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NRC REGULATORY ISSUE SUMMARY 2015-XX
SEISMIC STABILITY ANALYSIS METHODOLOGIES FOR SPENT FUEL DRY CASK LOADING STACK-UP CONFIGURATION

ADDRESSEES

All holders of, and applicants for, general licenses and certificates of compliance (CoC) for an independent spent fuel storage installation (ISFSI) under Title 10 of the *Code of Federal Regulations* (10 CFR) Part 72, “Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater than Class C Waste.”

All Radiation Control Program Directors and State Liaison Officers.

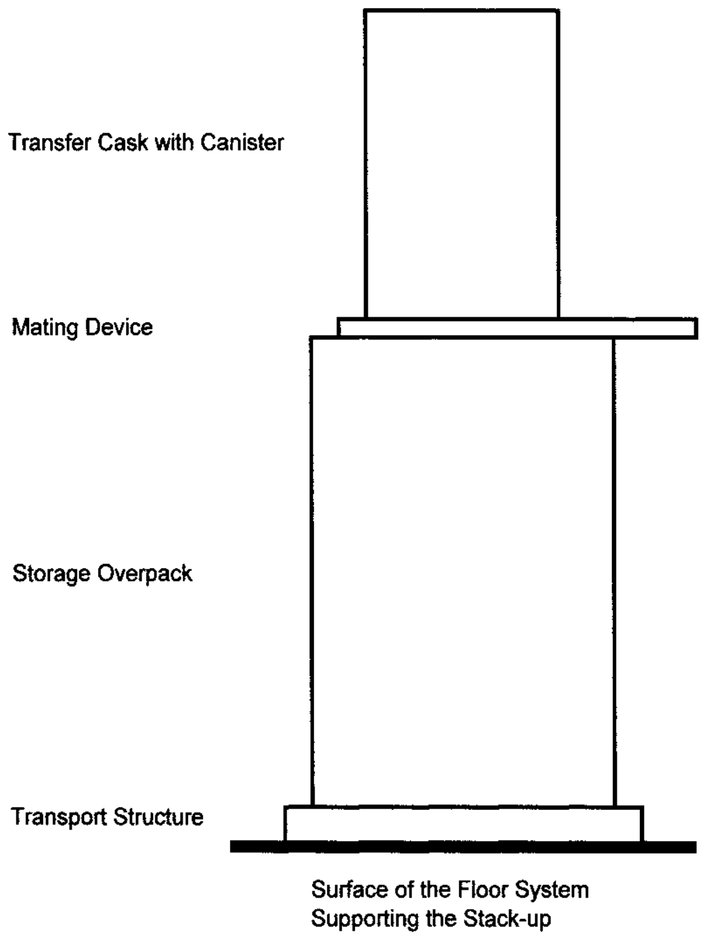
The U.S. Nuclear Regulatory Commission (NRC) is also sending a copy of this regulatory issue summary (RIS) to NRC 10 CFR Part 50, “Domestic Licensing and Production and Utilization Facilities,” and 10 CFR Part 52, “Licenses, Certifications, and Approvals for Nuclear Power Plants,” licensees for information because these entities may have a general license, pursuant to 10 CFR 72.210, “General License Issued,” which allows persons authorized to possess or operate nuclear power reactors under 10 CFR Part 50 or 10 CFR Part 52 to store spent fuel in an ISFSI at power reactor sites.

INTENT

The NRC is issuing this RIS to share information regarding acceptable seismic stability analysis methodologies to determine seismic stability of spent fuel dry cask loading stack-up configurations. This RIS does not require any specific action or written response on the part of an addressee.

BACKGROUND INFORMATION

The stack-up configuration refers to the condition when a transfer cask containing a canister loaded with spent fuel is resting on a storage overpack. While in the stack-up configuration, the loaded canister is lowered from the transfer cask to the storage overpack. During this transfer, when the transfer cask is not attached to a single-failure-proof crane, the stack-up is free-standing and the potential exists for the stack-up configuration to become unstable and tip-over during a seismic event.



DEFINITIONS

Nonlinear time history analysis: an analysis which considers effects which vary with time (e.g., loading under seismic motion) and nonlinear effects such as material properties and movements in response to the applied loads.

Rocking stability: Rocking stability refers to whether the system will topple over under loading or remain standing after a seismic event.

Sliding stability: Sliding stability refers to whether the system will slide under loading or remain in place by the effect of friction after a seismic event.

Stack-up: Stack-up refers to the configuration when a transfer cask containing a canister loaded with spent fuel is resting on a storage overpack.

SUMMARY OF ISSUE

The NRC staff has reviewed several stack-up seismic stability analysis calculations performed by licensees under, for example, 10 CFR 72.122(b) and 72.212(b). Some of the concerns that the NRC staff has identified in these reviews include:

1. Using a single time history to perform a nonlinear seismic analysis. SRP (NUREG-0800) Section 3.7.1, II, 1, B recommends a minimum of five time histories.
2. Using time histories not derived from real earthquakes.
3. Significantly altering the phasing of frequencies in the time histories.
4. Using non-conservative, low safety factors for rocking and sliding response.
5. Double counting damping in rocking analyses leading to non-conservative low responses.
6. Not benchmarking finite element models against known solutions.
7. Not evaluating the stresses in the mating device.

The NRC staff is currently developing technical guidance for seismic stability evaluations for the stack-up configuration. In this RIS, the staff is providing some technical details related to this issue.

<u>STACK-UP CONFIGURATION ANALYSIS</u>

If a static equilibrium analysis shows that the accelerations at the center of gravity of the stack-up, considering the effects of floor flexibility and base support flexibility on frequency response, are so low that the stack-up does not pivot about the cask's edge (i.e., there is no incipient tipping); a nonlinear time history analysis is unnecessary to establish rocking stability of the stack-up configuration. Similarly, if the same accelerations show that from static equilibrium considerations the stack does not slide for the range of coefficients of friction applicable to the sliding surface, also considering the effects of uncertainty, a nonlinear time history analysis is unnecessary to establish sliding stability. For such cases, the NRC staff considers that static equilibrium provides an acceptable demonstration of kinematic stability.

Nonlinear time history analysis should be performed if the acceleration values at the center of gravity of the stack-up do not support a static demonstration of stability as provided for in the foregoing. As described in NUREG-0800 Section 3.7.1[1], to perform this analysis, a minimum of five sets (each set comprised of three components: North-South, East-West, Vertical) of ground motion time histories should be selected from real recorded ground motions, and the three time histories from each set should be statistically independent. The input time histories should be baseline corrected such that they yield zero final displacement and zero final velocity. In generating the earthquake time histories, the phasing of the Fourier components associated with the real seed motions must be maintained to the maximum extent practicable. However, there may be minor distortion of the phase angle spectrum due to baseline correction.

The three-dimensional seismic (time history) analysis of the stack-up configuration should be performed for each of the five time history sets generated in accordance with Section 3.7.1 of NUREG-0800 to identify a maximum rocking angle. In addition, for each generated earthquake,

[1] U.S. Nuclear Regulatory Commission, NUREG-0800 “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition,” Section 3.7.1 (Rev. 3, Agencywide Documents Access and Management System (ADAMS) Accession No. ML070640306, Draft Rev. 4, ADAMS Accession No. ML12352A305)

the friction coefficient at the stack-up configuration's base should be varied within its lower and upper bound range to account for uncertainty in the friction value. The response of the stack-up configuration should be obtained for more than two discrete values of the friction coefficients, since the worst response could come from a minimum, maximum, or intermediate value. The maximum from the mean plus one standard deviation value of the response (maximum rocking angle, maximum sliding displacement, maximum vertical load and shear load) from each discrete simulation should be defined as the "computed" response for the stack-up configuration, where a discrete simulation consists of five earthquake time history analyses using one friction value.

The value of the permissible angle of rotation should be equal to one third of the critical angle of rotation of the stack-up configuration (i.e., the angle of tilt at which the center of gravity of the stack-up configuration (with the canister assumed to be at the highest elevation in the stack-up configuration) is directly over the stack-up configuration's edge), consistent with, for example, American Society of Civil Engineers/Structural Engineering Institute (ASCE/SEI) Standard 43-05, "*Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities*." Further, consistent with the above, the computed maximum rocking angle of the stack-up configuration should be less than the permissible angle of rotation.

Regarding the acceptance criterion for sliding, for base support surfaces that provide no restraint to lateral sliding, the maximum permissible lateral migration of the stack-up configuration's base should be limited to one third of the value at which the outer edge of the storage overpack base reaches the edge of the support surface to help ensure the integrity of the support pad. The sliding criterion is not applicable to base support surfaces that are equipped with a physical barrier at their periphery that would prevent uncontrolled sliding. However, such physical barriers should be included in the nonlinear rocking analyses.

Regarding analytical computer codes, the code, element types, and analysis options used in the finite element model should be validated in accordance with Spent Fuel Storage and Transportation Interim Staff Guidance 21.[2]

Regarding essential features of the finite element model, the stack-up consists of four components: the transfer cask with canister, the mating device, the storage overpack, and the base support structure. The transfer cask, mating device and storage overpack behave as rigid bodies. Therefore, one way to model the stack-up is as a series of rigid bodies connected by contact elements with in-line damping at the interfaces. Such a modeling technique, however, places a dependence on the location of the contact elements and the accurate calculation of bolt element and contact stiffness, which in turn determines the accuracy of the bolt forces and impact loads produced from the analysis.

Another approach is to model all components as deformable bodies. Such models may use reduced integration hexahedral elements which require hourglass control to inhibit zero energy modes. The hourglass control methods of Flanagan and Belytschko can be used for linear and mildly nonlinear problems for stack-up analysis.[3,4] Fully integrated elements may also be used

[2] U.S Nuclear Regulatory Commission, Spent Fuel Storage and Transportation Interim Staff Guidance 21, "Use of Computational Modeling Software," (ADAMS Accession No. ML061080669).
[3] LS-DYNA® Keyword User's Manual Vol. 1 LS-DYNA R7.1 May 26, 2014 (revision: 5471) Livermore Software Technology Corporation.
[4] Flanagan, D.P. and T. Belytschko, "A Uniform Strain Hexahedron and Quadrilateral and Orthogonal Hourglass Control," Int. J. Numer. Meths. Eng., 17, 679-706 (1981).

in regions of large deformation, such as where components undergo direct impact. Thick shell elements in the critical load path (e.g., the mating device top plate, the mating device bottom plate, or the transfer cask bottom flange) should use higher-order element formulations with at least five integration points through their thickness to achieve accurate results. All contact interfaces should be modeled using standard “part-to-part” contact. The sliding energy should be tracked to ensure that all contact interfaces are numerically stable. Bolted connections should be modeled using a combination of higher order beam elements to simulate the bolts and one-dimensional spring elements to simulate the interface between the bolt and the bolt hole, as described, for example, in S. Narkhede, “Bolted Joint Representation in LS-DYNA to Model Bolt Pre-Stress and Bolt Failure Characteristics in Crash Simulations”.[5] The stack-up finite element model should be described in detail (element size, type, and integration order, hourglass controls, friction parameters, contact definitions, damping, etc.). The quality of the model should be sufficient to produce accurate results (e.g., sensitivity and convergence studies should be performed as necessary to demonstrate the quality of the model). Plots of, for example, kinetic energy, internal energy, sliding energy, and/or hourglass energy should be provided for the entire model and individual parts to show that results are within acceptable limits.

For the simulation of damping at the stack-up configuration/support-surface interface, the support-surface interface may be simulated by a set of discrete viscous dampers. The damping assigned to the interface dampers or the materials at the contact surfaces should be equal to the value necessary to provide the same (or lesser) rate of decay of the rocking amplitude of the stack-up configuration when subject to an initial tilt as that predicted by Housner’s classical solution[6]. The initial tilt assumed in the calibration should be equal to the maximum permissible angle of tipping, and 50 percent of the maximum permissible angle of tipping. The lower of the two values of viscous damping thus determined should be used in the dynamic analysis to ensure a conservative result.

When relying on friction to restrict relative movement of the components of the stack-up configuration (the storage overpack, the transfer overpack and the mating device which joins the two), the interface friction coefficient between interfacing components should be an appropriately conservative value (e.g., for steel surfaces with an oxide layer, the lowest value is given as 0.27 in Table 3.2.3, pg. 3-22 of Mark's Standard Handbook for Mechanical Engineers[7]).

Regarding the gap between the transfer cask and canister the effect of the gap between the transfer cask and canister reduces the dynamic response of the stack-up. Therefore, the gap need not be modeled.

Regarding bolt and plate stresses, the bolts joining the mating device to the transfer cask and storage overpack should meet American Society of Mechanical Engineers Subsection NF Level D stress limits. The joint moment and shear should be taken as the mean-plus-one standard deviation value of the maximum moments and shear forces recorded for each discrete simulation.

[5] Narkhede, S, “Bolted Joint Representation in LS-DYNA to Model Bolt Pre-Stress and Bolt Failure Characteristics in Crash Simulations, (11th International LS-DYNA Users Conference).
[6] Housner, G.W., "The Behavior of Inverted Pendulum Structures during Earthquakes," Bulletin of the Seismological Society of America, Vol. 53, No. 2, pp 403-417, February 1963
[7] Mark's Standard Handbook for Mechanical Engineers, McGraw-Hill, Tenth Edition, (2006)

Test data provided by the material manufacturer is acceptable as input data for commercially sold products used in the stack-up configuration, provided the data used in the analysis represents either the minimum or maximum material properties (as appropriate for the analysis), where minimum and maximum are defined as the 95 percent exceedance probability and 95 percent non-exceedance probability, respectively.

BACKFITTING AND ISSUE FINALITY DISCUSSION

This RIS describes seismic stability analysis methodologies for dry cask spent fuel storage systems which the NRC regards as acceptable for meeting NRC regulatory requirements in 10 CFR 72.212(b) and implementing provisions in individual cask FSARs [8], when preparing procedures for loading and unloading dry spent fuel storage casks at generally-licensed ISFSIs. The RIS is addressed to holders of general licenses for ISFSIs under 10 CFR Part 72. The RIS requires no action or written response on the part of these addressees.

The staff did not prepare a backfit analysis under 10 CFR Part 50, 10 CFR Part 72, or further address the issue finality criteria in 10 CFR Part 52, based on the following considerations.

> *The RIS does not constitute backfitting under 10 CFR Part 72 for existing ISFSI general licensees*

Issuance of this RIS does not constitute backfitting as defined in 10 CFR 72.62 ("the addition, elimination, or modification, after the license has been issued, of… [s]tructures, systems, or components of an ISFSI or MRS [Monitored Retrievable Storage installation], or… [p]rocedures or organization required to operate an ISFSI or MRS."). The information provided does not require any general ISFSI licensee to add, eliminate, or modify structures, systems, or components of a general ISFSI or MRS or the procedures or organizations required to operate them. However, this RIS addresses the underlying bases and documentation for procedures for loading and unloading spent fuel casks. The information in the RIS may cause licensees to change these procedures because they have determined that they are not in compliance with one or more provisions in 10 CFR 72.212(b). These provisions require general ISFSI licensees to, *inter alia*, address terms and conditions and specifications of each referenced CoC, to design the ISFSI consistent with applicable loads, including seismic loads, and to ensure that the cask and ISFSI activities such as loading and unloading are performed in accordance with the general licenses, the casks' terms, conditions and specifications, and the safety analysis report for the casks. Nonetheless, the NRC has determined that issuance of the RIS does not constitute backfitting. The RIS does not establish, recommend or suggest new safety requirements with respect to the consideration of seismic stability analysis. General ISFSI licensees are already required by existing NRC regulations, general license provisions, and their approved cask designs, to consider the site-specific seismic information when preparing procedures for loading and unloading dry spent fuel storage casks. In addition, the seismic stability analysis methodologies described in this RIS constitute one acceptable way for meeting an ISFSI licensee's regulatory obligations in 10 CFR 72.212(b) and applicable provisions of casks utilized at each licensee's ISFSI. General licensees are free to adopt other approaches, so long as licensees are able to demonstrate compliance with applicable requirements in 10 CFR 72.212, and the referenced casks' terms, conditions and specifications, and the safety

[8] Final Safety Analysis Reports (FSARs) for spent fuel storage casks licensed under Part 72 contain specific provisions addressing consideration of seismic loads in determining cask stability. *See*, *e.g.*, FSAR for the HI-STORM 100 Cask System, Rev. 4 (ML061040056), Chapter 2 "Principal Design Criteria," pages 2.3-15 and 16.

analysis report. Accordingly, the NRC concludes that the RIS does not constitute backfitting for general ISFSI licensees under 10 CFR Part 50, 10 CFR Part 72, or a violation of issue finality criteria in 10 CFR Part 52.

> *The RIS contents do not apply to holders of operating licenses under 10 CFR Part 50, or to holders of early site permits, design approvals, design certifications, and combined licenses under 10 CFR Part 52*

This RIS does not apply to holders of operating licenses under 10 CFR Part 50, or to holders of early site permits, design approvals, or design certifications. Although an ISFSI licensee who is an addressee of this RIS may also be a holder of a 10 CFR Part 50 operating license or a holder of a 10 CFR Part 52 combined license, the discussion in this RIS is directed to activities and matters conducted under the authority granted by the NRC's general license for an ISFSI and NRC-approved cask designs. The RIS is not directed to the activities controlled by either a nuclear power plant operating license under Part 50 or a combined license under Part 52 (including the matters accorded issue finality in a referenced design certification rule). Therefore, the matters within the scope of this RIS are within the scope of matters accorded backfitting protection in the backfit rule, 10 CFR 50.109, or matters accorded issue resolution and issue finality under the applicable issue finality provisions in 10 CFR Part 52.

FEDERAL REGISTER NOTIFICATION

[Discussion to be provided in final RIS]

CONGRESSIONAL REVIEW ACT

[Discussion to be provided in final RIS]

PAPERWORK REDUCTION ACT STATEMENT

This RIS does not contain new or amended information collection requirements subject to the Paperwork Reduction Act of 1995 (44 U.S.C. 3501 et seq.). Existing information collection requirements were approved by the Office of Management and Budget (OMB), approval number 3150-0132.

Public Protection Notification

The NRC may not conduct or sponsor, and a person is not required to respond to, an information collection unless the requesting document displays a currently valid OMB control number.

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