Selection of Preferred Highway Routes for the Shipment of Spent Nuclear Fuel Between Surry and North Anna Power Stations in Virginia

Antoine G. Hobeika, Barnham Jamei, and Iwan B. Santoso

ABSTRACT

The Virginia Electric and Power Company has proposed to transport irradiated nuclear fuel from its current storage location at the Surry nuclear power station to its North Anna nuclear generating station for storage at that facility. Five routes were proposed for the shipment of the irradiated nuclear fuel between the two power stations. However, after the available routes had been carefully reviewed, three more routes were added to give a total of eight feasible routes. The methodology used in this paper for selecting preferred highway routes for shipment of radioactive materials is based primarily on U.S. Department of Transportation (DOT) guidelines. Several modifications and additions were incorporated into the DOT guidelines to enhance their applicability to the route conditions under consideration.

Safety in transporting hazardous materials continues to be a significant concern. There are thousands of materials classified as hazardous materials, hazardous substances, and hazardous wastes, depending on their destination and the nature of the material. Hazardous materials are defined to be "those the U.S. Department of Transportation has found to be in a quantity and form that may pose an unreasonable risk to public health and safety or property when transported in commerce" (1). As an example, one of the major issues concerning the use of nuclear materials is the transportation and disposal of the resulting hazardous waste.

There are two general categories of civilian radioactive materials: those related to the nuclear fuel cycle and those not related to the nuclear fuel cycle. The first category involves the fuel, materials, and waste resulting from the production of electricity from nuclear energy. Less than 15 percent of radioactive packages shipped each year are associated with the nuclear fuel cycle (2). The second category, those not related to the nuclear fuel cycle, includes primarily radioactive elements and the wastes resulting from their use in medicine, research, and industry. Most of the civilian radioactive wastes in the United States are in this second category.

There are more than 100 million shipments a year of all types of hazardous materials in the United States. About 3 percent of these, or some 3 million packages, contain radioactive materials, of which about one-third are used for medical purposes, about one-sixth are related to the nuclear fuel cycle, and the balance are used for industrial and research activities. Shipments of nuclear wastes account for about 10 percent of the radioactive packages transported each year (2).

Some of the problems of transporting hazardous materials may be addressed by policies that affect the vehicle, the operator, the methods in which materials are handled and packaged, roadway design, and emergency response and preparedness to accidental releases. Both the public and private sectors have responded by developing programs in most of these safety areas. Another method to improve public safety when transporting hazardous materials is to reduce the potential exposure of public health and property to accidental releases of these materials. This could be done by selecting the most preferred routes to transport those hazardous materials. However, problems may be created when local or state governments effect routing without fully considering the impact of the hazardous material shipment. A simple ban or prohibition of hazardous materials from one route will obviously shift that risk to other routes and perhaps other communities. Furthermore, unless the impact on other routes and communities is assessed, there is no assurance that the overall safety has been enhanced. Routes should indeed be the safest and not be imposed merely for the parochial self-interest of one community (4).

The objectives of this study are

1. To minimize the accidential-release radiation risk to people and property and
2. To maximize the community preparedness in terms of emergency response and evacuation capability.

METHODOLOGY

This study used the guidelines of the U.S. Department of Transportation (DOT) (5) as a basic conceptual approach. This is the second application of these guidelines at the state level. The DOT guidelines evaluate the route comparison based on the following classification:

1. Primary risk factors
   a. Normal radiation exposure
   b. Public health risk
   c. Economic risk
2. Secondary factors
   a. Emergency response capabilities
   b. Evacuation capabilities
   c. Location of special facilities
   d. Traffic fatalities and injuries

The selection of the route is based primarily on the primary risk factors and the secondary factors can be used if no clear-cut choice emerges from evaluation of the primary factors or if unusual conditions exist in the state that increase the importance of one or more of the secondary factors (5).

Primary Factors

Normal Radiation Exposure

Packages containing radioactive materials emit low levels of radiation during normal transportation. The amount of radiation emitted depends on the kind and amount of material being carried. DOT regulations require that packages containing radioactive materials that are being shipped have sufficient radiation shielding to reduce the levels of emitted radiation to safe ones. Persons residing along a transportation route, passengers in other vehicles, people at truck stops, and the truck drivers will all receive small doses of radiation from these shipments.

Public Health Risk

A release of radioactive material during transportation accidents will occur only when the package carrying the material is subjected to accident forces that exceed the package design standards. Although the probability of release is small, the consequences of such an accident are severe. The public health risk factor for each route is determined by multiplying the accident release probability by the accident consequence. The number affected is considered the consequence of the public health risk. Because radioactive materials can disperse for relatively large distances, it is necessary to examine the population along the alternative routes to distances of about 10 mi.

Economic Risk

The accidental release of radioactive materials could also have economic impacts. The release frequency measure will be the same as that used for the public health risk. The consequences are associated with the decontamination costs, which vary with the type of property (e.g., farmland, residential, commercial, parks, and public areas).

Secondary Factors

Emergency Response Capabilities

Quick action by emergency response personnel can mitigate the potential consequences of a severe transportation accident resulting in release of radioactive material. The effectiveness of these safety measures depends on the time required for emergency response units to reach the accident site. Other factors that also affect the quick response of emergency personnel are manpower and equipment availability in addition to their level of training.

A relative ranking system on the basis of city, town, or rural or industrial area is suggested to evaluate the effectiveness of the emergency response.

Evacuation Capabilities

Evacuating those that could be exposed to the radioactive material released is one of the approaches for reducing the consequences of such an accident. Because the time and effort required to evacuate those along route segments are different from site to site, an evacuation comparison factor for selecting the preferred routes is justified. Elements contributing to an effective evacuation include extent and nature of the threat, the population and the type of area to be evacuated (residential commercial), means of egress (accessibility), level of planning, and effectiveness of implementing these plans by responsible authorities. This evaluation is simplified by using the relative ranking scheme.

Location of Special Facilities

In the route-selection process, it is important to give more consideration to certain facilities that have sufficient economic or public safety significance. These facilities might contain populations that are large (factories, stadiums), sensitive to radiation (children's hospitals, schools), or difficult to evacuate (nursing homes, prisons).

Parameters that affect the importance of special facilities in the route-selection process include the radiation dose sensitivity of the people normally occupying the facility, the economic importance of the facility to the local community, and difficulty associated with evacuating people from the facility. Relative ranking scales are applied for evaluating special facilities in relation to these parameters. Special facilities would only be considered if they are within 5 mi of a route.

Traffic Fatalities and Injuries

Accidents caused by trucks carrying radioactive materials could bring about negative public reactions, even though these accidents are not related to the radiological nature of the cargo. For that reason, it is recommended that a factor be included that favors radioactive material shipments on routes with low rates of fatal and injury accidents.

The numerical estimation of this route-comparison factor is straightforward. Data on the frequency of fatal and injury accidents for general traffic on a given segment in terms of number of accidents per million miles of travel are multiplied by the length of the respective route segment. Then these accident values are weighted for the entire route to obtain a single factor for each route.

FRAMEWORK OF ANALYSIS

In this study the Virginia Electric and Power Company (VEPCO) proposed to ship limited quantities of irradiated nuclear fuel from Surry to North Anna in Virginia. Eight routes, shown in Table 1, were considered as candidate routes for shipment.

To determine the preferred route and the alternative route for highway shipments of radioactive

TABLE 1 Candidate Routes for the Study

Route 1	Route 2	Route 3	Route 4	Route 5	Route 6	Route 7	Route 8
650 south	650 south	650 south	650 south	650 south	650 south	650 south	650 south
10 west	10 west	10 west	10 west	10 east	10 east	10 east	10 east
156 north	156 north	I-95 north	I-95 north	258 south	258 south	32-17-258 west	32-17-258 west
5 east	5 east	I-64 west	606 west	460 west	460 west	I-64 west	I-64 west
155 north	155 north	522 north	208 west	I-95 north	I-95 north	I-295 west	I-295 west
I-64 west	I-64 west	208 east	652 south	I-64 west	606 west	I-64 west	I-95 north
I-295 west	I-295 west	652 south	700 east	522 north	208 west	522 north	606 west
I-64 west	I-95 north	700 east		208 east	652 south	208 east	208 west
522 north	606 west			652 south	700 east	652 south	652 south
208 east	208 west			700 east		700 east	700 east
652 south	652 south						
700 east	700 east						

material, a conceptual approach is developed, based on the following three principles:

- Feasibility
- Evaluation
- Choice

The feasibility of a candidate route is established first. Then all feasible routes are evaluated under the same criteria, which would lead to the choice of the best feasible route.

Feasibility

A route is feasible for shipment if

1. It is cleared by the proper authorities [in this case, the Nuclear Regulatory Commission (NRC)] to be used as a potential route for the shipment of radioactive materials,
2. It is designated or was previously designated as a route to be used by overweight and overdimensional vehicles, and/or
3. It has actually been driven by a truck designed to carry radioactive materials (dry run).

All eight candidate routes shown in Table 1 proved to be feasible in terms of route geometrics, safety, and security. To make sure that the feasibility criterion is well established, an empty cask was actually carried by the overweight and overdimensional vehicle on all the routes and filmed from air and ground cameras.

Evaluation

In establishing the criteria for evaluating a route, three target groups that are influenced by the shipment are addressed:

1. The community at large,
2. The other traffic using the same route, and
3. The shipper.

Community at Large

One of the important factors to be considered is the radiological impact on the community. Radiological impacts are those associated with the accidental release of radioactive material during transportation and its effect on the surrounding population and property. They also include a consideration of the effects on surrounding population of low levels of radiation emitted during accident-free transportation (often called normal exposure).

The other concern that should be considered from the community standpoint is the community structure and preparedness, such as emergency response capabilities, evacuation capabilities, and the location of special facilities.

Other Traffic Using the Same Route

Transportation via overdimensional and overweight vehicles is a sensitive safety issue, especially on two-lane highways where geometric and operational characteristics may limit the vehicle's maneuverability as well as increase the delay of other vehicles using the same road. For these reasons, the highway geometric is also considered one of the important factors to be evaluated in this research in order to minimize the impact of the overdimensional and overweight vehicles on other traffic.

The Shipper

The shipment cost of radioactive material through highway systems is of concern to the shippers. This cost is usually more than that of a nonradioactive cargo because extra security is needed during transport of radioactive material. Most cost models estimate the truck travel cost based on the travel time and travel distance incurred on a route.

Choice

In this study the selection of a preferred route is based on the following factors:

- Radiation risk
- Nonradiation risk
- Community structure and preparedness
- Transportation cost

The relations between these factors and the target groups are shown in Table 2.

Scenarios were developed to select the best choice among the proposed eight routes, which will be described in the results.

MODIFICATION OF DOT GUIDELINES

Introduction

As stated earlier, the study approach is divided into the following factors: radiation risk, nonradiation risk, community structure and preparedness, and transportation cost. Modification of the DOT guidelines took place in estimating the public health risk, economic risk, special facilities, and emergency response, and the roadway geometric factor and transportation cost are additional considerations.

TABLE 2 Influencing Factors Versus Target Group Concerned

Influencing Factor	Target Group: Community	Other Traffic	Shipper
Radiation risk			
Public health	X		
Economic	X		
Normal exposure	X	X	X
Special facilities	X		
Nonradiation risk			
Roadway geometrics		X	
Traffic fatalities and injuries		X	
Community structure and preparedness			
Emergency response	X		
Evacuation	X		
Special facilities	X		
Transportation cost			X

The DOT guidelines are used for estimating the normal exposure, traffic fatalities and injuries, and evacuation capability.

Throughout this study, risk is defined as the product of the probability of a hazardous materials accident and the consequences of that accident. There exist two approaches for assessment of the risk. In the first, that for relative risk, one route is evaluated against another. The end result of such an assessment is that a particular route can only be found to be "better" or "worse" than another route. On the other hand, the absolute risk is a fixed measure of hazard. Even though it yields more information, it requires a much more complex analysis and more input data. In this study of route comparison, only relative risk is needed to conduct the analysis.

Radiation Risk

Modifications in the estimation of the radiation-related risks are basically applied to the public health and economic risks, which will be explained in the following sections.

Public Health Risks from Accidents

The public health risk factor for each route is determined by multiplying the accident release probability estimate by accident consequence. Release probability is presented here in terms of the tractor-trailer accident rate per 1,000 shipments in which the segment's average daily traffic (ADT) represents the total set of events from which the tractor-trailer accidents are drawn:

Release probability estimate = number of tractor-trailer accidents per year x 1,000/(ADT x 365).

Because it has been proved that the inhalation dose of radioactive materials is highly dependent on the wind direction, the wind rose data were used for each segment of the route as a modification of the suggested DOT methodology (5). To achieve the foregoing goal, the population around a segment of a route was considered to be in four quadrants, namely, north, south, east, and west. Then the population in each quadrant was multiplied by the relevant wind probability ratio and by the appropriate release consequence measure given in the DOT guidelines to obtain an overall release consequence factor. It is believed that modifying the DOT release consequence measure by the foregoing procedure results in a more realistic and accurate representation of this measure.

Finally, the public health risk measure for each route is determined by multiplying the release probability estimated value by the release consequence factor for each segment of the route and summing them to achieve a final figure of merit. For each route segment, the public health consequences are calculated as follows:

$$\sum_{i=1}^{4} [P1(i) \times W(i) \times 0.75 + P2(i) \times W(i) \times 0.25],$$

where

P1(i) = population of 0 to 5 mi in quadrant area i,
P2(i) = population of 5 to 10 mi in quadrant area i,
W(i) = wind direction probability in quadrant area i.

The population data were calculated from county maps by drawing a perpendicular line at both ends of each segment and extending it 10 mi on either side.

Economic Risks from Accidents

Economic impacts of accidental release of radioactive materials could be very significant. The economic risk is determined by multiplying the release probability estimate (the same as that used for the public health risk) by the release consequence, which is a function of the type of property alongside the road segment, and by the wind probability ratio for respective segments.

Decontamination costs given in the DOT guidelines (5) that correspond to each land use type and level of decontamination are used here. The only addition is that a decontamination cost has been determined for vacant land. The wind factor is added to the economic risk in the same way as was done for the public health risk. For each segment, the economic consequences are calculated as follows:

$$\sum_{j} \sum_{i=1}^{4} [L(ij) \times C(j) \times W(i)],$$

where

L(ij) = land use type j in quadrant area i,
C(j) = decontamination cost factor of land use type j,
W(i) = wind direction probability in quadrant area i, and
j = type of land use.

Land use data were collected by using the land use maps obtained from each county or city under evaluation. The area boundaries alongside the roadway segment from which the population estimates were obtained were also used to determine the land use data.

Special Facilities

In this study the special-facility comparison factor has been divided into two parts. The first part, which is influenced by radiation, namely, dose response and economics, was considered in the previous sections. The second part, which deals with evacuation of people as a result of an accident, was

classified under preparedness and evaluation capabilities.

Relative ranking scales suggested by DOT (5) are used in this study to evaluate the special facilities on each route by separating the scales of dose response and economics and the scales of evacuation. The locations of special facilities were obtained from detailed county and city maps.

Nonradiation Risk

The nonradiation risks are defined as those that are not actually related to the radioactive nature of the cargo (fatal and injury accidents during transportation) and inconveniences and delays to other traffic caused by roadway geometric design limitations (sharp curves, narrow bridges, etc.).

The accident data for general traffic along segments of the routes were obtained from the Division of Highway Traffic Safety at the Virginia Department of Highways and Transportation. The set of geometric factors was obtained as a result of observations made in actual travel on the roadway segments.

The DOT methodology was further modified by addition of a roadway-geometrics comparison factor. This was done in order to take into account some of the disadvantages of rural secondary roads, which usually are favored over Interstate highways in the DOT guidelines.

With regard to the truck's operational characteristics and its interaction with other vehicles on the road, the following geometric factors were considered to be significant and important for route selection comparisons:

- Miles of no-passing zone;
- Number of right and left turns;
- Number of on ramps, off ramps, and toll booths;
- Number of signalized intersections;
- Number of intersections with two-way and four-way stop signs;
- Number of at-grade railroad crossings; and
- Number of narrow bridges.

Because both the amount of traffic and the length of a roadway segment have significant effects on the number of geometric limitations, the foregoing factors were weighted by ADT and the length of road section as shown in the following formula:

$$[\sum G(c) \times ADT]/length,$$

where G(c) is the number of geometric factors.

Community Structure and Preparedness

There were no major modifications of the DOT guidelines under the preparedness factor except for the new relative ranking of emergency response effectiveness, which is assigned for each city or county along the proposed route. This was determined by contacting every county and city along the candidate routes.

Emergency Response Effectiveness

Because all the factors that influence the effectiveness of emergency response personnel are location dependent, a ranking scale is needed to assign values to these parameters based on counties and cities. In this study a relative ranking for counties and cities was established to assess the effectiveness of their emergency response. The ranking is based on the timely action, personnel availability, personnel training for encountering the radioactive material, and availability of equipment concerned with radioactive materials. The following formula is used to determine the emergency response effectiveness:

$$\left[\sum_{1}\sum_{x} A(x) \times f(x)\right]/TA,$$

where

A(x) = area of county or city (x) in 0- to 5-mi band in route section 1,
f(x) = emergency response factor in county or city (x), and
TA = total route area in 0- to 5-mi band.

Transportation Cost

A model developed for the trucking industry has been used here that recommends the following impedance factors for estimating the transportation cost:

1. Travel time impedance factor = 0.7 x route travel time and
2. Travel distance impedance factor = 0.3 x route length.

The travel time was determined by actually driving along the proposed routes. The travel distance was obtained from a previous safety study done by the Virginia Department of Highways and Transportation.

Because the differences in travel times and travel distances along proposed routes for this study are not very significant, use of the foregoing model did not influence the overall decision. In addition, the public response obtained through a questionnaire administered to public agencies and local jurisdictions gave the transportation cost a very low ranking among the influencing factors.

RESULTS AND CONCLUSIONS

Introduction

The results are classified according to radiation and nonradiation risk, preparedness, and transportation costs. Because the values for each of these comparison factors are calculated in different units, simply adding the values would produce misleading conclusions. For that reason, the values of each comparison factor have to be normalized. Mathematically, normalization is carried out by dividing each comparison factor by the sum of the values for that factor for all the routes being considered in the analysis.

The comparison factors for radiation-related risk are given in Table 3. The public health risk for routes 1 and 2 is significantly lower than that for the rest of the proposed routes. This is because these two routes bypass the only major city, Richmond, and as a result less population is affected in case of an accident. Even though routes 7 and 8 bypass Richmond, they go through Newport News and Hampton, which have a reasonably high population.

The accident probability of segments of a route has a major effect on the magnitude of the economic-risk comparison factor. The weighted accident probabilities for routes 1 and 2 are higher than those for routes 5, 6, 7, and 8. Therefore, the economic-risk comparison factors for routes 1 and 2 are very high, even though the land development types along-

TABLE 3 Normalized Comparison Factors for Radiation and Nonradiation Risk

	Radiation Risk				Nonradiation Risk	
Route	Public Health	Economic	Normal Exposure	Special Facilities	Traffic Fatalities and Injuries	Roadway Geometrics
1	.0471	.1252	.1233	.0888	.1344	.1338
2	.0407	.1273	.1208	.0925	.1288	.0852
3	.2324	.1556	.1087	.1205	.1225	.1240
4	.1582	.1442	.1105	.1223	.1169	.0760
5	.2054	.1190	.1325	.1428	.1307	.1477
6	.1312	.1077	.1343	.1446	.1251	.0997
7	.0957	.1094	.1362	.1424	.1241	.1910
8	.0893	.1116	.1337	.1461	.1176	.1423

side these two routes require less expensive decontamination costs.

The elements that influence the normal-exposure comparison factor are population density, truck velocity, total length of the route, and ADT along each segment of the route. Shorter distances and higher speeds on routes 3 and 4, which even go through highly populated areas, contribute to lower values for the normal-exposure comparison factors for these routes.

For the special-facilities comparison factor, routes 1 and 2 are heavily favored. These two routes bypass every large city and town and consequently are less exposed to major facilities such as hospitals, churches, schools, and factories.

The normalized values of the comparison factors for nonradiation-related risks are also presented in Table 3. There are basically no significant differences among normalized values for traffic fatalities and injuries for all the routes. However, more geometric limitations such as narrow bridges, signalized intersections, and railroad crossings along routes 1, 3, 5, and 7 result in higher values of the geometrics comparison factors for those respective routes. Overall, routes that use more Interstate highway systems are favored over the ones that use secondary roads because of the high safety and design standards used for the former system.

Comparison factors for emergency response and evacuation capabilities of routes 1 and 2 are significantly lower than those for the rest of the proposed routes as shown in Table 4. The elements contributing to low values of the preparedness comparison factors for those two routes are mainly the fewer special facilities along these routes and low population densities. Because routes 1 and 2 pass through counties and no large cities and towns, evacuation capabilities along these routes are significantly better than those along the rest of the proposed routes.

The transportation cost comparison factor depends primarily on travel time and travel distance. Because routes 3 and 4 go through Richmond and do not use the bypass around the city, their travel time and distance are much less than those for the remaining proposed routes. Also, large portions of these two routes use the Interstate highway system, which enables them to travel at higher speeds. All the foregoing factors result in lower transportation costs for routes 3 and 4, as shown in Table 4.

TABLE 4 Normalized Comparison Factors for Community Preparedness and Transportation Cost

	Community Preparedness			Transportation Cost	
Route	Emergency Response	Evacuation Capability	Special Facilities	Travel Time	Travel Distance
1	.1272	.1112	.0942	.1248	.1212
2	.1298	.1111	.0971	.1234	.1240
3	.1245	.1330	.1225	.1066	.1023
4	.1255	.1316	.1254	.1098	.1096
5	.1256	.1350	.1431	.1307	.1315
6	.1264	.1338	.1460	.1343	.1387
7	.1192	.1222	.1344	.1357	.1350
8	.1217	.1220	.1373	.1343	.1377

The decision to select the best route depends on the priority and degree of importance of each individual category. In order to cover all aspects of the problem, it was decided to consider three different scenarios. Each scenario emphasizes a certain viewpoint and accordingly suggests a preferred route.

In the next sections, preferred routes under each scenario in addition to the reasoning behind that specific scenario are detailed.

Pessimistic Scenario

In the worst-case scenario it is assumed that radiation release from an accident involving a truck carrying radioactive material is probable, and the route selection should be primarily based on minimizing the impacts of such a release.

Three radiation-related risk comparison factors are influenced by the occurrence of an accidental release and accordingly are given higher priorities than the other factors. They are the public health, economic, and special-facilities comparison factors.

Table 5 shows the figures of merit calculated for the foregoing three factors. As can be seen, routes 1 and 2 are tied for the best preferred shipment route.

TABLE 5 Results of Scenario Analyses

	Pessimistic Scenario		Optimistic Scenario		Combined Scenario	
Route	Value	Rank	Value	Rank	Value	Rank
1	0.261[a]	First	0.392	Fifth	0.290	First
2	0.261[a]	First	0.335	Second	0.292	Second
3	0.509	Eight	0.355	Fourth	0.457	Eighth
4	0.425	Sixth	0.303	First	0.426	Sixth
5	0.467	Seventh	0.411	Seventh	0.442	Seventh
6	0.384	Fifth	0.359	Third	0.393	Fifth
7	0.348	Fourth	0.451	Eighth	0.359	Third
8	0.347	Third	0.394	Sixth	0.361	Fourth

[a]Routes 1 and 2 are tied for first place.

A previous study performed by the Virginia Polytechnic Institute and State University for the Virginia Department of Transportation Safety located sections of the highway system in Virginia that have the highest potential for accidents involving haz-

ardous materials (6). Two of these sections are along I-95, one of which is in Caroline County (one of the sections on route 2). In addition, some sections of route 2 are currently under construction and repair for widening and will be for the next few years. Last, there are higher ADT and total number of accidents on route 2. All these drawbacks to route 2 lead to the selection of route 1 as the preferred route under this scenario.

Optimistic Scenario

The assumption under this scenario is that there will be no radiation release as a result of an accident involving a truck carrying radioactive material, no matter how severe the accident might be.

The risk comparison factors considered under this scenario are normal radiation exposure, road geometrics, and traffic fatalities and injuries unrelated to the radioactive nature of the cargo. The figures of merit for these comparison factors are presented in Table 5. The transportation cost comparison factors were not considered under this scenario because of the lack of public interest in these factors, which was revealed in the results of a survey performed for this study.

As shown in Table 5, route 4 is the best preferred shipment route under this scenario. The results of this scenario should not influence the final decision for selecting the preferred route because the consequences of the risk comparison factors under this scenario are not at all critical compared with the consequences resulting from the accidental release of radioactive materials. Except for the normal-exposure comparison factor, which is mainly negligible in this case, the other risk factors are not different from those for any other overweight and overdimensional truck on the road.

Combined Scenario of Risk and Preparedness

To satisfy the overall objective of the study in terms of minimizing radiation release risks and maximizing community preparedness, the combined effects of the following comparison factors were considered in this scenario:

1. Radiation release risk factors
   a. Public health
   b. Economic
   c. Special facilities
2. Preparedness factors
   a. Emergency response effectiveness
   b. Evacuation capabilities
   c. Evacuation of special facilities

These comparison factors were combined and multiplied by some weighting ratios obtained from the results of a questionnaire designed for this study and circulated to the representatives of the jurisdictions influenced by the proposed eight routes. The values of weighting ratios were 0.6 for radiation-release risk factors and 0.4 for emergency preparedness and evacuation factors.

Results of the analysis under the combined scenario are shown in Table 5.

Conclusions and Recommendations

Results of scenarios, especially the pessimistic and combined cases, suggest that route 1 should be preferred over the remaining proposed routes. This conclusion was drawn with the goal in mind of minimizing the radiological risks of an accidental release of radioactive material from the truck carrying the material. The recommended alternative route for the northern section of Richmond would be route 2, as the results indicate. The alternative route for the southern section of Richmond would be route 7.

The biggest advantage of route 1 is that it bypasses the areas with large population densities and as a result minimizes the possible radiological risk. Even though route 1 is selected as the preferred route for highway shipment of controlled quantities of radioactive material, the following recommendations are strongly suggested for an extra measure of safety:

1. Two escort vehicles, one in front and the other in back of the truck with communication capabilities, must accompany the shipment. It is also advisable that a radiation specialist accompany the shipment in one of the escort vehicles.
2. Shipment during peak traffic hours should be avoided, especially in areas close to cities and towns.
3. The shipment during nighttime, because of reduced visibility, should be avoided.
4. An evacuation planning study for the northern and eastern sections of Richmond is highly recommended.
5. Emergency response capabilities for counties and cities along the recommended route should be improved if they are inadequate.

ACKNOWLEDGMENT

The authors wish to thank the Virginia Department of Emergency Services for supporting this study. In particular, special recognition is extended to A.E. Slayton and J. Holloway. Several agencies have kindly assisted in the completion of the study, such as the Virginia Department of Highways and Transportation, Virginia Electric and Power Company, and the U.S. Department of Transportation.

REFERENCES

1. L.W. Bierlin. Hazardous Materials--A Guide for State and Local Officials. U.S. Department of Transportation, 1982.
2. G. Swindell. Obtaining Safety Assurance Through International Agreements. Nuclear Engineering International, Dec. 1980.
3. L. Wallis. Perspective on Nuclear Material Transport Risks. Nuclear Power Newsletter (General Electric), fall 1979.
4. F.J. Ivancie. Establishing Routes for Trucks Hauling Hazardous Materials: The Experience in Portland, Oregon. Office of Emergency Management, Portland, Ore., 1984.
5. Guidelines for Selecting Preferred Highway Routes for Highway Route Controlled Quantity Shipments of Radioactive Materials. U.S. Department of Transportation, June 1984.
6. D.L. Price, W. Schmidt, and R.W. Kates. Multimodal Hazardous Materials Transportation in Virginia. Virginia Polytechnic Institute and State University, Blacksburg, Sept. 1981.