CURRENT STATUS OF THE PACKAGE PERFORMANCE STUDY

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ABSTRACT

In 1999, the United States Nuclear Regulatory Commission (NRC) initiated a confirmatory research program, the Package Performance Study (PPS), to study the response of spent nuclear fuel transportation casks to extreme accident conditions. The purpose of the test is to demonstrate the robustness of the rail transportation cask design and overall transportation system. The NRC has actively engaged the public and encouraged participation throughout all phases of the PPS program. Already, the NRC has held twelve public meetings, as well as collected and evaluated thousands of public comments related to the study. Based on preliminary staff research and public comment, the Commission recently approved full-scale testing of an accident scenario involving a single NRC-certified spent nuclear fuel rail transportation cask [1]. The test will consist of a train traveling at an appropriate speed colliding at a ninety degree angle with a transportation cask on its rail carrier car in a normal transportation configuration. Instrumentation and video cameras will be used to document the impact and resulting cask condition. The staff is currently outlining the details and projected costs of the demonstration test. The demonstration test should help increase public confidence on the viability of existing spent fuel transportation casks in the United States. This paper discusses the process for selection of this scenario and the uncertainties associated with the testing.

INTRODUCTION

Over the past 25 years, the staff has conducted and published a series of studies assessing cask response to accidents and the risks associated with the transportation of spent nuclear fuel. The latest of these studies, the PPS, proposed a full-scale test to demonstrate the robustness of spent nuclear fuel transportation casks. Through public meetings and a public comment period, a wide range of stakeholders have provided input to the staff concerning the scope and parameters of such a test.

In February 2003, the staff published NUREG-1768, "Package Performance Study Test Protocols," which documented a proposed test plan for performing extra-regulatory impact and fire tests (i.e., testing beyond the regulatory criteria) on certified rail and truck spent fuel transportation casks **[2]**. During the 90-day public comment period on NUREG-1768, NRC held four facilitated public meetings to discuss the proposed testing protocols and to elicit public comments. Over one thousand pages of transcripts were taken, and over 250 comment letters were received. This amounted to over 2,300 individual comments, suggestions or questions **[3] [4]**. In general, the public wanted NRC to develop more clearly stated objectives with strong ties to the technical approach of the PPS. NRC staff identified, through the comment review process, the following four dominant public comment themes: the NRC should (1) conduct full-scale tests to the regulatory limits, (2) conduct realistic demonstration tests based on realistic accident scenarios, (3) test the casks to failure and (4) address terrorism in the PPS.

After deliberation, the NRC staff decided to include only consideration of the first two themes (full-scale testing and realistic testing) in developing test options. The staff considered conducting testing to failure,

but believes that pursuing such testing would not be realistic – realism being one of the four major public comment themes. Primarily, the staff believes that there are no realistic accident scenarios that are sufficiently severe to lead to cask failure (e. g., rupture, leakage, etc.). Furthermore, there is no readily agreed upon definition of cask failure among the various stakeholders. The NRC staff identified testing to failure as outside the scope of the PPS. Regarding addressing terrorism assaults to casks, the NRC staff points out that the PPS has always been a safety study based on transportation accidents. Such terrorism issues are explicitly being addressed by other ongoing NRC activities (i.e., consequence assessments that focus upon security and are not suitable for the public participatory approach).

NRC staff considered all public comments received and subsequently proposed four testing options in a Commission paper (SECY-04-0029) for Commission consideration and direction in February 2004 **[5].** One option presented was the testing approach published in NUREG-1768, involving an impact and fire test for both a full-scale rail cask and a full-scale truck cask with impact limiters and no conveyance. The other three options were new approaches, reflective of public comments on NUREG-1768, and involved various combinations of regulatory and demonstration tests on rail and truck transportation casks.

In May, 2004, the NRC Commission approved the testing of a single full-scale, NRC certified rail transportation cask of a type that is currently being used, or is expected to be used in the foreseeable future to transport spent nuclear fuel **[6**]. The NRC staff was requested to submit for Commission approval, a plan for a demonstration test with sufficient instrumentation to collect data to confirm the validity of key analytical methods and assumptions, including scaling. In particular, the Commission specified that the demonstration test should be realistic and should include exposure to a fully-engulfing fire.

In July 2004, the NRC staff developed detailed test plans for conducting a full-scale demonstration test on a spent fuel rail transportation cask for Commission approval **[7]**. The staff proposed a demonstration test involving the collision of a locomotive with a rail cask attached to a conveyance (i.e. railcar) simulating a realistic derailment of the transportation cask and subsequent fire test.

Since submittal of the test plan, two drop tests of rail transportation casks occurred in Germany. Data from these tests could also be used to reaffirm aspects of the NRC's existing regulatory approach without the NRC replicating the tests.

On December 10, 2004, the Commission clarified aspects of the demonstration testing **[1]**. They directed the staff to conduct a specific full-scale demonstration test that simulated a rail crossing with a train traveling at an appropriate speed colliding at a ninety-degree angle with a transportation cask on its rail carrier in a normal transportation configuration. The test would consist only of the natural progression of the collision, i.e. it would not consider subsequent fire tests. The Commission recommended performing the test at an existing facility, such as the train testing facility in Pueblo, Colorado. The staff is currently outlining the details and projected costs for the demonstration test.

DISCUSSION

The staff's process for developing the initial demonstration test plan involved: 1) an assessment of accident statistics for rail transportation accidents for licensed material shipments and shipments involving spent fuel transportation and 2) an evaluation of potential 'realistic' accident scenarios to determine those that could result in a 'realistically conservative' challenge to a spent fuel transportation cask. "Realistically conservative", in this context, means that a test scenario will be selected that challenges the integrity of the transportation cask and is also deemed credible based on a review of accident history data.

Scenario Development

In order to develop a realistic rail accident scenario from which to base the demonstration test, the staff assessed accident statistics for rail transportation accidents for licensed material shipments involving spent fuel. Over the past 25 years, NRC-certified packages have been used in 1,300 spent fuel shipments, and none of those shipments has involved an accident that challenged a rail transportation cask. Moreover, since 1970, there have been only four rail accidents involving trains transporting casks (only one of the four involved a train carrying loaded spent fuel casks), and none of those accidents directly involved the rail casks. Consequently, the staff was not able to draw directly upon accident statistics to develop a "realistic" accident scenario that could result in a "realistically conservative" challenge to the containment integrity of a spent fuel rail transportation cask.

The staff, therefore, reviewed accident reports prepared by the Federal Railroad Administration (FRA), transportation studies conducted by Lawrence Livermore National Laboratory **[8]** and Sandia National Laboratories **[9] [10]**, and research conducted by the Volpe Center of the U.S. Department of Transportation (DOT). These data indicate that train accident scenarios with the highest conditional probabilities, relative to other types of train accidents, are train derailments resulting in impacts or collisions with soil, roadbeds, rock, structures, railcars or locomotives, and/or vehicles at railroad crossings. Moreover, the majority of these accidents would not be sufficiently severe to damage a cask. The staff, therefore, considered several hypothetical cask and railcar accident derailment scenarios such as a cask and railcar impacting a rock outcrop, a tunnel entrance, and a bridge abutment. In addition, the staff considered the collision of a locomotive with a rail cask attached to a railcar.

Each hypothetical accident was assessed for its likelihood of causing severe cask damage. For train derailment scenarios involving impacts with rock outcrops, transportation studies indicate that only a small percentage of the ground adjacent to commercial railroad right-of-ways involves "hard rock." Depending on impact speed and cask mass, hard rock is the only impact surface remotely capable of behaving like an unyielding surface. All other soil types would absorb significant energy while imparting energy to the cask. Thus, derailment scenarios involving impacts with soil are judged to be unlikely to challenge cask integrity.

Derailment scenarios involving an impact of the cask and its conveyance into a tunnel entrance or bridge abutment are possible derailment scenarios. However, a unique set of circumstances would have to occur for the cask to directly impact either a tunnel entrance or bridge abutment. The staff, therefore, concludes that while these types of derailment scenarios are more likely than derailments into hard rock surfaces, they do not represent a "realistically conservative" challenge to cask integrity (i.e., not much kinetic energy is transferred to the cask).

The staff also considered accident scenarios that involve a collision of a locomotive and a cask (attached to a railcar). This general class of accident is a more likely scenario when compared to the low-probability scenario involving an impact with hard rock, and the staff concludes that such a scenario could represent a "realistically conservative" challenge in that it would have the potential to impart enough energy into the cask to challenge cask integrity. In fact, the British used this accident scenario in "Operation Smash-Hit," the well-known demonstration test conducted by the United Kingdom's Central Electricity Generating Board (CEGB) in 1984 **[11]**. Specifically, the CEGB test involved the high-speed impact of a locomotive into a rail cask attached to a rail car at approximately 160 kph (100 mph), but did not involve a fire test.

FRA accident reports document that locomotive impacts into railcars have occurred in the past. In particular, a 1995 accident that involved three trains (one of which was stopped and impacted at low speed by a second train) resulted in a derailment of a railcar which overturned onto an adjacent track and

was subsequently struck by a third train at relatively high speed. To lend credibility to the degree of realism of the demonstration test scenario, the staff chose to develop a test plan based on this accident scenario in SECY-04-0135 **[7]**.

As stated above, the Commission approved a modified version of this scenario that it considered a viable transportation accident, rather than a worse case or hypothetical scenario involving multiple events to occur simultaneously. Specifically, the Commission approved a test that simulated a rail crossing collision between a train and a rail transportation cask in a normal transportation configuration. The test would not involve a separate fire or immersion test following the collision.

The staff notes that the probability of occurrence of a real-world accident with a spent nuclear fuel cask similar to the proposed demonstration test scenario is small. NRC requires that spent fuel transportation casks be designed to survive a sequence of tests including a 30-foot drop onto an unyielding surface. This is a very severe test for spent fuel cask designs, and encompasses an extremely high fraction (well over 99%) of vehicle impacts at high speed **[8]**. Only the most severe, incredible accidents might challenge a cask design, but their likelihood is so remote that the NRC considers the risk to public health acceptably low.

Uncertainties

The realistic accident conditions of a demonstration test provide complicated testing boundary conditions (e.g., crushing of railcar and the locomotive, and tie-down failure strength) when compared to well-controlled boundary conditions (e.g., unyielding surface) present in the certification testing process of 10 CFR 71.73. This introduces a number of uncertainties, stemming largely from the anticipated non-linear nature of the collision between locomotive and the cask-car assembly.

There are uncertainties associated with the demonstration test analysis predictions and testing conditions. Prediction results will be strongly dependent upon the accurate representation of material properties and structural details for the cask, rail car, and locomotive. These uncertainties will increase the error bounds in predicting the test results and will increase the uncertainty in key parameters to be measured during the test.

Instrumentation and Analysis

The instrumentation that is expected to be used in the proposed test (consisting of accelerometers, displacement transducers, thermocouples, strain gauges, photometrics, and physical measurements, combined with a state-of-the-art data acquisition system) will provide data for analytical comparison. The specific types of instruments, their locations and the anticipated ranges of parameters to be measured will be determined through pre-test predictions of the impact test.

Full-scale impact tests on spent nuclear fuel rail transportation casks have not been conducted in the U.S. in the past 20 years. Past rail cask demonstration tests have involved lighter, lower capacity designs, which would not likely be used in the foreseeable future to transport spent fuel. Conducting a full-scale, realistically conservative test can demonstrate the robustness of a cask design that is likely to be used in shipments of spent fuel.

For the proposed tests, the staff plans to use modern analysis techniques, such as those used in the current cask certification process. These modern analysis techniques take advantage of efficient, state-of-the-art, computing capabilities and the development of high-fidelity three-dimensional (3D) finite element models. These models allow for more accurate representation of cask structural details and material characteristics involved in a realistic accident scenario that is indeed three-dimensional.

In addition, the staff expects to develop a collaborative analysis effort (e.g., round-robin participation) with domestic and international stakeholders who are expected to use a wide variety of analytical tools and modeling techniques. By performing both pre- and post-test analyses, the collaborative analysis effort is expected to yield insights into the most accurate modeling techniques for the test. Prior experience with such collaboration has shown that all participants gain valuable experience and insights into conducting analyses of complex structure and dynamic loading conditions.

CONCLUSIONS

The Commission has approved the testing of a full-scale, certified rail transportation cask. The rail cask is to be a type of which is currently being used, or is expected to be used in the foreseeable future. The Commission has approved a specific demonstration test simulating a rail crossing and ninety-degree collision of a train and a rail transportation cask on a rail carrier car in a normal transportation configuration. The staff is currently developing a detailed test plan and estimating costs associated with the demonstration test. An equivalent demonstration test on a truck spent fuel transportation cask may be considered at an appropriate time in the future pending the results of the rail test and decisions by the United States Department of Energy regarding support of a truck demonstration test.

Data collected from the demonstration test will be used for assessing the analysis tools used to predict transportation cask response to severe accident conditions. Furthermore, the demonstration test will provide an indication of the degree of cask robustness when subjected to a realistic rail accident scenario with the intended goal of increasing public confidence on the viability of existing spent fuel transportation casks in the United States. Continued collaboration with domestic and international stakeholders will be pursued to exchange information on analysis techniques and modeling strategies.

REFERENCES

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2. US NRC, NUREG-1768, "United States Nuclear Regulatory Commission Package Performance Study Test Protocols, Draft Report for Comment," Office of Nuclear Regulatory Research, Washington, DC, February 2003.

3. US NRC, PPS March 03 Public Workshop Transcripts. Available through the NRC's Agency Document Access and Management System (ADAMS) found at www.nrc.gov using the following accession numbers: ML030930583 (Workshop at Headquarter NRC on March 6, 2003, ML030930588 (Workshop in Las Vegas, NV on March 12, 2003), ML030930601 (Workshop in Chicago, IL on March 19, 2003).

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