FULL-SCALE CASK TESTING REVISITED, AGAIN

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ABSTRACT
Full-scale physical testing of spent nuclear fuel shipping casks continues to be a major public policy issue. The U.S. Nuclear Regulatory Commission (NRC) does not currently require full-scale physical testing of shipping casks as part of its certification process. The State of Nevada and other stakeholders have proposed mandatory full-scale cask testing since the 1980s. In 2005, after five years of interactions with stakeholders, the NRC approved a plan for demonstration testing of a rail cask that could be used for shipments to the proposed high-level nuclear waste repository at Yucca Mountain, Nevada. In February 2006, the National Academies' (NAS) Committee on Transportation of Radioactive Waste released a study which endorses full-scale cask testing. The authors review various approaches to full-scale cask testing, provide a detailed critique of the demonstration testing proposed by NRC, and recommend an alternative testing plan.

INTRODUCTION
The U.S. Nuclear Regulatory Commission (NRC) does not currently require full-scale physical testing as part of its certification process for spent fuel shipping casks. None of the shipping casks currently used in the United States has been tested full-scale. None of the current cask designs likely to be used for shipments to Yucca Mountain has been tested full-scale. (1, 2)

Instead of full-scale testing, the NRC relies upon scale-model testing and computer analysis to assess cask performance under hypothetical accident conditions. According to the NRC, seven spent nuclear fuel truck cask designs and nine rail cask designs are currently certified for use in the United States. None of the sixteen cask designs have been tested full-scale to demonstrate their compliance with NRC regulations or their ability to survive severe accident conditions. In two cases half-scale models were subjected to drop (impact) tests. Four cases involved drop tests of 1/3-scale or ¼-scale models. (1)

DOE has no plans to independently conduct full-scale testing of the casks that would be used for shipments of spent nuclear fuel to Yucca Mountain. In the Final Environmental Impact Statement (FEIS) for Yucca Mountain, DOE asked the rhetorical question, "Will DOE conduct full-scale testing of transportation casks?" The FEIS answered: "The NWPA [Nuclear Waste Policy Act] requires DOE to use casks certified by the NRC when transporting spent nuclear fuel and high-level radioactive waste to a repository. A cask's ability to survive the tests prescribed by the regulations (10 CFR Part 71) can be demonstrated either through component analysis or through scale-model and full-scale testing to demonstrate and confirm the performance of the casks. The NRC would decide which level of physical testing or analysis was appropriate for each cask design submitted." (1)

PREVIOUS CASK TESTING PROGRAMS IN THE UNITED STATES

While none of the spent fuel shipping casks currently used in the United States has been tested full-scale, several full-scale transport package tests have been conducted in the US. Three obsolete spent fuel shipping casks were subjected to crash and fire tests at Sandia National Laboratories (SNL) in 1977. An obsolete spent fuel shipping cask was subjected to a sabotage test at SNL in 1981. The State of Nevada sponsored contractor studies of the Sandia cask tests and other U.S. Type B package full-scale testing programs, including tests of the TRUPACT II container for transuranic waste shipments, the NUPAC 125B internal canister for Three Mile Island core debris shipments, and private sabotage testing of a German storage-transport cask at the US Army Aberdeen Test Center. Nevada contractors also evaluated the "Operation Smash Hit" testing program for the Magnox reactor fuel cask, conducted in 1984 by the Central Electricity Generating Board (CEGB) in the United Kingdom. (3, 4, 5, 6, 7, 8)

Stakeholder demands for full-scale testing of specific repository shipping cask designs developed during the decade of the 1980s. These demands were strongly influenced by the Sandia crash tests and their depiction in films produced by DOE. Films of the tests quickly became a matter of heated dispute. The test designs and casks selected were adequate for the investigators' primary purpose – the benchmarking of computer programs and validation of scale model tests. The test designs and casks selected were not, however, appropriate for evaluating NRC accident performance standards, or the safety performance of casks currently in use. Yet the films of the tests produced by DOE were quickly pressed into public relations use, misrepresenting the Sandia test program and its findings, in an effort to assure the public that current spent nuclear fuel shipments were "safe." (9)

Some critics of the Sandia tests and test films later endorsed the CEGB approach, which combined regulatory confirmation testing and public demonstration testing, and the TRUPACT II testing program, which involved a high-degree of stakeholder participation.
"Operation Smash Hit" involved full-scale regulatory tests of a cask design currently in use, similar to the tests proposed by NANP. Post-event analysis of the "Operation Smash Hit" demonstration test concluded that the locomotive impact at 100 miles per hour actually applied less force to the cask lid, than did the regulatory drop test conducted earlier. (8)

Nevada contractor studies documented test results (including test program costs) and lessons learned, and developed recommendations to be applied to the DOE repository shipping cask development program. These studies were key inputs to the full-scale cask testing approach that Nevada recommended to DOE in 1990. (6) The lessons learned are summarized below:

- Full-scale testing should be a supplement to regulatory analysis, not a substitute for regulatory analysis.
- Full-scale tests should be performed on casks used for current and future shipments.
- Full-scale tests should be designed to challenge cask integrity.
- Demonstration testing is acceptable only in conjunction with regulatory testing.
- Stakeholders should be involved in the testing program.
- Safety claims should not be exaggerated in test reports, films, and videos.

NAS TRANSPORTATION STUDY

In February 2006, the National Academies' (NAS) Committee on Transportation of Radioactive Waste released a report entitled Going The Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States. (10)

The committee found that "the radiological risks associated with the transportation of spent fuel and high-level waste are well understood and are generally low, with the possible exception of risks from releases

in extreme accidents involving very-long-duration, fully engulfing fires. While the likelihood of such extreme accidents appears to be very small, their occurrence cannot be ruled out based on historical accident data for other types of hazardous material shipments. However, the likelihood of occurrence and consequences can be further reduced through relatively simple operational controls and restrictions and route-specific analyses to identify and mitigate hazards that could lead to such accidents." [SR.3]

The committee examined in detail previous accident consequence analyses, and previous full-scale cask testing programs, including the SNL testing program in the United States in the 1970s, and the "Operation Smash Hit" testing program. The committee directly addressed the issue of full-scale cask testing [SR.6-7]:

"FINDING: The committee strongly endorses the use of full-scale testing to determine how packages will perform under both regulatory and credible extra-regulatory conditions. Package testing in the United States and many other countries is carried out using good engineering practices that combine state-of-the-art structural analyses and physical tests to demonstrate containment effectiveness. Full-scale testing is a very effective tool for both guiding and validating analytical engineering models of package performance and for demonstrating the compliance of package designs with performance requirements. However, deliberate full-scale testing of packages to destruction through the application of forces that substantially exceed credible accident conditions would be marginally informative and is not justified given the considerable costs for package acquisitions that such testing would require.

RECOMMENDATION: Full-scale package testing should continue to be used as part of integrated analytical, computer simulation, scale model, and testing programs to validate the performance of package performance. Deliberate full-scale testing of packages to destruction should not be carried out as part of this integrated analysis or for compliance demonstrations."

DOE YUCCA MOUNTAIN TRANSPORTATION PROGRAM

Any full-scale cask testing program designed for the Yucca Mountain transportation program must accommodate serious uncertainties. Rail access to Yucca Mountain continues to be uncertain, with significant implications for shipment modal mix. The site lacks rail access, and the feasibility of direct rail transportation has not been demonstrated. In November 2005, the DOE announced that the estimated cost of constructing a new railroad along the Caliente Corridor was more than $2 billion, (10) compared to the original estimated life cycle cost (construction and operation) of about $880 million in 2002. Also during 2005, the State of Nevada's lawsuit against DOE's rail route selection continued, with a decision by US Court of Appeals for the District of Columbia Circuit expected in February or March 2006. The only transportation modes currently feasible are direct shipment by legal-weight truck (LWT), or shipment of LWT casks on rail cars to an intermodal transfer facility, with final delivery by truck. DOE has stated that even if rail access is constructed, all repository shipments for the first six years or so could be made directly by truck, or LWT casks on railcars. More than a thousand LWT shipments would be expected over 24 years even if the railroad was completed by the time the repository opened. (10)

Developments during 2005 created new uncertainties about the shipping cask designs that DOE might use for Yucca Mountain transportation. In April 2005 DOE announced a transport system that would make maximum use of available cask designs, with a preference for cask systems that provided maximum flexibility in terms of facility and fuel compatibility. In April and August 2005, DOE specifically stated that it had no plans to accept spent fuel shipped in welded canisters, such as those used in utility dry storage systems, and designed for shipment using the currently licensed HI-STAR 100 rail cask. In October 2005, DOE revised the current program approach to include the use of Transport, Aging, and Disposal (TAD) canisters, for the acceptance of spent fuel from utilities. The TAD concept is similar to the multi-purpose canister (MPC) concept, but use of welded canisters was not clarified. As of February 2006, DOE has not reported on the implications of the TAD concept for shipping cask design. (10, 11)

A third major uncertainty was added to the Yucca Mountain transportation program in February 2006 when President Bush announced plans for large-scale spent fuel reprocessing as part of a new global nuclear energy plan. The new reprocessing plan could have significant implications for both shipping cask design and the modal mix of shipments within the national waste management program. The proposal that Yucca Mountain might accept SNF and HLW shipments from foreign countries is an additional complicating factor. (12)

BALTIMORE TUNNEL FIRE STUDIES

In July 2001, a freight train derailment in the Howard Street Tunnel, Baltimore, Maryland, resulted in one of the most severe transportation accidents in recent U.S. history. Four and a half years later, after studies by the National Transportation Safety Board, the Federal Emergency Management Agency Fire Division, the Nuclear Regulatory Commission, and the Nevada Agency for Nuclear Projects, important facts about the fire are still in dispute, and the implications for nuclear waste transportation are unresolved. Analyses of that accident by Nevada consultants and by the NRC seem to agree that fire temperatures in the hottest region of the fire burned 2-3 hours at 1500-2000˚F or 800-1,000˚C, burned another 3-4 hours at lower temperatures, and cooled down over several days. They also agree that this was not the worst case rail fire, because its duration and temperature were limited by a water main break, tunnel oxygen supply, and other factors. The burning tank car contained enough fuel for a 6-7 hour fire.

In August 2005, the NRC released for public comment a draft contractor report (NUREG/CR-6886) on the Baltimore fire. Building upon previous NRC studies, including a fire study prepared by the National Institute of Standards and Technology (NIST), the new report evaluated the performance of three different cask designs subjected to a hypothetical accident based on the conditions estimated to have occurred in the July 2001 Baltimore tunnel fire. NUREG/CR-6886 concluded that there would have been no release of radioactive material from one of the casks (HI-STAR 100), and only minor releases from two other casks (TN-68 and NAC-LWT). The NRC report assumed that the casks could be no closer than 20 meters (66 feet) to the hottest region of the fire because of FRA regulations governing placement of sent fuel casks in mixed freight trains. (13)

Nevada consultants contend that NUREG/CR-6886 significantly underestimated the potential radiological consequences of the fire by assuming the casks would be located at least 20 meters from the hottest region of the fire. Even at 20 meters distance, NUREG/CR-6886 significantly underestimated consequences for NAC-LWT by assuming enclosure in ISO shipping container. Even at 20 meters distance, NUREG/CR-6886 may have significantly underestimated potential radiological consequences for all three casks because of uncertainties in NIST fire model, assumptions about SNF cladding performance, assumptions about release pathways from casks, and other factors. NUREG/CR-6886 also failed to assess impacts of loss of shielding.

Nevada consultants remain convinced that the Baltimore Tunnel fire is an important yard-stick for full-scale cask testing. The fire was much more severe than the hypothetical accident fire assumed in NRC regulations. If subjected to the hottest region of the Baltimore fire for its full duration, most, if not all, NRC certified shipping casks could experience failure of lid seals, neutron and gamma shielding, and fuel cladding failure, resulting in a potentially significant release and dispersion of fission products. One possible exception, the HI-STAR 100 with welded canister, requires more analysis.

Nevada consultants contend that the Baltimore fire is particularly relevant to any cask testing program directed towards Yucca Mountain transportation risk analyses. There are 14 rail tunnels within 50 miles of Caliente on the UP mainline. Each rail shipment to Yucca Mountain would pass through at least 6 tunnels within Nevada alone. DOE has proposed shipments to Yucca Mountain in rail casks without

welded canisters, and in LWT truck casks on railcars. DOE has not ruled out use of general freight service for some rail shipments to Nevada.

YUCCA MOUNTAIN ROUTING STUDIES

During 2005, independent studies by State of Nevada contractors and by the Midwest Council of State governments, identified and evaluated potential shipping routes for truck and rail shipments to Yucca Mountain. These studies generally confirmed that the representative shipping routes identified by DOE in the Final Environmental Impact Statement (FEIS) for Yucca Mountain, appear to be the most likely routes that would actually be used by repository shipments. (14)

These studies also confirmed earlier findings by State of Nevada contractors that truck and rail routes to Yucca Mountain could traverse up to 45 states, 700 counties, and 50 Indian Reservations. Rail routes could traverse 80-100 cities with population greater than 100,000. More than 120 million people live in counties traversed by likely truck routes to Yucca Mountain, and more than 100 million people live in counties traversed by likely rail routes. Eight to eleven million people reside within one-half mile of a potential highway or rail route to Yucca Mountain. Nevada consultants believe the findings underscore the importance of stakeholder participation in development and implementation of any cask testing program. (15)

NRC PROPOSALS FOR FULL-SCALE TESTING

In 1999, NRC began developing a proposal for demonstration testing of one or more selected casks as part of the Package Performance Study (PPS). NRC initiated an innovative public participation program. NRC held public meetings in Rockville, MD, Las Vegas, NV, Pahrump, NV, and Chicago, IL, and invited a wide range of participants to engage in detailed discussions of technical and institutional issues. NRC and its contractor SNL provided detailed technical proposals for public discussion, and provided timely access to information and transcripts of the meetings on the SNL PPS website. Many stakeholders, including the State of Nevada, commended the NRC and SNL for an exemplary public participation program. (2)

In April 2003, the NRC issued its proposed cask testing plan, NUREG-1768, for public comment. (16) Many non-industry stakeholders, including the State of Nevada, concluded that the proposed testing protocols were unacceptable, and called upon the NRC to reissue new draft test protocols for public comment. Instead, the NRC made no further commitment to public input. Between February 2004 and March 2005, NRC staff presented the Commission with three additional testing options (SECY-04-0029, SECY-04-0135, and SECY-05-0051). (17, 18, 19)

Sometime in 2004, the NRC apparently decided that full-scale tests conducted under the PPS would not involve drop tests or fire tests severe enough to challenge cask containment integrity. The Commission directed staff to prepare a plan for demonstration testing of a rail cask impacted by a locomotive in May 2004. NRC staff prepared such a plan and presented it the Advisory Committee on Nuclear Waste (ACNW) in July 2004. The ACNW then advised the NRC: "The ACNW has not seen any compelling science-based justification for the proposed test. In the Committee's opinion the proposed demonstration will add little new information of technical value. If a full-scale demonstration is deemed necessary, it should be justified on grounds other than technical needs." (20) The ACNW instead recommended use of scale model testing and computer analyses for demonstrating package compliance with regulations. (20)

The most recent NRC testing proposal (SECY-05-001), approved by the Commission in June 2005, calls for a demonstration test in which a cask mounted on a railcar is impacted by a speeding locomotive, and then subjected to a 30-minute fire engulfing fire. "The staff's proposed test plan as provided in this SECY is not the final word on this issue, as the project is subject to additional modifications and Commission

direction once additional information becomes available." (19) Further details of the test plan had not been made public as of February 2006.

Based on review of the available documents, Nevada consultants believe the test proposed in SRM SECY-05-0051 would not determine if the rail cask meets the accident performance standards set forth in the NRC regulations, would not determine the impact or fire failure thresholds of the cask tested, and would provide little data useful for validating the computer models used in safety evaluations. The demonstration test appears to have the same limits noted by NRC staff regarding the tests proposed in 2004: "The Commission's direction to confirm the validity of the scaling methodology will not be achievable in the context of traditional engineering analysis validation from the demonstration impact test." (2) The plan also lacks details regarding the basis for selection of a "representative" rail cask, no firm commitment to test a truck cask, no provision for meaningful stakeholder input, and no provision for independent peer review of the test protocols or results.

However, Commission stated that this plan "is not the last word of this issue." Nevada urges the Commission to consider the following concerns before proceeding further:

- SECY-05-0051 (SRM, 6/9/05) ignores major stakeholder concerns, even after revisions by Commissioners.
- The plan is primarily focused on rail cask testing, with no commitment to testing a truck cask.
- The plan includes no meaningful basis for selecting a currently certified rail cask "that DOE is likely to use" for Yucca Mountain shipments; in fact, there is no basis for making such a selection at the present time.
- The proposed impact scenario (a train traveling 60 mph impacts upright cask on railcar at 90-degree angle) is inadequate compared to real world rail accidents, previous demonstration tests ("Operation Smash Hit"), and regulatory drop test requirements.
- The proposed post-collision fire test (a 30-minute, engulfing, optically dense, hydrocarbon fire) is of questionable technical value & feasibility, absent further details.
- The anticipated cost of $11.2 million for the demonstration impact test only, is a questionable expenditure of resources compared to other test options.

REVISED NEVADA PROPOSAL FOR FULL-SCALE CASK TESTING

The Nevada Agency for Nuclear Projects (NANP) has advocated full-scale cask testing since 1990. (6) Nevada's original proposal called for a five-part approach to full-scale cask testing: meaningful stakeholder participation in development of testing protocols and selection of test facilities and personnel; full-scale physical testing (sequential drop, puncture, fire, and immersion) of each cask design prior to NRC certification or DOE procurement; additional testing (casks, components, models) and computer simulations to determine performance in extra-regulatory accidents and to determine failure thresholds; reevaluation of previous risk study findings, and if appropriate, revision of NRC cask performance standards; and evaluation of costs and benefits of destructive testing of a randomly-selected production model cask.

A comprehensive full-scale testing program would not only demonstrate compliance with NRC performance standards. It would improve the overall safety of the cask and vehicle system, and generally enhance confidence in both qualitative and probabilistic risk analysis techniques. It could potentially increase acceptance of shipments by state and local officials and the general public, and potentially reduce adverse social and economic impacts caused by public perception of transportation risks.

The authors of this paper recommend that NANP revise the Nevada proposal for full-scale testing. These revisions are based primarily on the authors' review of the recommendations presented by the National Academies Committee on Radioactive Waste Transportation in its 2006 study. These revisions also

reflect review of all stakeholder comments submitted to the NRC through the PPS public hearings and comment letters, the most recent NRC cask testing plan, the NRC draft contractor report on the Baltimore tunnel fire, recent developments in the DOE Yucca Mountain transportation program, and recent Yucca Mountain routing studies. These revised recommendations are summarized below, and discussed in greater detail in the following pages.

REVISED NEVADA CASK TESTING RECOMMENDATIONS

- Stakeholders should have a meaningful role in development of testing protocols & selection of test facilities and personnel.
- Full-scale regulatory tests (drop, puncture, fire, and immersion, in sequence) should be performed on each cask design to be used for repository shipments, either prior to NRC certification, or prior to DOE procurement.
- A truck cask, and possibly a rail cask, should be subjected to an extra-regulatory fire test based on the Baltimore Tunnel Fire conditions (an engulfing fire for 3 hours @ 1475˚F-1800˚F or 800˚C-1000˚C, followed by appropriate cool-down).
- Shipping cask and spent fuel failure thresholds should be determined by computer simulations, scale model testing and component testing (not by full-scale cask testing).
- There is no need at this time to evaluate costs and benefits of destructive testing of a randomly-selected, production model cask.

MEANINGFUL STAKEHOLDER ROLE

The federal agency responsible for testing (DOE or NRC) must provide a meaningful and substantive role for stakeholders in specifying the objectives of the tests, developing the testing protocols, selecting the testing contractors, and overseeing the implementation of the test program. The only way to assure that the testing program is accepted by stakeholders is to include the stakeholders in all phases of program development and implementation. Moreover, past experience with the TRUPACT-II testing program demonstrates that involvement of a broad range of stakeholders can make the tests more relevant to real world conditions. (1)

Stakeholder involvement in selection of testing facilities is especially important. Before a final selection of test facilities, all relevant issues and options should be discussed with stakeholders. The accessibility of the test facilities to stakeholders, and the willingness of facility personnel to facilitate stakeholder participation in testing, may be as important as technical testing capabilities and previous experience. Even the best-equipped and most-experienced facilities have known limitations regarding capabilities to perform drop tests on large rail casks, and to perform long-duration fire tests. These factors, plus the potential tens-of-millions dollar value of the testing program, create the potential for real or perceived conflict of interest if the testing facility is selected without a formal competitive evaluation. (1)

The approach used for testing of the TRUPACT shipping container is a model for effective stakeholder involvement. The TRUPACT-II shipping container is used for transporting transuranic waste to the Waste Isolation Pilot Plant (WIPP) in New Mexico. In that case, representatives from affected states, as well as outside consultants identified by the states, were fully involved in the design of the test program and in overseeing its implementation. Such involvement resulted in greater public confidence in container safety and acceptance of the entire WIPP shipping program. It also resulted in the identification of engineering and safety flaws, and corresponding package design changes. These problems likely would not have been found and resolved absent the involvement of "outside" participants. (1)

FULL-SCALE REGULATORY TESTING

The heart of Nevada's cask testing proposal is to subject full-scale casks to the four hypothetical accident conditions specified in the NRC regulations (10 CFR 71.73), in the specified sequence:

1. A free-drop test, in which the cask is dropped from a height of 9 m (about 30 feet) onto a flat, essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected. The cask would strike the unyielding surface at a speed of approximately 30 mph, which is roughly equivalent to an impact of 55-60 mph with a bridge support column or roadside out-crop. For most cask designs, the most damaging angle of impact would be a corner drop over the lid end (onto the impact limiter).

2. A puncture test, in which the same cask is dropped from a height of 1 m (about 40 inches) onto a 6-inch diameter, cylindrical, mild and steel bar, mounted upright on an essentially unyielding horizontal surface. The steel bar must be of a length sufficient to cause maximum damage to the cask. The cask would be dropped onto the bar in a position that is expected to produce maximum damage. Depending upon the cask design, this could be a drop designed to damage the neutron and gamma shielding, or the impact limiter.

3. A thermal test, in which the same cask is fully engulfed in a hydrocarbon-fuel fire with an average flame temperature of at least 800° C (about 1475° F) for a period of 30 minutes.

4. An immersion test, in which the same cask is immersed under a head of water of at least 0.9 m (3 feet) in the attitude for which maximum leakage would be expected.

Full-scale regulatory testing could be carried either by the NRC or by the DOE. Regardless of which agency takes lead responsibility, the important point is that full-scale regulatory testing should be a supplement to, and not a substitute for, the rigorous computer analyses currently required as part of the NRC certification process. Full-scale regulatory testing should be required in addition to the computer simulations currently required as part of the NRC cask certification process.

Full-scale regulatory testing could be implemented either as the final step in NRC certification, or as a preliminary step in the DOE procurement of casks already certified by NRC but not previously tested. Considering the political controversy associated with cask testing, Federal legislation would probably be required. Absent congressional action to require full-scale testing by statute, DOE might be able to require full-scale regulatory testing as part of its procurement process for Yucca Mountain transportation hardware. NRC action, independent of congressional direction, would almost certainly require formal rulemaking.

The number of casks which would need to be tested full-scale under Nevada's proposal, and the resulting costs, depend upon the final repository system design adopted by DOE. If the DOE were to adopt an approach based on standardization of transportation hardware designs, the number of regulatory tests could be as low as two, one truck and one rail. If, on the other hand, DOE decides to use all of the currently certified casks which the NRC has identified as potential casks for repository shipments, as many as seven or eight regulatory tests would be needed.

A cost analysis prepared in 2003 estimated that the regulatory testing program proposed by Nevada (drop, puncture, fire, and immersion) for a truck cask weighing up to 30 tons, would likely cost $7.8-8.4 million. Regulatory testing of a large rail cask would cost $9.1-12.0 million for each rail cask tested. In addition, a one time cost of about $10 million would be incurred upgrading the testing facility to lift and drop rail casks weighing up to 170 tons. (1) Table I summarizes the basis of these cost estimates.

The authors estimated test cost components based on contractor reports prepared for Nevada and DOE, and personal communications. Cost of cask acquisition assumes full compliance with NRC quality assurance and quality control procedures, and includes delivery to the test facility. Stakeholder participation costs assume intensive oversight of all planning, testing, and reporting activities; two major public meetings for each cask testing program; and large-scale stakeholder observation at the testing facilities. The relatively large contingency costs reflect uncertainty about instrumentation requirements, extent to which cask would be loaded with fresh fuel and heater elements, disposal of casks after testing, and compliance with environmental regulations.

The cost of physical testing assumes use of existing facilities in the United States or the United Kingdom. Test facility upgrading costs assume use of existing drop test facilities at SNL. Construction of a new cask testing facility would likely cost $15 million, compared to the $10 million upgrade cost. The NAS study (2006) found that a new drop test facility would probably be needed for truck as well as rail cask tests. However, a 1993 SNL report identified 12 facilities in United States with various capabilities for testing 40-ton and 100-ton containers, and a 1991 report prepared for Nevada identified 5 potential testing facilities in the United States, 2 in the United Kingdom, and 1 in Canada. (7, 21)

Table I. Estimated Cost of Full-Scale Cask Regulatory Testing (2003 Dollars)

Cost Component	Legal-Weight Truck Cask	Large Rail Cask (Up to 150 tons)
Cask	$2,750,000-3,250,000	$3,000,000-5,250,000
Physical Testing	530,000	1,190,000
Computer Analysis	800,000	800,000
Test Documentation	100,000	100,000
Technical Peer Review	600,000	600,000
Stakeholder Participation	775,000	775,000
Administration	425,000	525,000
Contingency (30%)	1,794,000-1,944,000	2,097,000-2,772,000
Subtotal for Testing	7,774,000-8,424,000	9,087,000-12,012,000
Facility Upgrade for Large Rail Cask Drop Tests (One-time)	0	10,000,000
Total for Testing First Cask	7,774,000-8,424,000	19,087,000-22,012,000

Ref. 1, 2.

A comprehensive regulatory testing program (drop, puncture, fire, and immersion as proposed for the first truck cask), would likely cost about $8-9 million. Comprehensive regulatory testing for the first large rail cask would cost about $20-22 million, including the one time cost of about $10 million for upgrading the testing facility to lift and drop rail casks weighing up to 170 tons. The authors estimate that it would cost about $30 million to complete the regulatory testing program for one truck cask and one rail cask (an additional $5 million in the event that a completely new cask testing facility would be needed). Subsequent tests, for additional cask designs, would likely cost considerably less per cask. The authors estimate that it would cost $50-80 million to conduct a comprehensive testing program, if five to eight truck and rail cask designs are used for repository shipments.

EXTRA-REGULATORY TESTING

NANP staff and contractors have re-evaluated Nevada's previous position on extra-regulatory testing of full-scale shipping casks, including testing to failure and destructive testing. Based on re-examination of previous analyses of cask testing issues, on studies of the 2001 Baltimore rail tunnel fire, on review of stakeholder comments to NRC under the PPS program, and on consideration of the recent NAS report, Nevada contractors recommend that the highest priority should be the thermal testing of a legal weight truck cask subjected to the conditions created by the 2001 Baltimore rail tunnel fire.

A legal weight truck cask design that DOE plans to use for Yucca Mountain shipments should be subjected to an extra-regulatory fire test. Based on the DOE FEIS and other program documents, the GA-4 truck cask would be an appropriate choice. The fire temperature and duration should be similar to the conditions of the Baltimore tunnel fire – a fully engulfing, hydrocarbon-fuel fire with a temperature of 1475˚F-1800˚F (800˚C-1000˚C) for three hours, followed by a cool down period of at least five hours.

Nevada contractors have evaluated various aspects of regulatory and extra-regulatory fire tests. (22, 23, 24) The minimum cost for regulatory thermal testing of a legal-weight truck cask would likely be $3.3-3.8 million. Based on previous studies, the estimated cost of a 3-hour fire test, including cask purchase, would be approximately $4-5 million for a truck cask, and $6-7 million for a rail cask.

TESTING AND ANALYSIS TO DETERMINE FAILURE THRESHOLDS

Full-scale cask testing is not necessary to determine failure thresholds of shipping casks and their contents. A combination of computer simulations, component tests, and scale model tests would be sufficient to determine the impact and fire conditions under which failure would occur. Failure of lid seals, shielding, and fuel cladding deserve thorough analysis. Failure in this sense means that one or more components fail, and the cask therefore fails to maintain its containment and shielding integrity as required under NRC regulations (10 CFR 71.51, 71.71, and Table A-2).

Further definition of failure may be needed regarding release of fission products, particularly release of the key radionuclide Cs-137, but even a release of less than one percent of the Cs-137 inventory could be considered a catastrophic failure. In this regard, cask designs with and without internal welded canisters could perform differently in severe fire environments, and both types of rail casks (with and without internal canisters) should be analyzed.

Nevada consultants agree with the NAS study finding "that extreme accident scenarios involving very-long-duration, fully engulfing fires might produce thermal loading conditions sufficient to compromise containment effectiveness." [SR.5]

Nevada consultants agree with the NAS recommendation that the NRC "should undertake additional analyses of very-long-duration fire scenarios that bound expected real-world accident conditions for a representative set of package designs that are likely to be used in future large-quantity shipping programs." The objectives of these analyses should be to: "Understand the performance of package barriers (spent fuel cladding and package seals). Estimate the potential quantities and consequences of any releases of radioactive material. Examine the need for regulatory changes (e.g., package testing requirements) or operational changes (e.g., restrictions on trains carrying spent fuel) to help prevent accidents that can lead to such fire conditions or to mitigate their consequences." [SR.6]

DESTRUCTIVE TESTING

In previous reports, Nevada has recommended that NRC undertake an evaluation of the costs and benefits of destructive testing of a randomly selected production model cask. The basis for this recommendation was that casks submitted for certification testing would of necessity be prototypes, and that prototypes might be constructed more carefully than production models, and might perform differently than production models, when tested. This concern was buttressed by documentation of a case in the 1970s, where a significant safety-related error had occurred in cask fabrication, and the error was only discovered, and the cask withdrawn from service, after the cask had been used for many shipments. (3, 9)

After reviewing cask performance issues as part of Nevada's participation in the NRC PPS program, Nevada consultants have advised the State that this concern should be directly addressed through cask fabrication quality assurance requirements, and not through cask testing proposals. The State has

therefore been advised to drop the recommendation for evaluation of destructive testing of a production model cask.

Moreover, this recommendation should be dropped because the term "destructive testing" is imprecise, and open to misinterpretation. The NAS and the NRC seem to have interpreted Nevada's recommendation as a request that casks be tested "to destruction". This is not the case. The regulatory and extra-regulatory testing that Nevada has recommended would be destructive tests, in the sense that the casks would not only be rendered useless for their original purpose, but would also likely be permanently disassembled for post-test examination.

Nevada consultants agree with the NAS study that "the failure of a package, in the sense that it can no longer perform its intended containment function, will generally occur under conditions that are much less severe than needed for destruction," and that "testing to destruction would provide little or no insight into the conditions that would cause a loss of package containment under real service conditions." [2.25]

CONCLUSION: THE COST OF FULL-SCALE TESTING

The cost of full-scale cask testing is the major argument against such tests. The cost of the casks themselves is a major factor, and was the reason that the Sandia testing program used obsolete casks in 1977. In selecting the test scenarios, investigators had to balance three conflicting considerations: "exposing the cask to very severe accident environments, amenability of the tests to analyses and scale model testing, and test costs." Cost was a major factor in the Sandia test design and in cask selection. "Financial constraints affected both test definition and equipment procurement. Because current generation spent fuel shipping casks cost from $500,000 for truck casks to $3,500,000 for rail casks, it was necessary to utilize used or retired equipment." (25)

Fifteen years later, a Sandia report revisited the cost advantages and disadvantages associated with full-scale testing:

> "The major disadvantage to full-scale package development and testing for large packages is the increased cost in relation to scale modeling. For example, the cost to manufacture a prototypical full-scale package is about two times greater than a one-half scale replica model. The overall testing cost and time to perform the tests will be greater in full-scale because of increased package size and weight. Large rail casks currently under development for the DOE Office of Civilian Radioactive Waste Management (OCRWM) can weigh more than 100 tons. Other casks, such as those developed for DOE naval Reactors, weigh up to 200 tons. The cost of temperature-conditioning to the regulatory -40ºF or 100ºF, when and if needed, will also be greater because of the increased thermal mass of the full-sized package. Depending on the extent of the testing program, this increased cost may be significant."
>
> "This increase in cost for full-scale testing must be weighed against the disadvantage that thermal package tests of scale models cannot be performed. If scale-model structural testing is performed, the thermal test must be evaluated analytically or individual components tested with proper boundary conditions to mock-up the entire package. The cost for these additional components must be included when comparing the overall costs of a full- and reduced-scale testing program. The ability to perform full-scale operational testing, as well as normal and hypothetical accident conditions, must be weighed against the [cost] advantages of scale-model testing." (21)

The NAS study committee returned to this issue in 2006: "Testing of full-scale spent fuel packages is not routinely carried out because of its cost. A full-scale package can cost more than a million dollars and it is generally not reusable after undergoing full-scale testing in accordance with Commission regulations. The paucity and costs of suitable testing facilities are also impediments." [2.4]

The cost argument against full-scale testing is not compelling when the test costs are compared to the overall cost of the Yucca Mountain transportation program. A comprehensive regulatory testing program as proposed by Nevada would likely cost $8-9 million for the first truck cask. Comprehensive regulatory testing for the first large rail cask would cost $20-22 million, including a one time cost of about $10-15 million for upgrading an existing testing facility, or building a new one, to lift and drop rail casks weighing up to 170 tons. Subsequent tests would likely cost considerably less per cask.

The authors estimate that a comprehensive testing program for Yucca Mountain shipping casks would cost $60-80 million, including regulatory tests for 4 or 5 rail casks and 1 or 2 truck casks, an extra-regulatory fire test of a full-scale truck cask, and cask and fuel failure analyses. If DOE were to adopt a standardized approach to transportation hardware, for example using a single rail cask design based on the TAD concept, and a single truck cask design such as the General Atomics GA-4/9, then a comprehensive regulatory and extra-regulatory testing program might cost less than $50 million.

Testing costs are small when compared to the projected costs of the Yucca Mountain transportation system. Independent analyses by the State of Nevada (1998) and by DOE (2002) concluded that the projected life-cycle cost of the repository transportation system would be in the range of $7.5 billion to $9.5 billion. DOE recently estimated the cost of constructing the Caliente railroad would be $2 billion, an increase of about $1.2 billion over the cost provided in the Yucca Mountain FEIS. In other words, a comprehensive cask testing program would cost about 1 percent of the overall transportation program cost, or about 7 percent of the cost increase for the Caliente railroad. From this perspective, cask testing is a bargain.

REFERENCES

1. R. HALSTEAD, F. DILGER, "Implications of the Baltimore Rail Tunnel Fire For Full-scale Testing of Shipping Casks," WM'03, Conference Proceedings, February 23-27, 2003, Tucson, AZ.
2. R. HALSTEAD, F. DILGER, "Testing to Failure: Design of Full-Scale Fire and Impact Tests for Spent Fuel Shipping Casks," WM'04, Conference Proceedings, February 29- March 4, 2004, Tucson, AZ.
3. MOUNTAIN WEST RESEARCH, "High-Level Nuclear Waste Transportation Needs Assessment," Prepared for State of Nevada Agency for Nuclear Projects, NWPO-TN-002-089 (1988)
4. NEVADA AGENCY FOR NUCLEAR PROJECTS, "A Report on High-Level Nuclear Waste Transportation: Prepared Pursuant to Assembly Concurrent Resolution No. 8 of the 1987 Nevada Legislature" (1988).
5. R.J. HALSTEAD, R. DiBARTOLO, "State of Nevada Nuclear Waste Shipping Cask Studies," High-Level Nuclear Waste Management, Proceedings of the International Topical Meeting, Las Vegas, NV, Vol. 1, 465-473 (April 8-12, 1990).
6. R.J. HALSTEAD, ET AL, "State of Nevada Comments on the OCRWM From-Reactor Spent Fuel Shipping Cask Preliminary Design Reports," NWPO-TN-009-90, Prepared for Nevada Agency for Nuclear Projects (NANP) (December 1990).
7. D.F. SNEDEKER, "Nuclear Waste Transportation Package Testing: A Review of Selected Programs in the United States and Abroad," Report Prepared for State of Nevada Agency for Nuclear Projects (December, 1990).
8. L. AUDIN, "Nuclear Cask Testing Films: Misleading and Misused," Report Prepared for State of Nevada Agency for Nuclear Projects (October 1991).
9. M. RESNIKOFF, L. AUDIN, "The Next Nuclear Gamble: Transportation and Storage of Nuclear Waste," New York: Council on Economic Priorities (1983).

10. NAS, "Going The Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States," Prepublication Release (February 2006)
11. USNWTRB, "Letter from J. Garrick to P.M. Golan," (December 19, 2005).
12. B. GROVE, "Nuclear Sleight of Hand, Nuclear Power Industry Recharged," Las Vegas Sun (February 26, 2006).
13. H.E. ADKINS, JR., J.M. CUTA, B.J. KOEPPEL, "Spent Fuel Package Transportation Package Response to the Baltimore Tunnel Fire Scenario," NUREG/CR-6886, Draft Report for Comment, (November 2005).
14. COUNCIL OF STATE GOVERNMENTS, MIDWESTERN OFFICE, "Midwest Route Identification Project Final Report," (December 2005).
15. F. DILGER, R. HALSTEAD, "Many Roads to Travel: Alternative Approaches to Route Selection for Yucca Mountain Shipments," WM'03, Conference Proceedings, February 23-27, 2003, Tucson, AZ.
16. NRC, "Package Performance Study Test Protocols: Draft Report for Public Comment," NUREG-1768 (February 2003). NRC PPS documents, including NUREG-1768 and comments on NUREG-1768 submitted to NRC during the public review process, and public meeting transcripts, can be accessed on the web at http://ttd.sandia.gov/nrc/modal.htm.
17. NRC, "Commission Voting Record, Options for Full-Scale Spent Nuclear Fuel Transportation Cask Testing Under the Package Performance Study," SECY-04-0029 (May 5, 2004).
18. NRC, "Demonstration Test Plan for Full-Scale Spent Nuclear Fuel Rail Transportation Cask Testing Under the Package Performance Study," SECY-04-0135 (July 27, 2004).
19. NRC, "STAFF REQUIREMENTS – SECY-05-0051 – DETAILS AND PROJECTED COST OF A DEMONSTRATION TEST OF A FULL-SCALE SPENT NUCLEAR FUEL RAIL TRANSPORTATION CASK UNDER THE PACKAGE PERFORMANCE STUDY," (June 9, 2006).
20. ACNW, "Letter from J. Garrick to N.J. Diaz," (July 30, 2004).
21. S.E. GIANOULAKIS, "A Description of Technical Issues Relative to Testing of the Cask Systems Development Program (CSDP) Radioactive Materials Package Designs," TTC#1265, Prepared by SNL (May 14, 1993)
22. M. GREINER, "Spent Nuclear Fuel Shipping Cask Performance in Severe Accident Fires: Performance Envelope Analysis, Fire Test Modeling, and Full-Scale Physical Testing," Report Prepared for State of Nevada Agency for Nuclear Projects (July 20, 2000).
23. M. GREINER, "Fire Durations of Concern for Legal Weight Truck Packages with Different Placements Relative to a 7.2-m-diameter Pool Fire," Report Prepared for State of Nevada Agency for Nuclear Projects (December 15, 2004).
24. M. GREINER, "Thermal Protection Provided by Impact Limiters to Containment Seal within a Truck Package," PVP 2005-71117 (July 2005).
25. R.M. JEFFERSON, H.R. YOSHIMURA, "Crash Testing of Nuclear Fuel Shipping Containers," SAND77-1462C (December 1977).