

Full-Scale Cask Testing and Public Acceptance of Spent Nuclear Fuel Shipments - 12254

Fred Dilger, PhD (fcd5@cox.net)
Black Mountain Research
Henderson, NV 81012

Robert J. Halstead (bearhalstead@aol.com)
State of Nevada Agency for Nuclear Projects
Carson City, NV 80906

James D. Ballard, PhD (ballard@csun.edu)
Department of Sociology, California State University, Northridge
Northridge, CA 91330

ABSTRACT

Full-scale physical testing of spent fuel shipping casks has been proposed by the National Academy of Sciences (NAS) 2006 report on spent nuclear fuel transportation, and by the Presidential Blue Ribbon Commission (BRC) on America's Nuclear Future 2011 draft report. The U.S. Nuclear Regulatory Commission (NRC) in 2005 proposed full-scale testing of a rail cask, and considered "regulatory limits" testing of both rail and truck casks (SRM SECY-05-0051). The recent U.S. Department of Energy (DOE) cancellation of the Yucca Mountain project, NRC evaluation of extended spent fuel storage (possibly beyond 60-120 years) before transportation, nuclear industry adoption of very large dual-purpose canisters for spent fuel storage and transport, and the deliberations of the BRC, will fundamentally change assumptions about the future spent fuel transportation system, and reopen the debate over shipping cask performance in severe accidents and acts of sabotage. This paper examines possible approaches to full-scale testing for enhancing public confidence in risk analyses, perception of risk, and acceptance of spent fuel shipments.

The paper reviews the literature on public perception of spent nuclear fuel and nuclear waste transportation risks. We review and summarize opinion surveys sponsored by the State of Nevada over the past two decades, which show consistent patterns of concern among Nevada residents about health and safety impacts, and socioeconomic impacts such as reduced property values along likely transportation routes. We also review and summarize the large body of public opinion survey research on transportation concerns at regional and national levels.

The paper reviews three past cask testing programs, the way in which these cask testing program results were portrayed in films and videos, and examines public and official responses to these three programs: the 1970s impact and fire testing of spent fuel truck casks at Sandia National Laboratories, the 1980s regulatory and demonstration testing of MAGNOX fuel flasks in the United Kingdom (the CEGB "Operation Smash Hit" tests), and the 1980s regulatory drop and fire tests conducted on the TRUPACT II containers used for transuranic waste shipments to the Waste Isolation Pilot Plant in New Mexico.

The primary focus of the paper is a detailed evaluation of the cask testing programs

proposed by the NRC in its decision implementing staff recommendations based on the Package Performance Study, and by the State of Nevada recommendations based on previous work by Audin, Resnikoff, Dilger, Halstead, and Greiner. The NRC approach is based on demonstration impact testing (locomotive strike) of a large rail cask, either the TAD cask proposed by DOE for spent fuel shipments to Yucca Mountain, or a similar currently licensed dual-purpose cask. The NRC program might also be expanded to include fire testing of a legal-weight truck cask. The Nevada approach calls for a minimum of two tests: regulatory testing (impact, fire, puncture, immersion) of a rail cask, and extra-regulatory fire testing of a legal-weight truck cask, based on the cask performance modeling work by Greiner.

The paper concludes with a discussion of key procedural elements – test costs and funding sources, development of testing protocols, selection of testing facilities, and test peer review – and various methods of communicating the test results to a broad range of stakeholder audiences.

INTRODUCTION

The paper reviews the literature on public perception of spent nuclear fuel and nuclear waste transportation risks. We review and summarize opinion surveys sponsored by the State of Nevada over the past two decades, which show consistent patterns of concern among Nevada residents about health and safety impacts, and socioeconomic impacts such as reduced property values along likely transportation routes. We also review and summarize the large body of public opinion survey research on transportation concerns at regional and national levels, including research conducted by H. Jenkins-Smith and P. Slovic.

Under the Nuclear Waste Policy Act (NWPA), shipments of spent nuclear fuel to a repository by the Department of Energy (DOE) would be largely self-regulated by the DOE(1). However, the NWPA requires that the packages used to transport the spent nuclear fuel to NWPA facilities would have to be licensed by the NRC. Prior to the closure of the Yucca Mountain Project, the DOE did not express an intention to independently conduct full-scale testing of the casks that would be used for shipments of spent nuclear fuel to Yucca Mountain. The Final Environmental Impact Statement (FEIS) for Yucca Mountain, strongly suggests that the DOE did not intend to perform such testing: "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 (2)."

Full scale cask testing is not a requirement for NRC certification for spent fuel shipping casks. Of the currently licensed shipping casks, none have been tested full-scale. In place of full-scale testing, the NRC relies on scale model testing and computer simulation. These techniques are used to assess the ability of the cask design to meet regulatory standards. The regulatory standards require casks demonstrate the ability to meet NRC requirements as they relate to containment of material, radiation control, and criticality control under normal conditions (3 described in 10CFR 71.71) and hypothetical accident conditions (described in 10CFR 71.73). The testing for accident conditions

require that the conditions be sequentially applied to the transportation package. This is done to ensure damage to the package is cumulative. The accident conditions are described in 10CFR 71.73. These conditions must be applied in sequence:

Free Drop: A 30-foot (9 meter) free drop of the cask onto a flat, unyielding, horizontal surface. The cask must strike the surface in a position for which maximum damage is expected.

Puncture: A 40-inch (1 meter) free drop of the cask onto a vertical steel bar, six inches (15 centimeters) in diameter, mounted on an unyielding, horizontal surface.

The cask must strike the steel bar in a position for which maximum damage is expected.

Thermal: Exposure of the cask in a fully-engulfing, hydrocarbon fuel/air fire with an average flame temperature of at least 1475 °F (800 °C) for a period of 30 minutes. The regulations specify the physical conditions of the fire, including the dimensions of the hydrocarbon fuel source around the cask and the position of the cask relative to the surface of the fuel source.

Immersion: Immersion under at least 3 feet (0.9 meters) of water. 10CFR 71.61 requires a deep immersion test for SNF packages with activity greater than 1 million Curies (37 PBq). The regulations require that the package's containment system withstand external water pressure of 290 psi (2 MPa) for a period of not less than one hour without collapse, buckling, or in-leakage of water.

As of 2011, seven truck and nine rail cask designs have been certified for use in the United States(4). The primary method for determining cask performance has been through the use of computer modeling. In some cases, half scale models were used to simulate compliance with the drop (impact) tests. Four other casks used 1/3 or 1/4 scale models to simulate the drop test portion of the regulation.

PUBLIC CONCERNS ABOUT TRANSPORTATION SAFETY

In the aftermath of the March 2011 Fukushima Daiichi nuclear disaster in Japan several implications for SNF transportation in the United States were noted by observers. The state of Nevada's Nuclear Waste Project Office initiated a meta-analysis of public opinion and perception research on the transportation of spent nuclear fuel (SNF) and other high level radioactive wastes.

Risk perception research relative to nuclear waste has a long history in the social sciences. One of the first examples was produced by three of the pioneers of risk perception research (5). This research used a combination of national level and localized Nevada public opinion polls to focus on risk perceptions of nuclear waste. While transportation was not a primary focus of these particular studies, they were the first national level risk studies related to nuclear wastes and the research findings, format and methodology informed many of the risk perception work that followed.

Near the same timeframe as the 1992 study, a significant text on risk perception research was released (6). This text's focus on citizen's perceptions was a change from

past practice wherein technical experts were the primary focus of risk perception work. Rather, these researchers looked at the public that would be exposed to the risk at the fixed sites, proposed sites like Yucca Mountain and the transport routes between these facilities. The anthology of public perception research herein remains the single most comprehensive examination of public perceptions in nuclear waste policy issues. Again the issue of transportation was not the singular focus of this collection of research, rather the text focused on the multiplicity of public risk perception issues facing any program that would ship these radioactive materials.

Risk perceptions are hotly debated when radioactive materials are concerned. Local communities have addressed the issue of transport risk perception as the result of significant shipment campaigns that may affect their jurisdictions, albeit with opinion leaders and not necessarily focused on the general public. For example, Binney, Mason, and Martsof (7) conducted a research project “to examine attitudes among community leaders to the transport of radioactive waste through local communities. Data were gathered from a survey of 28 community leaders who reside beside a planned route in Oregon along which nuclear waste from Hanford, Washington.” These shipments “would be trucked to a disposal site under consideration in New Mexico” (WIPP). “Findings reveal that problems of credibility regarding the U.S. Department of Energy as a message source and public distrust of the agency's performance are grounded in the risk communication of waste transport. It is concluded that a full alliance between the agency and local citizens could be an initial step in restoring lost credibility and trust on transport issues” (p. 283).

Such studies informed research projects on transportation risk perceptions (8). As part of the University of Maryland Omnibus Survey project, the authors investigated the perceived risks of transportation of highly radioactive nuclear wastes. This survey research found four significant transportation related public perception risks:

- Approximately 2/3 of the respondents felt that property values would be lowered as a result of transportation.
- Approximately 70% of respondents expressed concern for terrorist attacks against shipments.
- The majority of respondents were unwilling to live near SNF transportation routes.
- The majority of respondents always felt that the transportation of SNF was riskier than the transportation of industrial chemicals and volatiles like gasoline.

In summary, these publicly expressed fears of transportation issues— terrorism, loss of property values, unwillingness to live near transportation routes and perception of the risks for SNF all point to the need for policy makers to address the public's concerns in their transportation planning.

Nevada has addressed these concerns in a series of state sponsored public opinion surveys (Nevada 2002, 2003, 2004, 2006, 2010) (9). The most recent public opinion poll summarized the risk perception concerns of the public:

“Respondents were asked to rank risks potentially associated with the Yucca Mountain project as being little or no risk, slight risk, moderate risk, or high risk. Table I summarizes results from these questions”.

Table I Ranking of risks people associate with the Yucca Mountain project and related activities

		High/Moderate Risk	Low/No Risk
1	Rail and truck shipments of radioactive waste	75.8%	23.4%
2	Radioactive contamination of the environment	69.8%	27.4%
3	Losses to property values for homes and businesses near shipping routes	69.4%	29.6%
4	Adverse health effects	64.2%	43%
5	Damage to Nevada's reputation as a place to live or visit	56.8%	34.6%
6	Loss of public revenues due to reduced numbers of visitors/tourists	54.0%	45.4%
7	Economic damage to Nevada's major industries	51.8%	45.6%

"Risks associated with the transport of spent nuclear fuel and high-level radioactive waste by rail and highway ranked first, with almost seventy-six percent (75.8%) of respondents considering such risks to be of moderate to high risk. Of those, almost 59% considered waste transportation to be in the high risk category.

Radioactive contamination of the air and water ranked second (almost 70%), followed by the risk of loss to property values along nuclear waste shipping routes (over 69%), the risk of adverse health effects from the repository itself or from transportation operations (over 64%), the risk of damage to Nevada's reputation as a place to live or visit (almost 57%), the risk that public revenues would be lost due to decreased numbers of visitors and tourists (54%); and the risk of serious economic damage to Nevada's major tourism and gaming industries (almost 52%)."

The Nevada surveys also document the range of perceptions and risks the public may consider in their thinking about the potential of any shipment campaign. These were categorized as:

- Risks associated with transportation (documented in table 2 above).
- The public's perceptions of deal making v. continued opposition to shipments.
- Actions that states and local governments could undertake to oppose federal shipment programs.
- Impacts on local economies, industries, tourist choices and relevant issues for many local governments.
- Trust in DOE and government regarding the highly radioactive shipments and the repository siting process.

The research on transportation risks and public perceptions is clear, the public does not trust government agencies and in particular the DOE. The public fears economic, social,

and stigma related impacts from shipments and these fears will not be easily overcome given the mistrust of the DOE.

CASK TESTING PROGRAMS

Although none of the spent fuel shipping casks currently in service in the US have been tested full-scale, there have been several full-scale cask -testing programs. Each of these programs offers insight into how a cask testing program can proceed. In 1977, three obsolete spent fuel shipping casks were subjected to crash and fire tests at Sandia National Laboratories (SNL). 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. Other U.S. Type B package full-scale testing programs were also studied. These include: the TRUPACT II container for transuranic waste shipments, the NUPAC 125B internal canister for the Three Mile Island core debris shipments, and private sabotage testing of a German storage-transport cask at the US Army Aberdeen Test Center. The State of Nevada 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.

SANDIA

Films of Sandia cask tests were produced by DOE. These films became a matter of heated dispute because of their use to influence the public during debates over nuclear waste policy. Increased attention of the issue of spent nuclear fuel transportation led to stakeholder demands for full-scale testing of cask designs that would be used to move waste to a repository. These demands were driven in part by the films of the Sandia crash tests. Although the cask designs used in the tests were adequate for the investigators' primary purpose, benchmarking computer programs and validating scale model tests, the tests were not appropriate for evaluating NRC accident performance standards, or the safety performance of casks currently in use (10).

The DOE used these films in a public relations campaign in an effort to assure the public that current spent nuclear fuel shipments were "safe." (9) In so doing, the DOE misrepresented the Sandia test program and its findings. 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.

There were significant problems with the Sandia tests which limited their public influence. First, the test program was forced to use obsolete casks due to budget constraints. The casks used were different from currently licensed casks. The casks were not subjected to regulatory tests. The tests were spectacular, but did not show regulatory compliance. The written reports about the tests were objective and accurate, the films portraying the tests were less accurate, and some versions were sensational. The debate over the tests and their portrayal in the films increased stakeholder skepticism about cask performance in severe accidents (11).

SMASH HIT

“Operation Smash Hit” involved full-scale regulatory tests of a cask design currently in use, similar to the tests proposed by NANP. The tests were performed by the Central Electricity Generating Board (CEGB) in 1984. These tests consisted of rigorous full-scale regulatory tests which included impact and fire tests. The tests culminated in a public demonstration of a crash when a locomotive was driven into a cask on a derailed train car at 100 miles per hour. The cask sustained only minimal superficial damage and its integrity was not compromised. The railcar and the locomotive were destroyed by the test. 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.

Central Electric Generating Board (CEGB) tests of MAGNOX flasks in the United Kingdom in the 1980s appear to have succeeded in enhancing public confidence and acceptance.. The test program used shipping containers that were actually to be used for rail shipments of SNF. The test program began with tests designed to replicate the regulatory requirements (drop test, fire test). Testing identified a design deficiency – lid seal leak of coolant – which was corrected, although the amount released did not exceed regulatory limits. The cask was subsequently used in a public demonstration test – impact by a 140-ton locomotive and 3 freight cars, travelling at 100 mph – which did not represent the same actual impact as the drop test, but demonstrated a real world accident environment. The tests were recorded on high-speed film/video. The test results were accurately portrayed in public information materials (especially the film entitled “Operation Smash Hit”). The testing program and the test results were endorsed by key stakeholders - British local and central government officials. (10)

TRUPACT II

The Trupact II testing program in the 1980's was designed to examine the strength of casks destined for disposal in the Waste Isolation Pilot plant in Carlsbad, New Mexico. These tests succeeded in enhancing stakeholder confidence and acceptance.. The shipping containers tested used shipping containers that were actually to be used for transuranic waste shipments to WIPP. The tests conducted were the regulatory tests specified in the NRC regulations. The tests identified a design deficiency – O-ring performance – which was corrected.

The test results were reported in great detail in the Safety Analysis Report required for NRC certification. The tests were recorded on high-speed film/video. The test results were accurately portrayed in public information materials and emergency response training materials, materials in some cases produced by the states . The testing program and the test results were endorsed by key stakeholders in the affected states along the shipping routes to WIPP – tests allowed officials to assure the public that reasonable precautions had been taken coupled with extra-regulatory safety protocols for the ensuing shipments. (10)

NEVADA CONCLUSIONS ABOUT FULL-SCALE TESTING PROGRAMS

Nevada contractor studies documented results of the tests (including test program costs) and lessons learned (10). These lessons were used to inform the NANP recommendations to cask testing as they related to the DOE repository cask development program. These studies were key inputs to the full-scale cask testing

approach that Nevada recommended to DOE in 1990 (14). 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.

DOE YUCCA MOUNTAIN TRANSPORTATION PROGRAM

As part of its work on the now-defunct Yucca Mountain Program, DOE examined the problem of the necessary cask fleet size and design. DOE 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 Legal Weight Truck (LWT) casks on railcars. DOE expected more than a thousand LWT shipments would be expected over 24 years even if the railroad was completed by the time the repository opened.

In 2005, new uncertainties about the shipping cask designs that DOE might use for Yucca Mountain transportation arose. In April 2005, DOE announced that it would adopt a transport system that would make maximum use of available cask designs. This system would seek to achieve the maximum flexibility in terms of facility and fuel compatibility. In April and August 2005, DOE 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 again revised its program approach to include the use of Transport, Aging, and Disposal (TAD) canisters, for the acceptance of spent fuel from utilities. In the 2008 Supplemental EIS for Yucca Mountain, DOE proposed a base case transportation system that assumed that about 95 percent of the projected disposal inventory could be delivered to the repository by rail.

The issue of truck casks and rail access has gone largely unremarked. Rail access is a critical issue influencing the type and number of transportation casks. The number of nuclear power plants that can be accessed by rail is declining. The only currently feasible modes of transportation from all reactor sites are either 1) direct shipment by legal-weight truck (LWT), or 2) shipment of LWT casks to an intermodal transfer facility with final delivery by LWT. The cost and difficulty of establishing rail access to all of the nation's nuclear power plants is so great that there will inevitably be thousands of truck or truck to intermodal shipments of spent nuclear fuel. Any full-scale cask

BALTIMORE TUNNEL FIRE STUDIES

In July 2001, a freight train moving a railcar containing tripropylene in the Howard Street Tunnel, Baltimore, Maryland derailed and caught fire. This fire resulted in one of the

most severe transportation accidents in recent U.S. history. A decade 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 2005, the NRC commissioned a draft contractor report NUREG/CR-6886. The final version was released in 2006(15) that evaluated 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). This report evaluated the performance of 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 spent fuel casks in mixed freight trains

Nevada's evaluation of NUREG/CR-6886 argues that it significantly underestimates 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.

The Baltimore Tunnel fire is an important waypoint in policy discussion about full-scale cask testing. The fire was much more severe fire than the hypothetical accident fire assumed in 10CFR 71.73. 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. A possible exception, the HI-STAR 100 with welded canister, requires more analysis.

NRC PROPOSALS FOR FULL-SCALE TESTING

In 1999, NRC began the process of developing a cask testing demonstration study as part of the Package Performance Study (PPS). Laudably, the NRC engaged the public and stakeholders with an innovative public participation program. NRC held public meetings in throughout the country 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.

In April, 2003, the NRC issued its proposed cask testing plan, NUREG-1768, for public comment. 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). (12, 13, 14)

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 (15)." The ACNW instead recommended use of scale model testing and computer analyses for demonstrating package compliance with regulations.

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 (16)."

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 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. 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:

NAS TRANSPORTATION STUDY

The National Academies' (NAS) Committee on Transportation of Radioactive Waste released a report In February 2006 entitled Going The Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States (17). The committee found:

"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.”

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

“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.”

REVISED NEVADA PROPOSAL FOR FULL-SCALE CASK TESTING

The Nevada Agency for Nuclear Projects (NANP) has advocated full-scale cask testing since 1990. (22) The original Nevada proposal called for a five-part approach to full-scale cask testing: 1) meaningful stakeholder participation in development of testing protocols and selection of test facilities and personnel; 2) full-scale physical testing (sequential drop, puncture, fire, and immersion) of each cask design prior to NRC certification or DOE procurement; 3) additional testing (casks, components, models) and computer simulations to determine performance in extra-regulatory accidents and to determine failure thresholds; 4) reevaluation of previous risk study findings, and if appropriate, revision of NRC cask performance standards; and 5) 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 by demonstrating performance and reliability of a cask system.

The authors of this paper recommend that NRC adopt Nevada's revised 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 below.

Stakeholders should have a meaningful role in development of testing protocols & selection of test facilities and personnel

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 (10).

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.

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,

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.

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 (3).

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 onetime cost of about \$10 million would be incurred upgrading the testing facility to lift and drop rail casks weighing up to 170 tons (18). 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 (11).

Table II. 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

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 onetime 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.

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).

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. (26, 27, 28) 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.

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)

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.”

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.”

There is no need at this time to evaluate costs and benefits of destructive testing of a randomly-selected, production model cask.

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. (23)

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, 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.”

CONCLUSION: THE COST OF FULL-SCALE TESTING

The most compelling argument against full-scale cask testing is the cost. However, the cost of the cask itself is the main component. 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.”

In developing a full-scale cask testing program for future shipments, investigators must balance the same three conflicting considerations as they have for every other cask testing program: “exposing the cask to very severe accident environments, amenability of the tests to analyses and scale model testing, and test costs.”

The cost argument against full-scale testing is not compelling when the test costs are compared to the overall cost of a waste disposal 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 onetime 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 spent fuel 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 waste 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. From this perspective, cask testing-done properly- is a bargain.

REFERENCES

1. Public Law 100-203, Nuclear Waste Policy Act as Amended 1987, Washington, DC: U.S. Government Printing Office, December 1987.
2. DOE. Final Supplemental Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca

Mountain, Nye County, Nevada U.S. Department of Energy Office of Civilian Radioactive Waste Management DOE/EIS-0250F-S1 June 2008.

3. NRC. 10CFR 71.71. Available at:<http://www.nrc.gov/reading-rm/doc-collections/cfr/part071/part071-0071.html>
4. NRC. List of Licensed Spent Fuel Transportation Casks.<http://www.federalregister.gov/articles/2008/11/21/E8-27715/list-of-approved-spent-fuel-storage-casks-magnastor-addition>List of NRC licensed casks
5. Desvousges, Kunreuther and Slovic. Public Opinion, Perceived Risk, and Nuclear Wastes: National and Nevada Perspectives. 1992
6. Dunlap, Kraft and Rosa. Public Reactions to Nuclear Waste: Citizen's Views of Repository Siting. Durham, NV: Duke University Press 1993.
7. Binney, Mason, and Martsolf Credibility, Public Trust, And the Transport of Radioactive Waste Through Local Communities. Environment and Behavior, 28 (May 1996), pp. 283-301.1996.
8. Flynn, Mertz and Slovic, Results of a 1997 National Nuclear Waste Transportation Survey. Eugene, OR. Decision Research. 1998.
9. Bisconti, A.S. 1998-2010. Data Listed Back to 1983. Perspectives on Public Opinion Surveys and Public Opinion Polls Sponsored by the NEI. Bisconti Research, Inc.
10. 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).
11. Lindsay Audin, "Nuclear Cask Testing Films Misleading and Misused," NWPO-TN-012-91, Report prepared for State of Nevada, Agency for Nuclear Projects, October 1991.
- 12, 13, 14 NRC cask testing proposals. SECY-04-0029, SECY-04-0135, and SECY-05-0051.
15. Advisory Commission on Nuclear Waste, "Letter from J. Garrick to N.J. Diaz," (July 30, 2004).
16. Secy 05-001. Nuclear Regulatory Commission. "Staff Requirements--Details and Projected Cost of a Demonstration Test of a Full-Scale Spent Nuclear Fuel Rail Transportation Cask Under the Package Performance Study. 2006.
17. NAS, "Going The Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States," Prepublication Release (February 2006)

18. 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.
19. 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.
20. MOUNTAIN WEST RESEARCH, "High-Level Nuclear Waste Transportation Needs Assessment," Prepared for State of Nevada Agency for Nuclear Projects, NWPO-TN-002-089 (1988)
21. 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).
22. 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).
23. M. RESNIKOFF, L. AUDIN, "The Next Nuclear Gamble: Transportation and Storage of Nuclear Waste," New York: Council on Economic Priorities (1983).