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PLANNING FOR AN UNPREDICTABLE EVENT: VULNERABILITY AND CONSEQUANCE REASSESSMENT OF ATTACKS ON SPENT FUEL SHIPMENTS

Robert J. Halstead (bearhalstead@aol.com)
State of Nevada Agency for Nuclear Projects
Carson City, NV 89706

James D. Ballard, Ph.D. (ballard@csun.edu)
Department of Sociology, California State University, Northridge
Northridge, CA 91330-8318

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

ABSTRACT

This paper offers a summary of DOE, NRC, State of Nevada, and other scholarship that demonstrates both vulnerability and significant consequences relative to potential terrorist attacks on shipments of SNF and HLW. The paper offers suggestions for future response planning and training, recognizing the profound changes that have resulted in the post-September 11, 2001 social world.

INTRODUCTION

Planning emergency response to any low probability, high consequence event, is inherently difficult. Preparation for emergency response to a terrorist attack on a spent nuclear fuel shipment, an unusual event to emergency responders, is complicated by differing assessments of the likelihood and potential consequences of a successful attack. Yet emergency response organizations routinely plan and train for unusual events despite their apparent unpredictability. Relevant examples may include earthquakes, hurricanes, floods, tsunamis, mass fires, and any number of large scale socially disruptive events.

Emergency response planners and trainers should assume that a successful terrorist attack on a spent fuel shipment could result in a significant release and dispersal of radioactive material so that they can field response protocols like the unified command structure under the most realistic and pragmatic conditions they are likely to face. This preplanning and advanced training is necessary and warranted despite differential assessment of the potential for an attack and varying assessments of the consequences of a human initiated event involving spent nuclear fuel (SNF) and high-level radioactive waste (HLW) shipments.

The advice is based on years of scholarship on the subject and advice from various government agencies. For example, the United States General Accounting Office (GAO) recently concluded: “NRC and DOE studies show a low likelihood of widespread harm to human health from terrorist attacks or severe accidents involving spent fuel."(1) However, the U.S. Department of Energy (DOE), in its Final Environmental Impact Statement (Final EIS) for the Yucca Mountain repository, took the position that it "is not possible to predict whether sabotage events would occur and, if they did, the nature of such events."(2) Yet, this same DOE report concluded that a successful attack in an urban area could cause dozens of latent cancer fatalities, clearly a significant consequence. Likewise, State of Nevada contractor studies[a] found a credible attack scenario could result in substantially greater human health effects and sizable cleanup costs than even DOE acknowledged. (3) This paper documents some of the issues associated with the transportation of highly radioactive materials like SNF and HLW as a means to assist policy planners and emergency response professionals in the understanding of vulnerabilities and consequences of potential terrorist attacks against shipments of these materials.

SPENT NUCLEAR FUEL SHIPMENTS AS TARGETS FOR ATTACKS

At the present time, SNF shipments occur relatively infrequently in the United States. Should a Federal repository begin operations at Yucca Mountain, the numbers and characteristics of annual domestic SNF and HLW shipments would change dramatically? Additionally, significant increases in the number of shipments of these materials would occur if one or more, national or regional, interim storage facilities were to begin operations, with or without a Federal repository at Yucca Mountain. The resulting large-scale, long-distance, national level transport of SNF and HLW to either a permanent geologic repository or an interim storage site would create new and difficult to predict opportunities for terrorism against such radioactive material shipments. Some of the salient issues relative to new transportation circumstances are noted in the sections that follow. (4, 5)

Even under the most optimistic version of the DOE "mostly rail" shipment scenario to Yucca Mountain, over a period of 24 years there would be on average one or two train shipments (three casks per train) per week, and three or four truck shipments (single cask per truck) per month, once repository operations begin. Under other scenarios, the number of shipments could be much greater, up to six shipments per day under the mostly truck scenario. For all scenarios, the average shipment distance would be more than 2,000 miles. (2)

Using the mostly rail scenario and the representative routes in the Final EIS, state level emergency planners could expect about one train-load per week from the Chicago area to Nevada, plus another train-load per week from the Midwest, Northwest, or West. In addition, planners could expect about four truck shipments per month from reactors in Florida, New York, or Minnesota. Transit times for train shipments would likely be 50-80 hours under expedited arrangements, and 40-60 hours for truck shipments. In addition, there would 80 heavy haul truck and/or barge shipments per year from the 24 reactor sites that lack rail access. Barge shipments could occur in or near the ports of Boston, New York, Wilmington, Baltimore, Norfolk, and Miami. (2)

These numbers translate into a reality that few emergency managers have planned for to date: Every day, loaded casks of SNF or HLW would be moving somewhere in the United States. Every 2-4 days, shipments would be arriving in, and traveling through, Nevada by truck and/or rail. The result would a totally new and enormous security and emergency response challenge for Federal, state, local, and tribal authorities.

The authors have previously argued that DOE SNF and HLW shipments to a centralized, national facility (e.g., Yucca Mountain) would likely be viewed by terrorists as a highly desirable symbolic target. (8, 18, 24) This assessment reflects the findings of DOE-supported research on the symbolic value of DOE nuclear facilities as terrorist targets. (12, 13) Reflecting a similar sentiment, John Ritch, Director General, of the World Nuclear Association, recently described the symbolic value of nuclear reactor accidents, and the need to prevent accidents through collective safety efforts, by stating that in the world today, an accident anywhere would be viewed as an accident everywhere. (27) Similarly, the authors believe that a successful terrorist attack on a SNF shipment anywhere would be viewed as a successful attack on shipments everywhere.

SHIPPING CASK CERTIFICATION

Under current U.S. laws and regulations, all shipments of SNF and HLW, including shipments by the DOE, must use shipping containers certified by the U.S. Nuclear Regulatory Commission (NRC). None of the shipping casks currently used in the United States, and none of the casks that could be used for waste shipments to the proposed Yucca Mountain repository in Nevada, or to the proposed Private Fuel Storage facility in Utah, has been subjected to full-scale tests. 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. NRC does not require full scale testing of these casks, and none of them have been tested full-scale to demonstrate their ability to survive severe accident conditions or terrorist attacks. (6)

Instead of full-scale testing, the NRC relies upon scale model testing and computer analysis to assess cask performance under hypothetical *accident* conditions. However, many experts believe that such simulations must be validated with full scale testing before reliance can be placed in said computer analysis based on the scale models. To date, none of the casks that could be used for waste shipments to Yucca Mountain or other facilities has been subjected to full-scale tests representing the hypothetical accident conditions specified in NRC regulations. (6) To date, NRC has no specific cask performance standards regarding terrorist attacks, (7) despite decades-long advocacy by the State of Nevada (8) and other researchers. (9) Actual test data would enable more realistic terrorism related research on shipment vulnerabilities and attack consequences, much like that conducted in a recent North Atlantic Treaty Organization (NATO) working group report[b] on the safety and security of nuclear power plants and waste shipments. (10)

SHIPPING CASK CONTENTS

SNF, or irradiated reactor fuel, remains dangerously radioactive for many decades. These assemblies represent the majority of the materials to be shipped across the country to a repository and/or an interim storage facility. Irradiated fuel assemblies contain a large inventory of dangerous radionuclides, including strontium-90 (half-life 28 years), cesium-137 (half-life 30 years), and cobalt-60 (half-life 5 years). Even after 50 years of cooling, the surface dose rate of the typical spent fuel assembly is in excess of 8,000 rem/hour, (11) an exposure rate that is sufficient, absent shielding, to deliver a life-threatening acute radiation dose in less than 5 minutes.[c]

For shipments to the proposed Yucca Mountain repository, DOE assumed in the Final EIS,[d] that commercial SNF would have an average age of about 23 years. Each rail cask of spent fuel shipped to the repository would contain, on average, a total radionuclide inventory of 2.1 million curies, including 816,000 curies of Cesium-137. The average truck cask would contain about one-sixth as much SNF as the rail cask (355,000 curies total activity, including 136,000 curies of Cesium-137). (2)

For accident and sabotage consequence analysis, DOE assumed in the Yucca Mountain Final EIS, that shipping casks would be loaded with SNF aged 14-15 years, which would nearly double the radiological hazard, compared to average SNF noted above. (2) However, repository shipments could include 5-year cooled SNF in truck casks and 10-year cooled SNF in rail casks, resulting in even greater radiological hazards than those DOE evaluated for accident and sabotage consequences. Thus, the cask inventory characteristics must be addressed in assessments of consequences and perhaps even vulnerabilities.

CASK VULNERABILITY

Regarding cask vulnerability, one frequently-cited article asserts: "Only the latest antitank artillery could breach them [shipping casks], and then the result was to scatter a few chunks of spent fuel onto the ground." (14) This assertion is misleading and inaccurate, given the state of the art of tactical knowledge and the weapon capabilities of terrorists. Additionally, such a comment shows ignorance of even the most readily available public scholarship on the subject.

In fact, twenty years of tests and studies have demonstrated the vulnerability of casks to a broad range of potential terrorist weapons and tactics. According to studies sponsored by DOE and NRC in the 1980s, an off-the-shelf, Korean War-era, military demolition charge could breach the wall of a truck cask, deeply penetrate the cask interior, and eject one-percent of the spent fuel cargo, including a small but dangerous respirable release. (15, 16)

U.S. Army peer review of these studies confirmed the findings and added that the reference weapon would completely perforate current-generation truck casks (which have thinner walls than the obsolete cask that was used during this test) and that the use of typical military tactics that involve two explosive devices, one to breach the cask wall and another to disperse the cask contents, could significantly increase the amount of radioactive materials released. (17)

Other reviewers of the DOE- and NRC-sponsored reports commented that commercial shaped charge explosives and military antitank weapons could cause equal or greater damage to a cask and its contents, and that the release and dispersion of radioactive materials could be greatly increased if coupled with the use of incendiary devices. (18)

In 1999, DOE sponsored a study of cask sabotage by Sandia National Laboratories (SNL) in support of the Draft EIS for Yucca Mountain. (19) SNL re-evaluated the earlier tests, albeit apparently also without incorporating the Army peer review findings. SNL also conducted additional simulations and analyses of a second device type (anti-tank weapon), but did not perform any additional full-scale or scale model tests, nor report findings relative to the results of such an attack using a secondary device, or multiple devices. Despite this omission, this research concluded both truck and rail casks could be breached by means of a single stage attack.

To summarize, SNL confirmed that the casks are vulnerable to a breach from military shaped charges and antitank weapons. SNL concluded that the respirable release would be six times larger than previously reported, due mainly to blowdown from the pressurized fuel rods. The SNL study also found that if the weapon used fully perforated the cask, the amount of respirable radioactive material released could be ten times greater than even these new release estimates. (20)

In 1998, an additional demonstration of cask vulnerability was sponsored by a private company, International Fuel Containers, Incorporated, (IFCI) at the U.S. Army Aberdeen Test Center.[e] In that test, U.S. Army experts demonstrated that a static mounted TOW missile warhead could breach a large, nodular cast iron cask, of the type currently used for SNF storage and rail transport in Europe. (21) While the European cask that was tested is not certified for transport use in the U.S., it is similar to the new US rail casks in its overall design, wall thickness, and capacity.

A study prepared for the State of Nevada evaluated the ICFI test scenario, and compared vulnerability of cask walls constructed of iron, steel, and steel-lead-depleted uranium. This study concluded the new U.S. casks being designed for rail shipments to Yucca Mountain or PFS would be equally vulnerable to an attack using a TOW missile, and that the TOW missile would be expected to completely perforate the truck cask design assumed for Yucca Mountain shipments. (22)

The Sandia and ICFI tests, and the DOE- and NRC-sponsored analyses, support the conclusion that shipping casks are vulnerable to attack. Yet both the tests and the analyses are based on what may be outdated assumptions. They assume what military and civilian experts may rightfully deem to be less than realistic attack scenarios in the post-September 11, 2001 world of terrorism. The notion of a small group of attackers using a single shaped charge against a cask may reflect pre-September 11, 2001 threat assessment philosophy. Such thinking fails to recognize the possibility and potential effect of an attack conducted by a relatively large number of perpetrators who could use asymmetrical tactics and/or various combinations of weapons (for example, to breach the cask and disperse its contents as suggested in the 1983 Army peer review document).

Recently completed, but not yet publicly available, a NATO study assesses several updated attack scenarios and analyses of cask vulnerabilities. (10) Based on the NATO study and other published sources, the authors of this paper believe that even the two phase attack described in the U.S. Army 1983 peer review report may underestimate current technical planning knowledge and tactical capabilities of known terrorist organizations in Chechnya, Iraq, and elsewhere. The NATO study on the other hand divides the tactical aspects of a potential attack against nuclear waste transports into three phases: isolation events (stopping the transport vehicle – rail or highway); breach events (penetration or perforation of the cask); and dispersal events (use of a secondary device or devices to disperse cask contents). Combinations of these three phases should be expected, since they represent basic military tactics and knowledge currently available in many parts of the world, and to many adversaries, both foreign and domestic.

Future assessments of cask vulnerability must carefully consider both current and projected intentions and capabilities of potential adversaries. More realistic assessments must evaluate complex attack scenarios specifically designed to breach a cask and disperse its contents, especially if the perpetrators are willing to use suicide tactics and/or have insider knowledge of shipments. The current threat profile is focused primarily on foreign and Islamic sources, but this may change significantly over the decades-long time frames for transportation to Yucca Mountain or other facilities. Threat profiles must not ignore domestic terrorists, especially those who have military training combined with hostility towards Federal assets and programs. Assessments must also be continuously updated, to ensure that they accurately reflect the best available information.

CONSEQUENCES OF ATTACK

The consequences of a successful terrorist attack using explosives against a shipping cask have been debated for more than two decades. In 1984, the NRC concluded that that the expected consequences of a successful attack in "a heavily populated area such as New York City would be no early fatalities and less than one (0.4) latent cancer fatality." NRC then issued a proposed rule eliminating physical protection requirements (10CFR73.37) for most spent fuel shipments. (16) Three years later NRC terminated the proposed rule without explanation, but throughout the 1990s the NRC continued to downplay attack consequences in its public information pamphlets. (18) The 2002 Chapin article in Science sums up the prevailing nuclear industry view of attack consequences: "There seems to be no reason to expect harmful effects of the radiation any significant distance from the cask." (14)

Yet studies sponsored by DOE, NRC, and the State of Nevada (previously noted above), all indicate that major radiological health impacts could be caused by the downwind dispersion of respirable material (mainly particles with a diameter less than 10 microns) that could be ejected from the cask. Depending upon the meteorological conditions present at the time of an attack, the respirable aerosol of radioactive materials could affect an area of 10 square kilometers (3.9 square miles) or more.

The highly radioactive larger fragments, those "chunks of spent fuel" referred to earlier, would contaminate the area within 100 meters of the attack site (about 8 acres), but are not included in the NRC and DOE consequence assessments. (3, 18) Moreover, all of the previous consequence assessments cited in this paper were restricted to single-phase attack scenarios, and thus did not consider the consequences of combining a dispersal device with a breaching device, nor did these consequence assessments consider multiple penetration points.

DOE acknowledged that shipping casks are vulnerable to terrorist attack in both the 1999 Draft EIS for Yucca Mountain (19) and in the 2002 Final EIS for Yucca Mountain. (2) Additionally, in support of the Draft EIS, DOE sponsored a 1999 study of cask sabotage by SNL. (20) According to the Draft EIS, the SNL study demonstrated that high-energy devices (HEDs) were "capable of penetrating a cask's shield wall, leading to the dispersal of contaminants to the environment." The SNL study also concluded that a successful attack on a truck cask could release more radioactive materials than an attack on a rail cask, even though rail casks would contain, on average, up to six times more SNF than truck casks.[f]

In the Final EIS, DOE updated its sabotage analysis, assuming more highly radioactive SNF, a larger respirable release, and a higher future average population density for U.S. cities. The Final EIS estimated that a successful attack on a GA-4 truck cask in an urbanized area under average weather conditions would result in a population dose of 96,000 person-rem and 48 latent cancer fatalities. For a successful attack on a large rail cask, DOE estimated a population dose of 17,000 person-rem and 9 latent cancer fatalities.[g] In neither case did DOE evaluate any environmental impacts other than health effects, and ignored the economic impacts of a successful act of sabotage. While the DOE did not specifically estimate cleanup costs after such an attack, the FEIS states that clean-up costs following a worst-case transportation accident could reach $10 billion.[h]

Analyses prepared for the state of Nevada by Radioactive Waste Management Associates (RWMA) calculated that sabotage impacts could be considerably greater than those estimated by DOE. RWMA replicated the DOE Final EIS sabotage consequence analyses, using the RISKIND model for health effects and the RADTRAN model for economic impacts, the SNL study average and maximum inventory release fractions, a range of credible values for the gap inventory of Cesium-137, and a range of population densities and weather conditions. RWMA concluded that an attack on a GA-4 truck cask using the same common military demolition device assumed in the DOE analysis could cause 300 to 1,820 latent cancer fatalities, assuming 90% penetration of the cask by a single blast. For the same device used against a large rail cask, RWMA estimated 46 to 253 latent cancer fatalities, again assuming 90% penetration.[i] RWMA estimated cleanup costs ranging upward from $668 million for the rail incident, and $6.1 billion for the truck incident, to more than $10 billion. Full perforation of the truck cask, likely to occur in an attack involving a state-of-the art anti-tank weapon, could cause as many as 3,000 to 18,000 latent cancer fatalities, and cleanup and recovery costs could far exceed $10 billion. (3)

The authors emphasize that all of the consequence assessments discussed in this paper assumed single-phase attack scenarios. None of these consequence assessments have evaluated the effects of an attack involving the simple impact-exacerbating tactics identified by the U.S. Army peer review report more than two decades ago: combined use of a breaching device and a dispersal device, or use of multiple breaching devices. Most significantly, none of these consequence assessments have evaluated any of the impact-exacerbating tactics studied by counter-terrorism experts in the post-September 11 environment. Credible hijack and control scenarios, specialized truck bomb scenarios, and/or concealed weapons (like improvised roadside devices) scenarios, coupled with suicide tactics, could potentially result in radiological consequences far greater than those previously estimated by DOE or the State of Nevada.

NEVADA PETITION FOR RULEMAKING

Well before the terrorist suicide attacks of September 11, 2001, concern about the terrorist threat to repository shipments led Nevada's Attorney General to file a petition for rulemaking with the NRC in June 1999.[j] In the petition, Nevada documented the vulnerability of shipping casks to high-energy explosive devices.[k] Nevada also submitted evidence that shipments to a national repository would be dramatically different from past shipments in the United States and that these differences would create greater opportunities for terrorist attacks and sabotage. The petition requested a general strengthening of the current transportation safeguards regulations and a comprehensive reexamination of the consequences of radiological sabotage. (8)

The NRC published Nevada's petition (Docket PRM-73-10) in the *Federal Register* on September 15, 1999, and accepted public comments through February 2000. The Western Governor's Association endorsed Nevada's petition on behalf of 18 western States. Five other states (LA, MI, OK, VA, and WV) also endorsed all or part of the petition. (23) Five years after the close of the comment period, three plus years after the 9/11 attacks, the NRC has still not officially responded to the Nevada petition.

LESSONS LEARNED FROM 9/11

The tragic events of September 11, 2001 clearly indicate that a thorough reconsideration of potential terrorist attack scenarios is necessary. Such reassessments of the "new" terrorism are in progress around the world.[l] Yet discussion of the "new" terrorism is eerily absent in the United States with respect to spent nuclear fuel transportation. (24) In addition to the recommendations in Nevada's petition for NRC rulemaking, spent fuel transportation risk assessments must also consider such emerging factors as: suicide attacks on casks; attacks involving large groups of well-trained adversaries; terrorist infiltration of trucking and railroad companies; coordinated use of hijacked vehicles;

attacks based on active insider participation and knowledge; and attacks at locations with a highly symbolic social, political, or economic value.

Additionally, the post-September 11th recovery efforts in New York and Washington, demonstrate the importance of addressing standard socioeconomic impacts, including cleanup and disposal costs and opportunity costs to affected individuals and business, and economic losses resulting from public perceptions of risk and stigma effects. The necessity of addressing impacts on emergency responders and recovery workers is now also clear. Social-economic factors are more widely felt in such large scale attacks then previously recognized by researchers and regulatory agencies. The inclusion of a radiological component to the assessment equation may increase consequences assessments.

Finally, the events of September 11th underscore the importance of immediately adopting a national policy to protect and shelter in place the spent nuclear fuel currently stored at commercial nuclear power plants. Current wet and dry storage facilities will require protection from terrorist attack for the operating life of the plants and well beyond the onset of decommissioning efforts. This need for on-site security and storage will be true regardless of current proposals for centralized storage or geologic disposal. Even if such shipments were to begin within the next decade, it would still be necessary to protect both the storage facilities and the shipments for decades. (25) The key vulnerability to attack may well be during the transportation of these materials, not the fixed sites where they are stored and where security will be greatest.

IMPLICATIONS FOR RESPONSE TRAINING AND PLANNING

At the present time, SNF shipments occur relatively infrequently in the United States. This situation would change dramatically with the opening of a centralized repository or interim storage facility. The resulting large-scale, long-distance, national level transport of SNF and HLW would create new and difficult to predict opportunities for terrorism against such shipments. Every day, for three or four decades, loaded casks of SNF or HLW would be moving somewhere in the United States.

The result would a totally new and enormous security and emergency response challenge for Federal, state, local, and tribal authorities. The body of existing public literature demonstrates that shipping casks are vulnerable to terrorist attacks, and that the attacks could result in significant adverse consequences. The risks can reduced – for example, by shipping the oldest fuel first, by maximizing use of rail, and requiring rail shipments be made in dedicated trains (1) - but the risks cannot be completely eliminated. The question, then, becomes how to plan for, and train responders for, such incidents.

Response planning and training for such radiological contingencies is complicated by programmatic and institutional uncertainties. These include: uncertainty about the numbers, modes, routes, and characteristics of future shipments; overlapping, disputed, and changing agency authority at the Federal, State, and local levels; and present and future budgetary constraints.

Furthermore, planning and training must address issues of special concern to urban and rural emergency responders. Issues of special concern in urban areas include: threats from outside groups that may reside in the urban location; higher probability of attacks due to proximity of the media, availability of attack supportive supplies, and the symbolic value of the attack site; the difficulty of mandatory or self evacuation, quarantine, and cleanup in commercial and residential areas; and multiple-agency decision-making and communications.

Issues of special concern in rural areas include: potential resource deprivation attacks directed against water supplies and transportation infrastructure; large size and remote location of many rural jurisdictions; communications difficulties; higher rates of turn-over, availability and commitment, and related personnel issues; and competition between urban and rural areas for funding and personnel.

Certain aspects of the institutional complexity of planning for shipment security can be determined. Truck and rail routes to Yucca Mountain could traverse up to 45 states, 700 counties, and 50 Indian Reservations. Rail routes could traverse 80-100 cities with population greater than 100,000. More than 120 million people live in counties traversed by likely truck routes to Yucca Mountain, and more than 100 million people live in counties traversed by likely rail routes. (26)

Three conclusions can be drawn at the present time. First, jurisdictional complexities along the transportation corridors will challenge the current division of responsibility between Federal, state, tribal, and local authorities. Federal security planning and training will need to be fully integrated with accident prevention and emergency response planning and training for state, local, and tribal governments. Federal operations planning will need to ensure intergovernmental coordination regarding physical protection of shipments, protection of information about shipments, and many aspects of intelligence activities.

Second, given the threat profile of the contemporary world situation, current shipment protocols need to be reassessed and updated to match the threat of terrorism. A transportation specific design basis threat (TDBT) must be developed to account for variables like multiple adversaries, military tactics, suicidal terrorists, and active insider knowledge. Such a TDBT may necessitate federalization of transportation security under the auspices of the Department of Homeland Security. Likewise, the pre-placement of federal response assets in parallel to shipment corridors could enhance the ability to respond and mitigate consequences in the event of an attack against shipments.

Third, event training for public safety, police, fire, medical, and other emergency responders, must account for the new threat environment that repository shipments may face. Forty-five states may require training infrastructure, coordinated with up to 700 counties (the primary governmental unit for emergency response in many jurisdictions), and with up to 50 Indian tribes. Tens of thousands of individuals will likely require initial training, update training, and longitudinal skill/knowledge assessments. Equipping, updating, post-training, certificating and validating, and many other issues will arise during the projected twenty-four to thirty-eight year life cycle of the repository shipment campaign. Obtaining and distributing funds for such training and equipment will be an on-going challenge.

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FOOTNOTES

[a] The majority of contractor reports prepared for the State of Nevada Agency for Nuclear Projects may be accessed online at Hhttp://www.state.nv.us/nucwaste/trans.htmH. However, most reports dealing specifically with transportation terrorism and sabotage issues must be requested in writing from Mr. Joseph Strolin, Administrator, Agency for Nuclear Projects, Office of the Governor, 1761 E. College Parkway, Suite 118, Carson City, NV 89706.

[b] The draft NATO report is not currently available for public distribution. Issues referenced in this paper represent only James David Ballard's knowledge of portions of the report. Ballard's views do not necessarily represent the final NATO report, the views of various team members who contributed to the NATO report, or the position of NATO.

[c] Death can occur following acute, whole-body doses of 200 to 300 rads. Because of the predominance of gamma and beta radiation from fission products, the absorbed dose (rads) and the dose equivalent (rems) would be roughly equivalent following direct exposure of a human

to an unshielded spent fuel assembly. See the discussion of radiation health effects in Ref. 2, Appendix F, and page 5.

[d] This discussion is based on the data presented in Chapter 6, Appendix A, and Appendix J. See especially Ref. 2, Pp. 6-46, A-13, J-33, and J-52.

[e] The 1998 test is recorded in a videotape available from International Fuel Containers, Inc., (ICFI), New York, NY. Part of the test footage was shown on a national television broadcast of CBS 60 Minutes on October 26, 2003. The broadcast was repeated on July 25, 2004. IFCI conducted two tests with identical warheads, one with the cask in its transport mode, and a second test with the cask in its storage mode, protected by a concrete jacket. In its storage configuration, the cask suffered only superficial surface damage from the second TOW warhead explosion. ICFI believes the test clearly demonstrated that the CASTOR cask in a protected storage installation would survive a missile attack, with no release of radioactive material. The CASTOR cask in its concrete jacket would, in the authors' opinion, represent a hardened target consistent with our previous recommendations for a shelter-in-place approach to protecting at-reactor storage facilities and centralized storage facilities. The authors have not been able to obtain any of ICFI's written documentation regarding the tests. Our assessment is based on interviews with ICFI and Army personnel, analysis of the videotape, and information derived from publicly-available, unclassified literature.

ICFI's use of static warheads rather than actual missile strikes has resulted in additional technical debate. Critics of the IFCI test argue that use of a perfectly placed, static warhead, resulted in optimal weapon performance, and caused more damage to the cask in its transport mode, than would be expected from the same warhead delivered by a missile fired under real world conditions. Other viewers believe that damage to the cask in its transport mode would have been greater, due to the kinetic energy delivered by the fast moving projectile, and that the cask and its contents would have suffered greater damage due to internal cask gas and explosive overpressures that could be generated from the missile impact. This debate suggests the need for additional weapon-specific testing, using a full-scale cask, and development of specialized software that can account for multiple breach points and other tactical contingencies.

[f] DOE addressed the impacts of acts of sabotage in Ref. 19, pages 6-33 to 6-34. "The estimated impacts would be greater for an act of sabotage against a legal-weight truck shipment than against a rail shipment, even though the amount of spent nuclear fuel in a rail cask would be as much as six times that in a truck cask, The greater impacts would be a result of the estimate that an event involving the smaller truck cask would release greater quantities of radioactive materials (Luna, Neuhauser, Vigil 1999, all)." Ref. 19, page 6-34.

[g] DOE addressed the impacts of acts of sabotage in Ref. 2, pages 6-50 to 6-52.

[h] Accident cleanup costs are discussed in Ref. 2, Appendix J, and page J-73.

[i] Ref. 3, pages 2-3, provides the following explanation:

> In the RISKIND and RADTRAN calculations presented later in this report, we calculate the consequences of the release of these fractions of respirable aerosol and gas, and their subsequent downwind dispersion and intake. However, we neglect the contribution of the non-respirable fraction of the cask inventory which will be released from the protection of the fuel rods and/or the cask, but will not be small enough to disperse far

downwind. If we were to include this fraction, there would be a significantly higher level of contamination modeled close to the damaged container, resulting in a higher dose to the MEI and population dose to those closest to the cask location. Therefore, it is important to keep in mind that the above release fractions are only for those particulates having a diameter less than 10 microns, leading to an underestimate of the dose to persons closest to the event.

[j] The petition is available at http://www.state.nv.us/nucwaste/news/ag990622b.htm.

[k] The comments submitted to the NRC are available on the web at http:3/26/01/ruleforum.llnl.gov/cgi-bin/rulemake?source=NV_PETITION.

[l] These reassessments are described in J. D. BALLARD, "Prepared Statement of J.D. Ballard", Before the Committee on Energy and Natural Resources, United States Senate, 107th Congress (May 22, 2002). See also: M. B. MAERLI, "The Threat of Nuclear Terrorism," and A. SCHMID, "How Real is the Threat?", Papers presented at the May 2001 International Conference on Measures to Prevent, Intercept, and Respond to Illicit Uses of Nuclear Material and Radioactive Sources, IAEA (May 2001); Y. ALEXANDER, Super Terrorism: Biological, Chemical, and Nuclear (2001); R. D. HOWARD, R. L. SAWYER, Terrorism and Counterterrorism: Understanding the New Security Environment, Readings and Interpretations (2003); G. MARTIN, The New Era of Terrorism: Selected Readings (2004); W. LAQUEUR, The New Terrorism: Fanaticism and the Arms of Mass Destruction (2000); N. GURR, B. COLE, The New Face of Terrorism: Threats from Weapons on Mass Destruction (2000); I. O. LESSER, et al. Countering the New Terrorism (1999); and J. WHITE, Terrorism: An Introduction, 2002 Update (2002).