

ASSESSMENT OF MODE AND ROUTE SELECTION FACTORS FOR SHIPPING HIGH-LEVEL RADIOACTIVE WASTE AND SPENT NUCLEAR FUEL

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ABSTRACT

Many different factors have been promoted and used as criteria for selecting modes and routes for the shipment of radioactive materials. The Department of Transportation has developed regulatory requirements for route selection (49CFR397.101) for radioactive materials and has developed a set of routing guidelines for States to use in support of their route designated process. However, these regulations and guidelines allow considerable flexibility in determining what and how specific factors could be used. There are no regulations for mode selection. Since the passage of the Nuclear Waste Policy Act in 1983, route and mode selection has been the subject of extensive debate between DOE, State and regional governments, and various stakeholders. As the number of DOE shipments increase dramatically over the next several years to support its accelerated facility cleanup program, mode and route selection will continue to be a major issue.

Recently, DOT published a report on the “Identification of Factors for Selecting Modes and Routes for Shipping High-Level Radioactive Waste and Spent Fuel Nuclear Fuel” (1). This report will be called the “DOT Mode/Route Study” in this paper. This report includes an exhaustive review of all mode and route factors that have been recommended, either by regulation or legislation, or used in previous environmental or risk assessment studies. A comprehensive list of mode and route factors was developed and then evaluated using a hierarchical analysis. Based upon this analysis, eight primary mode and route selection factors were recommended. The purpose of this paper is to briefly review and highlight the findings of this report related to mode and route factors.

The author served as the Project Manager for the DOT Mode/Route Study under contract to the U.S. DOT’s Volpe National Transportation Systems Center. This paper includes portions of the original contractor report submitted to DOT/Volpe (2) and which also appear in the final DOT Mode Route Study.

INTRODUCTION

The U. S. Department of Transportation has established regulations for the routing of radioactive materials at 49CFR 397.101-103 (promulgated under the more familiar reference known as Docket HM-164). Specific regulations apply to Highway Route Controlled Quantity (HRCQ) radioactive materials, which would include high-level radioactive waste and spent nuclear fuel. Carriers of HRCQ radioactive materials must operate over preferred routes. Preferred routes are Interstate System highways for which

an alternative route is not designated by a State routing agency. If a State has not designated a route, the Federal rule is to select an Interstate System highway to reduce time in transit, except for the required use of Interstate System bypasses or beltways around a city. Deviations from the preferred route are allowed under certain conditions, for example pickup and deliveries; food, fuel and rest stops; and emergency conditions.

Thus, if a State does not designate a route, the Federal routing regulations for high-level waste and spent nuclear fuel are relatively straightforward. The primary routing factors are the Interstate System highways (commonly seen as the highway class with the best infrastructure and lowest accident rate), reduced transit time, and use of beltways to avoid heavily populated areas where available. If the State decides to designate a route, it must follow the DOT “Guidelines for Selecting Preferred Highway Routes for Highway Route Controlled Quantity Shipments of Radioactive Materials” (DOT Guidelines) or an equivalent routing analysis which adequately considers overall risk to the public. This allows considerable flexibility to States and Tribal governments on what factors to consider for route selection, other than the requirement that the factors must have an impact on “overall risk to the public”, an extremely broad point of reference. Even the DOT Guidelines themselves allow considerable leeway in the manner in which factors are identified and considered for route designation.

The net result of DOT’s routing regulation for HRCQ materials is that it leaves open to interpretation and negotiation the types of factors that can be used as criteria for selecting routes. Of course, this will depend largely on the role the States and tribal governments choose to play in route designation. The Department of Energy has begun an aggressive program to cleanup most of its facilities that will result in a significant increase in the number of shipments of HLW and SNF beginning in the next several years. In addition, commercial spent nuclear fuel must ultimately be transported from nuclear power plants to either an interim storage site or a repository. As DOE shipping campaigns become more defined and specific origin and destinations become clear, there will be increasing pressure on the States (or perhaps regional State groups on their behalf) and tribes to work with DOE and the many stakeholders to designate routes (or at least to consider alternatives to the default Federal rule that would require the carrier to simply use an Interstate highway that reduces time in transit). Ultimately, the process of designating routes for specific shipping campaigns will be achieved through a process of negotiation of both the specific factors to be used and the manner in which the factors are evaluated. An understanding of the types of factors that could legitimately be used to select routes under the umbrella of DOT’s HM-164 rule is an important first step.

It should be noted that there are no routing criteria whatever for rail or barge shipments, so the field is even more open to interpretation and negotiation outside of highway shipments. Another major issue with DOE stakeholders is the mode of transport to be used to ship high-level radioactive waste and spent nuclear fuel. There are no mode selection criteria established by DOT. In fact, DOT takes the position that it is the purpose of its regulations to ensure that all modes are safe for hazardous materials generally (with a very few specific exceptions).

The purpose of this paper is to highlight work conducted on behalf of DOT and the Volpe National Transportation System Center to identify potential factors that could be used for both mode and route selection for high-level radioactive waste and spent nuclear fuel. DOT was directed by Congress in the Hazardous Materials Transportation Uniform Safety Act (HMTUSA) of 1990 to conduct a study “to decide which safety factors, if any, shippers and carriers should consider when selecting routes and modes that would enhance overall public safety related to the transportation of high-level radioactive wastes and spent nuclear fuel.” DOT/Volpe initiated the study in 1994 and it was published in 1998 and is commonly referred to as the “DOT Mode/Route Study”.

Congressional direction for this study made it clear that the emphasis was on identifying factors for industry consideration, not developing a routing methodology or requiring their use. Also, the benchmark for identifying mode and route factors was “impact on overall public safety”, not economics or operating efficiency of shippers and carriers. DOT developed a working project definition of “overall public safety” to serve as a reference for the identification and categorization of mode and route factors. The definition was as follows: (1) minimizing exposure of the public and the environment to spent nuclear fuel and high-level radioactive waste during transportation. This includes minimizing incident-free radiological exposure of both the public and transportation workers and minimizing the potential exposure caused by a radiological release into the environment as a result of an incident during transportation, and (2) minimizing the impact of accidents during transportation when no radiological release occurs (non-radiological effects).

Within these constraints, the approach of the study was to identify all conceivable mode and route selection factors and conduct an evaluation of their relationship to the project definition of “overall public safety”. The emphasis was on factor identification.

IDENTIFICATION OF MODE AND ROUTE FACTORS

A comprehensive list of candidate mode and route factors was compiled using the project definition of overall public safety as a guide. The factors were collected from several sources including (1) current regulations and routing guidelines, (2) HMTUSA, (3) a literature review, and (4) a Technical Advisory Group (TAG). The TAG was convened to act as an expert panel for the DOT/Volpe study. The group represented broad interests including carriers; shippers; local, state and federal governments; public interest groups; and regional energy groups.

Potential Mode and Route Factors Identified in Existing Regulatory Guidelines

The U.S. DOT has prepared guidelines for states and other jurisdictions to use when designating routes for both general hazardous materials and for highway route controlled quantities of radioactive materials. Similarly, Transport Canada has developed a set of hazardous materials routing guidelines for shipments in Canada. The primary and

subjective factors for each of these guidelines are shown in Table I. Each of the factors is further broken down into more specific factors in the second column of the table and into measurable components in the third column.

Guidelines for Routing General Hazardous Materials. The DOT routing guidelines for general (non-radioactive) hazardous materials are based on the concept of relative risk. Risk is measured using two primary factors: 1) the expected, per-mile population exposure to a release (population risk), 2) the expected, per-mile property value exposure (property risk). (The estimation of property risk is considered optional in the route selection process.) Population risk is estimated using accident rate and population density information. Property risk is also estimated using accident rate information but considers property values instead of population density.

The DOT suggests that, when available, the analyst should use accident rates that are based on the most severe accidents (such as fatal accidents). Population density information along each route is necessary to estimate the number of people who would be at risk during an accidental release. The approach recommended in the guidelines is to use census tract data to estimate the fraction of the population along a route within the release impact zone. The choice of width for the impact zone along each route is based on the suggested evacuation distance for each class of hazardous material. Property value is estimated by measuring lineal frontage and its value along each route. Four types of secondary subjective factors are considered in the guidelines: special populations located in facilities that are difficult to evacuate (nursing homes, schools, hospitals and prisons), special properties (utilities, transportation bottlenecks and difficult-to-reach facilities), emergency response capability, and other subjective factors of special interest to a community.

DOT Routing Guidelines for Highway Route Controlled Quantity Shipments of Radioactive Materials. These DOT routing guidelines provide a methodology for states and other jurisdiction to use when determining the lowest relative risk route for the transport of highway route controlled quantity (HRCQ) radioactive materials. The methodology used in the guidelines is to develop a “figure of merit” for each route considered. This figure represents the comparative risk between routes; it is not a measure of absolute risk. Each figure of merit is developed based upon three primary risk factors: normal radiation exposure, public health risk from accidents and economic risk from accidents.

Normal radiation exposure refers to the amount of radiation emitted during normal or incident-free transportation operations. An equation is used to calculate the normal radiation exposure factor. This equation includes the following components: average population density, length of route, vehicle speed and average traffic count. Public health risk from accidents refers to the potential number of people exposed if a transportation accident were severe enough to lead to a release of the radioactive materials from the transport container. Risk from accidental release of radioactive materials depends on two factors: 1) the frequency of accidents that could result in release, and 2) the consequence

from such accidents, in terms of the number of people that could be exposed to radioactive materials if a release occurs.

Accident release frequencies are calculated by multiplying the accident rate by the route length. The guidelines suggest the use of accident rates that represent the most severe accidents involving the types of vehicles expected to carry HRCQ. DOT provides a list ranking the types of accident rates that could best represent accident release frequencies. Accident release consequences depend on a number of factors, many of which (such as atmospheric conditions and type of material transported) would be similar for two alternate routes. This greatly simplifies the calculation of consequences to a consideration of the differing levels of population along the route or route segment. Economic risk from accidents refers to the potential contamination of property near the roadway that could result if a transportation accident were to occur. The cost of removing contaminated property would vary widely based on the type of property adjacent to the roadway. To determine the risk, the type of property along the route segment is classified as rural, residential, commercial/industrial, park or public area.

Canadian Route Screening Guidelines for Dangerous Goods by Truck. The Canadian route screening guidelines provide the Canadian national approach for routing hazardous materials (dangerous goods). This methodology is similar to the current U.S. DOT hazardous materials routing guidelines, but it puts greater emphasis on emergency response and environmental impacts to make the final routing decision. Overall, four major factors are identified to help select routes: population risk, property risk, environmental risk and emergency response. The routing method relies on three major inputs: (1) accident probability, (2) accident consequences and (3) emergency response capabilities. Accident consequences are further subdivided into population, property and environmental exposure.

Accident probabilities are composed of accident rate data and length of route segments. Consequences are estimated assuming a hazard exposure corridor two kilometers in width (other corridor widths can be used). Reference data are provided to help quantify population, property and environmental exposure. Emergency response capability is defined as the number of qualified response units that could respond to the accident within 10 minutes divided by the length of the relevant route segment.

Potential Mode and Route Factors from Legislation

HMTUSA contains several provisions that relate directly to mode/route selection criteria. Section 15 of HMTUSA identifies a number of specific factors that are to be considered in the DOT/Volpe study. These factors include: population density, types and conditions of modal infrastructure, quantities of high-level waste and spent nuclear fuel, emergency response capabilities, exposure and other risk factors, terrain considerations, continuity of routes, available alternative routes, and environmental impact factors.

Section 4 of HMTUSA also directed DOT to establish federal standards for the states and Indian tribes to use to designate routes. Congress also included a list of factors that DOT is to consider for this rulemaking including the following: population density, type of highways, type and quantities of hazardous materials, emergency response capabilities, results of consultation with affected parties, exposure and other risk factors, terrain considerations, continuity of routes, alternative routes, effects on commerce, and delays in transportation. The Federal Highway Administration has since included each of these factors for consideration by States who wish to establish designated routes for Non-Radioactive Hazardous Materials (NRHM) in 49CFR Part 397.

Potential Mode and Route Factors Identified in Previous Studies/Analyses

An extensive review of over 200 documents was conducted for the DOT/Volpe study to identify factors that carriers, shippers and other interested parties have identified as being particularly important in selecting a mode and route to improve safety. The documents reviewed for this project could be categorized as modal studies, routing studies/evaluations, risk assessments, environmental assessments, and general hazardous material transportation studies. An exhaustive list of every potential factor identified from the review of past studies and documents as important for route and/or mode selection was also included in the comprehensive list of factors developed for consideration for the Mode/Route Study.

Screening of Comprehensive List of Factors

The factors identified from routing guidelines, legislation and the literature review were consolidated into a comprehensive list of potential mode and route factors and then screened carefully. The purpose of the screening process was to narrow down the number of candidate mode and route factors so that, ultimately, the most important factors could be identified as primary mode and route factors. Key considerations in the screening process included (1) a factor's relationship to the definition of public safety, (2) the extent to which a factor could affect mode or route choice, (3) interdependencies among factors, and (4) the extent to which candidate factors can be measured and applied. The factors were organized into categories for analysis as shown in Table II.

Only three factors were found to be mode-only selection factors: (1) mode accessibility, (2) cask availability, and (3) amount of material to be shipped. The first two factors are obvious practical constraints in mode selection. The amount of material to be shipped is the single most important factor that could affect the choice of mode exclusively, because of the substantial difference in payload between truck and rail casks. This differential has an obvious impact on the number of shipments required for a given amount of material. The number of shipments, in turn, has a direct impact on the overall safety of a shipping campaign.

The rest of the factors on the comprehensive list did not affect either mode or route exclusively, but must be considered within the context of the mode and route

combination. For example, when comparing the safety of highway and rail between common origin and destination points, more than one route will usually be possible by either mode. The risk of one rail route may be lower than the risk of a highway route, yet the corresponding risk of another rail route may be higher. Thus, it cannot be concluded that one mode is safer than another without considering the specific route

DEVELOPMENT OF FACTOR HIERARCHY

At first glance, the comprehensive list seems to be a jumble of apples and oranges. Upon further analysis, however, it became apparent that many of the factors were interrelated. Many factors were subsets of other factors or have a significant effect on other factors. The project team was able to develop a hierarchy of factors based upon these interrelationships. This hierarchy was organized according to the three components of the project definition of public safety: incident-free radiological exposure, radiological accident exposure, and non-radiological accident exposure.

A hierarchical approach to selecting mode/route factors allows the analyst to adjust for the level of analysis to be conducted. Many of the very detailed (“microscopic”) factors that have been identified in the past are valid for very short distances. The details, however, become unmanageable for regional and national shipments. To evaluate a route at the local level decision makers may want to consider such microscopic factors as high-accident locations (“hot spots”), grades or structures along the route of travel. On the other hand, if the shipment is cross-country, the level of analysis needs to be more general. The analyst would not, and probably could not, be able to account for the myriad of microscopic factors. Taken together, however, all three of the microscopic factors mentioned above can be related to the infrastructure along the route, which in turn, is a prime determinant of the accident rate. Accident rate, therefore, represents a higher level factor than can be used for regional and national analyses to help select modes/routes. This higher level factor implicitly accounts for the factors below it in the hierarchy, if the accident rate for a given route is derived from data for that route or otherwise reflects the characteristics of that route (i.e., if a national average or other generic rate is not used).

The factor hierarchy allows the analyst to conduct very detailed local or regional routing analyses using factors at the lower end of the hierarchy. The analyst can also conduct a national-level analysis by using factors at the upper end of the hierarchy, since they are fewer and more feasible to measure, and data are more readily available for them. Furthermore, these higher level factors are legitimately representative of the lower level factors, as shown by the hierarchical relationships.

The three categories of impact from the definition of overall public safety (incident-free radiological exposure, radiological accident exposure and potential non-radiological impact) were considered separately in establishing a hierarchical factor matrix. Each factor from the comprehensive list was evaluated to identify which category or categories is affected and how it was related to other factors within that category. These relationships could be divided into two types: (1) factors that were subsets of other

factors and (2) factors that could have a direct effect on another factor. An example of the first type would be people in hospitals as a subset of special populations, which is a subset of total population. An example of the second type would be road conditions that could affect the speed of the vehicle, which in turn would affect the overall shipment duration, which then affects the amount of incident-free radiological exposure.

Hierarchy for Incident-Free Radiological Exposure

The comprehensive list of factors was carefully reviewed to determine which factors affect incident-free radiological exposure during transportation. These factors were then evaluated for interrelationships. The major factors influencing incident-free exposure from radioactive material transportation were: (1) general population exposure, (2) occupational exposure, (3) shipment duration and (4) amount of material (See Table III.)

General population exposure can be segmented into several major subfactors: residential, non-residential and “special.” Residential population represents census population. Non-residential population can be broken down into employment population (which recognizes that time-of-day population varies considerably as people go from home to work and back), tourists, people in other vehicles along the right-of-way and people at stops. Special populations are those people believed to be more sensitive to the effects of radiation (e.g., children) and/or those located in large facilities that would be difficult to evacuate, such as hospitals, schools, prisons and stadiums.

Occupational population exposure consists primarily of two subgroups: (1) on-board crew and nearby escorts and (2) support workers (such as handlers) at the shipment origin, destination and transfer points, as well as inspectors and security staff. This would also include emergency response and service personnel at the scene of a non-radiological traffic accident or other incidents involving a vehicle carrying radioactive material.

Shipment duration, or time of exposure, is another primary factor for incident-free exposure. Many factors in the comprehensive list could affect shipment duration. These can be categorized into three major subfactors: (1) route length, (2) vehicle speed and (3) stops en route. Vehicle speed can be influenced by many factors, including both normal operations and delay conditions. Some of these include the speed limits, type of transport link, traffic density and time of day. Stops en route include the number of stops and stop times. These can be affected by the number of interchanges, inspections, classifications, breakbulk operations, equipment changes, union rules, fuel stops and other factors.

Amount of material is not a selection factor that affects incident-free radiological exposure on a per shipment basis. The amount of material, however, can become a factor for mode selection, if multiple shipments are necessary. If the amount of material to be shipped exceeds the capacity of a single truck cask, then the shipper may choose to use the larger rail/barge cask, which would reduce the number of shipments, needed. That, in turn, affects the total incident-free exposure from an entire shipping campaign.

Hierarchy for Radiological Accident Exposure

Seven primary factors affect mode/route choices because of their influence on radiological accident exposure: (1) accident rate, (2) trip length, (3) general population exposure, (4) occupational exposure, (5) sensitive environments, (6) emergency response, and (7) amount of material. Amount of material is included because it could affect cask payload and the number of shipments required. (See Table IV).

Using the same procedure as for incident-free radiological exposure, the comprehensive list was scanned to identify factors that could conceivably affect radiological accident exposure. This category of public safety is more complex than the incident-free category however. First, two major subcategories of factors influence potential accidents that are severe enough to cause a release of material: (1) accident likelihood (probability) and (2) accident consequences. Each of these is composed of a number of other factors. Second, two major types of impact could result from a release: (1) impact on people and (2) impact on property and the environment. Finally, emergency response capability must be considered, since it can have a significant effect on the magnitude of consequences following an accidental release.

Accident Likelihood. All factors that could affect the likelihood of an accident during transportation, particularly one that could cause the release of RAM, were identified. A number of these fall under the category of infrastructure. These include the classification of the right of way, grade and elevation, geometry and curvature, structures and clearances along the right-of-way, bottlenecks and even maintenance practices of the authority responsible for the quality of the right-of-way. Two other subfactors that could contribute to accident likelihood are the operating practices of carriers and quality control. Although these would not normally be considered routing-related factors, they could vary by mode and they could have an influence on accident potential because they address the issue of quality of carrier. Carrier operating practices, although subject to minimum regulatory rules (such as driver service hours) can be substantially different from one mode to another and from one carrier to another. Quality control factors include training, maintenance policy, hiring policy, and drug and alcohol enforcement.

Each of these three factors—(1) infrastructure, (2) operating practices, and (3) quality control—could contribute to the accident likelihood along a given mode/route combination. Thus, accident rate is considered a primary factor. Length of trip is also considered a primary factor, since it is traditionally used in conjunction with the number of accidents to calculate the accident rate. The amount of material to be shipped affects mode choice and so indirectly affects accident likelihood in two ways. First, the accident rate varies with mode. Second, cask capacity affects the overall number of shipments and, therefore, the likelihood of an accident during the campaign.

Accident Consequences. Three major factors relate to this category: (1) general population, (2) occupational population, and (3) environment. Obviously, the population within the proximity of an accidental release of radioactive materials is the major

component of accident consequences. The subfactors of general population exposure and occupational exposure were discussed in the previous section. A third major factor under accident consequences is sensitive environments, because of the growing concern about long-term public health effects of contamination of sensitive environmental areas as a result of transportation spills. The lack of a universally accepted definition for “sensitive environments” and the difficulties inherent in determining what can reasonably be avoided during long-distance shipments, however, make this factor difficult to measure. The two principal environmental subfactors initially identified are water supply areas (such as reservoirs) and sensitive areas (such as wetlands, refuges and sacred tribal grounds).

A fourth component of accident consequences, emergency response, was identified separately as a primary factor. The emergency response along potential modes and routes of travel can be significant in limiting the consequences of an accident. Several key subfactors determine the level of efficiency of emergency response. Emergency preparedness (training, plans and equipment) and actual emergency response operations (capability including number of personnel, proximity and accessibility) are the key factors. Finally, amount of material to be shipped is also a major determinant of accident consequences as discussed in the last section

Hierarchy for Non-Radiological Impact

Three primary factors were identified that could effect the mode/route choice because of their influence on non-radiological impacts: (1) accident rate, (2) length of trip, and (3) amount of material. (See Table V.) The non-radiological impact was handled differently than the first two categories, because its impacts are related to injuries or deaths resulting from vehicular accidents and are unrelated to the radioactive nature of the cargo. It is included as a public safety impact because shipping spent nuclear fuel may necessitate additional trips on the transportation infrastructure, introducing an additional non-radiological traffic impact that otherwise would not exist. This would certainly be true for highway, dedicated train and probably barge shipments, although probably not for regular train shipments.

The two major factors in this category are (1) accident rate and (2) trip length. Accident rate is represented by a number of other lower level factors, as discussed earlier. The major subfactors include infrastructure, carrier operating procedures and quality control. Amount of material is also included as a primary factor because it affects both accident rate through mode choice and the number of shipments required.

IDENTIFICATION OF PRIMARY FACTORS

Table VI presents a list of primary mode/route factors identified for the three categories of impacts on overall public safety (incident-free radiological, radiological accident exposure, and non-radiological accident risk). These factors are primary because they are at the top of the factor hierarchy previously discussed and are representative of a number

of subfactors positioned lower in the hierarchy. The applicability of these factors to each of the three components of public safety is given in the next three columns. For example, “general population exposed” includes all of the population along the route of travel for incident-free radiological exposure and the population within an affected area for accident-induced radiological exposure. The other primary factors are treated in a similar manner.

Finally, the amount of material is listed as a primary factor because of its effect on the number of shipments required, which is perhaps the key factor for mode selection. The number of shipments required is determined by the quantity of material to be shipped and the cask payload. This difference must be taken into account when comparing the relative impact on public safety among the three modes. A rail or barge cask has a significantly higher payload than a truck cask. It also is possible to include more than one cask per shipment for rail and barge shipments. Multi-cask shipments by rail have the potential to significantly reduce risk (not to mention cost) on a shipping campaign basis.

SUMMARY OF IDENTIFICATION AND SELECTION OF PRIMARY MODE/ROUTE FACTORS

The approach employed in the DOT Mode/Route Study was a hierarchical approach that was based on identifying the most important mode/route factors through a review of all factors that had previously been considered or proposed as important for selecting modes or routes. To ensure that all viewpoints would be considered, a comprehensive candidate list of factors was developed. Each factor was qualitatively evaluated in terms of criteria such as impact on safety, interrelationships among the factors, measurability and feasibility of implementation. This qualitative evaluation resulted in several important findings:

- There are many legitimate mode/route factors. The validity and importance of each factor is ultimately dependent upon the level of analysis to be conducted.
- A hierarchy of mode/route factors can serve as a decision-making tool to help shippers and carriers. The hierarchy allows the analyst to see the relationships and interdependencies among the many potential factors.
- A hierarchy allows the analyst to adjust for the level of analysis to be conducted. The factors at the highest end of the hierarchy are at a level of detail suitable for a national level of mode and route analysis. The lower end of the hierarchy is more suitable for a state or local level of analysis.
- Mode and route factors are difficult to evaluate separately. They must be considered together for a particular mode/route combination and then compared with mode and route factors for other mode/route combinations.
- The only separable mode choice factors found were cask availability, mode accessibility and amount of material to be shipped. Amount of material is perhaps the single most important factor in mode selection because it directly impacts the number of shipments required. If there is enough material to warrant use of the larger rail/barge cask, then the number of cask shipments can be significantly reduced

which, in turn, cuts the overall risks. Moreover, if the amount of material makes multiple-cask shipments possible, risk can be reduced still further when rail or barge modes are used.

The hierarchical approach used by the project team led to the identification of eight primary mode/route selection factors. These factors are (1) general population exposure, (2) occupational population exposure, (3) environmental exposure, (4) accident rate, (5) shipment duration, (6) trip length, (7) emergency response, and (8) amount of material. These eight factors are believed to be the most suitable as national-level mode/route selection factors.

Finally, this paper just serves to highlight the fact that there are many potential mode and route selection factors and lots of room for disagreement. Unfortunately, the identification and agreement on which factors should be used to select modes and routes for high-level radioactive waste and spent nuclear fuel is just the first step in the process of selecting actual routes. The real challenge is then to determine the methodology or process to be employed in using the factors to make a decision on actual routes (e.g. establishing priority factors or establishing weights for various factors). A neat, clean algorithm, would be nice, but would just not be possible given the inherent tradeoffs required when considering various factors. Ultimately, this difficult process will involve negotiation and compromise between all stakeholders.

REFERENCES

- (1) "Identification of Factors for Selecting Modes and Routes for Shipping High-Level Radioactive Wastes and Spent Nuclear Fuel", Volpe National Transportation Systems Center for the Office of Hazardous Materials Safety, U. S. DOT/RSPA, April, 1998.
- (2) "Identification of Factors for Selecting Modes and Routes for Shipping High-Level Radioactive Wastes and Spent Nuclear Fuel", Battelle Memorial Institute for Volpe National Transportation System Center, U.S. DOT, 1994.

Table I – Routing Factors Used in Regulatory Routing Guidelines

Generic Factors	Specific Factors	Measurable Components
U.S. DOT Hazmat Guidelines		
Primary Factors:		
Relative Population Risk	Accident probability	Accident rate
	Population potentially at risk	Population within "impact" zone
Relative Property Risk	Accident probability	Accident rate
	Property potentially at risk	Property value of lineal frontage
Subjective Factors:		
Special Populations	Type of special populations (schools, hospital, etc.)	Number along route
Special Properties	Type of special properties (utilities, structures, etc.)	Number along route
Emergency Response	Emergency response facilities	Proximity to route segments
U.S. DOT HRCQ Guidelines		
Primary Factors:		
Normal Radiation Exposure	Population potentially exposed	Population within 0-5 mile band; Transport workers (drivers, handlers, etc.); Passenger in other vehicles; People at stops
	Travel time	Shipment distance; Vehicle speed
Public Health Risk from Accidents	Accident release consequence	Population within 0-5 mile band; Population within 5-10 mile band
	Accident release frequency	Accident rate
Economic Risks from Accidents	Accident release consequence	Types of property within 0-5 mile band; Types of property within 5-10 mile band
	Accident release frequency	Accident rate
Secondary Factors:		
Emergency Response	Response time; equipment availability; training; manpower availability; type of land use	None-Subjective scaling
Evacuation	Population density; egress availability; manpower/equipment; evacuation time; evacuation impacts; land use type	None-Subjective scaling
Special Facilities	Dose response; accident evacuation; economics; type of facility	None-Subjective scaling
Traffic Fatalities and Injuries	Fatalities and injuries	Accident rate
Canadian Route Screening for Dangerous Goods by Highway		
Population Risk	Population potentially exposed	Population within impact area
	Accident probability	Accident rate
Property Risk	Property potentially exposed	Property within impact area
	Accident probability	Accident rate
Environmental Risk	Sensitive environments potentially exposed	Sensitive environments within impact area
	Accident probability	Accident rate
Emergency Response	Emergency response capability	Number of units within 10 minutes

Table II – Comprehensive List of Candidate Mode and Route Selection Factors

Safety Factor	Example
<u>Population and Environment</u>	
Occupational: on-board	Crew on vehicle
Occupational: support	Handling, security, interchange
Public: residential	People at home
Public: non-residential	People at work, tourists
Public: shared-facility users	Other traffic en route, at stops
Public: special populations	Hospitals, schools, arenas, prisons
Sensitive environments	Wetlands, refuges, reservoirs, tribal sacred grounds
<u>Transportation Infrastructure and Utilization</u>	
Functional classification	Arterial, collector, local or class 1, class 2
Opposing traffic separation	Median or two tracks
Grade	Uphill or downhill
Curvature	Curve in alignment
Crossings	Intersections, rail crossings, river confluences
"Hot Spots"	Known problem areas
Accident likelihood	Number of accidents per mile along route or by mode
Posted speed	Speed limit
Route length	Distance for mode
Clearance/weight limitations	Bridge clearances, channel depth
Traffic density	Vehicles per length per time period
Maintenance	Upkeep of roads or rails or channels
Accident rate and severity	National or local accident statistics
System elasticity	Ability to resume normal conditions after an incident
Travel times/delays	Congestion
Structural impediments	Light poles or guardrails
Hazmat traffic density	Density of other hazmat vehicles
Wayside detectors	Hotbox, dragging equipment
Available detours	System rerouting of traffic
<u>Operating Procedures</u>	
Time of day	Rush hour conditions
Operating speed	Controlled speed
Number of stops	Rests or sidings for other traffic to pass, refueling, locks and dams
Stop times	Average time of stops
Crew distance from cask(s)	Locating crew on vehicle
Configuration	Dedicated vs. regular trains, convoys, other hazmat involved
Escorts	Chase vehicles, ER, armed guards, medical
Interchanges	Changing rail carriers
Classifications	Rail yard classification
Handlings	Casks are loaded/unloaded on vehicle
Equipment changes en route	Changing locomotives
Inspections	Checking equipment at stops
Origin/destination	Beginning and end of route
Pick up/drop off en route	Adding vehicles from sidings

Work rules	Hours for driver operation
Available alternatives	Other routes or modes available to serve O/D
<u>Emergency Response (ER)</u>	
Proximity/accessibility	Location of ER with respect to route
Capability	Ability to respond to nuclear waste accident
Evacuation potential	Can surrounding population be evacuated
Communication	Remote computer, fax links
Equipment replacement	Availability of equipment (rail cars, tractor trailers)
Restoration to normal operations	Time for normal activity to resume
Medical care	Type of care for radiation exposure
Response times	Time to provide effective response
Training	Quality and amount of training for ER
Available manpower	Number of available responses
<u>Quality Control</u>	
Movement control	Signalization
Communication	Procedure for contacting vehicle
Training	Driving, emergency, handling
Hiring practices	Driver experience, previous driving record
Enforcement	Company procedures
Dispatching	Hours of operation
Vehicle maintenance/inspection	Company procedures
Licensing	State procedures
System monitoring	Ability to track vehicle
Substance abuse enforcement	Monitoring for substance abuse
Sabotage and vandalism	Obstruction on right of way (ROW), destruction of signs and signals
<u>Weather/Climate Terrain/Conditions</u>	
Seasonal road conditions	Snow or sleet, hot or cold
Terrain	Mountainous, hilly, flat
Wind speed, direction, stability	Wind conditions for dispersal
Visibility	Fog, dust, fires
<u>Shipment Characteristics</u>	
Waste type and level of radioactivity	Age and type of nuclear waste
Number of waste shipments	Number of shipments per time
Quantity per shipment	Size of shipment
Cask capacity	Size of cask
Release rates	Non-accident material release
Cask availability	Type and size of cask
Cask size limitations	Physical constraints (weight, length, etc.)
<u>Regulation and Other Restrictions</u>	
Cask design and fabrications	Type of cask
Legal restrictions	Existing legal restrictions due to overweight, oversize or hazmat
Time of day restrictions	City blackouts (no-travel times)
Jurisdictional cooperation	State-Federal cooperation
Continuity of routes	Continuous route for carrier
Effects on commerce	Increased transit times
Consultations with affected parties	Discussions with surrounding communities
Community Safety Index	Subjective rating of local conditions

Table III – Factor Hierarchy for Incident-Free Radiological Exposure

<u>General Population</u>	<u>Shipment Duration</u>
Residential	Length of route
Non-Residential	Origin/destination distance
People at work	Vehicle speed
Tourists	Normal operation
Pedestrians	functional classification
Shared-facility users in other vehicles at stops	posted speed
Shared-facility users en route	operating speed
Special Populations	traffic density
Hospitals	traffic mix
Schools	maintenance
Prisons	time of day
Events	work rules
	movement control
<u>Occupational Population</u>	enforcement
	time of day restrictions
On-board/nearby	Delays
Crew	communication
Escorts	seasonal road conditions
Support	hot spots
Handlers	incident/accident rate
Security	available detours
Inspectors	right-of-way maintenance
Emergency	weather/climate
Responders to non-radiological incident	visibility/lighting conditions
	Stops
<u>Amount of Material</u>	Number of stops
	interchanges
Number of shipments	classifications
Packages per shipment	handlings
Size of cask	inspections
Cask availability	equipment changes
Waste type/level of radioactivity	pick-up/drop-off route
Cask size limitation	union vs. non-union rules
	delays in/out of origin/destination
	priority passing
	locks and dams
	sabotage
	Stop times

Table IV – Factor Hierarchy for Radiological Accident Exposure

<u>Accident Rate</u>	<u>Length of Trip</u>	<u>Sensitive Environment</u>
Infrastructure	Distance	Water supply
Functional classification	Weather conditions	Reservoirs
Opposing traffic separation	Route restrictions	Sensitive areas
Grade		Wetlands
Curvature	<u>General Population</u>	Refuges
Crossings	Residential	Sacred tribal grounds
Hot spots	Non-residential	
Posted speed	People at work	<u>Emergency Response</u>
Clearance	Tourists	Preparedness
Maintenance	Pedestrians	Training
Structural impediments	Share-facility users in other vehicles	Equipment
Wayside detectors	at stops	Response
Operating procedures	Share-facility users in other vehicles	Proximity
Time of day	en route	Accessibility
Work rules	Special populations	Capability
Quality control	Hospitals	Communication
Training	Schools	Time to medical care
Movement control	Prisons	Evacuation
Hiring practices	Events	
Enforcement		<u>Amount of Material</u>
Vehicle maintenance/inspection	<u>Occupational Population</u>	Number of shipments
Licensing	On-board/nearby	Size of cask
Substance abuse enforcement	Crew	Cask availability
Sabotage and vandalism	Escorts	Waste type/level of radioactivity
Human error	Support	Cask size limitations
Weather/climate	Handlers	
Seasonal road conditions	Security	
Visibility/lighting conditions	Inspectors	
	Responders	
	Fire, police, etc.	

Table V – Factor Hierarchy for Non-Radiological Accident Risk

<u>Accident Rate</u>		<u>Amount of Material</u>
Infrastructure	Quality control	Number of shipments
Functional classification	Training	
Opposing traffic separation	Movement control	<u>Length of Trip</u>
Grade	Hiring practices	Distance
Curvature	Enforcement	Weather conditions
Crossings	Vehicle maintenance/inspection	Route restrictions
Hot spots	Licensing	
Posted speed	Substance abuse enforcement	
Clearance	Sabotage and vandalism	
Maintenance	Human error	
Structural impediments	Weather/climate	
Wayside detectors	Seasonal road conditions	
Operating procedures	Visibility/lighting conditions	
Time of day		
Work rules		

Table VI – Recommended Primary Mode and Route Selection Factors

	Incident-Free	Accident-Induced	Non-Radiological
Primary Factor	Radiological Exposure	Radiological Exposure	Impact
General population exposed	People along route	People in area affected by accident	Not a primary factor
Occupational population exposed	People moving and handling material	People moving material and responders	Not a primary factor
Environment exposed	Not a factor	Environment in area affected by accident	Not a factor
Shipment duration	Length of time material is transported	Not a factor	Not a primary factor
Accident rate	Not a factor	Likelihood of accident releasing material	Likelihood of traffic accident with injury/fatality
Trip length	Not a primary factor	Distance material moves	Distance material moves
Emergency response	Not a factor	Length of time for trained responders	Not a primary factor
Amount of material*	Number of shipments required	Number of shipments required	Number of shipments required

*Amount of material is the only primary factor identified that could dictate mode by itself. This is because of its impact on the number of shipments required, given the cask payloads of highways vs. rail transport modes.