

SPENT FUEL TRANSPORTATION PACKAGE PERFORMANCE STUDY – EXPERIMENTAL DESIGN CHALLENGES

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ABSTRACT

Numerous studies of spent nuclear fuel transportation accident risks have been performed since the late seventies that considered shipping container design and performance. Based in part on these studies, NRC has concluded that the level of protection provided by spent nuclear fuel transportation package designs under accident conditions is adequate. [1] Furthermore, actual spent nuclear fuel transport experience showcase a safety record that is exceptional and unparalleled when compared to other hazardous materials transportation shipments. There has never been a known or suspected release of the radioactive contents from an NRC-certified spent nuclear fuel cask as a result of a transportation accident. In 1999 the United States Nuclear Regulatory Commission (NRC) initiated a study, the Package Performance Study, to demonstrate the performance of spent fuel and spent fuel packages during severe transportation accidents. NRC is not studying or testing its current regulations, as the rigorous regulatory accident conditions specified in 10 CFR Part 71 are adequate to ensure safe packaging and use. As part of this study, NRC currently plans on using detailed modeling followed by experimental testing to increase public confidence in the safety of spent nuclear fuel shipments. One of the aspects of this confirmatory research study is the commitment to solicit and consider public comment during the scoping phase and experimental design planning phase of this research.

INTRODUCTION

In 1999 the U.S. Nuclear Regulatory Commission (NRC) initiated the Package Performance Study (PPS), a confirmatory research project to demonstrate the safety performance of spent fuel and spent fuel packages during unlikely, severe transportation accidents. The goals of the PPS are to demonstrate the inherent safety in spent fuel cask design; confirm finite element analyses as a valuable tool to accurately capture cask and fuel response to severe mechanical and thermal environments, to provide empirical data and new or updated transport statistics, and to enhance public confidence in package performance. [2] NRC plans on building upon the past studies by using enhanced detailed modeling analyses and performing experimental testing. It is expected that bringing together insights learned from earlier studies with those of the PPS modeling evaluations and experimental test results will lead to the development of a strong technical basis to support the proposed PPS cask-testing strategy (cask type versus each cask). NRC is not studying or testing its current regulations, as the rigorous regulatory accident conditions specified in 10 CFR Part 71 are adequate to ensure safe packaging and use. Rather, the PPS will reexamine the level of protection provided by the NRC certified spent fuel transportation package designs under severe accident conditions.

NRC often refers to the PPS as a “program” that involves performing ongoing studies that examine how spent nuclear fuel casks under highly unlikely severe accidents will perform. This effort has been referred to as “extra-regulatory” in nature because it will investigate and experimentally test the performance of NRC certified casks and the behavior of fuel when subjected to thermal and impact forces that exceed the hypothetical accident conditions specified in 10 CFR Part 71. [3]

Study History

NUREG-0170, entitled "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes" (Vols. I and II, December 1977), was the first major NRC document that reported the impact on public health and safety that result from transportation activities. [4] The report contains an assessment of spent nuclear fuel shipment risk using the 1975 level of shipments, and a projection of risks for 1985, based on the assumption of a reprocessing fuel cycle.

After considering the information developed and received, and the safety record associated with the transportation of radioactive material, the Commission determined in 1981 that the regulations then in place were adequate to protect the public against unreasonable risk from the transport of radioactive materials, and that no immediate changes in the regulations were needed to improve safety (46 FR 21619). The Commission also found, however, that regulatory policy concerning transport safety warranted close and continuing review, for example as technologies change and analysis capabilities improve. [5] The U. S. Department of Transportation also used NUREG-0170 to assess the impact of radioactive material transportation under its "Hazardous Materials Regulations" (49 CFR Subchapter C, Parts 171-180). [6]

Several spent nuclear fuel shipments were planned in the mid-1980s to return spent nuclear fuel from the West Valley facility in western New York to the originating utilities. These shipments drew considerable public interest. A key issue was communicating the comparison of NRC's spent nuclear fuel cask accident standards with actual 'real-world' accident conditions. This issue, among others, motivated NRC to initiate further research in this area.

Accordingly, NRC sponsored an examination of the response of generic steel-lead-steel truck and rail spent nuclear fuel casks to collision and fire accident conditions, using finite element impact and thermal heat transport calculations. Probabilities and forces associated with severe transportation accidents were also assessed. This study was performed by the Lawrence Livermore National Laboratory and is often referred to as the "Modal Study," ("Shipping Container Response to Severe Highway and Railway Accident Conditions," NUREG/CR-4829, Volumes I and II, February 1987). [7] The probabilities and magnitudes of the accident source terms developed for Modal Study were compared to those developed for NUREG-0170. Data indicated that the risks per spent nuclear fuel shipment for shipments by both truck and rail were "at least 3 times lower than those documented in NUREG-0170." The results from the earlier NUREG-0170 clearly bounded spent nuclear fuel shipment risks. Subsequently, the NRC staff concluded that the Modal Study clarified the level of safety provided under real accident conditions by spent fuel packages designed to current standards and practices. These conclusions reaffirmed the Commission's 1981 decision regarding the adequacy of the transportation regulations.

CHALLENGES

The Package Performance Study encompasses a scoping phase to identify pertinent transportation issues, a development phase for formulation of test protocols, a test phase for obtaining experimental data and an evaluation phase to interpret the results and put changes that have occurred in cask design into perspective. Due to the complex nature of this study, NRC expects to encounter and resolve challenges under each phase. Challenges and current staff strategies are summarized below.

Past Challenges

The scoping phase of the study has three objectives: 1) examination of the need to revisit the conclusions of the 1987 Modal Study, to evaluate their continued validity, and to extend the methods used to develop those conclusions; 2) identification of studies needed to confirm the risk results documented in NUREG/CR-6672; and 3) obtaining public and stakeholder comment on the possible studies to increase confidence in the safety of spent fuel transportation. The challenge was to ensure that the public's concerns about the safety performance of spent fuel and spent fuel packages during the unlikely but severe transportation accidents were clearly identified and

their ideas on the type of research that could be conducted were captured for PPS consideration. NRC held a total of eight public meetings to ensure that the PSS would address stakeholder concerns and NUREG/CR-6672 issues. The scoping phase served as a guide to the first leg of the quest to finalize the experimental development and testing approach. The overarching issues began to emerge from these public meetings. An Issues Report, NUREG/CR-6768 was written that presented the results of the PPS scoping phase which was conducted by NRC with contract support from Sandia National Laboratories (SNL). NRC staff concluded that four tasks would address the primary concerns raised by stakeholders: 1) Use recent accident data to reanalyze truck and rail accident speed and fire duration statistics developed by the Modal Study; 2) Perform high-speed collision tests on full-scale rail and truck casks and compare results to pretest damage predictions developed by computer models; 3) Expose full-scale rail and truck to fully engulfing, long-duration fires and compare the measured cask temperatures to pretest temperature predictions developed by computer models; and 4) Conduct laboratory tests to examine rod failure, pellet fracturing and the release of particles from the failed rods and use the test results to determine the response to extreme temperature impacts of fuel pellets, fuel rods, and fuel rods containing fuel pellets. The PPS scoping phase outcome allowed the staff to confidently move forward to the design phase and begin conceptualizing the test experimental designs.

Test and Analysis Protocols Challenges

The developmental phase is a multifaceted gem. The first facet reflects the early public outreach and the use of the Issues Report with the publication of the Draft Test Protocols Report. The second facet, in plane view presently, is reflecting the staff's plans to actively engage the public in the design of the proposed field tests. The work scope has become better defined and the staff is presenting its draft conceptual design to obtain meaningful stakeholder feedback. The third facet will reflect the staff's internal product, synthesized with the consideration of the additional internal and external comments, ready for Commission approval. The final facet will reflect the Commission's decision on how to proceed. The approved conceptual design will be then developed into a detailed plan and mounted on a setting available once again for public review and comment before finalized.

The NRC staff is not surprised with the amount of discussion and wide range of opinions on the methods of testing and analysis among experts in spent nuclear fuel transportation package design, testing, and analysis, as well as individuals with experience in shipping spent nuclear fuel and high-level radioactive wastes. Testing methods as identified in the PPS's Issues Report and as discussed at a recent Advisory Committee on Nuclear Waste (ACNW Transportation Working Group workshop[8], have been a key point of discussion amongst stakeholders and the NRC staff. NRC is committed to fairly consider all testing methods and analysis technical design suggestions through meaningful stakeholder participation in the development of testing protocols. As mentioned earlier, the scoping phase was critical to guide the testing approach. However, the PPS was purposely designed to take another look at stakeholder views in the design phase. This foresight will be advantageous, especially since there has been recent legislative action and increasing interest in the proposed permanent federal waste repository and spent fuel transportation issues.

As part of the process for preparing release of the protocols for comment, the NRC staff briefed ACNW, in June 2002, and, in this connection, provided it with a draft copy of the protocols report. Although NRC expected to release the protocols report in Summer 2002 and convene August 2002 meetings, these activities were delayed. These delays were necessary to develop accurate and clear communication of the testing goals and proposals, which should enhance the ability of stakeholders to effectively participate and comment.

The NRC's current strategy for the development of the test protocols is to consider internal suggestions and public comments collectively, before coming to a final position on the testing.

Requests have gone beyond technical experimental design issues. For example, in a letter dated December 9, 2002, the State of Nevada's Agency for Nuclear Projects expressed that it is not opposed to full-scale testing of one or two "representative" casks as part of the PPS. It believes that if appropriately designed and implemented the planned tests can provide significant information on risk assessments and risk and has made several recommendations to the Commission concerning the proposed PPS cask tests. However, Nevada urged the NRC to require full-scale testing as part of the certification process for any new cask that could be used for shipments to

Yucca Mountain. [9] Also, in a letter to the Commission in December 2002, the Nye County Department of Natural Resources and Federal Facilities noted that it ... “prefers testing each cask design, rather than representative casks” but has requested that some of the tests be conducted in Nye County. [10]

The level of detail of the Test Protocols report may be a concern for some. It does not contain detailed specifications of the test conditions for the proposed tests. The Draft Test Protocols report states that the reason for this approach was “... that detailed planning and procurement for a specific series of tests will be resource intensive. The NRC anticipates that the public comments could result in worthwhile changes to the underlying test approaches and plans.” [11] After receiving and considering all stakeholder comments on the test protocols, the NRC staff will develop detailed test plans and procedures for each of the PPS testing programs.

TEST PROTOCOLS

The staff plans to address the issues by first presenting its current positions on them as outlined in the draft Test Protocols for public review and comment – a ninety day review. This report, NUREG-1768, was issued in February 2003. Second, conduct three public workshops to obtain stakeholder positions and to obtain ideas that are expressed as a result of workshop participant interaction. In the Test Protocols report, the staff has directly asked for feedback on many specific issues, but urges reviewers to comment on any other technical issues they may have. Specific issue subjects include the cask designs to be tested, whether the tests should be a full or partial scale test, whether the impact test should be a drop test or a rocket sled test, the orientation, and the speed of the impact test, the type and number of surrogate fuel assemblies contained in these test units and the duration of the thermal fire tests.

One of the most important messages to communicate at these workshops is that the test protocols are not finalized. Public comments’ can be instrumental in influencing the design of the test protocols. The staff expects comments that could identify important additional test design details. The test protocols report will not be ready for Commission approval until the staff has considered the public’s comments and those comments received internally from the ACNW and others during the preliminary draft stage in view of the public comments. In addition, the staff plans to describe more fully the proposed PPS cask impact test and fire test and continue the PPS dialogue from 1999 and 2000 related to the test protocol issues identified in the Issues Report. Detailed plans, procedures will be developed after the public has a chance to comment on the tests as described in the Test Protocols report. Procurement of equipment such as the casks to be tested, development of testing setups and arranging for the personnel to conduct and evaluate the testing, must also be addressed before the experimentation and evaluation occur.

The protocols report is the first major PPS document since the Issues Report. The Test Protocols describe, at a conceptual level, the impact and fire fuel tests that are currently planned for PPS, along with the goals for these tests. Several other PPS tasks, including the accident statistics/data work, investigations of fuel behavior under impact and thermal stresses, historical accidents investigation, and uncertainty/sensitivity analyses for risk assessments, are planned as part of PPS, but they are not part of the Test Protocols report as it focuses on field testing. Publication of these test protocols does not imply any commitment on the part of the NRC to conduct any of these tests, or to conduct any test exactly as described in the Test Protocols report.

Collision Test Protocol

Within the context of the PPS, the NRC plans to conduct separate high-speed impact tests of a full-scale rail spent fuel cask and full-scale truck spent fuel cask using a drop impact as opposed to a horizontal impact test. The drop impact test was proposed after weighing such factors as test objectives, costs, local environmental and logistical concerns, and modeling issues. The staff will then compare the results of these tests to detailed pre-test damage predictions developed by computer models. (The computer model analyses conducted in the process of developing

the preliminary design of the impact test are described in NUREG-1768.) The staff proposes the following tasks for the collision test protocol:

- Subject a full-scale rail cask to an extreme impact onto a flat, unyielding surface (The staff proposes an unyielding surface because (1) the proposed impact test is intended to evaluate cask performance and an unyielding surface causes all of the cask kinetic energy to be spent deforming the cask, and (2) an unyielding surface simplifies the analysis by deforming only the cask and not the target.)
- Equip the lid end of the test cask with an impact limiter; ensure the cask contains a fuel canister, if the test cask design uses canisters, with one real fuel assembly containing surrogate fuel, and sufficient dummy assemblies to fill the canister or cask.
- Structure the test to deliver the impact onto the lid end of the cask that is equipped with the impact limiter.
- Orient the cask so the impact is on the corner or edge of the lid.
- Test cask performance on impact with an unyielding surface at an impact speed of 26.8 to 40.2 m/s (60 to 90 mph).
- Subject a full-scale truck cask to an extreme “back-breaker” impact onto one of the internal flat sides of the cask, midway between the impact limiters onto a rigid semi-cylinder. Ensure that the cask contains one real fuel assembly and sufficient dummy assemblies to fill the cask.
- Test cask performance on impact with an unyielding surface at an impact speed of 26.8 to 40.2 m/s (60 to 90 mph) (based on preliminary analysis of the computer model).

Proposed Speed for Rail Impact Test

The NRC staff with contractor support obtained preliminary impact analyses to support the development of the test protocols. These analyses spanned the range of impact speeds from 26.8 to 40.2 m/s (60 to 90 mph); the Test Protocols report presents the results of these analyses for impact speeds of 26.8 and 33.5 m/s (60 and 75 mph). The NRC staff reviewed these SNL analyses and developed three criteria for proposing test parameters for the PPS impact and thermal tests. The NRC staff conducted a trial application of these criteria to determine the speed for the rail cask impact. The NRC staff optimized the benefits of the three criteria, i.e., (1) enhancing public confidence, (2) validating the computer models, and (3) ensuring realism in the probability of the occurrence of the test parameters. On the basis of that optimization, the NRC staff proposes the impact speed of 33.5 m/s (75 mph).

Fire Test Protocol

Within the context of the PPS, the NRC plans to conduct separate fire tests of a full-scale rail cask and a full-scale truck cask. For these thermal tests, PPS will use a fully engulfing, optically dense fire, which completely surrounds the test specimen and obscures visibility of the test specimen through the flames. In each test, the fire will burn for more than the half-hour duration of the thermal certification test. The NRC staff will compare the measured temperature history of the cask at various points to the detailed pretest predictions developed by computer models. (Again, the computer model analyses conducted in the process of developing the preliminary design of the thermal test are described in the Test Protocols Report.)

Public Comments

The NRC published and distributed the Test Protocols report in early 2003, for a 90-day comment period. In addition, the NRC plans on conducting during March, a series of public meetings to obtain comments on the report. The NRC is currently considering the comments received. The agency particularly sought comments and stakeholders' views on the following eleven key issues:

- How many casks and what types of cask designs should be used in the tests?
- At what scale should the cask impact tests be conducted (e.g., full-scale or a partial-scale)?
- Should the impact tests be conducted as drops from a tower, as proposed in this report, or along a horizontal track using a rocket sled?
- What should the impact speed and orientation be for the rail cask impact test?
- Is 26.8 to 40.2 m/s (60 to 90 mph) a reasonable speed range for the rail cask impact test given that the frequency for a rail cask impacting a hard rock surface within this speed range is 10^{-6} to 10^{-8} per year?
- Is the 33.5 m/s (75 mph) rail cask impact speed proposed by the NRC staff appropriate?
- What should the impact speed be for the back breaker truck cask impact test?
- What should be the duration and size of the cask fire tests?
- What should be the cask position relative to the fire?
- How many and what types [real or surrogate, pressurized-water reactor or boiling-water reactor] of fuel assemblies should be in the casks during the tests?
- Will the proposed tests be able to yield risk insights consistent with NRC's risk-informed regulatory initiatives?

After receiving and considering all stakeholder comments on the test protocols, the NRC staff will develop detailed test plans and procedures for each of the PPS testing programs, again using contractor expertise. The NRC will make these detailed plans, procedures, and tests available to the public for comment before finalizing and conducting the planned tests. Thus, the finalized detailed plans will reflect public comments on these test protocols, constraints imposed by NRC's programmatic priorities, and the available funding to support these tests.

CONCLUSIONS

The PPS will identify and implement near-term confirmatory research transportation work for the NRC. The design phase of the PSS considers many technical and public confidence issues. The PPS strategy was designed to capture stakeholder feedback. The production of draft test protocols is the signpost that signals the stakeholders that the design phase has jelled and their feedback will act as a firming ingredient in the design process. The Test Protocols Report, NUREG 1768, was made publicly available for comment in February 2003. Along with descriptions of the testing protocols, the report includes the rationale for selection of specific test parameters (cask type, impact speed, duration of fire test, etc.). Through the PPS, the NRC plans to demonstrate, by pretest prediction coupled with actual physical testing, the ability of computer models to predict cask performance. The staff will then compare the results to these tests to detailed pre-test damage predictions developed by computer models.

Non -testing issues in the PPS will be handled separately and are not included in the test protocols. These issues include the reconstruction of the accident events trees and accident speed and fire duration distributions, and policy issues not reflected by experimental results.

REFERENCES

- [1] R.J. Lewis, et al., "Spent Fuel Transportation Package Performance Study," WM02 Conference, February 2002.
- [2] J.L Sprung, et al., Spent Nuclear Fuel Transportation Package Performance Study Issues Report, NUREG/CR-6768, SAND2001-0811P, June 2002.
- [3] A.J. Murphy, United States Nuclear Regulatory Commission Package Performance Study Test Protocols, Draft Report for Comment, NUREG-1768, February 2003.
- [4] "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes," NUREG-0170, U.S. Nuclear Regulatory Commission, Washington, D.C., December 1977.
- [5] "10 CFR Parts 71 and 73, Radioactive Material: Packaging and Transportation by Air. Agency: U.S. Nuclear Regulatory Commission. Action: Withdrawal of Advance Notice of Rulemaking." U.S. Federal Register, Vol. 46 Page 21619. April 13, 1981
- [6] Title 49, Subtitle B, Chapter 1, U.S. Code of Federal Regulations, Parts 171-185
- [7] L. E. Fischer, et al., "Shipping Container Response to Severe Highway and Railway Accident Conditions," NUREG/CR-4829, Lawrence Livermore National Laboratory, Livermore, CA, February 1987.
- [8] "Proposed Package Performance Study Protocols," ACNWR-0184 letter from George M. Hornberger to Chairman Richard A. Meserve, June 28, 2003
- [9] "Full-Scale Physical Testing for Spent Fuel Shipping Casks," Letter from R.R. Loux , State of Nevada Agency for Nuclear Projects, to NRC Chairman Meserve, December 9, 2002
- [10] "Full Scale Testing of Spent Fuel Transportation Casks," Letter from L.W. Bradshaw, Nye County Department of Natural Resources & Federal Facilities, to NRC Chairman Richard Meserve, December 17, 2002
- [11] Ibid 3