

**HIGH HAZARD FEATURES ASSOCIATED WITH THE
TRANSPORTATION OF SPENT NUCLEAR FUEL
AND
HIGH-LEVEL RADIOACTIVE WASTE UNDER THE NWPA
THROUGH THE WEST**

The Western Interstate Energy Board High-Level Radioactive Waste Committee's Strategic Plan and Schedule for developing a transportation system for shipments under the Nuclear Waste Policy Act includes an analysis of high hazards found along western transportation routes. Such information would feed into decisions on the appropriate routes and modes to assure safe routine transportation. Under the current DOE/WIEB cooperative agreement scope of work, the Committee is to "identify high hazard features on western transportation routes and review the need for high hazard as a routing criterion." Following is a Committee paper on the types of potential high hazards along western routes. The identification of high hazards can help in the planning of full-scale cask testing and the development of related modeling capabilities to address route-specific concerns.

Introduction

Shipments of spent nuclear fuel and high-level radioactive waste (HLW) are regulated by the U.S. Department of Transportation (DOT), the Nuclear Regulatory Commission (NRC) and state agencies. The regulatory goals of the framework for NWPA shipments include: (1) reducing the probability of transportation accidents; and (2) minimizing risks from a radiological release or exposure resulting from an accident. DOT is the governmental agency primarily responsible for issuing route selection regulations. States, however, also have authority to designate shipping routes pursuant to HM-164.¹ The NRC's primary role is to certify the acceptability of casks and to ensure the physical security of spent fuel and HLW shipments.

While the Department of Energy (DOE) is not mandated to promulgate routing regulations for NWPA shipments, it will accept title to spent fuel and HLW from generators requesting disposal services in accordance with the terms and conditions of the Standard Contract for the Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste (the Standard Contract).² Additionally, DOE will furnish casks and provide for the transportation of the radioactive waste from the site of origin to a monitored retrievable storage (MRS) facility and/or repository. DOE is currently evaluating the use of multipurpose canisters in the federal waste management system. DOE's decision to pursue development of the multipurpose canister may significantly impact current practices in spent fuel and HLW interim-storage, transportation and disposal.

With a few exceptions, DOT highway routing regulations require spent fuel and HLW carriers to operate over "preferred routes."³ Preferred routes encompass the nation's Interstate System highways

¹ HM-164 refers to the docket number assigned to the rulemaking proceeding for 49 CFR Part 177.825.

² Codified in 10 CFR Part 961.

³ Carriers are allowed to deviate from preferred routes only under the following conditions: (1) for pick up and delivery of highway route controlled quantities of radioactive materials; (2) rest stops; (3) fuel stops; (4) repair stops; and (5) when emergency conditions make continued use of a preferred route unsafe or impossible. (49 CFR

and/or alternative routes designated by state routing agencies. DOT regulations prohibit use of preferred routes through cities where Interstate System bypasses, beltways or state designated alternate routes are available to circumvent the city. A state designated alternate preferred route must be selected in a manner consistent with DOT Guidelines⁴, or "an equivalent routing analysis which adequately considers overall risk to the public." (49 CFR 1 77.825(b))

To help states select highway routes that minimize radiological impacts, the Guidelines encourage states to conduct a comparative risk assessment based on seven factors. The seven factors identified in the Guidelines are grouped into two categories, primary risk factors and secondary risk factors (see box).

177.825(b)(2))

⁴ These guidelines are presented in a 1992 DOT publication entitled *Guidelines for Selecting Preferred Highway Routes for Highway Route Controlled Quantity Shipments of Radioactive Materials*.

Primary and Secondary Route Comparison Factors

Primary Factors

Normal Radiation Exposure

Spent fuel and HLW shipping casks emit small amounts of radiation during incident-free, routine transportation. While these low levels of radiation are not expected to adversely impact public health or the environment, exposure to this radiation should be minimized.

Public Health Risks from Accidents

The number of people that may be affected by a radiological release resulting from a transportation accident will vary depending on the population densities specific to available shipping routes. Radiological risks to the public can therefore be reduced by including population size as a routing criterion.

Economic Risk from Accidents

Radioactive matter released from a shipping cask may contaminate property within the vicinity of the transportation accident. The economic consequences stemming from the loss of use of the contaminated property, in addition to the costs of decontaminating the property, may be particularly severe for some routes compared to others.

Secondary Factors

Emergency Response Capabilities

The ability of emergency response personnel to effectively deal with radiological accidents involving shipping casks depends on such things as the availability of special equipment, the level of training of the emergency responders, and the amount of time required to reach the scene of an accident. These factors may vary significantly from one route to the next.

Evacuation

Prudent practice calls for the evacuation of segments of the public which may be affected by a release or potential release of radioactive material. The time, effort, and economic impacts associated with population evacuations may also be included as part of a route selection methodology.

Location of Special Facilities

Special facilities (e.g., stadiums, hospitals, and schools) situated near potential NWPA shipping routes present unique exposure and evacuation problems as they are especially sensitive to disruption. Stadiums generally accommodate large numbers of people, hospitals can not be evacuated quickly, and school children may be particularly vulnerable to radiation.

Traffic Fatalities and Injuries

Traffic accident rates will vary among different shipping routes. To reduce the likelihood of a transportation accident, routing analyses need to take this factor into account.

State routing agencies reserve the right to evaluate additional risk factors at their own discretion.

(Guidelines, pp. 6, 7)

In addition to DOT and state participation in routing highway shipments of spent fuel and HLW, DOE has the authority as the NWPA shipper to choose the routes its carriers will take from among those authorized by DOT, NRC and the states. DOE has the authority to implement safety protocols through its negotiated contracts with carriers. Safety protocols may include: procedures for dealing with bad weather conditions, road construction, safe parking areas, driver training requirements, speed limits, and use of escorts. In past spent fuel shipping campaigns, such procedures effectively contributed to safe routine transportation. Similar protocols have been developed for highway shipments of transuranic radioactive waste to the WIPP facility in New Mexico. DOE's supplemental Environmental Impact Statement for WIPP also specified the highway routes that would be used.

To date, regulations governing rail route selection for NWPA shipments have not been developed. However, pursuant to Section 4 of the Hazardous Materials Transportation Uniform Safety Act of 1990 (HMTUSA), DOT has the authority to develop rail routing criteria and regulations. Section 15 of HMTUSA mandates DOT to "amend existing regulations...to provide for the safe transportation by rail of high-level radioactive waste and spent nuclear fuel by various methods of rail transportation...." These regulatory changes are required to take into consideration the findings of a DOT study, also mandated by Section 15, comparing the safety advantages associated with dedicated trains to other methods of rail transportation. (This study has yet to be completed.) Additionally, Section 15 requires DOT to determine which factors, if any, should be considered by shippers and carriers in selecting modes and routes for spent fuel and HLW shipments. As part of that determination, DOT must assess the safety impacts of various factors, including population densities, infrastructure, quantities of materials, emergency response capabilities, exposure and other high-risk factors, terrain, continuity of routes, alternative routes, and environmental impacts.⁵

Although DOE is not required to issue regulations governing rail route selection, it has the authority as the NWPA shipper to stipulate certain routing criteria in its contracts with railroads. For instance, DOE may require carriers to operate only on high-grade track, or use dedicated trains. According to DOE, it will develop rail-route planning criteria if DOT fails to develop rail-routing regulations.⁶ It should be kept in mind however, that certain rail routing options will only be viable if DOE decides to mandate use of dedicated trains.

The current regulatory framework for NWPA shipments does not specify a methodology for selecting highway and rail transportation routes based on high hazard factors. High hazards are defined as hazards along transportation routes that could result in: (1) a severe accident and possible release of radioactive materials contained in casks; and (2) a severe accident that does not result in a release of radioactive materials but which creates significant problems. In light of the absence of high hazard routing criteria, this analysis focuses on the types of high hazards found along potential western NWPA shipping routes and the need to avoid or mitigate such hazards. The premise of the analysis is that high hazard areas can be identified and avoided or mitigated and thus the probability and consequences of accidents diminished.

Prudent planning suggests that high hazards should be avoided when possible to preclude an accident from occurring. Where high hazards are known to exist along preferred highway routes, alternate preferred highway routes, or rail routes, NWPA shipments may be rerouted to enhance safety. However, where high hazards cannot be completely avoided by rerouting, mitigation strategies should be

⁵ The DOT report, entitled Identification of Factors for Selecting Modes and Routes for Shipping High-Level Radioactive Waste and Spent Fuel, is currently in draft form.

⁶ Draft Mission Plan Amendment, September 1991, p. 113.

adopted to minimize the frequency and severity of transportation accidents. Mitigating strategies include special operational procedures such as reduced speed limits, severe weather protocols, time-of-travel restrictions, additional rail inspections, special operating procedures such as escorts, and use of dedicated or special trains. Notwithstanding the effectiveness of rerouting and mitigation strategies, the NWPA shipping campaign through the West is not expected to be accident-free.

To minimize risk from a radiological release during a shipping accident, NRC requires spent fuel and HLW casks to meet a number of regulations before they can be certified for use.⁷ These regulations govern cask testing procedures and requirements, performance standards, and safety features. The conceptualization of the particular strengths and vulnerabilities of the casks identified in this analysis is based on the generic cask evaluated in the NRC commissioned Modal Study.⁸ However, present day cask designs (including the multipurpose canisters being studied by DOE), incorporating advanced materials and engineering not addressed in the Modal Study, may or may not be resilient enough to withstand some of the severe accident conditions discussed below. Critics of the Modal Study argue that the assumptions used in the study are not representative of the realm of actual transportation accident scenarios and that a second study should be done to test the new cask designs under additional accident conditions.⁹

The remainder of this paper is divided into three sections. The first two sections address: (1) transportation accidents involving a release of radioactive materials; and (2) transportation accidents that do not result in a release, but which create significant problems, particularly in cask retrieval. Each of these sections begins with a discussion of the relevant high hazards and concludes with suggestions on the type of high hazard factors which should be examined in route-specific analyses in the West.¹⁰ The third section summarizes the findings of this report and presents a number of recommendations to enhance the level of safety provided in a NWPA transportation strategy.

I. Accidents That May Result in a Release of Radioactive Materials

Spent fuel rod assemblies are restrained within a cask's inner containment cavity which in turn is encapsulated by a protective outer layer. For a radiological hazard to occur, either of two conditions must be met. First, the cask's containment systems (including fuel rods, inner cavity and outer shell) must be breached, thus allowing gaseous, volatile, or solid radioactive matter contained in fuel rods to escape into the environment. Secondly, if a cask is not breached, external emissions of neutron and gamma radiation must exceed NRC regulatory limits.¹¹

⁷ Shipping casks must be certified by the NRC pursuant to 10 CFR Part 71, "Packaging and Transportation of Radioactive Materials."

⁸ The Modal Study, entitled *Shipping Container Response to Severe Highway and Railway Accidents*, was prepared for the NRC in February 1987 by Lawrence Livermore National Laboratory (NUREG/CR-4829).

⁹ *Nuclear Waste Shipping Container Response to Severe Accident Conditions: A Brief Critique of the Modal Study*, Lindsay Audin for the State of Nevada Agency for Nuclear Projects/Nuclear Waste Project Office, 1990, pp. 1-3.

¹⁰ Sabotage will not be addressed as part of this analysis for it involves a host of other hazards not necessarily specific to western transportation routing criteria.

¹¹ *Transporting Spent Fuel*, p. 17.

Accidents that could cause a release of radioactive material involve impact damage, thermal damage, water immersion, and impact and thermal forces acting in tandem.

A. Impact Damage: Impact damage results from excessive impact trauma from collisions. Stress delivered to a cask's outer shell makes a release from the inner cavity possible. Casks incur impact damage as they collide with moving and stationary objects and/or as objects in motion collide with stationary or moving casks.¹²

NRC cask testing regulations require casks to be able to withstand, through either actual testing or analysis, hypothetical impact trauma incurred during an accident.¹³ (10 CFR 71.73) NRC regulations specifically require two tests for impact: a free drop and a puncture test. The free drop involves a cask being dropped 30 feet in such a manner that the cask's weakest point strikes an unyielding surface. If the cask passes the free drop test it is then subjected to the puncture test, wherein a cask is dropped 40 inches onto a metal spike.

When evaluating highway and rail routes for spent fuel and HLW shipments one needs to consider potential high hazards along the route which could challenge the integrity of a cask in an accident. For an impact event to potentially cause a release there must be sufficient deceleration and sufficient mass in the impacting objects. Thus, in examining routes, one needs to consider the speed and "hardness" of the impacting objects. As an example, the Modal Study indicates that a locomotive sill impacting the midpoint of a truck cask at a velocity of 30 mph will result in a level of strain on the cask's inner chamber of 3.7% and subsequent release of radioactive material.¹⁴ Examples of other conditions to examine include:

< Mountain passes where a descending truck or train can move at high speed and, because of road or rail conditions (e.g., track geometry), can leave the right-of-way and impact a hard surface, such as granite rock.

¹² According to the Modal Study, a level of strain between 0.2% and 2% on the cask's inner chamber was assumed to result in cladding failure of 10% of the fuel rods. At 2% strain, partial cladding failure may also be accompanied by failure in closure seals. At levels of strain greater than 2%, all fuel rods were assumed to be breached and radionuclides in gaseous and volatile form would be able to escape through small cracks in the cask. (*Shipping Container Response to Severe Highway and Railway Accident Conditions*, 4-4 — 4-6)

¹³ For a Type B package to successfully withstand the hypothetical accident conditions specified in 10 CFR 71.73, there must be "no escape of krypton-85 exceeding 10,000 curies in one week, no escape of other radioactive material exceeding a total amount A_2 in one week, and no external radiation dose rate exceeding one rem per hour at one meter from the external surface of the package." (10 CFR 71.51)

¹⁴ Additional examples illustrating the level of impact velocity necessary to attain strain levels of at least 2% on the inner chamber of the cask include: (1) a truck cask impacting a hard rock surface such as granite endwise at 46 mph; (2) a truck cask impacting a tillable soil (e.g., dirt or sand) lengthwise at 51 mph; (3) a rail cask impacting hard rock endwise at 48 mph; and (4) a rail cask impacting a soft rock surface such as concrete endwise at 48 mph. (*Shipping Container Response to Severe Highway and Railway Accident Conditions*, Table E.25 and Table E.26)

It is important to note that the impact forces presented here are specific to the representative cask evaluated by Lawrence Livermore National Laboratory as part of the 1987 Modal Study. The impact data contained in that report is therefore not applicable to casks currently under development, such as OCRWM's multipurpose canister (MPC). It is appropriate for DOE and NRC to update the Modal Study in order to assess the response thresholds of new casks to severe highway and railway accident forces.

< Steep slopes or drop-offs where a cask may: (1) plunge a great distance, thus increasing its velocity at impact; and/or (2) incur multiple impacts with boulders, rock outcroppings, or rock faces before final impact.

< Railroad links where trains travel at high speed.

< Railroad links where parallel tracks carry trains in opposite directions at moderate to high speed.

< Railroad crossings where the impact of a train hitting a cask-carrying truck is backstopped by massive objects, such as granite outcroppings.

< Elevated overpasses and bridges where a cask may fall more than 30 feet prior to impact.

In an analysis of potential shipping routes, forces capable of creating levels of strain on the cask in excess of 2% need to be identified.

B. Thermal Damage: Thermal damage to casks results from prolonged exposure to intense thermal energy sources. Excessive exposure to intense thermal energy may compromise the integrity of certain protective materials of the cask structure and lead to a radiological release.^{15 16}

In addition to the impact tests discussed above, NRC regulations require cask systems to pass a thermal exposure test before they can be certified for use. During the thermal test, a cask is engulfed in a 1475°F fire for at least 30 minutes. NRC regulations do not require particular surface areas or certain sections of the cask (e.g., closure lids) to be exposed to concentrated sources of heat, rather, the whole cask is consumed in fire.

In addition to engulfing fires, shipping casks may also be subjected to concentrated sources of extremely high heat. For example, if a train carrying casks derails and ruptures an underground natural gas pipeline (under complete combustion conditions and without excess air, natural gas can burn at 3250°F), a resulting torch fire limited to one exposed end of a cask may cause seal failure and degradation of the cask's lead shielding.¹⁷ Two catastrophic events involving train derailment and pipeline infernos

¹⁵ According to the Modal Study, temperatures at the mid-thickness of the lead shield between 500°F and 600°F may potentially lead to cask closure seal degradation, but any radiological hazard would likely be within regulatory limits. At temperatures between 600°F and 650°F melting of the lead shield occurs (the melting point of lead is 621°F), and resulting voids or gaps in the shield may lead to increased radiation levels and radioactive material releases in excess of regulatory limits. At temperatures between 650°F and 1050°F all fuel rods were assumed to be breached, leading to further increases in radiological hazards. (*Shipping Container Response to Severe Highway and Railway Accident Conditions*, pp. 4-9 - 4-12; *Transporting Spent Fuel*, p. 14)

¹⁶ The amount of radionuclides released in thermal accidents is expected to be greater than a release caused by impact rupture. This is because pressure inside fuel rods increases when they are exposed to a sufficient supply of heat. When cladding failure occurs, radioactive gases, volatiles and particulates are swept out of the rods with more force than is the case from impact trauma. Additionally, it should be noted that PWR (pressurized water reactor) fuel assemblies are expected to be more susceptible to thermal energy induced cladding failures than are BWR (boiling water reactor) fuel assemblies under the same conditions. PWR fuel rods rupture at a temperature 100°C below the thermal threshold point for BWR spent fuel. This difference in thermal threshold is attributed to the fact that PWR spent fuel typically undergoes higher burnup than BWR spent fuel. (*Transportation Accident*, pp. 15, 39)

¹⁷ A 1980 study performed by Sandia National Laboratories entitled *Assessment of Accident Thermal Tests and Analysis Procedures*, noted that torch fires (concentrated heat) could severely degrade a cask's protective features if

occurred in 1989, one in the former Soviet Union and the other in San Bernardino, California.¹⁸ (Note: pipeline maps typically fail to indicate pipeline depth.)

Potential western NWPA shipping routes include high hazards capable of generating intense thermal energy.¹⁹ Examples of high heat sources include:

- < Burning petroleum product or chemical tanker trucks/rail cars sharing the same routes used for spent fuel and HLW shipments.
- < Buried natural gas and petroleum pipelines sharing rights-of-way with highway or train routes.
- < Storage tanks/tank farms adjacent to NWPA shipping routes.
- < Military facilities, such as bases, training sites and munitions depots, where the potential exists for collisions involving spent fuel shipments and truck shipments of military explosives and/or hazardous materials (e.g., the Hawthorne Munitions Depot off of U.S. 95 in Nevada; Kirtland Air Force Base in Albuquerque, NM; and Hill Air Force Base, north of Salt Lake City, UT).
- < Areas in close proximity to military overflights (e.g., bombing ranges and/or munitions air transport corridors such as Fallon Naval Air Station, Nellis Air Force Base in Las Vegas, and the Nellis bombing range adjacent to the Nevada Test Site).
- < Civilian mining facilities.

In analyses of potential shipping routes, sources of large quantities of materials burning at high temperatures which are found on or adjacent to rail and highway rights-of-way should be identified.

C. Water Immersion: Water at certain depths is capable of exerting tremendous pressure against rigid objects such as the cask. A submerged cask could therefore be breached while under the strain of deep water.

NRC's multi-step cask testing process also requires the same cask used for the impact and thermal tests to be submerged under at least 3 feet of water for eight hours. In addition, all cask systems must

the thermal energy is hot enough and applied to heat vulnerable areas of a cask. For example, the torching of a cask's seal at a temperature greater than 500°F could lead to a breach of that seal. Additionally, torching could potentially melt a small section of a cask's lead gamma shield. Emissions of gamma radiation may then increase to a level above NRC regulatory limits. (*A Brief Critique of the Modal Study*, p.28)

¹⁸ The pipeline explosion which occurred in the former Soviet Union (perhaps the worst rail fire in history) was not attributed to train derailment, rather, a passing train ignited the fumes from a leaking natural gas pipeline. Five hundred people reportedly died as a result of the pipeline explosion and inferno. (*A Brief Critique of the Modal Study*, p. 14) In San Bernardino, California a train derailment led to the rupture of a section of the Calnev petroleum pipeline. The damaged pipeline burned out of control for seven hours, killing two people and destroying eleven homes. (*Railroad Accident Report*, p. 33)

¹⁹ Flame temperature for a burning material is dependent upon the amount of oxygen present in the flame and the extent of combustion of the particular material. Following are some examples of flame temperatures achievable for various fuels and commonly transported chemicals: hydrocarbon fuels such as diesel and gasoline, 1400-2400°F; jet fuel, 1800°F; natural gas, 3250°F; oil, 3750°F; methanol, 3578°F; ethanol, 3605°F; propane, 3661°F; toluene, 3767°F; benzene, 3799°F; acetylene, 4190°F. (*Hydrocarbon Fuels*, Appendix 2; *A Handbook of Petroleum, Asphalt & Natural Gas*, p. 454; *Transportation of Hazardous Materials*, p. 101)

undergo a separate test wherein a cask is submerged under 50 feet of water for eight hours. These two immersion tests, however, are not as rigorous as the immersion test standard adopted by the International Atomic Energy Agency (IAEA) in 1985. IAEA cask testing regulations require casks to be able to withstand submersion under 200 meters (656 feet) of water for at least one hour.²⁰ In June 1988, the NRC proposed a rule which would revise its existing regulations governing cask integrity by requiring transportation casks to meet the 200 meter water immersion standard.²¹ NRC approval of the proposed rule is pending.

Compared to the potential for impact forces and thermal energy sources to breach a cask's protective features during a transportation accident, water immersion will not present a serious threat to NWPA shipments occurring throughout the West. This is due principally to the fact that western NWPA shipping routes are not situated near bodies of water with depths exceeding 200 meters.

D. Destructive Forces Operating in Tandem -- Impact and Heat: NWPA shipping accidents caused and/or exacerbated by high hazards may involve casks being subjected to the synergistic effects of impact trauma and thermal damage. The combined effects of these forces may result in the degradation of the cask's protective features, leaving the inner chamber vulnerable to a release.

NRC cask certification regulations take into account some of the synergistic effects of both impact and thermal damage incurred during transportation accidents by requiring casks to be subjected to the three previously mentioned tests in a sequential manner: (1) the cask is dropped 30 feet onto an unyielding surface; (2) dropped onto a metal spike; and (3) engulfed in a 1475° F fire. The same cask must be used for all three tests. This cask testing sequence is strict and inflexible; it does not take into account possible variations in the order by which casks may incur damage from impact and thermal forces. For example, during a transportation accident a cask may first be exposed to intense thermal energy before suffering severe impact damage.

In evaluating potential shipping routes, one should consider the potential for impact and thermal forces to act in tandem and identify: (1) hazards where the thermal or impact force may exceed NRC standards and (2) hazards involving thermal or impact forces less than the NRC standards, but where the thermal event may precede an impact on the cask (e.g., sequential train derailments where the first train accident involved a ruptured natural gas pipeline and the second train plowed into the wreckage of the first train.)

II. Incidents Without a Release of Radioactive Materials

Past accident histories indicate that there are unlikely to be NWPA shipping accidents that result in a release of radioactive materials or emissions of neutron and gamma radiation beyond regulatory limits. There is, however, a higher probability that there will be severe accidents that do not cause a release, but which present major problems. Non-radiological problems may include cask retrieval under arduous conditions and/or economic and population disruptions. A prudent route selection strategy should include an identification of hazards that can contribute to such problems.

²⁰ Staff has not found data indicating that potential routes to a western repository have water depths necessary to cause cask failure.

²¹ The NRC published the proposed rule in the June 8, 1988 edition of the *Federal Register*.

DOT routing guidelines account for some of the hazards which can contribute to severe, non-radiological accident problems. For example, DOT's primary route comparison factors include the economic risk resulting from accidents. DOT's secondary factors account for: (1) the availability and quality of emergency response services; (2) evacuation time, effort and associated economic impacts; (3) the location of special facilities such as stadiums, hospitals and schools; and (4) traffic accident rates.

In light of the significant problems that can be created by severe accidents not involving a radiological release, routing analyses should consider additional factors which are discussed below.

A. Difficulties in Cask Retrieval: The variety of terrain along potential shipping routes in the West can make cask retrieval following severe accidents very difficult, further exacerbating the economic, environmental and social impacts from the accidents. For example, retrieval of a cask from a deep canyon ravine that has no access may require special equipment not readily available. Construction of new access routes in environmentally sensitive areas may therefore be necessary. Additionally, as a result of precautionary measures such as quarantining water supplies from the canyon river, economic and social impacts may be extended

In evaluating potential routes, one needs to examine the types of terrain which may impede cask retrieval, such as:

- < Deep and/or swift moving water such as rivers, oceans and lakes.
- < Ravines with steep slopes and lack of access.
- < Wetlands that may encumber heavy emergency response equipment.

Examples of such terrain include crossing of Hoover Dam on U.S. 93, the narrow canyon along the Weber River on I-84 near Morgan, Utah, and the Denver and Rio Grande rail line near the Continental Divide west of Denver.

B. Chronic and/or Episodic Adverse Weather Conditions: Adverse weather conditions such as snow, icy conditions, high winds, fog and heavy rain result in greater incidents of accidents.²² The problems presented by adverse weather on a potential route would be at least partially reflected in the accident rate for that route. However, the full impact of adverse weather conditions may not be reflected in western accident statistics, since it is common practice in parts of the West to close highways during adverse weather. With road closures there will be fewer accidents, however, there may be increased radiological exposure from stranded trucks parking for extended periods of time while waiting for roads to reopen.

Prudent routing analysis requires that one consider chronic and/or episodic adverse weather conditions when evaluating shipping routes. During seasons of adverse weather, treacherous sections along routes should be circumvented, or in the alternative, shipping restrictions should be adopted to reduce the likelihood of transportation accidents. Both the states and DOE have included the avoidance of severe weather conditions in planning for WIPP shipments.

²² It is estimated that in 1991, almost 1.5 million traffic accidents occurred during adverse weather conditions. (*General Estimates System*, 1991)

C. Transit in Heavily Populated Areas. DOT's primary routing factors include the number of people that may be affected by a radiological release resulting from a transportation accident. The number of people near an accident will also affect the impacts from a severe accident not involving a release. For example, it is likely that precautionary evacuations will occur following a severe NWPA shipping accident. The economic and social impacts stemming from such precautionary evacuations are likely to vary based on the size of the population evacuated.

DOT guidelines do not explicitly require an evaluation of the time of day during which shipments occur in populated areas. Prudent routing analysis should consider the impact of the time of travel on the size of the population potentially impacted by a severe NWPA shipping accident.

D. Transportation Infrastructure. The quality of transportation infrastructure will affect the probability of accidents, including severe accidents. While general accident rates may reflect many of the differences in infrastructure along different routes, it would be prudent to examine infrastructure conditions during an assessment of routes. Features that could exacerbate the likelihood and/or consequences of an accident include, but are not limited to:

- < Double decked freeways in earthquake zone.
- < Bridges vulnerable to failure (either because of poor maintenance or support structures vulnerable to collapse due to floods/impact trauma).
- < Lack of grade separations.
- < Lack of opposing traffic separation.
- < Steep grades, dangerous curve alignments and river crossings.
- < Poor maintenance.

Routing around infrastructure deficiencies, correcting infrastructure deficiencies, and/or adopting operational restrictions to minimize the hazards presented by the infrastructure deficiencies can improve the safety of shipments and should be considered in the selection of routes.

III. Conclusion

To date, there has not been a release of radiological materials as a result of a spent nuclear fuel transportation accident. However, once a MRS facility and/or permanent repository begin(s) accepting radioactive waste, the number of spent fuel and HLW shipments taking place through the West will increase dramatically. Statistical projections indicate that the NWPA shipping campaign is not likely to be accident free. Only a small fraction of NWPA shipping accidents are expected to result in potential radiological hazards; the remainder are more likely to involve non-radiological risks which may complicate efforts to resume safe routine transportation following an accident (e.g., difficulty of cask retrieval, transportation delays and precautionary evacuations). The ability to resume safe routine transit following an accident (the system's elasticity) will be a major factor in the public's perception of the safety of NWPA shipments. To reduce overall risk and thus increase the margin of safety provided in a NWPA transportation strategy, it is necessary to devise a route selection methodology which seeks to minimize the frequency and consequences of shipping accidents.

A prudent approach to routing analysis would identify and evaluate: (1) high hazards that can potentially result in radiation levels or radioactive material releases in excess of regulatory limits; and (2) high hazards that can result in severe non-radiological accidents which create major problems. Examples of high hazards found in the West that may challenge a cask's protective features include: (i) steep slopes and mountain passes where in an accident the velocity of a cask may increase significantly before the cask strikes a hard surface; (ii) thermal forces such as chemical and petroleum product storage tanks and pipelines situated adjacent to shipping routes; and (iii) impact and thermal forces working synergistically against a cask such as when a train derails or collides with another train prior to or after incurring thermal damage. Examples of high hazard features which may cause and/or exacerbate non-radiological shipping accidents include: (i) inclement weather; (ii) routes bordered by inaccessible terrain; and (iii) weak infrastructure components.

DOT's list of primary and secondary route comparison factors (the Guidelines) address many, but not all of the hazards identified in this analysis. Most notably absent from the DOT Guidelines is mention of factors which may impede cask retrieval. Since nearly all NWPA transportation accidents are expected to be of the non-radiological variety, cask retrieval and subsequent reloading onto a cask transporter may prove to be a fundamental challenge faced by emergency responders. Routing analysis for NWPA shipping campaigns should be expanded to encompass the full range of radiological and non-radiological accident risk factors discussed in this analysis. Preferred highway routes, state designated routes and rail routes should then be surveyed for the presence of these types of accident preconditions and encumbrances.

Where high hazards are known to exist along potential western transportation routes, NWPA shipments should be rerouted to avoid such hazards. However, where it is not feasible to reroute shipments, special operational procedures such as reduced speed limits, severe weather protocols and time-of-travel restrictions should be adopted to reduce risk. Prudent planning in anticipation of spent fuel and HLW shipments through the West requires that high hazards along candidate routes be identified, evaluated and either avoided or mitigated.

BIBLIOGRAPHY

Cashwell, J.W. et al, 1990, The Impacts of Transportation Within the United States of Spent Reactor Fuel from Domestic and Foreign Research Reactors, Sandia National Laboratories, SAND88-0714.

Cross, R., 1928, A Handbook of Petroleum, Asphalt & Natural Gas, Kansas City Testing Laboratory.

Goodger, E.M., 1975, Hydrocarbon Fuels, Halsted Press.

Lawrence Livermore National Laboratory, 1987, Shipping Container Response to Severe Highway and Railway Accident Conditions, Vols. 1 & 2, prepared for U.S. Nuclear Regulatory Commission, NUREG/CR-4829.

Office of Technology Assessment, 1986, Transportation of Hazardous Materials, OTA-SET-304.

State of Nevada Agency for Nuclear Projects/Nuclear Waste Project Office, 1990, Nuclear Waste Shipping Container Response To Severe Accident Conditions: A Brief Critique of the Modal Study, NWPO-TN-005-90.

TRW Environmental Safety Systems, Inc., 1992, National Transportation Impact Assessment, prepared for U.S. Department of Energy, Office of Civilian Radioactive Waste Management.

U.S. Department of Energy, Office of Civilian Radioactive Waste Management, 1991, Draft Mission Plan Amendment, DOE/RW-0316P.

U.S. Department of Transportation, National Highway Traffic Safety Administration, General Estimates System 1991.

U.S. Department of Transportation, Research and Special Programs Administration, 1992, Guidelines for Selecting Preferred Highway Routes for Highway Route Controlled Quantity Shipments of Radioactive Materials, DOT/RSPA/HMS/92-02.

U.S. National Transportation Safety Board, 1990, Railroad Accident Report: Derailment of Southern Pacific Transportation Company Freight Train on May 12, 1989, and Subsequent Rupture of CalNev Petroleum Pipeline on May 25, 1989, San Bernardino, California, NTSB/RAR-90/02.

U.S. Nuclear Regulatory Commission, 1987, Transporting Spent Fuel: Protection Provided Against Severe Highway and Railroad Accidents, NUREG/BR-0111.

Western Interstate Energy Board, High-Level Radioactive Waste Committee Meeting Final Minutes, Las Vegas, Nevada, April 16-17, 1992.

Western Interstate Energy Board, 1991, Rail Primer: Legal, Technical and Business Aspects of Rail Transportation.

Wilmot, E.L., 1981, Transportation Accident Scenarios for Commercial Spent Fuel, Sandia National Laboratories, SAND80-2124/TTC-0156.