

## **IMPLICATIONS OF THE BALTIMORE RAIL TUNNEL FIRE FOR FULL-SCALE TESTING OF SHIPPING CASKS**

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

Fred Dilger (fcd@co.clark.nv.us)  
Clark County Nuclear Waste Division  
Las Vegas, NV 89101

### **ABSTRACT**

The U.S. Nuclear Regulatory Commission (NRC) does not currently require full-scale physical testing of shipping casks as part of its certification process. Stakeholders have long urged NRC to require full-scale testing as part of certification. NRC is currently preparing a full-scale cask-testing proposal as part of the Package Performance Study (PPS) that grew out of the NRC reexamination of the Modal Study. The State of Nevada and Clark County remain committed to the position that demonstration testing would not be an acceptable substitute for a combination of full-scale testing, scale-model tests, and computer simulation of each new cask design prior to certification. Based on previous analyses of cask testing issues, and on preliminary findings regarding the July 2001 Baltimore rail tunnel fire, the authors recommend that NRC prioritize extra-regulatory thermal testing of a large rail cask and the GA-4 truck cask under the PPS. The specific fire conditions and other aspects of the full-scale extra-regulatory tests recommended for the PPS are yet to be determined. NRC, in consultation with stakeholders, must consider past real-world accidents and computer simulations to establish temperature failure thresholds for cask containment and fuel cladding. The cost of extra-regulatory thermal testing is yet to be determined. The minimum cost for regulatory thermal testing of a legal-weight truck cask would likely be \$3.3-3.8 million.

### **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. (1) None of the current cask designs likely to be used for shipments to Yucca Mountain has been tested full-scale. (2) Cask designers are allowed to demonstrate compliance with the NRC performance standards through a combination of scale-model testing and computer simulations. (3)

The State of Nevada, Clark County, other potentially affected state and local governments, Indian tribes, and public interest organizations have long urged NRC to require full-scale testing. (4,5,6) Nevada has specifically proposed full-scale testing, prior to certification, to assure compliance with the sequential impact, puncture, fire, and immersion tests proscribed in the NRC regulations. Nevada has also proposed testing of a sample production model cask. Alternately, Nevada has suggested that the U. S. Department of Energy (DOE) require full-scale testing as part of the cask procurement process for the proposed Yucca Mountain repository transportation system. (7)

NRC is currently proposing demonstration testing of one or more "representative" shipping casks. The proposed testing program is an outgrowth of the Package Performance Study (PPS) being conducted for NRC by Sandia National Laboratories (SNL). NRC commissioned the PPS to update previous studies of spent fuel shipping cask response to severe highway and railway accident conditions. (8)

During 1999 and 2000, the State of Nevada and Clark County actively participated in the PPS meetings and document reviews. Nevada and Clark County advised the NRC that demonstration testing would not be an acceptable substitute for full-scale testing of each new cask design prior to certification. Nevada recommended the PPS instead utilize a combination of half-scale replica cask testing, full-scale component testing, and computer simulations to assess cask performance under extremely severe accident conditions. (9) Both Nevada and Clark County made specific recommendations regarding selection of casks, use of heater elements and fresh fuel, drop test heights, and fire test temperatures, in the event that NRC proceeded with demonstration cask testing. (10,11)

At the time of this writing, February 2003, the NRC is preparing to issue a draft PPS cask testing protocol for public review and comment. (12) The State of Nevada and Clark County remain committed to the position that demonstration testing would not be an acceptable substitute for a combination of full-scale testing, scale-model tests, and computer simulation of each new cask design prior to certification. However, based on analyses of the July 2001 Baltimore rail tunnel fire, both Nevada and Clark County are reexamining the issue of demonstration full-scale testing by NRC as part of the PPS.

In July 2001, a freight train derailment in Baltimore, Maryland, resulted in one of the most severe transportation accidents in recent U.S. history. Analyses of that accident by Nevada consultants and by the NRC both conclude that fire temperatures in the Baltimore rail tunnel reached or exceeded 1500°F, although estimates of the fire duration at this temperature vary from seven hours to more than 24 hours. (13,14) Performance envelope analyses indicate that large rail casks subjected to such fire environments for 20-22 hours could suffer massive failure of cask seals and fuel cladding. A truck cask subjected to the same fire could fail massively in 2-8 hours. (13,15)

The Baltimore Tunnel Fire typifies an extreme accident condition that could occur in a rail environment. It also directs attention to potential truck accidents involving severe fires. Therefore, Nevada and Clark County are now developing a cask testing recommendation to the NRC that addresses cask performance in accident fires significantly more severe than specified in NRC regulations. The intent of this recommendation is to focus scarce testing resources on accident conditions where the most serious damage to a cask can occur.

#### **ABSENCE OF CASK TESTING REQUIREMENTS**

Instead of full-scale testing, the NRC relies upon scale-model testing and computer analysis to assess cask performance under hypothetical accident conditions. (3) 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 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 1/4-scale models. These facts, recently confirmed by NRC Chairman Richard Meserve, (1,2) are summarized in Table 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.” [p.S-40] (16)

Table I. U.S. Commercial Spent Fuel Transport Casks

Certificate Number and Cask Name	Full-Scale Cask Testing	Half-Scale Model Testing	Other Scale-Model Testing	Cask Certified Based on Analysis
6346 & 9277 FSV-1 (Truck)	None	None	None	Yes
9001 IF-300 (Rail)	None	None	None	Yes
9010 NLI-1/2 (Truck)	None	None	None	Yes
9015 TN-8 (Overweight Truck)	None	Drop Tests	¼-scale Drop Tests	Yes
9016 TN-9 (Overweight Truck)	None	None	None	Yes
9200 125-B (Rail)	None	None	¼-scale Drop Tests; Scale-model Impact Limiter Tests	Yes
9202 TN-BRP (Rail)	None	None	1/3-scale Impact Limiter Tests	Yes
9206 TN-REG (Rail)	None	None	None	Yes
9023 NLI-10/24 (Rail)	None	None	Scale-model Impact Limiter Tests	Yes
9225 NAC-LWT	None	None	None	Yes
9226* GA-4 (Truck)	None	Drop Tests	¼-scale Impact Limiter Tests	Yes
9235* NAC-STC (Rail)	None	None	¼-scale Drop Tests; 1/8-scale Impact Limiter Tests	Yes
9253 TN-FSV (Truck)	None	None	½-scale Impact Limiters	Yes
9255* NUHOMS MP187 (Rail)	None	None	1/4-scale Impact Limiters	Yes
9261* Hi-Star 100 (Rail)	None	None	1/4-scale and 1/8-scale Impact Limiters	Yes
9293* TN-68 (Rail)	None	None	1/3-scale Drop Tests; Scale-model Impact Limiters	Yes

\*Cask designs most likely to be used for large shipping campaigns to a disposal facility.  
Ref. 1,2

**ADVANTAGES OF FULL-SCALE CASK TESTING**

In 1993, Sandia National Laboratories (SNL) prepared a report for DOE evaluating technical issues associated with cask testing. (17) SNL specifically addressed the advantages and

disadvantages of full-scale testing compared to scale-model testing. The case for full-scale testing has rarely been stated more clearly. According to the SNL report, "Full-scale package testing has several advantages:

1. For packages tested in full scale, a single test article can be subjected to all normal and hypothetical accident conditions defined by the regulations. The package being tested can be impacted, punctured, and thermally tested in sequence. The data from these tests can directly demonstrate the compliance of a design with the radiological acceptance criteria of 10 CFR 71.
2. Through full-scale testing, a clear characterization can be developed of the behavior of a package when subjected to normal conditions and accident environments. Through this characterization, refinements can be explored which will lead to increased confidence and reliability in the design. This benefit is characteristic of both full- and reduced-scale modeling.
3. Prototypic full-scale package closure and seal response can be directly measured. Because the package is full size, the closure seal response to the different test conditions represents the actual package containment system response.
4. The fabrication of full-scale prototypic hardware allows evaluation and monitoring of the fabrication process before production and manufacturing of several packages. Problems that might not be encountered during a scale-model fabrication can be identified and resolved. Fabrication of a full-scale package also allows an accurate measure of the cost and fabrication schedule.
5. The full scale package could be used to perform operational testing of the system. Engineers can evaluate loading and unloading operations and provide additional information on package performance that can be integrated into the transportation cycle.
6. Data collected during testing, such as acceleration and surface deformations, are direct measurements of the structural response. These direct measurements eliminate the need for scaling relationships based on scale factors, time, or weight.
7. The visual impression of full-scale testing is significant. Photos and videos of full-scale scenario testing of truck and rail systems that were taken for the DOE in the late 1970s are a visual tool for understanding the response of transportation systems in severe accidents. Video tapes of these tests continue to show the robustness of packages almost 15 years later. The size and weight of a large Type B package cannot be visually appreciated in a scale model. There has been some criticism of these scenario tests recently because no clear acceptance criteria for these tests were determined beforehand.

(17)

The 1993 SNL report also addressed the cost issues 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 -40°F or 100°F, 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. [Pp. 12-13] (17)

### **NEVADA PROPOSAL FOR REGULATORY TESTING**

The State of Nevada has proposed a five-part approach to full-scale 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) prior to NRC certification; (3) additional 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. (18)

Comprehensive full-scale testing 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 comprehensive 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. Comprehensive 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 150 tons. Table II summarizes the basis of these cost estimates.

The authors estimated the cost components in Table II based on contractor reports prepared for Nevada and DOE, and personal communications. (5,6,11,15,17,19,20,21,22) Cost of cask acquisition assumed full compliance with NRC quality assurance and quality control procedures, and included delivery to the test facility. Cost of physical testing assumed use of existing facilities in the United States or the United Kingdom. Stakeholder participation costs assumed 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. Test facility upgrading costs assumed use of existing drop test facilities at SNL. 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.

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

By comparison, Nevada estimates the life-cycle cost of the repository transportation system at about \$9.2 billion (1996 Dollars). (23) DOE has estimated that the costs of cleaning up after a worst-case transportation accident could be as high as \$10 billion (2002 Dollars). (16) The additional costs of full-scale cask testing are trivial in the context of the larger DOE program.

#### **BALTIMORE RAIL TUNNEL FIRE**

In July 2001, a CSX freight train derailed in the Howard Street tunnel, Baltimore, Maryland, resulting in one of the most severe transportation accidents in recent U.S. history. Analyses of that accident by Nevada consultants and by the NRC conclude that fire temperatures in the Baltimore rail tunnel probably reached or exceeded 1500°F (815°C). Estimates of the fire duration at this temperature vary from up to seven hours, to more than 24 hours. Because of the severe fire conditions, and because the accident occurred on a potential shipping route to Yucca Mountain, Nevada and NRC separately evaluated the potential consequences of a similar accident involving a rail shipment of spent fuel. (13,14)

The Nevada Agency for Nuclear Projects (NANP) commissioned a study of the July 18-23, 2001 Baltimore accident by Radioactive Waste Management Associates (RWMA). Based on preliminary information, NANP and RWMA hypothesized that the Baltimore accident might be comparable to the Modal Study's category 5 or category 6 accidents. Such an accident could result in a significant release of Cesium-134 and Cesium-137. NANP and RWMA also felt that it was credible to hypothesize that one or more spent fuel casks could have been part of such a train. U.S. Department of Transportation regulations allow spent fuel casks to be shipped in mixed freight trains. DOE has stated that spent fuel could be shipped to the proposed repository in general freight rail service. The accident occurred on a potential rail route, identified by DOE, for shipments from the Calvert Cliffs reactor to Yucca Mountain. (13)

RWMA assembled background information on the Baltimore accident and the surrounding environment. RWMA developed a credible scenario for a hypothetical accident, patterned on the actual event, but including a spent fuel shipping cask. RWMA modeled the radiological consequences and potential cleanup costs resulting from the hypothetical accident.

RWMA concluded that Baltimore fire burned for three days with temperatures as high as 1500°F. These conditions were consistent with a hypothetical accident fire environment, based on the Modal Study (category 6), sufficient to cause a loss of cask containment, and a significant release of radioactive cesium. RWMA evaluated the potential consequences of an identical accident

involving two different rail cask designs (steel-lead-steel and monolithic steel), loaded with 10 year-cooled spent fuel from Calvert Cliffs. RWMA assumed a spent fuel gap inventory of 9.9 percent for radioactive cesium. RWMA used the RISKIND and HOTSPOT computer models, weather data from Baltimore-Washington International Airport, and Baltimore population data from the 1990 and 2000 Census. (13)

Regarding the fire characteristics most relevant to performance of the cask and spent fuel cladding, RWMA concluded: "Evidence suggests that the fire burned at temperatures exceeding the regulatory fire for an extended period of time, perhaps 24 hours or more, since the presence of orange-hot rail cars suggests they reached temperatures of 1,200-1,800°F. Further, the tripropylene tanker car, which was believed to be the source material for the hot-burning fire, was completely empty when it was removed from the tunnel." [p.9] (13)

Using the NUREG/CR-6672 temperature thresholds for performance of rail casks in a regulatory fire, RWMA estimated that the steel-lead-steel cask internal temperature would reach 750°C (1382°F) in about 6.3 hours. The monolithic steel cask internal temperature would reach 750°C (1382°F) in 11-12.5 hours. At temperatures greater than 750°C, fuel rods would begin to fail by burst rupture. Failure of fuel rods by creep rupture, and failure of the cask seals, would have already occurred. RWMA summarized: "In our opinion the fire burned long enough and hot enough to reach the maximum threshold whether we use the assumptions of the Modal Study or NUREG/CR-6672." [p.11] (13)

The maximum release of radioactive materials would have occurred, according to RWMA, "between 5 and 12.5 hours after initiation of the fire, depending on the cask type." [p.11] Using the cesium gap inventory estimates developed by Pacific Northwest Laboratories for DOE, RWMA calculated a release of 5,000 curies of Cesium-134, and 68,000 curies of Cesium-137. RWMA assumed that 50 percent of the material released from the cask would remain inside the tunnel, and modeled downwind dispersion of the other 50 percent as "a puff release being released equally from the North and South ends of the tunnel." [p.11] (13)

Because the plume from the South end would directly impact PCINet Stadium, home of the Baltimore Ravens football team, RWMA calculated two population exposure scenarios, one including consequences if the accident occurred during a Ravens home game. RWMA also calculated two population exposures using the 1990 and 2000 Census. The more detailed 1990 population data was used to calculate exposures, then adjusted downward 11.5 percent to reflect the Baltimore population decline between 1990 and 2000.

Table III presents the radiological impacts for short-term (24-hour) exposure, 1-year exposure, and 50-year exposure. Table IV shows the RWMA estimate of cleanup costs. The RWMA exposure estimates assume no evacuation or cleanup, in order to provide a bounding result.

Table III. Impacts of Hypothetical Baltimore Tunnel Fire with Spent Fuel Cask

	Exposure to Baltimore Residents	Exposure at PCINet Stadium if filled to capacity during incident
Affected Population, 1990 (2000)	390,388 (345,493)	69,400
Area with acute dose of at least 10 mrem	11.0 km <sup>2</sup>	11.0 km <sup>2</sup>
Max. Downwind Distance of 10 mrem acute dose plume	6.8 km	6.8 km
Area with acute dose of at least 1 mrem	173 km <sup>2</sup>	173 km <sup>2</sup>
Max. Downwind Distance of 1 mrem acute dose plume	38.7 km	38.7 km
Acute Population Dose, 1990 (2000) [person-rem]	17,509 (15,495)	38,170
Range of Estimated Excess Latent Cancer Fatalities from Acute Dose, 1990 (2000)	9-56 (8-50)	19-122
1-Year Population Dose, 1990 (2000) [person-rem]	495,498 (438,516)	--
Range of Estimated Latent Cancer Fatalities from 1-year Dose, 1990 (2000)	248-1,586 (219-1,403)	--
50-Year Population Dose, 1990 (2000) [person-rem]	9,944,974 (8,801,302)	--
Range of Estimated Latent Cancer Fatalities from 50-year Dose (2000)	4,972-31,824 (4,401-28,164)	--

Ref. 13

Table IV. Decontamination Cost Estimates: Hypothetical Baltimore Tunnel Fire with Spent Fuel Cask

Area heavily contaminated (km <sup>2</sup> )	9.9
Area moderately contaminated (km <sup>2</sup> )	10
Area lightly contaminated (km <sup>2</sup> )	62.4
Cost/km <sup>2</sup> , heavy contamination	\$394,604,748
Cost/km <sup>2</sup> , moderate contamination	\$182,592,165
Cost/km <sup>2</sup> , light contamination	\$128,263,609
Total Cleanup Costs*	\$13.7 billion

\*Total cleanup costs are the sum of light, moderate and heavy cleanup costs, all in 1995 dollars.

Ref. 13

RWMA concluded that the contamination resulting from the release would cause a policy-maker's nightmare. On the one hand, the cost of cleanup could be \$13.7 Billion. On the other



hand, failure to cleanup could result in up to 1,580 latent cancer fatalities over one year, and up to 31,800 latent cancer fatalities over 50 years. "The potential health and economic consequences ... presented ... give some indication of the tradeoff likely to take place between preventing future health effects and expending [a] large amount of money to properly remediate a large area." [p.16](13)

At the time of this writing, February 2003, the Baltimore rail tunnel fire is still being investigated, and full details of the fire history may never be known. Because of potential litigation, the authors are precluded from commenting upon the NRC studies. However, the following aspects of the Baltimore accident, and the controversy over its fire history, have major implications for the full-scale, cask testing program proposed by the NRC.

First, the Baltimore fire illustrates the potential for real world fires that could result in significant release of radioactive materials from a shipping cask. It is possible that a rail tunnel fire could burn at 1500°F (815°C) for 24 hours or more. Performance envelope analyses indicate that an intact (undamaged) rail cask involved in such fire environments (temperature exceeding 800°C) for 24 hours could experience massive failure of cask seals and fuel pellet cladding. The same analyses indicate that shorter fires at higher temperatures, for example, 13 hours at 1000°C, or 7 hours at 1300°C, could also cause massive failure of an undamaged rail cask. If the accident involved structural damage to the cask neutron shield or impact limiters as well as fire, cask failure could occur in substantially shorter or lower-temperature fires. (15)

Second, each new-generation rail cask shipped to a repository or disposal facility would contain an enormous inventory of dangerous radionuclides. While larger cask payloads would reduce the total number of shipments, the potential radiological hazard associated with each cask-shipment would increase. For shipments to Yucca Mountain, DOE assumes that the average age (cooling time) of spent fuel would be about 23 years. The average rail cask shipped to the repository would contain a total inventory of 2.1 million curies, including 816,000 curies of Cesium-137. Repository shipments could include 10-year cooled spent fuel, which would pose more than twice the radiological hazard of the average shipment. (16,18)

Third, rail accidents involving long duration, high-temperature fires, represent the most severe potential accident consequences identified by DOE and Nevada. (11,13, 16, 24,25,27,28) Such accidents could result in a substantial respirable release of radioactive cesium, and wide dispersion of radioactivity by way of the fire smoke plume and concurrent meteorological conditions. The most severe accident evaluated by DOE in the Draft EIS for Yucca Mountain was a rail accident in an urban area that inflicted a 61,000 person-rem collective population dose and caused about 31 latent cancer fatalities. (25,18) In the Final EIS, DOE reduced its rail accident radiological consequence estimate to 9,900 person-rem and 5 latent cancer fatalities, but still acknowledged that clean-up costs following a worst case transportation accident could reach \$10 billion. (16,18) Nevada studies estimated that a credible severe rail accident could cause hundreds to thousands of latent cancer fatalities in urban area, and hundreds of latent cancer fatalities in a rural area. (28)

Fourth, the furious debate over the Baltimore fire, and the analytical tools used to evaluate the fire, remind us that there is a serious lack of measured data on rail cask performance in severe fire environments. The last full-scale, rail cask fire test in the U.S. was performed almost 25 years ago, on an obsolete rail cask built to standards more stringent than today's. In that test, the lead shielding began to fail after about 100 minutes. (6) Scale-models are not generally recommended for thermal tests, because "the relationships for hypothetical fire events are not easily scaled." (17) The computer codes used for thermal analysis have been validated by tests using large

calorimeters or full-scale components of casks, not full-scale casks. (15) Many experts, including consultants for the NRC, DOE, and Nevada, agree that there is little useful physical data available on cask performance in severe fires, and agree that thermal testing of full-scale casks to obtain such data would be desirable. (6,8,9,11,20,29,30)

### **PROPOSAL FOR EXTRAREGULATORY TESTING**

During the preliminary phase of the Package Performance Study (PPS), 1999 - 2000, the NRC repeatedly acknowledged the importance of establishing stakeholder confidence in the PPS study process and in its findings. The upcoming PPS testing program could provide an important opportunity for NRC to demonstrate its commitment to stakeholder participation. Yet the NRC has still not issued the draft PPS testing protocol for public review and comment, as promised in June-July, 2002, nor has NRC rescheduled the promised PPS public meetings in Nevada, originally planned for August-September, 2002. On the other hand, it appears that NRC presented "draft pre-decisional" PPS testing protocols to the Commission's Advisory Committee on Nuclear Waste (ACNW) in June 2002. This document has not been provided to the stakeholders who previously participated in the PPS public meetings. (31)

The State of Nevada and Clark County plan to review and formally comment upon the PPS test protocols as soon as NRC makes them available. In the meantime, the following recommendations are offered regarding the proposed PPS cask tests.

#### **Stakeholder Participation**

The 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 has relevance to real world conditions is include the full range of affected stakeholders.

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, that likely would not have been found absent the involvement of these "outside" participants. (19)

#### **Selection of Cask Testing Facilities**

The NRC, with stakeholder input, must fully consider all options before selecting cask testing facilities. Press reports state that NRC has already selected Sandia National Laboratories (SNL) in New Mexico "because it was the only facility capable of challenging the containers." (32) While SNL has extensive testing experience, other competent facilities are available. Indeed, SNL has identified 12 facilities in United States with various capabilities for testing 40-ton and 100-ton containers. (17) A report prepared for Nevada identified 5 potential testing facilities in the United States, 2 in the United Kingdom, and 1 in Canada. (19)

Before a final selection of test facilities, NRC should discuss all relevant issues and options 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. (15,17,19,22) These factors, plus the potential multi-million 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.

### **Selection of Casks to Be Tested**

The NRC should test the actual cask designs most likely to be used for spent nuclear fuel and HLW shipments to the proposed Yucca Mountain repository. A legal-weight truck cask should be tested, since legal-weight truck is the only transport mode for Yucca Mountain that is currently feasible. All 72 power plant sites and all 5 DOE sites can ship by legal-weight truck. (16) At present, there is no railroad access to Yucca Mountain, and the feasibility of long-distance heavy haul truck (HHT) transport of rail casks in Nevada is unproven. (28)

Based on the information presented in DOE's Final EIS for Yucca Mountain, the General Atomics GA-4 cask, designed to transport 4 PWR assemblies, is the most appropriate choice for testing. The GA-4 could be used for about two-thirds of all shipments under DOE's "mostly legal-weight truck" national shipping scenario. (16) However, availability and cost of the GA-4 are uncertain. To our knowledge, no full-scale GA-4 casks have yet been fabricated, although NRC has certified the design. Lead-time from GA-4 purchase to delivery is unknown, but if similar to other truck cask options, it could be 2 years or more. (15) Delivered cost could exceed the \$2.75-3.25 million estimated in Table II.

Selection of the rail cask for PPS testing should be deferred until after discussions with DOE, cask suppliers, and the affected stakeholders. Considering the potential impacts of an accident similar to the Baltimore tunnel fire, early selection of the most appropriate rail cask is crucial to the credibility of the PPS testing program. This choice is also important because of DOE's stated intention to maximize use of rail, even though DOE has not yet demonstrated the feasibility of the "mostly rail" shipping scenario for Yucca Mountain. NRC has identified four currently licensed rail cask designs as "most likely to be used" for repository shipments – the NAC-STC, NUHOMS MP187, Hi-Star 100, and TN-68. (1,2) Although similar in overall dimensions, gross weight (125-141 tons) and payload capacity, these four rail casks exhibit differences in design that should be fully evaluated before selection of a test subject. Cost and availability of these casks may constrain selection. Other designs may also merit consideration. One of the first orders of PPS business should be development of substantive decision criteria and standards, and a realistic schedule for selection of a rail cask.

### **Selection of Test Scenarios**

The authors strongly urge the NRC to give highest priority to extra-regulatory fire testing of an appropriate truck cask and an appropriate rail cask. A credible, severe accident fire could cause massive failure of both the cask and its contents, resulting in widespread dispersal of radioactive materials in a respirable form, followed by deposition and long-lived contamination. Equally important, very severe accident fires are perceived to be exceedingly dangerous, especially when they occur in highly populated areas. The PPS testing program will provide the NRC a rare opportunity to address both the technical and the perceived dimensions of transportation risk.

The authors plan to offer more specific details for extra-regulatory fire testing after reviewing the NRC's draft PPS test protocols, and after discussing the test protocols with affected stakeholders. For now, the authors reiterate that the preferred approach to assessing package performance should be a combination of computer analyses and full-scale cask testing, supplemented by scale-model testing, full-size component testing, and spent fuel testing. NRC and stakeholders need to address the following issues before PPS testing plans are finalized:

1. Computer simulations prior to testing;

2. Temperature and duration of thermal test, and duration of cool-down period;
3. Extent of damage to cask, from impact and puncture, prior to thermal tests;
4. Loading of cask with fresh fuel and heaters;
5. Cask instrumentation;
6. Test documentation;
7. Peer review; and
8. Costs.

To date, there has been little discussion about the availability of funding for the PPS testing program, or the extent to which design of the PPS testing program will be constrained by cost. The managers of the 1977 Sandia crash tests wrote: "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." (21) A recent report for Nevada estimated that the minimum cost of a regulatory fire test, using a purchased truck cask, would be \$3.3 to 3.8 million. (15)

### **CONCLUSIONS**

Over the next 40 years, the overwhelming majority of spent nuclear fuel and high-level radioactive waste shipments in the US, would be shipments to the proposed Yucca Mountain repository. Shipment of these wastes would be a highly visible, difficult, and expensive endeavor. The truck and rail casks used for these shipments should be tested full-scale. The most reasonable course of action would be to test each cask design, full-scale, to demonstrate compliance with existing regulations. In addition to regulatory testing, full-scale demonstration or research testing should be conducted to investigate failure thresholds and evaluate safety margins. In both instances, full-scale testing must be supported by computer analyses, and supplemented by scale-model testing and component testing. It is a false dichotomy to pit full-scale testing against other types of tests and analyses. Ultimately, an extensive cask testing and analysis program will offer the best chance to evaluate the design and fabrication of all of the transportation system components, improve equipment designs to increase safety and ensure efficient operations, and to demonstrate safety to the public and stakeholders.

### **REFERENCES**

1. NRC, "Table of Commercial Spent Fuel Transport Casks," Enclosure 1, Correspondence from R.A. Meserve, NRC Chairman, to The Honorable H. Reid, United States Senate (April 2, 2002).
2. NRC, "Test Details for Certain Spent Fuel Transport Casks," Enclosure, Correspondence from R.A. Meserve, NRC Chairman, to The Honorable H. Reid, United States Senate (April 24, 2002).
3. NRC, "Physical Testing of Spent Fuel Transport Casks," Enclosure 2, Correspondence from R.A. Meserve, NRC Chairman, to The Honorable H. Reid, United States Senate (April 2, 2002).
4. R.J. HALSTEAD, R. DiBARTOLO, "State of Nevada Nuclear Waste Shipping Cask Design Studies," High-Level Nuclear Waste Management, Proceedings of the International Topical Meeting, Las Vegas, NV, Vol. 1, 465-473 (April 8-12, 1990)
5. 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).

6. L. AUDIN, "Nuclear Cask Testing Films: Misleading and Misused," NWPO-TN-012-91, Prepared for NANP (October 1991).
7. R.J. HALSTEAD, "Nuclear Waste Transportation: Key Policy Issues & Recommendations," Presentation to DOE OCRWM Transportation Workshop, Dallas, TX (August 7, 1997).
8. D.J. AMMERMAN, ET AL, "Spent Nuclear Fuel Transportation Package Performance Study Issue Report," Prepared by SNL for NRC (June 30, 2000).
9. R.J. HALSTEAD, "Comments Regarding the NRC Study Assessing Risks of Spent Nuclear Fuel Transportation Accidents (Modal Study Update)," Henderson, Nevada (December 8, 1999).
10. NANP, "Comments on Spent Nuclear Fuel Transportation Package Performance Study Issue Report," (September 29, 2000).
11. M. LAMB, M. RESNIKOFF, "Review of NUREG/CR-6672, Reexamination of Spent Fuel Shipment Risk Estimates," Prepared for Clark County, Nevada, by Radioactive Waste Management Associates (October 2000).
12. F.X. CAMERON, Personal Communication (February 4, 2003).
13. M. LAMB and M. RESNIKOFF, "Radiological Consequences of Severe Rail Accidents Involving Spent Nuclear Fuel Shipments to Yucca Mountain: Hypothetical Baltimore Rail Tunnel Fire Involving SNF," Prepared by Radioactive Waste Management Associates for NANP (September 2001). This and other reports prepared for NANP can be accessed on the web at <http://www.state.nv/nucwaste/trans.htm>.
14. C.S. BAJWA, "An Analysis of A Spent Fuel Transportation Cask Under Severe Accident Conditions," Prepared for NRC (September 2002).
15. M. GREINER, "Spent Nuclear Fuel Shipping Cask Performance in Severe Accident Fires: Performance Envelope Analysis, Fire Test Modeling, and Full-Scale Physical Testing," Prepared by University of Nevada, Reno, for NANP (July 20, 2000).
16. DOE, "Final 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," DOE/EIS-0250 (February 2002). (Available on the web at [http://www.ymp.gov/documents/feis\\_a/index.htm](http://www.ymp.gov/documents/feis_a/index.htm)).
17. 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).
18. "Testimony of Robert J. Halstead, on Behalf of the State of Nevada, before the Committee on Energy and Natural Resources, United States Senate, May 22, 2002."

19. D.F. SNEDEKER, "Nuclear Waste Transportation Package Testing: A Review of Selected Programs in the United States and Abroad," NWPO-TN-004-90, Prepared for NANP (December 1990).
20. R.A. WIRTZ, ET AL, "Nuclear Waste Transportation Cask Accident Testing: Annual Report," Prepared for DOE by University of Nevada, Reno (February 1995).
21. R.M. JEFFERSON and H.R. YOSHIMURA, "Crash Testing of Nuclear Fuel Shipping Containers," SAND-77-1462C (August 1977).
22. M.M. WARRANT, Personal Communication (February 21, 1990).
23. PLANNING INFORMATION CORPORATION, "An Independent Cost Assessment of the Nation's High-Level Nuclear Waste Program," Prepared for NANP (February 1998).
24. G.M. SANDQUIST, ET AL, "Exposures and Health Effects from Spent Fuel Transportation," RAE-8339/12-1, Prepared for DOE by Rogers & Associates Engineering Corporation (1985).
25. DOE, "Draft 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," DOE/EIS-0250 (1999).
26. J.L. SPRUNG, ET AL, "Reexamination of Spent Fuel Shipment Risk Estimates," NUREG/CR-6672, SAND2000-0234, Prepared by SNL for NRC (March 2000).
27. M. LAMB, M. RESNIKOFF, R. MOORE, "Worst Case Credible Nuclear Transportation Accidents: Analysis for Urban and Rural Nevada," Prepared by Radioactive Waste Management Associates for NANP (February 2002).
28. "A Mountain of Trouble: Report on Impacts of the Proposed Yucca Mountain High-Level Nuclear Waste Program," Prepared for NANP (February 2002).
29. D. AMMERMAN, "Summary of Sandia National Laboratories Research," Presentation to NRC Advisory Committee on Nuclear Waste, Transportation Working Group Workshop, Washington, DC (November 19, 2002).
30. L. FISCHER, "Summary of Lawrence Livermore National Laboratory Research on Transportation," Presentation to NRC Advisory Committee on Nuclear Waste, Transportation Working Group Workshop, Washington, DC (November 19, 2002).
31. NANP, Correspondence from Robert L. Loux to Richard Meserve (December 9, 2002).
32. "NRC Plans Tests on Nuclear Waste Shipping Containers," Las Vegas Sun (November 15, 2002).