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PHYSICAL TESTING OF SPENT FUEL TRANSPORT CASKS

U.S. Nuclear Regulatory Commission (NRC) regulations in 10 CFR Part 71 specify performance standards for transportation packages under normal conditions and hypothetical accident conditions. These regulations are consistent with International Atomic Energy Agency (IAEA) Safety Standard TS-R-1, "Regulations for the Safe Transport of Radioactive Material." The IAEA and NRC regulations require the package design to be evaluated either by subjecting a specimen or scale model to a specific test, or by other methods, such as analyses.

Description of Physical Tests

Physical testing of transport packages is commonly performed as a part of the evaluation of the structural integrity of the package under hypothetical accident conditions. For spent fuel casks, the physical testing may consist of scale model testing or testing of the impact limiters. Impact limiters are components of the cask, normally attached to each end of the cask, that are designed to absorb impact energy in a transportation accident. Impact limiters are typically made of a deformable material, and serve to protect the cask body during an impact event. The performance of impact limiters may be evaluated by: (1) static tests, where the impact absorption of the impact limiter is measured in a compression fixture; or (2) dynamic tests, where the cask is dropped to observe the performance of the impact limiters in an actual impact event. Cask body design standards include large safety margins against structural failure and deformation. Additionally, actual drop tests may be used to confirm the physical behavior of the cask upon impact.

For static tests of impact limiters, several models are normally constructed. The model impact limiter is then positioned in a compression fixture that measures applied force and deformation at various points. Models are often tested in several different orientations, so that data are collected over a wide range of possible impact orientations. These data are then used to evaluate how much energy would be absorbed by the impact limiter during an impact, and how much energy would be transferred to the cask body. Dynamic tests, in which a free-drop test of an impact limiter attached to a mock cask body that simulates the weight of an actual cask, may be used to confirm that the impact limiter behavior has been properly predicted and that the impact limiter attachments are adequate.

Package tests, that include scale model casks with impact limiters, may also be used to confirm cask behavior as predicted by computer models. Typically, cask models are subjected to an equivalent 9-meter (30-foot) free drop in at least one orientation. The drop surface must be essentially unyielding (i.e., the drop surface is hardened to assure that the brunt of the impact force is transferred to the package). Typical drop surfaces are large, thick, reinforced concrete pads, covered with thick steel plates. The drop orientation is normally the most damaging orientation, as determined by analyses. A single cask may be subjected to free drops in several different orientations. Measurements are taken to record actual cask deceleration and deformation during the short duration of the impact.

Evaluation of Test Results

The results of all physical tests are reviewed in detail. For impact limiter tests, the staff reviews the force-deflection curves to assure that the cask analysis considered: (1) appropriate impact loads; (2) the behavior of the impact limiters at high- and low-ambient temperatures; and (3) various impact angles. In general, the package tests would be acceptable if the tests confirm calculated values for impact deceleration, and cask and impact limiter deformation. Tests may show design failure if the test specimen damage is not consistent with predictions, or if the damage indicates the possibility of an unstable structural failure, such as buckling of the cask shell or significant permanent deformation of the cask closure bolts. The physical test results are applicable to all technical disciplines in the design review process.

- For structural performance, the physical tests are reviewed to assure that they have addressed the appropriate tests and conditions specified in the regulations. Specific areas that are normally addressed include: (1) the description of the test facility, equipment, and test specimen; (2) the test methods that were used; (3) the test results, such as impact limiter deformation, including any failure or unexpected damage or component behavior; and (4) comparison of the results to predicted behavior and other supporting analyses. The supporting analyses are typically finite element structural analyses that are used to predict cask behavior and are used to calculate the physical stresses on the cask body. Analyses are also normally used to determine the most damaging orientation, both for the cask body and for internal components such as the fuel assembly basket. Acceptance standards for these analyses are based on widely accepted codes and standards that have been established for nuclear pressure vessels (for example, the American Society of Mechanical Engineers Boiler and Pressure Vessel Code) and include appropriate design margins and safety factors.

- The thermal performance of a cask is normally evaluated by analysis. The analysis must show that the cask can withstand a 30-minute, fully engulfing hydrocarbon fire environment with an average environmental temperature of 800°C (1475°F) or higher. Analyses are normally performed with finite element analyses that can model the components of the cask and include the heat generated by the radioactive contents. Results must show that temperature-sensitive components of the cask, such as elastomeric seals and lead shielding, remain within their allowable temperature limits. Any damage to the package from the free-drop and puncture tests must be considered in the thermal analysis, since it could affect how a cask might withstand a fire.

- For the containment evaluation, the physical tests and structural analyses are reviewed to assure that components of the containment system, for example, the closure bolts, sealing surfaces, and cask body, remain essentially undamaged.

- Radiation shielding provided by the cask is evaluated by various types of computer codes, including Monte Carlo codes that can calculate dose rates from both neutron and gamma emissions. The structural and thermal analysis results, as well as the physical tests, must show that the shielding of the package is not degraded during the drop, puncture, or fire tests, such that the post-accident acceptance standard for external dose rate is met.

- Nuclear subcriticality is assured by a combination of: (1) limiting the types of fuel assemblies that are authorized for transport in a particular cask design; and (2) including features in the basket and cask design, e.g., neutron poison materials and physical separation of fuel assemblies, that assure nuclear subcriticality in a transportation accident. The structural and thermal analyses must show that the damaged condition of the cask after an accident would still assure subcriticality of the fuel. The criticality analysis normally is performed using Monte Carlo computer codes that incorporate safety margins with respect to the properties of the fuel, the geometric configuration of the fuel, and the presence of neutron-absorbing materials. The computer codes must be benchmarked to actual published critical experiments, to demonstrate the adequacy of the code and computer system.