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CERTIFYING THE TN-BRP AND TN-REG TRANSPORTABLE STORAGE DEMONSTRATION CASKS

INTRODUCTION

The Shippable Storage Cask Demonstration Project is intended to demonstrate casks which can be used for both shipping and storing spent nuclear fuel assemblies. The demonstration included the requirement that the casks be certified for shipping by the U.S. Nuclear Regulatory Commission (NRC). After a lengthy review process which resulted in the resolution of several important technical issues, designs for two similar casks have been certified.

This paper describes the certification phase of the demonstration. Based on experience gained during certification, observations and recommendations have been developed which can benefit others seeking NRC approval of transportation cask designs.

BACKGROUND

Two casks were provided for this demonstration project: the TN-BRP and the TN-REG. The casks were originally intended to be shipped under U.S. Department of Energy (DOE) Certificates of Compliance (CoC). However, after the casks were built, DOE determined that the casks should be certified for shipping by NRC. This meant that the cask designs were essentially fixed in the as-built configuration, with only minor modifications possible.

Each cask consists of a thick-walled forged carbon steel cylindrical shell, with an integrally welded forged steel bottom and a bolted forged top. Inside the casks is a borated stainless steel (bss) basket to position the fuel and maintain criticality control. Impact limiters made of balsa and redwood encased in a carbon steel shell are attached to the ends of the casks. The casks are lifted and rotated using four trunnions bolted to the cask body. Cask lid and penetration openings are sealed with viton O-rings for shipment and metal O-rings for storage. The casks weigh approximately 100 tons each. The TN-BRP casks holds 85 boiling water reactor assemblies from the Big Rock Point power plant. The TN-REG cask holds 40 pressurized water reactor fuel assemblies from the R. E. Ginna power plant. A schematic of the casks will be provided in the paper.

CERTIFICATION ISSUES

Eight important certification issues were resolved during the certification process. These issues are discussed in the following paragraphs: (1) fracture toughness of the carbon steel cask body; (2) structural performance of the borated stainless steel basket; (3) impact limiter performance; (4) trunnion attachment; (5) lid attachment bolt loading; (6) seal performance at low temperature; (7) structural analysis; and (8) SAR format.

Fracture Toughness of the Carbon Steel Body

Because the casks were built using carbon steel bodies, fracture performance at low temperature was an important consideration. NRC requires the casks function at -40°F for normal conditions and -20°F for hypothetical accident conditions. At the time the casks were designed, NRC had not defined any fracture criteria. Based on recommendations from Oak Ridge National Laboratory, design criteria were established which led to the selection of SA-350, Grade LF3 as the cask material.

During certification review, NRC published draft Regulatory Guide MS501-4, "Fracture Toughness Criteria for Ferritic Steel Shipping Containers with a Wall Thickness Greater than Four Inches." Using Regulatory Guide criteria, it was determined a nil ductility transition temperature of -137°F was required for TN-BRP and -135°F for TN-REG. Samples were tested for shell, bottom, lid, and weld material. Results from the samples showed the material essentially met NRC's criteria. These results were judged to be acceptable. This was very fortunate since the cask structural material could not be changed at this point. The paper will include detailed information on sampling and test results.

Structural Performance of Borated Stainless Steel Basket

The bss baskets consist of a multi-tiered "egg crate" assembly of interlocking flat plates which form square fuel compartments running the full length of the interior of the cask. The BRP basket consists of 44 compartments which each can accommodate two BRP fuel assemblies stacked end-to-end. The REG basket consists of 40 compartments which can accommodate one REG fuel assembly per compartment.

In its review NRC identified significant concerns about the bss baskets:

1. The basket was made of bss, with no established ASTM-like standards for the material.

2. There were no accepted codes or standards which would permit the use of bss as a structural member, particularly at high levels of stress.

3. An analysis performed by Lawrence Livermore National Laboratory (LLNL) calculated basket stresses beyond specified yield stresses for the bss under hypothetical accident conditions. Stresses were particularly high for basket orientations not considered in the SAR.

4. The analysis performed by LLNL also indicated basket members were susceptible to buckling at various side drop orientations where the basket members are not parallel and perpendicular to the impact surface.

5. The application did not include a fatigue evaluation of the material and the fatigue curves in the ASME Code are not applicable.

As a result of uncertainties about basket structural performance, NRC could not be assured the fuel would remain in a subcritical configuration in the drop test.

Several options were evaluated for resolving NRC concerns about basket performance: (1) justify the existing basket; (2) replace the basket; and (3) revise the loading pattern. The decision was made to alter loading pattern so subcriticality would be assured without relying on bss as a structural material. This was accomplished by designing the baskets to be shipped half full of fuel, with structural inserts placed in the empty fuel compartments in a checkerboard pattern. Inserts were also to be placed in the peripheral slots to further position the fuel assemblies. The fuel compartment inserts will be removed for storage. However, this reduced this shipping capacity by half.

The basket inserts are designed to support the full weight of a column of fuel assemblies and basket plates. Thus, even if the plates fail and some fuel assemblies collapse, the fuel will still remain in a subcritical configuration. Criticality studies were done for a variety of possible accident configurations to assure the fuel arrays would remain subcritical. Additional information on criticality analysis and inserts design will be provided.

Impact Limiter Performance

The impact limiters were originally designed using a computer code proprietary to Transnuclear. Since the computer code was proprietary and had not been benchmarked against test results, NRC asked numerous questions regarding methods employed in the code and results obtained. Of particular concern were the following items:

1. Force-displacement relationships for the impact limiters in each of the impact orientations were requested. The methods and equations used had to be fully justified.

2. Fully justified stress-strain curves for impact limiter materials, including effects of grain orientation were required.

3. Assumptions on how the portion of the limiter not backed up by the cask would perform had to be fully justified.

4. For each drop height and orientation considered, the application had to show maximum g-load, maximum deformation and strain, and the margin against lock-up.

Rather than attempt to justify the computer code, a comprehensive test program using one-third scale model impact limiters was conducted. Two thirty foot drop tests were performed at Sandia National Laboratories to determine dynamic effects and to evaluate attachment adequacy. These tests were performed for the 90 degree end drop and the 10 degree slapdown. Static crush tests were performed at the National Institute of Standards and Technology to establish load versus displacement curves for 90, 60, 30, and 0 degree crush orientations. The 90 degree end crush test was performed for the same orientation as the end drop to permit comparison of static and dynamic tests.

The drop tests produced data traces of acceleration vs. time at specified locations on the simulated cask body. Displacement vs. time was measured on the impact limiters and body using high speed photography. Raw data were processed to produce acceleration, velocity, and displacement vs. time curves. Force-displacement curves were also developed. Examples of the data curves and results will be presented in the paper.

The slapdown test also caused the instrumented impact limiter attachment bolts to fail. This necessitated redesigning the attachments by providing larger attachment bolts and tire rod connectors between the impact limiters.

Static crush tests were conducted at the National Institute of Standards and Technology (NIST). These tests were performed on one-third scale model limiters. The tests directly produced force-displacement curves for the limiters at the tested angles. Samples will be presented in the paper and results compared to drop test results.

Trunnion Attachment

The casks are lifted and rotated using four trunnions attached to the cask body. The trunnions are located in recesses in the cask body and are bolted to the cask using fourteen bolts. The original trunnion attachment design used the bolts to compress the trunnion against the body, and then friction between the trunnion and body helped carry the lateral load. NRC objected to the use of friction to carry the load.

The trunnion attachment design was modified to eliminate reliance on friction. The trunnion diameter was sized to create a tight fit between the trunnion and cask body. Thus the load was carried by the cask body. Also, on TN-BRP, where the body recess was not sufficiently deep, shoulder bolts were provided on the lower trunnions to help carry the load.

Lid Attachment Bolt Loading

The lid on each cask is attached to the cask body using 48 1.45-inch diameter hex head bolts. For the original 30-foot drop analysis, stresses above yield were calculated in portions of the highest loaded bolts. NRC stated that absolutely no yielding would be allowed in the bolts.

To resolve this issue, slightly longer bolts made of stronger material, SA-540, Grade B24, Class 1, were provided. Stress analysis of these stronger bolts showed no yielding in any of the bolts.

Seal Performance at Low Temperature

Cask penetrations, including the main lid, are sealed using viton O-rings in a dovetail groove machined in the lid. NRC questioned the performance of viton at temperatures in the range of -20°F to -40°F.

Review showed there was insufficient data available to demonstrate performance of viton seals at low temperature. Since only two shipments are planned for each cask, NRC accepted a proposal that certification for shipment be limited to the months April through October. These dates were determined based on weather data.

Structural Analysis

Several NRC questions concerned structural analysis. Two primary concerns were analysis of stresses in the tapered bottom end of the cask and lack of clarity in the overall presentation.

The analysis was revised to provide greater detail on the tapered region using a three dimensional finite element model. The format was revised to include tables of stresses with specific locations, free body diagrams, and load combinations from NRC Regulatory Guides.

SAR Format

NRC commented that the original SAR was difficult to review because of format organization and content. The document was completely revised to make it much easier for reviewers to read.

LESSONS LEARNED AND RECOMMENDATIONS

Based on experience certifying these casks, the following recommendations have been developed.

1. Certification of the cask body material went smoothly because accepted standards were in place to evaluate its performance. By contrast, it was not possible to certify borated stainless steel for basket structural use because there were no standards. Designs should use materials with accepted standards, or new standards should be developed.

2. Standardized methods are needed for impact limiter design. Testing is time consuming and expensive. Availability of an accepted design computer code or methodology would be extremely beneficial. Also, static testing produced the required force-displacement curves with greater ease and lower cost. Drop testing requires more facilities and sophisticated instrumentation and data collection capability. Data analysis is much more complex and requires a high level of expertise.

3. **Structural analysis should explicitly follow NRC requirements and Regulatory Guides, and should use well established structural computer programs. Presentation should be clear and easily understood.**

4. **It is vital to meet with NRC early and often to establish clear understanding of the applicant's intentions and NRC's requirements. It is easier to change paper than hardware.**

5. **Better information on performance of seal material at low temperature is needed.**

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