of the model or analysis methodology. For example, accounting for certain conditions that occur during the hypothetical accident condition (HAC) fire, such as combustion of materials, the turbulent flow of hot gasses in the pool fire environment, and material anomalies that may manifest themselves in a fire can be done with specialized CMS codes (specifically, coupled CFD-FEA codes such as Sandia National Lab's CAFE code), high performance computer hardware and extended compute times. Each of these conditions can be treated in a conservative fashion using standard CMS; however, validation of the CMS against actual data (such as open pool fire test data or material combustion data), to demonstrate the applicability of the CMS under the HAC fire, for a configuration similar to that which is being modeled, would be necessary.

Justification of Bounding Conditions/Scenario for Model Analysis

Title 10 of the Code of Federal Regulations, Parts 71 and 72, do not provide a specific definition of most damaging orientation and worst case conditions for analysis of transportation packages or dry cask storage system designs. The regulations place the responsibility on the applicant to make the determination of the most damaging orientation and worst-case conditions for a given design and document how the analytic model was configured for the scenario.

The reviewer should verify that the applicant provided sufficient justification for selecting the most damaging orientation and worst-case conditions.

Description of Boundary Conditions and Assumptions

- The reviewer should verify, as necessary, that boundary conditions and assumptions are addressed in the textual description included in the SAR or other documents (e.g., emmissivity values, absorptivity values, convective coefficients, radiation view factors,

symmetry planes, and rigid surfaces). This information should be presented in either tabular form or in a complete textual manner. Justifications and bases for such items should also be included in the textual description.

- Values or quantities indicating performance enhancements, i.e., increasing material conductivity values to mimic internal convection or substantially reduced design load factors (DLF's) reflecting an unusually high degree of impact damping, should be accompanied with justifications and should be closely reviewed and independently verified, if needed, by staff.

Documentation of Material Properties

As needed, the reviewer should assess that:

(1) units for material properties are consistent throughout the individual SAR chapters.

(2) material properties for all applicable temperature ranges are included.

(3) references to materials used by the CMS application and specific material properties based on geometry (e.g., conductivity in the X, Y and Z directions), are listed in the SAR or related documents.

Description of Model Assembly

- The reviewer should verify that the types of elements used in the model are listed in the SAR, preferably in tabular format, along with the corresponding materials or components in which they are used in the analysis model. (i.e, the reviewer should quickly be able to discern what elements and materials are associated with specific components of the analysis model.)

- The reviewer should verify that a sufficient explanation of the logic behind the creation of each specific computer model is provided, for effective confirmatory calculations to be performed.

- The reviewer should verify that the applicant has provided annotated input files (as appendices to the SAR or in related documents), that clearly outline the various steps in building the computer models submitted. If input files are not provided or do not adequately describe model assembly, the applicant should provide an adequate explanation of how computer models were assembled using the CMS in the appropriate SAR chapters or related documents.

Loads and Time Steps

- The reviewer should verify that loads, load combinations, and, if used by the analytical code, the load steps utilized in the computer model are clearly explained by the applicant. The staff should evaluate all loads, how they are placed on the computer

models, load combinations, and if used, the time steps applied in the analysis.

- The reviewer should verify that the time steps specified for the solution of the analysis are sufficiently small to accurately capture the behavior of the structures, systems, or components being modeled.

- The reviewer should verify that incremental time steps (or sub-steps) are adequately converged. Information of convergence may be obtained from the output generated by the execution of the analysis solution.

Sensitivity Studies

The discussion of sensitivity studies should be included in the general Computer Model Development discussion, as noted above, with relevant references to examples included in the SAR or related documents.

- The reviewer should verify that the applicant has completed sensitivity studies for relevant CMS modeling parameters. This includes mesh type and density, load step size, interfacing gaps or contact friction, material models and model parameters selection, and property interpolation, if applicable. For example, a mesh sensitivity study should be conducted not only for mesh density but also for mesh density/refinement in areas of thermal or structural concern or where performance of the material is crucial, such as seal areas, lid bolts, etc.

- The reviewer should verify that the results of applicable sensitivity studies are clearly described in the SAR or related documentation and can be independently verified, if necessary.

- The reviewer should verify that the applicant's documentation includes at least a brief discussion of the different models used in their mesh sensitivity studies.

Results of the Analysis

- The reviewer should verify that the SAR, or related document(s), include all relevant results (tabular and computer plots) for applicable load cases and load combinations evaluated for design code compliance, and that all governing results (stresses/deformation) are clearly identified in the tables and on plots.

- The reviewer should verify that results are consistent throughout the SAR, and that the correct results are used in calculations of other cask or package performance parameters (e.g., calculated temperatures used in the internal pressure calculation should be verified).

Recommendation: Revise NUREGs as follows:

NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems"

Revise, as follows:

1. Replace Section V.d.ii(1) of Chapter 3.0, Structural Evaluation, with the following:

   (1) Computational Modeling:

   Verify that the applicant has provided information on any computer-based modeling as described in Appendix A to this chapter, and review the structural analyses submitted by the applicant in accordance with the Appendix.

2. Replace Section V.5.a of Chapter 4.0, Thermal Evaluation, with the following:

   a. Computational Modeling

   Verify that the applicant has provided information on any computer-based modeling as described in Appendix A to this chapter, and review the thermal analyses submitted by the applicant in accordance with the Appendix.

3. Insert the Technical Review Guidance section of this ISG in Chapter 3.0 as Appendix A.

NUREG-1567, "Standard Review Plan for Spent Fuel Dry Storage Facilities"

Revise, as follows:

1. Replace the first paragraph of Chapter 5.0, Section 5.5.1.4, *Structural Analysis Methods for Confinement Structures* with the following:

   NUREG 1536 has a detailed discussion of structural analysis methods and procedures which are appropriate for evaluating structural integrity of confinement SSCs. These procedures include discussion of computational methods, closed-form calculations, and prototype or scale model testing. In addition, guidance on what type of computational modeling information should be provided by applicants, and how the staff should review this information, is provided in Appendix A to this chapter.

2. Replace the text of Section 6.5.4 Analytical Methods, Models, and Calculations, of Chapter 6.0, Thermal Evaluation, with the following:

   Guidance on computational methods and computer codes to model dry cask storage systems is provided in Chapter 4 of NUREG 1536. Additional guidance on what type of computational modeling information should be provided by applicants, and how the staff should review this information, is provided in Appendix A to Chapter 5.0, Structural Evaluation.

3. Insert the Technical Review Guidance section of this ISG in Chapter 5.0 as Appendix A.

NUREG-1609, "Standard Review Plan for Transportation Packages for Radioactive Material"

Revise, as follows:

1. Replace the fourth bullet of Section 2.5.5.2 Evaluation by Analysis with the following:

   Verify that the applicant has provided information on any computer-based modeling as described in Appendix A to this chapter, and review the structural analyses submitted by the applicant in accordance with the Appendix.

2. Replace the text of Section 3.5.3.1 Evaluation by Analysis with the following:

   For each thermal analysis, verify that the applicant has provided information on any computer-based modeling as described in Appendix A to Chapter 2, Structural Review, and review the thermal analyses submitted by the applicant in accordance with the Appendix.

3. Insert the Technical Review Guidance section of this ISG in Chapter 2.0 as Appendix A.

NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel"

Revise, as follows:

1. Replace the text of Section 2.5.4.1 Evaluation by Analysis with the following:

   If the structural evaluation is by analysis, verify that the applicant has provided information on any computer-based modeling as described in Appendix A to this chapter, and review the structural analyses submitted by the applicant in accordance with the Appendix.

2. Replace the text of Section 3.5.3.1 Evaluation by Analysis with the following:

   Verify that the applicant has provided information on any computer-based modeling as described in Appendix A to Chapter 2, Structural Review, and review the thermal analyses submitted by the applicant in accordance with the Appendix.

3. Insert the Technical Review Guidance section of this ISG in Chapter 2.0 as Appendix A.

Approved: E. William Brach /RA/ Date: April 5, 2006

SFPO DIRECTOR