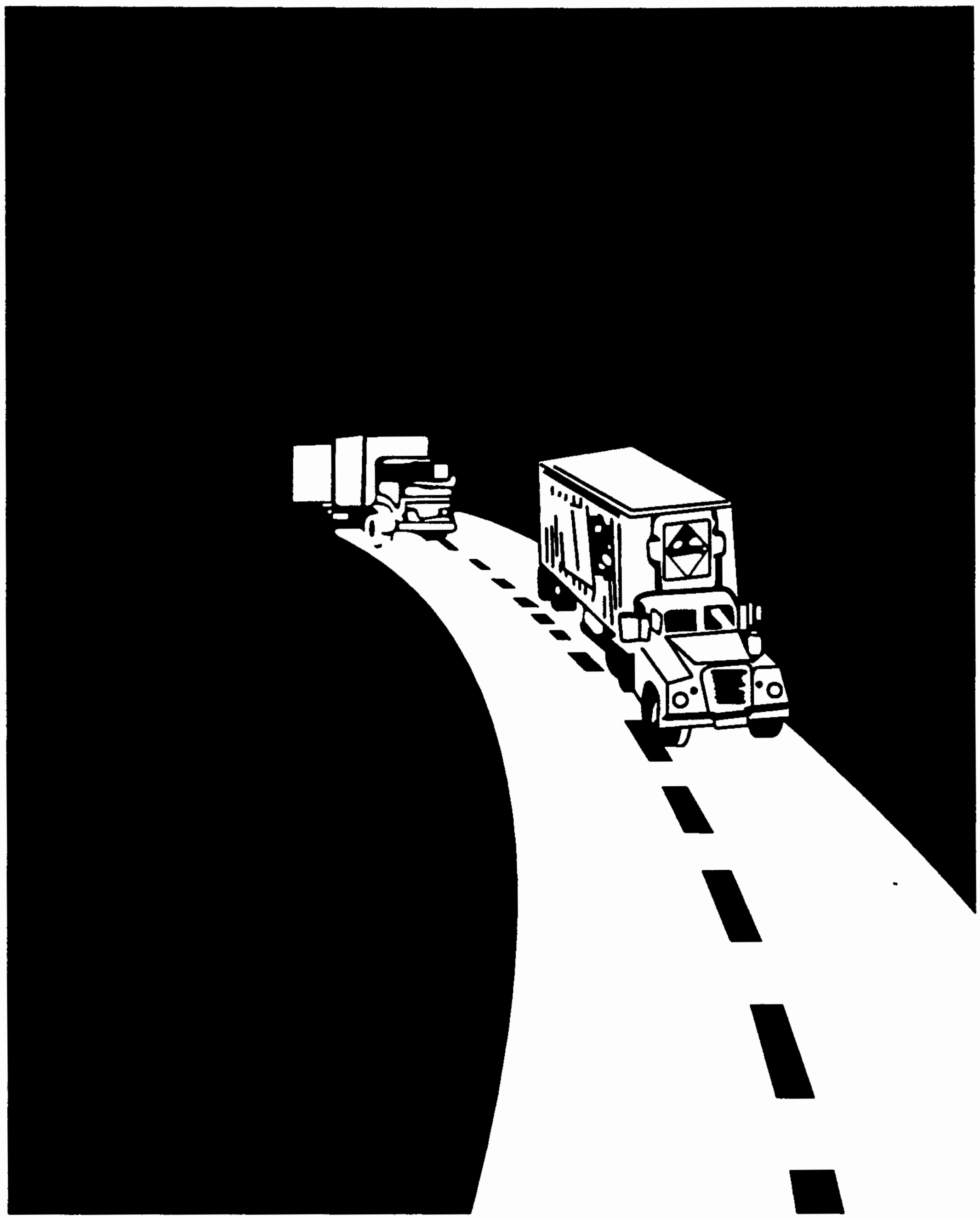
DOT/RSPA/HMS/92-02

U.S. Department
of Transportation
Research and
Special Programs
Administration

Guidelines for Selecting Preferred Highway Routes for Highway Route Controlled Quantity Shipments of Radioactive Materials



August 1992

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Guidelines for Selecting Preferred Highway Routes for Highway Route Controlled Quantity Shipments of Radioactive Materials*

*NOTE: This publication was formerly titled "Guidelines for Selecting Preferred Highway Routes for Large Quantity Shipments of Radioactive Materials (DOT/RSPA/MTB-81/5), dated June 1981. This printing corrects errors found in the previous versions of this document. The corrections are highlighted.

August 1992

FOREWORD

This document presents guidelines for use by State officials in selecting preferred routes for highway route controlled quantity shipments of radioactive materials. A methodology for analyzing and comparing safety factors of alternative routes is described. Technical information on the impacts of radioactive material transportation needed to apply the methodology is also presented. Application of this methodology will identify the route (or set of routes) that minimizes the radiological impacts from shipments of these radioactive materials within a given State. Emphasis in this document is on practical application of the methodology. Some details of the derivation of the methods and data are presented in the appendices. All references in the body of this report can be found listed in the Bibliography (Appendix F).

This document supersedes all previous editions of Department of Transportation (DOT) publications (DOT/RSPA/OHMT-89/0, January 1989), (DOT/RSPA/MTB-84/22, June 1984) with the same title, and a previous edition (DOT/RSPA/MTB-81/5, June 1981), entitled "Guidelines for Selecting Preferred Highway Routes for Large Quantity Shipments of Radioactive Materials" in that it corrects a fundamental error that characterizes the previous editions. Both the public health risk and economic risk equations as presented in the 1989 Guidelines (and earlier editions) utilize the same methodological approach: a consequence term -- either the number of people potentially exposed during an accident, or the land use types potentially exposed during an accident -- is multiplied by an accident probability term (accidents per segment), to obtain the risk value. The consequence terms have a serious flaw in that they apply the effect of a single accident to the population and land use along the whole segment length; whereas, in fact, a single accident affects only a specific area that is independent of the length of the segment. Revised sections and worksheets that incorporate these corrections have been shaded for convenience.

These guidelines were developed in part under contract with DOT by Battelle Pacific Northwest Laboratories, a research organization which has conducted numerous risk studies in radioactive material transportation. The Department also received helpful information in developing the guidelines through pilot tests conducted with the help of State officials in Oregon and California. The U.S. Nuclear Regulatory Commission provided some useful guidance in their review of the draft guidelines. The most recent revisions to the guide were made with assistance from ICF Incorporated under contract with DOT.

The responsibilities in 49 App. U.S.C. § 1804 (b) and (c) have been delegated to the Federal Highway Administration (FHWA). These responsibilities include regulation of the highway routing of hazardous materials, including radioactive materials currently included in 49 CFR 177.825. However, because RSPA was responsible for preparing and issuing the Guidelines, RSPA is correcting the error and regrets any inconvenience caused to the users of the Guidelines.

This guide is organized in four main sections. Section 1 contains a description of the history, regulatory framework and philosophy underpinning these guidelines. The route selection methodology is reviewed in Section 2, while Section 3 describes the application of the methodology and presents technical data needed to evaluate the safety factors that form the basis for the route selection process. The use of these safety factors to select preferred routes is also discussed. A sample case illustrating the application of the methodology is presented in Section 4. Worksheets to facilitate application of the method and documentation of the analysis are contained in Appendix E. A bibliography of general reference materials on radioactive material transportation is also provided as an appendix.

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1. INTRODUCTION

The Department of Transportation has established specific highway routing requirements for certain radioactive materials. These requirements are codified in 49 CFR 173.22 and 177.825 and are extensively discussed in the January 19, 1981, Federal Register (Docket HM-164, 46 FR 5298). In addition to the requirement that carriers follow "preferred routes," which will be discussed further, the carrier must prepare and file route plans, provide specialized driver training related to radioactive materials and emergency response capabilities, and comply with security requirements of the Nuclear Regulatory Commission (or equivalent requirements as approved by DOT) when appropriate.

"Preferred routes" are defined in the rules as any route designated by a "State routing agency" (see definition in 49 CFR Sec. 171.8) and any Interstate System highway for which an alternative highway has not been designated by a State agency. In recognition of the many site-specific factors involved in selecting the safest available highway routes, DOT is strongly encouraging the States to examine their own highway network and designate "preferred routes" to supplement the Federally-prescribed Interstate highway system, or provide suitable alternatives to portions of the Interstate system. The purpose of this document is to provide State officials with a set of guidelines which will identify the important factors involved in a routing analysis, and assist in their selection of routes which result in the lowest public risks from the transportation of highway route controlled quantity radioactive materials.

The routing requirements apply to highway shippers and carriers of "highway route controlled quantity" packages of radioactive materials. "Highway route controlled quantity" is a term specifically defined in the Federal Hazardous Materials Regulations (49 CFR Parts 171-179) in Section 173.403(l). Whether or not a package contains a highway route controlled quantity depends upon the radionuclide in the package, the activity of the radionuclide as measured by the number of curies present, and the form of the radionuclide (dispersible or not). These packages can be identified by the shipping paper, which must accompany each shipment, and the warning placard on the vehicle. The shipping paper must contain the term "highway route controlled quantity" in association with the material description required for any shipment of radioactive material. A highway route controlled quantity shipment can also be uniquely identified by the square white background which is required for the standard radioactive material vehicle placard. Although many different radioactive materials could be packaged such that they would meet the definition of highway route controlled quantity, in practice, most of these shipments can be identified as either irradiated reactor fuel (spent fuel) from a nuclear power plant, certain large source medical shipments such as Cobalt-60 for teletherapy uses, or possibly some other large source industrial isotopes.

It is important to emphasize that the guidelines presented in this document do not represent the only method of conducting an adequate routing analysis. Under the regulatory scheme established by the routing requirements, the States are extended considerable flexibility in carrying out the routing function, as exemplified by the following definition found in Sec. 171.8:

> "State-designated route" means a preferred route selected in accordance with U.S. DOT "Guidelines for Selecting Preferred Highway Routes for Highway Route Controlled Quantity Shipments of Radioactive Materials" <u>or an equivalent routing analysis which adequately considers overall risk to the public</u> (emphasis added). Designation must have been preceded by substantive consultation with affected local jurisdictions and with any other affected States to ensure consideration of all impacts and continuity of designated routes.

The important point is that the State adequately considers public risk to all those who may be affected by radioactive material transportation. The Department believes that these guidelines identify the important risk factors to be considered and provide one methodology of estimating these risk factors for the purpose of identifying the lowest risk route. States may be able to develop a better method of risk assessment or identify other important risk factors relating to peculiar situations.

It is also important to emphasize that the methodology presented in this document is not a true risk analysis in that actual risk figures are not developed. As will be explained later in more detail, risk factors developed under these guidelines are for comparative purposes only. Risk index figures are developed in order to compare routes and identify the highway which is likely to minimize the transportation impact associated with these materials. The comparative figures are computed by simplifying certain factors that are not route-specific. Nevertheless, the risk factors are representative of the actual risk involved and are believed to be valid for the purpose of route selection.

Various studies have been conducted to assess the actual risk involved in the transportation of radioactive materials. Perhaps the most comprehensive study was completed for the NRC by Sandia National Laboratories entitled "Final Environmental Statement on The Transportation of Radioactive Materials by Air and Other Modes" (NUREG-0170). In order to estimate risk to the U.S. population, this study required the development of sophisticated computer models to account for such factors as the health effects resulting from both external and internal radiation sources; the atmospheric dispersion of materials released from a damaged package; the severity of an accident involving nuclear shipments and the resulting damage to a package; and the fraction of material released from the damaged package. This type of analysis is far beyond the capacity and resources available to a State routing agency and is beyond the scope and purpose of these routing guidelines. NUREG-0170 and other risk studies have concluded that the risk from the transportation of radioactive materials is quite low by any measure of comparison. The intent of the Department's routing regulations and the guidelines presented here is to minimize the public risk even further by providing for the use of the safest available highway routes.

In performing a routing analysis, States are required to solicit and consider input from other jurisdictions which are likely to be impacted by a routing decision. This will necessitate coordination with local government authorities along the prospective routes of travel and with other adjacent State Authorities to obtain relevant information and to ensure continuity of designated routes, should an alternative route be selected.

The manner of consultation with local governments as well as public participation is left to the discretion of the State government. However, DOT encourages the State to provide public notice, opportunity to comment and a hearing if justified. The State should consider making individual notifications to appropriate local jurisdictions. One possible procedure to ensure adequate local consultation would be to establish a State advisory group composed largely of city and county officials. The purpose of this group would be to provide oversight of the route designation process to ensure meaningful State/local cooperation.

Coordination with other State routing authorities may be a crucial factor in selecting highway routes for large quantity radioactive materials. Obviously it is essential that designated routes match up at State borders. It is DOT's opinion that interstate or regional coalitions for the designation of routes may be the most effective way of ensuring continuity. Also, States may want to enter into an agreement designating as a portion of the preferred route a ferry route for the transport of motor vehicles on waters within the jurisdictions of those States.

2. METHODOLOGY OVERVIEW

Implementation of the routing regulations for highway route controlled quantity shipments of radioactive materials necessitates a methodology for selecting preferred routes. This methodology is needed to provide a basis for State agencies to select from alternative routes available within the State. A number of factors can be important in comparing available routes and the methodology is needed to provide a systematic treatment of these factors. It may also be that some comparison factors important in choosing preferred routes may vary according to the circumstances in the State in which they are being applied. The methodology therefore needs to provide the flexibility to treat these varied situations, as well as provide for consistent application from State to State. Finally, the methodology needs to be straightforward to apply and should not require expertise beyond that normally found in State regulatory agencies.

The general methodology developed to meet these needs is based on a common decision-making approach consisting of six basic steps. These steps and their application to a routing analysis are outlined below:

	Steps		Routing Analysis
1.	Define objective	-	Determine highway route that minimizes impacts
2.	Identify courses of action to meet the objective	-	Identify alternative highway routes available in consultation with affected jurisdictions
3.	Identify factors that could affect the objective	-	Develop list of route comparison factors
4.	Evaluate the factors in relation to the objective for each course of action	-	Evaluate route comparison factors for each alternative highway route
5.	Select the alternative that best satisfies the objective	-	Select route that best minimizes impacts based on evaluation of route comparison factors
6.	Document each step in the analysis	-	Document entire routing analysis to serve as the basis for the routing decision

The application of this methodology will be discussed in more detail in Section 3. First, however, it is appropriate to introduce two key elements of the routing analysis: (1) identification of the route comparison factors; and (2) the process of selecting a preferred route based on these factors.

2.1 Route Comparison Factors

The risk from transportation of radioactive materials can be affected by a number of factors. These factors are predominantly categorized as either radiological impacts or non-radiological impacts. Additional factors influencing the risk of radioactive materials transportation include certain actions which have the potential of mitigating exposure to radioactive materials.

Radiological impacts are those associated with the accidental release of radioactive materials during transportation and its effect on the surrounding population and property. They also include the effects on surrounding population of low levels of radiation emitted during accident-free transportation (often called normal exposure).

Non-radiological impacts are those associated with transportation by any heavy truck and its effect, regardless of the nature of the cargo being transported, on surrounding population (primarily other motorists) and property. An example is a truck accident resulting in death, injury or property damage when there is no release of radioactive material.

Other factors can be important to consider for the purpose of selecting a highway route. These factors, such as effectiveness of emergency response activities, evacuation capabilities, and avoidance of certain special facilities (e.g., schools, hospitals, stadiums) can serve to reduce radiological consequences, primarily consequences from accidents. These factors however, become important only <u>after</u> an accident has occurred.

The primary objective of this routing analysis is to determine the route which will minimize the radiological impacts. It is believed that the emphasis in route selection should be placed on the risk which is associated with the radiological nature of the cargo. This approach will result in the selection of a route that will minimize the total impact associated with normal exposure and the potential consequences of an accidental release of radioactive materials, so that mitigating factors such as emergency response may not be necessary. Consequently, the following are considered to be the primary route comparison factors:

- Radiation exposure from normal transport
- Public health risk from accidental release of radioactive materials
- Economic risk from accidental release of radioactive materials

All other factors are considered secondary to the basic goal of minimizing the radiological risk from transportation. These other factors may be useful to consider in the route selection process, but only after careful analysis reveals that alternative routes have essentially the same level of risk based on the three primary comparison factors. The following are therefore considered secondary comparison factors:

- Emergency response effectiveness
- Evacuation capabilities
- Location of special facilities such as schools or hospitals
- Traffic fatalities and injuries unrelated to the radioactive nature of the cargo

Each of these factors is discussed in more detail below. Suggested methods for evaluation of these factors are described in Section 3.2 of this report. It is believed that these seven factors represent the most important elements to consider for the purpose of conducting a comparative risk assessment to identify preferred routes. Other factors that may be important in a particular application of the methodology may be identified by the State agency responsible for the route selection process. It is important that the State document the reasons for considering additional factors and that consistent methods for evaluating these factors be developed. It is also expected that some of the secondary factors identified above may not be important in all applications. These factors may be deleted from the analysis when appropriate.

A brief discussion of each of the route comparison factors follow.

PRIMARY RISK FACTORS

- Normal radiation exposure. Shipping packages containing radioactive materials emit radiation during transport. Sufficient shielding must be contained in the package to reduce this radiation to safe levels as specified in DOT regulations. These levels still result in exposure of people along the route to small amounts of radiation. Although these levels of radiation are not expected to adversely affect the exposed population, it is still prudent to minimize the exposure. Exposure could vary significantly among available routes and therefore is one impact to consider for route selection.

- Public health risks from accidents. Highway route controlled quantity shipments contain amounts of radioactive materials that are potentially harmful to the public if released. For this reason, these materials may only be transported in shipping packages designed to isolate the materials from the public, even in severe transportation accidents. It is theoretically possible, however, that a truck carrying one of these packages could be involved in an accident that creates forces beyond the package design standards. Principal differences affecting public health risk from one route to another are: (1) the frequency of severe transportation accidents, and (2) the number of people that could be affected by a release of radioactive material in an accident.

- Economic risk from accidents. A very severe transportation accident could also result in contamination of nearby property. If contamination exceeds safe levels, it would have to be removed or otherwise reduced to safe levels before that property could be returned to normal use. The cost of these decontamination operations varies considerably for the kinds of property that could become contaminated. The relative amount of each kind of property along each route provides a way of determining potential differences in economic consequences from accidents. The frequency of severe transportation accidents which could cause contamination must also be considered.

SECONDARY FACTORS

- Emergency response capabilities. If a severe transportation accident results in radioactive material being released from the shipping package, actions by emergency response personnel can mitigate the potential consequences from the release. The effectiveness of these measures is generally dependent on many considerations, such as the availability of response equipment, the expertise of response personnel or the time required for emergency response units to reach the accident scene. These factors could vary significantly among available routes.

- Evacuation. One method of mitigating the consequences of a radioactive material release is to evacuate the people that could potentially be exposed to the material. The time and effort required to evacuate a segment of the population may vary for the available routes. Evacuation is often ordered as a precautionary measure if an accident occurs, even if a release has not been confirmed. Evacuation has economic impacts which may also be considered in comparing available routes.

- Location of special facilities. Some private and public facilities along transportation routes contain populations requiring special consideration when analyzing the potential effects of accidental releases of radioactive materials or exposure during normal transport. These facilities contain populations that are either large (such as stadiums), may be more sensitive to radiation (such as schools) or are difficult to evacuate (such as hospitals). The number and type of such facilities provide a basis for comparing alternative routes.

- <u>Traffic fatalities and injuries</u>. Trucks carrying radioactive materials can be expected to be involved in traffic accidents, just like other vehicles. Only very severe accidents have the potential to result in release of radioactive materials. Many accidents will result in injuries and fatalities, however, as with any heavy truck accident. Other things being equal, routes that minimize these accidents would be preferred.

2.2 Route Selection

Previous risk studies on radioactive material transportation have shown that the most important impacts are associated with normal radiation exposure, radiation exposure from releases of radioactive materials in transportation accidents and economic impacts from property cleanup following such accidents. These "primary" route comparison factors will form the basis for route selection decisions. The remaining or "secondary" factors could 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.

In many applications of the route selection methodology, one of the primary factors may favor one route, while others favor a different route. A method is needed to combine the various route selection parameters to arrive at an overall figure of merit for each route. In the approach used in this guidebook, the values of the primary comparison factors are converted to unitless fractions and then summed for each route to arrive at the overall figure of merit. Because the comparison factors provide a basis for identifying potentially adverse impacts, the route with the lowest figure of merit would be selected as the preferred route. This process will be demonstrated in the sample case presented in Section 4.

In some cases there may be very little difference between the figures of merit computed for alternative routes. In other words, the level of radiological risk to public health and property may be essentially the same for the prospective routes. In this event, it may be appropriate to consider one or more of the secondary factors to distinguish between the routes. This is an important decision to be made by the State officials conducting the analysis based upon the particular circumstances involved.

3. METHODOLOGY APPLICATION

The methodology described in the previous section will facilitate the selection of preferred routes for highway route controlled quantity shipments of radioactive materials. The methodology provides the flexibility needed for the variety of situations that will be treated under the routing regulations. It parallels the decision-making process normally followed by a regulatory agency in making these decisions. It should facilitate participation of the public, other State agencies and local jurisdictions in the route selection process and documentation of the decision-making process. Application of the methodology would follow the basic steps outlined below:

1) Determine routes potentially available for shipping materials between the points being considered in the analysis.

2) Evaluate each primary comparison factor for each route, using the data on the routes being considered and input from other agencies and local jurisdictions affected by the decision, as presented in Section 3.2.

3) Apply the route selection approach presented in Section 3.3 to select the "preferred" route.

4) Document the route selection process.

5) Obtain public comment and appropriate reviews or approvals of other agencies and affected local jurisdictions.

The information needed to perform the analysis may be held by a number of different State or local agencies. The lead agency for the route selection process will need to establish liaison with other involved agencies early in the route selection process. Some basic information needed to evaluate the primary route comparison factors includes:

- Accident frequencies (accidents/vehicle mile) for each route.
- Traffic counts on each route.
- Average vehicle speed on each route.
- Population distribution along each route.
- Land use data along each route.

In addition, if secondary factors are to be evaluated, information such as the following is needed:

- Location and capabilities of organizations near the routes that would be involved in emergency response or evacuation.

- Location of special facilities such as schools, hospitals, stadiums, and nursing homes.

The agencies that collect and use this information will vary from State to State but may include the equivalent of the state highway or transportation department, the state police or highway patrol, the public utility commission, the radiological protection agency, state and local emergency service units, state and county planning agencies, and the state energy agency. Other information needed in the route selection process is included in this guide.

The methodology can be applied whenever two or more routes are potentially available for designation as a preferred route connecting two points in the State. The Interstate system highways are Federally preferred routes unless the State wishes to designate alternative routes in accordance with these guidelines or an equivalent routing analysis. Consequently, although it is not necessary, the State may wish to apply this methodology to all Interstate highways for comparison with other available non-Interstate alternatives. The route selection method described in this guide would also be useful when it is desired to designate additional preferred routes. An example of a situation where additional preferred routes might be beneficial is the case of a nuclear power plant that is located some distance from an Interstate highway. Designating a preferred route from the plant would assure that these shipments are made over a route that has been shown by analysis to minimize the radiological impacts resulting from the shipments. Another example is the situation where an Interstate beltway route does not exist around a large urban area. The State, in cooperation with the city, may want to identify a non-Interstate by-pass route as an alternative to the Interstate route through the city.

3.1 Identifying Alternative Routes

It is expected that identification of available alternative routes will be straightforward, because the agency applying these guidelines will have detailed knowledge of the highway systems in the State. Information on routes currently being used in the State for radioactive material shipments may be useful in identifying alternatives for consideration. Interstates connecting the points being considered may be included in the analysis in cases where it is desired to remove the preferred status from a segment of the Interstate system. Such a removal can only be done if the comparative analysis shows that there is an alternative route that results in lower overall impacts from highway route controlled quantity shipments than the available Interstate route.

Routes selected for consideration as alternatives for designation as preferred routes should meet minimum requirements for heavy truck use. Fuel and repair stops should be available and the routes should be maintained for year-round use in the same manner as other major highways in the State. <u>Preferred routes in one State must also match up at the borders with preferred routes in other States</u>. This will require coordination with State agencies responsible for route selection in neighboring States.

In some peculiar situations, States may want to include consideration of an existing ferry route which crosses a body of water separating available highway segments. This could be done for the purpose of comparing a combination highway-ferry route with an all highway route in cases where a body of water may limit the number of available highway routes to be considered.

3.2 Evaluation of Comparison Factors

This section contains suggested procedures and non-route specific data needed to evaluate the comparison factors for the routes being considered. As discussed previously, the three primary factors are always included in the analysis. Additional secondary parameters may be included for completeness of the evaluation process or to establish a preference among routes with little variation in the primary parameters. It may also be necessary to identify other secondary factors. It is expected that the agency designated to carry out the route selection process will determine which secondary factors are appropriate for the analysis being performed. The reasons for selecting these factors would be included in the documentation of the route selection process. If other factors are added to the route comparison study, methods for evaluating these factors will need to be developed. This should also be included in the documentation of the selection process.

The numerical results from the computations are only valid for use in comparison with similar numbers for alternative routes. In most cases the number used in the comparison will be proportional to the actual value of the factor being evaluated. For example, the routing exposure factor is proportional to the actual radiation exposure that would result from a shipment of radioactive material traveling along that route, but is not numerically equal to the actual exposure. Because the numerical value obtained from the evaluation factor will only be used in comparison with similar values for other routes, it has been simplified for calculation purposes by factoring out constants and variables that do not change from one route to another.

Each of the primary comparison factors in the analysis must be evaluated for each of the routes being considered. Methods for combining these factors to select the route that minimizes the impacts from highway route controlled quantity shipments of radioactive material are discussed in the next section. Many of the comparison factors can utilize data (such as vehicle speeds, accident rates or population densities) that are averaged over the entire route being considered. In some cases, it may be advantageous to break a route down into segments and evaluate one or more factors for these segments, rather than for the whole route at once. Route segmentation results in a more valid and detailed analysis when there is wide divergence in accident rates or population along different portions of a prospective route.

PRIMARY ROUTE COMPARISON FACTORS

3.2.1 Normal Radiation Exposure Comparison Factor

Shipping 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 the shipping packages containing radioactive materials have sufficient radiation shielding to reduce the levels of radiation emitted to safe levels. 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. These doses are not expected to adversely affect these people. However, federal regulatory agencies such as the Environmental Protection Agency, the Nuclear Regulatory Commission and DOT have adopted policies based on a position that it is prudent to avoid unnecessary radiation exposure and to eliminate or minimize exposure when practicable. Routes that minimize normal radiation exposure would therefore be preferred if all other comparison factors were equal.

The method for evaluating normal exposure from highway route controlled quantity shipments of radioactive material is summarized below. The method is derived in Appendix A. In general, the radiation dose (D) from normal highway transport of radioactive materials along the entire route or a route segment is given by the following equation (Greenborg 1980):

$$D = \begin{array}{c}\text{dose to persons}\\ \text{residing along}\\ \text{route } (D_1)\end{array} + \begin{array}{c}\text{dose to passengers}\\ \text{in other vehicles}\\ (D_2)\end{array} + \begin{array}{c}\text{dose to}\\ \text{truck crew}\\ (D_3)\end{array} + \begin{array}{c}\text{dose to people}\\ \text{at truck stops}\\ (D_4)\end{array}$$

The exposure is a function of parameters that depend on characteristics of the particular shipment and parameters that vary with the route being used. Because the dose factor is being used for route comparison purposes only, the shipment-specific factors can be factored out, or representative values used. The normal radiation exposure factor then reduces to the following equation (calculations in Appendix A):

$$D = (PL/v)*C_1 + (LT/v^2)*C_2 + (LT^2/v^3)*C_3 + L/v$$

where,

$D =$ normal radiation exposure comparison factor

$P =$ average population density along the route or route segment (people per mi^2)

$L =$ length of route or route segment (mi)

$v =$ average speed of vehicles on the route or route segment (mi per hour)

$C_1 =$ a constant $= 6.8 \times 10^{-5}$

$T =$ average traffic count on the route (vehicles per hr)

$C_2 =$ conversion factor determined from Table 3.2-1

$C_3 =$ conversion factor determined from Table 3.2-1

TABLE 3.2-1

Conversion Factors for Use in Estimating Normal Radiation Exposure Factor

Distance Between Opposing Traffic Lanes (ft)	C_2	Vehicle Separation Distance = $\frac{v}{T}$ (ft)	C_3
10	4.9×10^{-3}	10	1.8×10^{-5}
20	2.5×10^{-3}	50	1.6×10^{-5}
30	1.5×10^{-3}	100	1.5×10^{-5}
40	1.1×10^{-3}	200	1.3×10^{-5}
50	9.4×10^{-4}	300	1.0×10^{-5}
60	7.5×10^{-4}	400	8.6×10^{-6}
70	6.5×10^{-4}	500	7.3×10^{-6}
80	5.7×10^{-4}	600	6.0×10^{-6}
90	4.9×10^{-4}	700	5.0×10^{-6}
100	4.1×10^{-4}	800	4.0×10^{-6}
150	2.6×10^{-4}	900	3.3×10^{-6}
200	1.9×10^{-4}	1000	3.0×10^{-6}
300	1.0×10^{-4}	1200	1.3×10^{-6}

Conversion factor C_2 in the equation for normal exposure is a function of the distance between opposing lanes of traffic on the route. A centerline to centerline measurement would provide the most accurate estimate of C_2. For a two-lane road, this would reduce to the width of a traffic lane. For a four-lane road, this measurement would be the distance from the line dividing the two traffic lanes on one side of the road to the corresponding line for traffic moving in the other direction. Conversion factor C_3 is a function of the distance between vehicles in a traffic lane. This average vehicle separation distance can be estimated by dividing the average vehicle speed by the average hourly traffic count and converting the results from miles to feet for entry into Table 3.2-1. The average population density, P, can be obtained from the total population in a 0-5 mile band along the highway. This band is identified and explained in the next section. Dividing the total population by the area of the band (10xL) will provide a reasonable estimate of the population density for use in the normal exposure calculations.

3.2.2 Public Health Risks from Accidents Comparison Factor

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. Packages containing highway route controlled quantity radioactive material are required by DOT and NRC regulations to be designed to retain their contents in severe transportation accidents. Accidents that could cause release of material from these packages are therefore expected to occur very infrequently. A number of studies have found that public risks are quite low from accidental releases of radioactive materials from the type of packages used for highway route controlled quantity shipments (BNWL-1846, BNWL-1996, PNL-2030, PNL-211, PNL-2588, NUREG-0170).

Because accidental releases of radioactive material could occur, however, it is appropriate to include consideration of the public health risks from these accidents in the selection of preferred routes. Risks from accidental release of radioactive material depend 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. Both of these factors are expected to vary among available routes for radioactive material shipments. Suggested methods for determining these accident release frequencies and the measure of the consequences are discussed below. The overall accident risk factor for each route is determined by multiplying the accident release frequency by the accident release consequence measure. The method presented here yields a result that will indicate differences in risks among the routes being analyzed. The numerical results are not equal to the actual risk, because of the simplifying assumptions that are possible in a comparative measure.

Accident Release Frequencies

Exact determination of the frequency of radioactive material releases from these shipments would require detailed information on the forces that could be produced in transportation accidents and on the response of the shipping packages to these forces. Development of this information would require extensive data analysis and detailed engineering evaluations. This level of effort is beyond that necessary for routing decisions (State routing agencies are, however, encouraged to conduct such a detailed evaluation if it seems appropriate). NUREG-0170, a document mentioned in the Introduction and listed in the bibliography, provides an example of a more sophisticated method of computing both release frequencies and consequences. Because routing decisions are based on comparative assessments of the available routes, the analysis can be greatly simplified. It is sufficient to obtain an accident frequency measure for each route. Accident frequencies that inherently include a measure of accident severity are preferred for the comparative analysis.

Accident rate information and damage estimates based on observations of actual accidents are generally available from State and local agencies with responsibilities for highway safety. It is suggested that the comparative assessments be based on this data. Accident rates in units of accidents per vehicle mile are most convenient to use in the assessment. If they are not available directly, they can usually be developed from accident frequency and traffic volume information. The accident rate is multiplied by the route length to obtain the release frequency measure for use in the comparative analysis.

It is believed that rates for accidents that result in the death of the driver of a truck carrying hazardous materials provide the best overall indicator of accident frequency for use in the comparative assessment. Suggested accident frequency measures in decreasing order of desirability include:

- Hazardous Material Truck Driver Fatality Rate
- General Truck Driver Fatality Rate
- Hazardous Material Truck Fatal Accident Rate

- General Truck Fatal Accident Rate
- General Truck Accident Rate
- General Vehicle Traffic Fatality Rate
- General Vehicle Traffic Accident Rate
- Accident Rate Predictive Models

Fatalities are used as a measure of accident severity because of data availability and the implication that damage is sustained by the vehicle. Narrowing the class of vehicles considered to those most like the shipments of interest results in more realistic estimates.

The quality of data available should also be considered in selecting an accident frequency measure for use in the analysis. Development of several accident rates would permit evaluation of the data quality. A study of accident frequency information and truck traffic volumes could require the rejection of very narrowly defined accident rates due to a lack of data in these categories. An indication of poor data would be equal accident rates for several of the above classifications. Accident rates, in general, will increase from the top of the list to the bottom with the exception of the accident rate predictive model. The predictive models are intended for use when little data is available locally. One such model is described in a report entitled "Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials" (Peat, Marwick, Mitchell and Co. 1980).

Accident Release Consequences

The consequences of an accidental release of radioactive material depend on a large number of factors. Many of these factors would be essentially identical for two alternative routes. These would include atmospheric conditions and quantity and type of material transported. Differences between alternative routes that contribute to a preference of one over another on the basis of accident consequences result primarily from differing levels of population and types of property along the routes. Population has therefore been selected as the comparative measure for release consequences relating to public health risk. Types of property and land use is the comparative measure for release consequence relating to economic risk which is considered further in Section 3.2.3.

If a radioactive material is released in a transportation accident, it will generally be dispersed downwind. The typical consequences from such a release are the exposure of the people in an approximately 25 square mile area of land to low levels of radioactivity. Because radioactive materials can disperse over relatively large distances, it is necessary to examine the population along alternative routes to distances of about 10 miles. A suggested method for accomplishing this is summarized in Table 3.2-2.

TABLE 3.2-2

Release Consequence Measure

Population Band Boundary	Health Consequences Band Multipliers
0-5 mi	0.75
5-10 mi	0.25

The health consequences multipliers were developed from atmospheric dispersion calculations for radioactive material releases (see Appendix B). They take account of the fact that concentrations of radioactive materials in the air will be higher near the accident site, resulting in a somewhat higher radiation dose to persons nearer the highway.

The actual formulation of the public health risk from the accidents comparison factor is more complex than what will be presented here. While a complete treatment of this formulation is given on page B-6 of Appendix B in this document, with the steps taken to simplify clearly outlined, only the resulting simplified formulation will be presented here. This suffices for the purposes of the <u>comparative</u> public health risks calculated in the worksheets.

To apply this method, the number of persons within each of the population bands in the table is determined from maps, census data, or other available information. Counting by thousands or tens of thousands will not affect the results provided each of the routes under consideration is counted in the same way. Note that the bands cover the indicated distance on either side of the highway, i.e., the first band, the 0-5 mile band, is 10 miles wide and centered on the highway. The population count for each band is then adjusted by the multiplier, and those band totals are added. This figure is then divided by the length of the route or segment thereof (in miles) to obtain the public health consequence measure.

In many applications of the route selection methodology, the number of people in each band can be determined by adding the population of cities, counties, towns, and villages that lie within the band. This method will usually be appropriate when relatively long routes are being compared that pass through or near a number of population centers of various sizes. More detailed data, using census districts, for example, may be required when comparing shorter routes. This type of analysis would generally be associated with comparisons of Interstate through routes with alternative bypass routes for a major city.

If a closer evaluation of large urban areas is believed necessary, a simplified method of computing the public health consequence measure can be used. Because distances are much more limited than in the case of a Statewide analysis, the 10-mile band is not practical. In some cases, alternative routes through and around urban areas may not even be 10-20 miles apart. Therefore, a 5-mile band (on either side of highway) is more practical. When using the 5-mile band for examining urban alternative routes, the health consequence band multiplier can be considered 1.0 since all individuals in that proximity may be considered as receiving the same dose of radioactivity if a severe accident did occur. Consequently, the public health consequence measure in this limited analysis would be simply the population count in the 5-mile band divided by the length of the route or segment thereof. This is then multiplied by the accident rate for the segment to yield the public health risk factor.

3.2.3 Economic Risks from Accidents Comparison Factor

An accidental release of radioactive materials could also have economic impacts. The economic risk is determined by considering the release frequency (probability of an accident) and the release consequences similar to the determination of public health risk. The release frequency measure will be the same as used for public health risk, i.e., the accident rate along the prospective route. It is important to apply the same accident rate (hazardous material truck driver fatality, general truck driver fatality, etc.) that is used for public health risk.

The release consequence measure for economic risk is based on the type of property along the prospective route. Property in the vicinity of an accident could become contaminated with radioactive materials. When contamination exceeds safe levels, it would have to be removed or otherwise reduced to safe levels before the property could be returned to normal use. The expenses associated with decontamination are expected to be the primary economic consequence of a transportation accident that releases radioactive materials.

Decontamination costs vary with the type of property being decontaminated (WASH 1400 1975). The relative amounts of various property types along a transportation route can be used along with information on the relative decontamination costs for each property type to develop a comparative economic consequence measure for alternative radioactive material transportation routes. A suggested method for performing this analysis is summarized in Table 3.2-3. The consequence multipliers are derived in Appendix C.

TABLE 3.2-3

Economic Consequence Measure

Land Use Type	0-5 mi Band	5-10 mi Band
Rural[1]	0.002	0.0002
Residential		
Single-Family	0.10	0.04
Multi-Family	2.0	0.20
Commercial/Industrial	0.20	0.01
Parks	0.03	0.02
Public Areas	0.50	0.05

The multipliers presented in the table are proportional to the anticipated decontamination cost for each land use type. The bands of land along the route are used in analyzing the economic risk factor because areas closer to

[1] Rural land designation may be applied to farm land and vacant land also.

the accident site generally become contaminated to a higher level, requiring more extensive decontamination efforts. As with the public health consequence measure, the formulation of the economic consequence measure has been simplified for comparative purposes here. The reader can refer to page C-3, Appendix C for a complete derivation of the methodology used to obtain the economic risk factor, including an explanation of all simplifications made. To apply the resulting method, then, the amount of area within each band occupied by each of the six land use types is determined from maps, local land use planning information or other available data. The area may be measured in square miles, square kilometers, acres or any other convenient unit. The measures must be consistent over the entire route, for all land use types and between alternative routes. The land use areas are multiplied by the appropriate economic consequence multiplier, and summed to obtain a total value for each band of each route or segment thereof. These values for the 0-5 and 5-10 mile bands are added, and then divided by the length of the segment (in miles), to reach the economic consequence factor for that segment. This is then multiplied by the accident rate for the segment to yield the economic risk factor for that route. This process will become clear in section 4 when applied to a sample case.

SECONDARY ROUTE COMPARISON FACTORS

If alternative routes cannot be clearly distinguished by consideration of the Primary Route Comparison Factors, State officials may want to consider other factors which have the potential of mitigating the consequences of a release of radioactive materials. Most of these secondary route comparison factors are much more difficult to quantify and estimate. The following methodology provides a useful approach for considering these factors. The process involves the establishment of arbitrary scaling systems which are totally dependent upon the judgement of the State officials performing the analysis.

3.2.4 Emergency Response Comparison Factor

Timely action by emergency response units has the potential for reducing the magnitude and extent of a radioactive material release in a transportation accident. The primary factors influencing the effectiveness of emergency response are manpower, timing, planning and equipment. Each of these parameters is location dependent. The time taken to get emergency personnel to the accident site is important for establishing control of the immediate area and determining the nature of the hazard. First order response times are limited by the accident locations and access to the accident site. These response times can typically be on the order of a few minutes.

Secondary response to accidents includes the mobilization of police to aid evacuations if needed, contacting specialized technical personnel and obtaining radiation monitoring and cleanup equipment at the accident site. These secondary times depend on adequate pre-accident planning, local equipment availability and distances to be traveled. Minutes to hours are required for these operations.

Route comparisons can be based on a relative ranking of available routes. Exact determination of all the parameters that affect emergency response is therefore not required. If emergency response is to be evaluated as a secondary route comparison factor, it is suggested that arbitrary scales be established for each emergency response parameter and each route be ranked on these scales. An example of such a ranking scale is presented in Table 3.2-4. Evaluation parameters selected for use in this example include the time required for emergency response personnel to reach potential accident sites; the availability of specialized equipment such as radiation detection instruments; the amount of training that local public safety personnel have received in dealing with hazardous material spills; and the availability of trained manpower to respond to an incident. The scales assign low numbers to routes that are most favorable for that parameter.

A factor representing the quality of emergency response can be determined for each land use development type that a route may pass through, as illustrated in Table 3.2-4. An overall comparison factor for alternative routes can then be developed by determining the fraction of land by development type within a five-mile-wide band on either side of the route, multiplying by the emergency response factor for those development types, and summing the results. For example, a route that passes by 5 square miles of urban area, 3 square miles of suburban area, 90 square miles of rural area and 2 square miles of industrial area would have an emergency response comparison factor of 11.6 (which is generated from .05 x 7 + .03 x 10 + .90 x 12 + .02 x 6).

It should be emphasized that the parameter ranking system presented in Table 3.2-4 is intended only as a starting point for any particular route selection case. Of necessity, the scaling system is arbitrary in nature. It is expected that the scales and ranking of the land development types may need to be adjusted to best describe local conditions.

TABLE 3.2-4

Sample Emergency Response Parameter Scaling System

Land Use Type	Response Time	Equipment Availability	Hazardous Material Training	Manpower Availability	Land Use Emergency Response Weight Factor
Rural	3	3	3	3	12
Suburban	1	3	3	3	10
Urban	2	2	2	1	7
Commercial/ Industrial	2	1	1	2	6

3.2.5 Evacuation Comparison Factor

Public exposure to radiation during a transportation accident is not likely to result in immediate fatalities because the radiation dose received by any individual would be relatively low. Public dose can be further reduced, however, through evacuation of persons in the affected areas. A method for considering evacuation in route selection is summarized below. Further details are presented in Appendix D.

Factors affecting the promptness of an evacuation include the type of area to be evacuated (i.e., residential, industrial, etc.); means of egress; level of pre-accident planning; effectiveness of implementing these plans by responsible authorities; and the nature of the threat. Radioactivity is not detectable by human senses. Large amounts of manpower may be required to communicate the need for evacuation in the absence of an apparent threat. Communication is more difficult in areas of low population density and results in longer evacuation times. The most common means of evacuation is the private automobile. Routes away from the accident site are required for its use. Large public and private facilities pose special problems in an evacuation. Examples include schools, hospitals, prisons, nursing homes, churches, stadiums, and theaters. Detailed plans for the evacuation of special facilities are essential to the minimization of injuries and confusion.

The evaluation of evacuation capabilities can be simplified by using a relative ranking scheme similar to emergency response. Arbitrary scales are established to rank route alternatives relative to each other for each of the important evacuation parameters. An example of one approach is shown in Table 3.2-5. Parameters selected for use in this evaluation include the number of people affected; the availability and capacity of egress routes; the availability of evacuation coordination personnel; the time required for effective evacuation; and the economic and other impacts of the evacuation on the affected population.

As Table 3.2-5 illustrates, evacuation parameters are evaluated for each major land use type along the routes being compared. The values of the ranking factor for each parameter are added to provide a single factor for each land use type. An overall comparison factor for each route can be developed by determining the fraction of land area by development type within 5 miles of the route, multiplying these fractions by the respective factor totals in Table 3.2-5, and summing the results. For example, a route that passes 90 square miles of rural area, 4 square miles of suburban development, 1 square mile of urban area, 5 square miles of commercial development and industrial area would have an overall evacuation factor of 11.6 (which is generated by: .9 x 11 + .04 x 13 + .01 x 28 + .05 x 17).

Again, it should be emphasized that the parameter ranking system presented in Table 3.2-5 requires subjective judgement and is intended only as a starting point for any particular route selection case. It is expected that the parameter ranking scales and the relative ranking of the land use types on these scales may need to be adjusted to fit local conditions for the routes being analyzed.

TABLE 3.2-5

Sample Evacuation Parameter Scaling System

Land Use Type	Population Density	Egress Availability	Manpower and Equipment Availability	Evacuation Time	Evacuation Impacts	Land Use Evacuation Weight Factor
Rural	1	3	3	3	1	11
Suburban	5	2	2	2	2	13
Urban	20	1	1	1	5	28
Commercial/ Industrial	9	2	2	1	3	17

3.2.6 Special Facilities Comparison Factor

Certain localized areas have sufficient economic or public safety importance to require special consideration in the route selection process. These facilities or areas could be unique and vital to local economies. Examples would be a factory employing a large fraction of the local population. Other facilities have enhanced potential for public health consequences. These facilities contain populations that are either large, sensitive to radiation, or difficult to evacuate. For example, an occupied stadium would be difficult to evacuate quickly. Experts in radiation health effects believe children are more sensitive to radiation than adults (BEIR Report 1972). Schools would therefore be considered special facilities for route selection purposes. Hospitals and nursing homes are examples of populations that are difficult to move without threat of injury.

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 suggested for evaluating special facilities in relation to these parameters. Each facility is evaluated on all criteria. Points are assigned for each factor and facility type. They are then combined into an overall facility factor. Table 3.2-6 illustrates the use of relative scales to rank each factor. In this example, an arbitrary scale of 1 to 5 was chosen to indicate relative degrees of impact for the listed facilities. Higher values were assigned to facilities with higher potential impacts. Scale size and values assigned to each factor could vary depending on local situations. Only relative rankings are important. Larger scales could be used to weight some factors more than others. Factors in Table 3.2-6 were all weighted equally and then summed to obtain the facility factor.

TABLE 3.2-6

Sample of a Special Facility Scaling System

	Dose Response	Accident Evaluation	Economics	Facility Factor
Children's Hospital	5	5	2	12
Hospital	4	5	2	11
Prison	1	4	2	7
Nursing Home	2	5	1	8
School	5	3	1	9
Churches	2	2	1	5
Stadium	3	3	3	9
Shopping Center	1	1	3	5
Theaters	2	2	1	5
Factory	2	2	5	9

To apply this method, special facilities that could be encountered along any of the alternative routes are identified. An overall facility factor is then assigned to each type of facility using the procedure outlined above. The special facility comparison factor is determined for each route by counting the number of each type of special facility along the route, multiplying by the appropriate facility factor, and summing the results. For example, using the facility factors in Table 3.2-6, a route passing near one hospital, three churches, two schools, and a shopping center would have a special facility comparison factor of 49 (which is generated from: $1 \times 11 + 3 \times 5 + 2 \times 9 + 1 \times 5$). In general, special facilities would only be considered if they were within 5 miles of a route. A distance of 5 miles is selected to be consistent with the emergency response and evacuation factors. The special facility comparison factor may be most useful when comparing shorter routes, for example routes through or around a major city.

3.2.7 Traffic Fatalities and Injuries Comparison Factor

Trucks carrying shipments of these radioactive materials can be expected to be involved in traffic accidents at about the same rate as other large trucks carrying hazardous materials. Because the packages of highway route controlled quantity radioactive materials are designed to survive very severe accidents, the consequences of most accidents involving trucks carrying these materials will be the same as any other accident involving a large truck. Vehicles involved in the accident will be damaged and vehicle occupants may be injured or killed. This factor accounts for accident impacts which are not related to the radiological nature of the cargo.

Involvement of these vehicles in fatal and injury accidents also could produce negative public reactions. The public may tend to associate the fatalities and injuries with the cargo, even though this association is not accurate. There may also be a tendency on the part of local officials to order precautionary evacuations in accidents that result in fatalities or injuries. This could be especially true in cases where these officials do not have radiation detection equipment readily available to monitor the release of radioactive materials. These factors provide an incentive to send radioactive material shipments by routes with low fatal and injury accident rates.

If it is desired to include this factor in the route selection process, numerical estimates for route comparison purposes should be straightforward. Data on the frequency of fatal and injury accidents is usually available from State and local agencies with highway safety responsibilities. Rates expressed in fatalities and injuries per vehicle mile are the easiest to apply in the analyses. If these rates are not readily available, they can usually be calculated from the number of fatalities and injuries that have occurred on a given route and the traffic counts for the route. Rates for accidents involving hazardous materials trucks would provide the most accurate estimates. If the rates are not available, rates for truck transportation in general or for all vehicle traffic can be used. Multiplying the rate per mile by the route length will provide a reasonable comparative measure for this factor.

3.3 Selection of Preferred Route

The route comparison factors provide the technical basis for selecting the shipping route that minimizes the impacts from shipments of highway route controlled quantity radioactive materials. The selection of a preferred route is based on the primary route comparison factors - public health risks from accidents, economic risks from accidents and normal radiation exposure. If all three of the primary factors clearly favor one route, that route would be selected as the preferred route. If one primary factor favors one route, while the other primary factors favor other alternatives, an overall figure of merit for each route can be developed. The route selection is then based on a comparison of the figures of merit for the routes. The figure of merit is developed by normalizing each comparison factor. The normalization is accomplished by dividing each comparison factor by the sum of the values for that factor for all the routes being considered. For example, in a route selection case comparing three alternative routes, the normal exposure factor might be .25 for Route A, 1.5 for Route B and 6.5 for Route C. The total of these values is 8.3. The normalized comparison factors then become .03 for Route A, .18 for Route B and .79 for Route C. This factor is then added to the normalized comparison factors for public health accident risks and economic accident risks for that route to obtain the overall figure of merit. This will be more clearly shown in the sample case in Section 4.

Using this approach, the route with the lowest figure of merit will produce the least impacts from transporting highway route controlled quantity radioactive materials. In cases where the figures of merit are extremely close, it may be desirable to examine secondary comparison factors to assist in the route selection process.

4. SAMPLE CASE

A sample case has been constructed to demonstrate the analysis presented in these guidelines. Two hypothetical routes have been assumed between points x and y, as shown in Figure 4.1. The routes are represented in the figures as light and heavy solid lines. A corridor 10 miles to either side of each route is shown by dashed lines. Areas common to both routes inside the 10-mile bands exist near the ends of each route. Analysis of the impacts in these areas will not contribute to the differentiation between routes unless substantial differences exist in accident rates for the two routes at their end points.

In this sample case, Route A is an Interstate highway 490 miles long. Route B is a two-lane U.S. highway with a total length of 320 miles. Because Route A is an Interstate highway, it would be a preferred route under the DOT routing requirements. In this sample case, the analysis is undertaken because the shorter length and lower population along Route B may result in lower overall impacts from radioactive material shipments.

For this sample case, a number of secondary route selection factors will be analyzed in addition to the three primary factors. This will illustrate the analysis of these factors and their use in the route selection process. The factors analyzed in the sample case include:

- Normal radiation exposure
- Public health risk
- Economic risk
- Emergency response
- Evacuation
- Special facilities along routes
- Traffic fatalities

Tables 4.1 and 4.2 present a summary of data used to describe the two routes considered in the analysis. Route A is divided into four segments to provide better accuracy by accounting for differences in accident statistics.

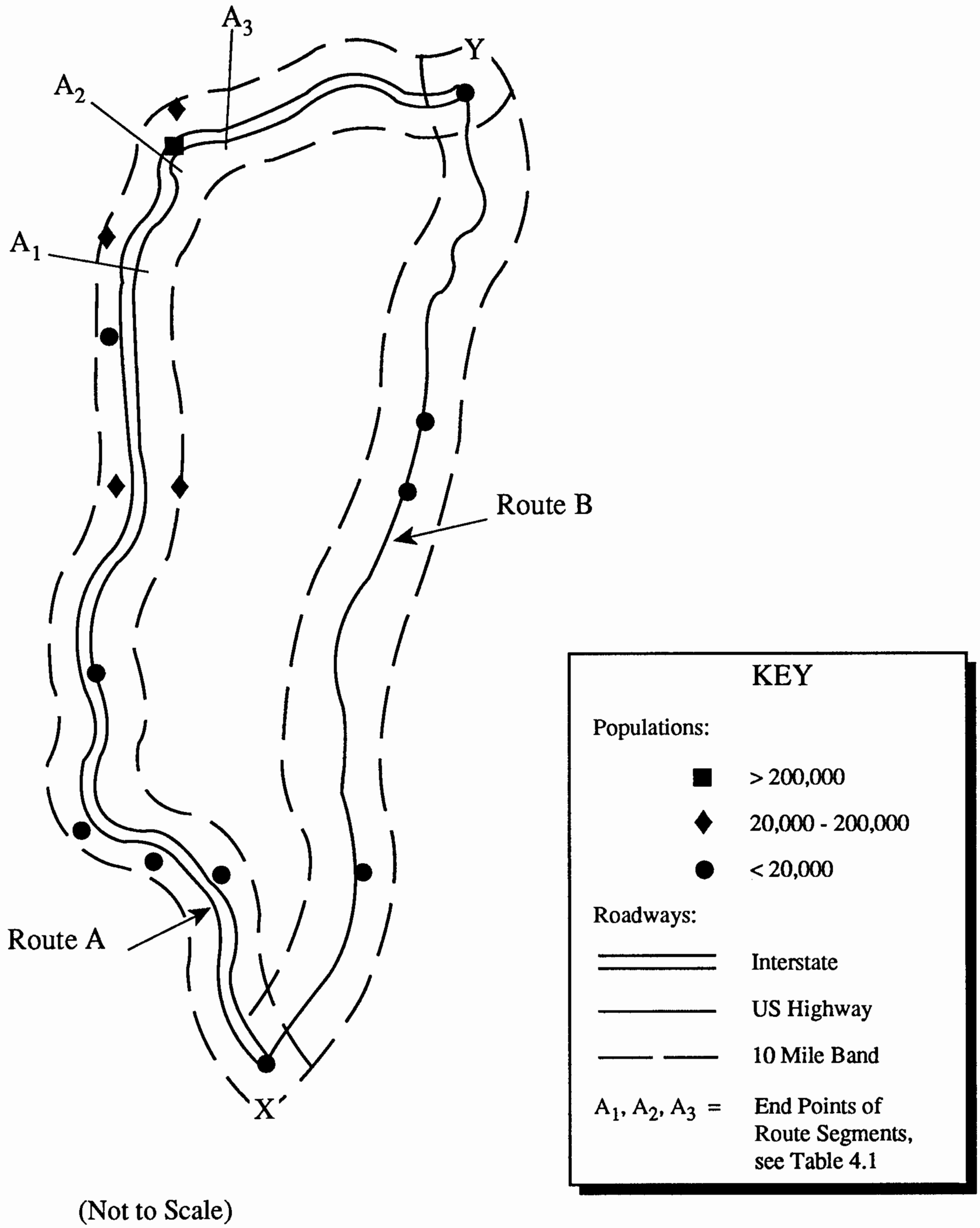

Figure 4.1
Routes Used in Sample Case Application of Route Selection Methodology

TABLE 4.1

Descriptive Data for Route A

ROUTE IDENTIFICATION: Route A - Interstate Highway

TOTAL DISTANCE: 490 miles

Accident Unit: Truck Driver Fatality

Segment	Segment End-Points	Segment Length	Average Speed	Distance Between Opposing Lanes	Pop. Count 0-5 Mile	Pop. Count 5-10 Mile	Daily Traffic Count	Daily Truck Count	Annual No. of Deaths	Accident Rate per Mil Tk-Mi	Accident Rate per Thou Shipments
1	$X - A_1$	290 mi.	45 mph	50 ft.	40,000	30,000	30,000	300	0.3	$.01/10^6$	0.003
2	$A_1 - A_2$	70 mi.	50 mph	40 ft.	180,000	50,000	50,000	1800	0.5	$.01/10^6$	0.0007
3	$A_2 - A_3$	30 mi.	50 mph	50 ft.	360,000	70,000	80,000	8700	2	$.02/10^6$	0.0006
4	$A_3 - Y$	100 mi.	50 mph	40 ft.	15,000	11,000	30,000	700	0.2	$.007/10^6$	0.0007

TABLE 4.2

Descriptive Data for Route B

ROUTE IDENTIFICATION: Route B - U.S. Highway

TOTAL DISTANCE: 320 miles

Accident Unit: Truck Driver Fatality

Segment	Segment End-Points	Segment Length	Average Speed	Distance Between Opposing Lanes	Pop. Count 0-5 Mile	Pop. Count 5-10 Mile	Daily Traffic Count	Daily Truck Count	Annual No. of Deaths	Accident Rate per Mil Tk-Mi	Accident Rate per Thou Shipments
1	X - Y	320 mi.	40 mph	50 ft.	28,000	7,000	25,000	220	0.5	$.02/10^6$	0.006

Segment 1 of Route A is a six-lane rural highway, segments 2 and 4 are four-lane rural highways, and segment 3 is a six-lane urban highway. All segments are limited access highway. There are twelve population centers along Route A and the land is divided among urban, suburban, commercial, and rural uses. Undeveloped land is considered the same as farmland. Route B is primarily two-lane with opposing traffic flow. Because of the consistent road type the route is not broken into segments. If local data on population, accident rates, etc. were available, then segmentation of the route might have been desirable. Land uses are divided into the same categories as for Route A.

Much of the information needed to compute the route comparison factors is presented in the tables. This includes population counts within the two highway bands, average truck speeds, traffic volume for both general and truck traffic, and accident information pertaining to each route segment. The basic accident unit of measure chosen for the sample case is the truck driver fatality rate (measured in accidents per million truck miles). This is converted into truck accidents per thousand shipments as will be discussed further.

The remainder of this section consists of a sample evaluation package for this route selection case. Worksheets have been filled out for each route in accordance with the discussions in Section 3. (Blank worksheets are furnished in Appendix E.) The filled-in worksheets form part of the official documentation of the route selection process.

4.1 Calculation of Primary Route Comparison Factors

The first six worksheets (see pages 35-43) show evaluation of the primary comparison factors for both Routes A and B.

Worksheet 1 examines normal transport exposure for Route A. Several pieces of information are needed for this evaluation. If a route is divided into segments, the data must be developed for each segment. The comparison factor for the route will be the sum of the factors for each segment. The first piece of data necessary for this evaluation is the average population density (P) along the route. This is found by determining the number of persons inside the 5-mile band and dividing that number by the area inside the band. The area is 10 times the segment length (L) since the band lies on both sides of the pathway. For example, for segment 1, from Table 4.1 we obtain the population count inside the 0-5 mile band (i.e., 40,000) and divide by 2900 (290 mi. x 10) to obtain a population density of 14 people per square mile.

Also needed for this calculation is the traffic density (T) in number of vehicles per hour. The number of vehicles per hour is found by dividing the daily vehicle count from Table 4.1 by 24 hours. For Route A, the daily vehicle counts for the four segments are 30,000, 50,000, 80,000 and 30,000 respectively. These yield vehicle per hour values of 1250, 2083, 3333 and 1250 vehicles per hour. The average speeds (v) for each of the segments can also be found in Table 4.1

As stated previously, C_1 is a constant (see derivation in Appendix A) which is always 6.8×10^{-5} (0.000068) in the route comparison analysis. Values for the variables C_2 and C_3 come from Table 3.2-1. C_2 is dependent upon the distance between opposing traffic lanes. For Route A, these distances are 50, 40, 40 and 50 feet for the four segments. This results in the values for C_2 shown on the worksheet. The value for C_3 is dependent upon the separation distance between vehicles. The separation distance is calculated by dividing the average vehicle speed by the traffic density (T). Since the traffic density is expressed in vehicles per hour, the average speed must be converted to feet per hour before the division. For Route A, the results of these calculations are 190, 127, 79, and 211 as shown on Worksheet 1. The values for C_3 can then be obtained from Table 3.2-1 and are then entered on the worksheet.

Each segment is then evaluated using the equation shown on the worksheet and the values are summed at the bottom of the worksheet to yield the route total. This total is the comparison factor value for the route and is entered in the appropriate location on the route comparison worksheet (Worksheet 13).

Worksheet 2 shows the calculations for determining public health risk from accidental releases of radioactive material for Route A. The segment risk factors are determined by tabulating the population count inside each of the bands of interest. For segment 1 these values are 40 for the 0-5 mile band and 30 for the 5-10 mile band. All population counts are given in thousands. Each population count for each band is multiplied by the appropriate band multipliers, summed together, and divided by the segment length. This results in a public health consequence factor of .13 for segment 1. Public health consequences are similarly calculated for segments 2, 3 and 4 as shown.

The total public health consequence factor for each segment must be multiplied by the accident rate to determine the segment risk factor. In this example, data for truck accidents that resulted in driver fatalities was available. The accident rate shown on the worksheets includes consideration of the segment lengths. This is done by converting truck accidents per million truck miles to accidents per thousand shipments. To make this conversion, the accident rate per million truck miles shown in Table 4.1 is multiplied by the segment length. This product is then multiplied by one thousand to arrive at the accident rate per thousand shipments shown in the last column of Table 4.1. Accidents per thousand shipments was chosen for the accident rate units on the health risk worksheet because it resulted in conveniently sized numbers. Accidents per shipment or per million shipments would be just as valid a number as long as all segments and alternative routes are figured the same way.

After each of the segment health risk factors are calculated, they are totaled to yield the comparison factor value. This number is found at the bottom of the public health risk worksheet. It is also entered on the comparison worksheet.

Worksheet 3 consists of two pages and shows calculation of the economic risk factor for Route A. The area inside two bands (Sheet #1 for the 0-5 mile band and Sheet #2 for the 5-10 mile band) on either side of the highway is examined to determine the area in each of the land use types shown on the worksheet. It is important to remember to consider both sides of the pathway. The amount of land in each of the use types is entered on the worksheet for each segment and band. The areas are multiplied by the appropriate weighting factor and entered in the weighted total column. Weighting factors used in the example were taken from Table 3.2-3. The bottom of the first page of

Worksheet 3 tabulates the weighted totals for each band and for each segment. For each segment, the band totals are added, and then divided by the segment length to produce the economic consequence factor. This is multiplied by the segment accident rate to obtain the segment economic risk factors. Finally, the segment factors are summed to obtain the route total. This total is entered in the appropriate location on the route comparison worksheet.

The next three worksheets show calculations of the primary comparison factors for Route B. All the variables in the Route B calculations must have the same units as the Route A calculations. If truck accident rates were described as the number of accidents per thousand shipments for Route A, then Route B rates must be described as accidents per thousand shipments. Data for these calculations will come primarily from Table 4.2.

Once all of the primary comparison factors have been computed for each alternative route, the route selection process can proceed. However, before the primary factors are evaluated and compared for the purpose of route selection, several secondary factors will be computed to illustrate the process.

4.2 Estimation of Secondary Route Comparison Factors

Worksheets 7 and 10 illustrate the use of the arbitrary scaling systems for the purpose of quantifying the very subjective secondary factors relating to emergency response and evacuation.[2] As emphasized previously, these estimates amount to nothing more than approximations which could be useful if the primary comparison factors for alternative routes are computed to be essentially the same. Also included in this analysis is the traffic fatality factor (Worksheet 9 and 12) which is directly dependent on available accident rates and therefore less judgmental in nature than other secondary factors.

Worksheet 7 evaluates the emergency response and evacuation factors for Route A. Completion of this worksheet is similar to the economic risk worksheet. The land areas (in square miles) for the categories shown are

[2] Worksheets 8 and 11 illustrate a method for considering special facilities in the route selection process.

determined for a band extending five miles on either side of the route. (Only the 0-5 mile band is considered for these factors.) When a route consists of more than one segment, the areas are summed across the segments for each land development type. This is necessary because the weighting factors need to be applied to the entire route at one time. The fraction of land area along the route for each development type is then multiplied by the appropriate weighting factor and these products are summed to arrive at the route's comparison factor. For this sample case, weighting factors for emergency response and evacuation for both Routes A and B are drawn from Tables 3.2-4 and 3.2-5, respectively. For Route A, the emergency response comparison factor is 10.77 and the evacuation comparison factor is 12.83. These values are entered in the appropriate location on the route comparison worksheet.

Worksheet 8 shows the calculations for the special facilities comparison factor for Route A. This comparison factor is determined by counting the number of various special facilities along the 0-5 mile band of Route A, and then multiplying them by their corresponding facility weight factors. (For this sample case, the facility weight factors for all types of facilities along Routes A and B were obtained from Table 3.2-6.) The sum of these products is the route's special facilities comparison factor. For Route A, this factor is 882. This value is then entered in the appropriate location on the route comparison worksheet, Worksheet 13.

Calculations for the traffic fatalities comparison factor for Route A are presented in worksheet 9. The accident unit of measure chosen for this analysis is truck accidents resulting in a fatality (truck accident fatalities per million truck miles). The emphasis in this comparison factor is on deaths or injuries that could result from a normal truck accident with no release of cargo. For this reason, any truck accident that results in death (either the driver or persons in other vehicles) was chosen as a comparative measure. If a route is broken into segments, each segment will have a separate accident rate. The mileage in each of the segments is multiplied by the accident rate to yield a segment comparison factor. The segment comparison factors are summed to arrive at the route comparison factor. This value is entered onto the route selection worksheet in the appropriate location.

Worksheets 10, 11 and 12 evaluate these same secondary factors for Route B.

4.3 Route Selection in the Sample Case

Worksheet 13 is a summary sheet for the data developed during the sample case analysis. It is clear from the sample case that Route B would be the preferred route since all three primary factors favor Route B. However, in many situations such a clear-cut choice may not be evident. In most cases it will be necessary to combine the factor values for each primary factor into one representative risk value. This can be accomplished by "normalizing" the factor values for each alternative route and then adding the normalized values to obtain one "figure of merit."

The third column of numbers on Worksheet 13 shows the total of factor values for each primary comparison factor. For example, the normal radiation exposure factor was computed to be 11.01 for Route A and 8.27 for Route B. This adds up to 19.28 as shown in the third column. The "normalized value" for Route A is simply the factor value for Route A divided by the total factor value for all routes (11.01/19.28 = 0.57). The normalized value for Route B for radiation exposure is 0.43 (the sum of the normalized values must be 1.0). The same process is followed for the public health risk and economic risk factors and the results are shown in the normalized value column for each route.

The reason for normalizing the factor values is that the factor values are disparate numbers, computed using different units of measure, and therefore cannot be combined into a final figure which has any meaning. For example, the factor values for public health accident risks are very small numbers because of the units of measure. Compare these numbers with the high units of measure for the normal exposure factor. Normalizing the factor values produces unitless fractions of the same magnitude. These fractions also retain the same relative magnitude for each comparison factor between the two routes.

The normalized values for each route are then added to obtain the figure of merit. Worksheet 13 shows the figure of merit for Route A to be 2.36 and for Route B to be .63. The lowest figure of merit identifies the route that is most likely to minimize the impacts from transporting highway route controlled quantity radioactive materials using the criteria developed in this guidebook; hence Route B is considered to be the preferred route for highway route controlled shipments of radioactive materials. Once again, if the figures of merit computed for alternative routes are essentially the same, secondary factors may be considered in making the final choice of a preferred route.

NOTE ON WEIGHTING OF THE COMPARISON FACTORS

Underlying this method of combining the comparison factors to select a route is the assumption that the three primary factors are of equal importance in reducing impacts and are therefore weighted the same. The figure of merit can be simply characterized as a number which is representative of the relative risk from transportation between Route A and Route B, given that the three primary factors contribute equally to that risk.

Past risk studies indicate that normal exposure often contributes a greater share of the health risks from transportation of radioactive materials than accidents resulting in public health impacts. This may suggest a greater weighting factor for normal exposure to recognize the difference in magnitude of impacts when it is compared with public health risks resulting from accidents. However, the primary purpose of these studies was to assess the actual risk in transportation, not to develop comparative risk figures for the narrower purpose of assessing routing alternatives. As demonstrated by NUREG-0170, a great deal of specific information is needed to develop actual risk numbers for both normal exposure and accident risks. If such numbers are developed, actual risk estimates could then be converted into comparable units to determine a weighting factor. If a State has the resources and capability to conduct a true risk assessment, and believes weighting factors should be assigned based on the risk figures developed during that assessment, they are encouraged to do so.

However, weighting factors would be difficult, if not impossible, to quantify for general use in a generic route selection guidebook such as this document. They could vary significantly depending on data such as population distribution and density, accident statistics, and other site-specific factors that vary from one routing situation to another. Therefore, relative weights have not been assigned to the three primary factors in these guidelines. It is believed that the route identified as having the lowest figure of merit, as calculated in the manner described in this document, will be the route most likely to minimize impacts from the transportation of highway route controlled quantity radioactive materials.

WORKSHEET 1 ROUTE A SHEET 1 of 2

WORKSHEET FOR NORMAL RADIATION EXPOSURE COMPARISON FACTOR

$$D = (PL/v)*C_1 + (LT/v^2)*C_2 + (LT^2/v^3)*C_3 + L/v$$

Segment 1 (0 - 5 Mile Band)

P = 14/sq. mi. = (40,000/2,900)

L = 290 mi.

v = 45 mph

T = 1250 veh. / hr. = (30,000/24)

$C_1 = 6.8 \times 10^{-5}$

Avg. Dist. Opposing Lanes = 50 ft.

C_2 (Table 3.2-1) = 9.4×10^{-4}

Avg. Veh. Separation Dist. = 190 ft.

C_3 (Table 3.2-1) = 1.3×10^{-5}

D = 6.68

Segment 2 (0 - 5 Mile Band)

P = 257/sq. mi. = (180,000/700)

L = 70 mi.

v = 50 mph

T = 2083 veh. / hr. = (50,000/24)

$C_1 = 6.8 \times 10^{-5}$

Avg. Dist. Opposing Lanes = 40 ft.

C_2 (Table 3.2-1) = 1.1×10^{-3}

Avg. Veh. Separation Dist. = 127 ft.

C_3 (Table 3.2-1) = 1.5×10^{-5}

D = 1.53

Segment 3 (0 - 5 Mile Band)

P = 1200/sq. mi. = (360,000/300)

L = 30 mi.

v = 50 mph

T = 3333 veh. / hr. = (80,000/24)

$C_1 = 6.8 \times 10^{-5}$

Avg. Dist. Opposing Lanes = 50 ft.

C_2 (Table 3.2-1) = 9.4×10^{-4}

Avg. Veh. Separation Dist. = 79 ft.

C_3 (Table 3.2-1) = 1.5×10^{-5}

D = 0.73

ROUTE TOTAL = ____________

WORKSHEET 1 ROUTE A SHEET 2 of 2

WORKSHEET FOR NORMAL RADIATION EXPOSURE COMPARISON FACTOR

$$D = (PL/v)*C_1 + (LT/v^2)*C_2 + (LT^2/v^3)*C_3 + L/v$$

Segment 4 (0 - 5 Mile Band)

P = 15/sq. mi. = (15,000/1,000)

L = 100 mi.

v = 50 mph

T = 1250 veh. / hr. = (30,000/24)

$C_1 = 6.8 \times 10^{-5}$

Avg. Dist. Opposing Lanes = 40 ft.

C_2 (Table 3.2-1) = 1.1×10^{-3}

Avg. Veh. Separation Dist. = 211 ft.

C_3 (Table 3.2-1) = 1.3×10^{-5}

D = 2.07

Segment ___ (0 - 5 Mile Band)

P =

L =

v =

T =

$C_1 = 6.8 \times 10^{-5}$

Avg. Dist. Opposing Lanes =

C_2 (Table 3.2-1) =

Avg. Veh. Separation Dist. =

C_3 (Table 3.2-1) =

D = ____

Segment ___ (0 - 5 Mile Band)

P =

L =

v =

T =

$C_1 = 6.8 \times 10^{-5}$

Avg. Dist. Opposing Lanes =

C_2 (Table 3.2-1) =

Avg. Veh. Separation Dist. =

C_3 (Table 3.2-1) =

D = ____

ROUTE TOTAL = 11.01

WORKSHEET 2 ROUTE A SHEET 1 of 1

WORKSHEET FOR PUBLIC HEALTH RISK COMPARISON FACTOR

Segment Release Consequences

	(0 - 5 Mile Band)					(5 - 10 Mile Band)			
Segment	Pop.Count	Multiplier		Total	Pop.Count	Multiplier		Total
1	40	x .75	=	30	30	x .25	=	7.5
2	180	x .75	=	135	50	x .25	=	12.5
3	360	x .75	=	270	70	x .25	=	17.5
4	15	x .75	=	11.25	11	x .25	=	2.75

Health Risk Calculations

Segment	0-5 Mile Total		5-10 Mile Total		Segment Length		Pub. Hlth. Conseq. Factor		Acc. Prob. (Ac. Rate)		Seg. Health Risk
1	(30	+	7.5)	÷	290	=	0.13	x	.003	=	.0004
2	(135	+	12.5)	÷	70	=	2.1	x	.0007	=	.0015
3	(270	+	17.5)	÷	30	=	9.6	x	.0006	=	.0058
4	(11.25	+	2.75)	÷	100	=	0.14	x	.0007	=	.0001

ROUTE TOTAL = .0078

WORKSHEET 3 ROUTE A SHEET 1 of 2

WORKSHEET FOR ECONOMIC RISK COMPARISON FACTOR
(0-5 Mile Band)

Land Use Type	Segment 1 Area		Weight[1]		Weighted Total	Segment 2 Area		Weight[1]		Weighted Total
Farmland	2300	x	0.002	=	4.6	500	x	.002	=	1.0
Single Family Residential	40	x	0.10	=	4.0	80	x	.10	=	8.0
Multi-Family Residential	20	x	2.0	=	40.0	20	x	2.0	=	40.0
Commercial	400	x	0.20	=	80.0	40	x	0.20	=	8.0
Parks	40	x	0.03	=	1.2	20	x	0.03	=	0.6
Public Areas	100	x	0.50	=	50.0	40	x	0.50	=	20.0
	WEIGHTED TOTAL			=	179.8	WEIGHTED TOTAL			=	77.6

Land Use Type	Segment 3 Area		Weight[1]		Weighted Total	Segment 4 Area		Weight[1]		Weighted Total
Farmland	-	x	.002	=	-	820	x	.002	=	1.6
Single Family Residential	-	x	.10	=	-	30	x	.10	=	3.0
Multi-Family Residential	80	x	2.0	=	160.0	-	x	2.0	=	-
Commercial	150	x	.20	=	30.0	100	x	0.20	=	20.0
Parks	20	x	.03	=	0.6	30	x	0.03	=	0.9
Public Areas	50	x	.50	=	25.0	20	x	0.50	=	10.0
	WEIGHTED TOTAL			=	215.6	WEIGHTED TOTAL			=	35.5

Economic Risk Calculations

Segment	0-5 Mile Wt. Tot.		5-10 Mile Wt. Tot.		Segment Length		Econ. Conseq. Factor		Econ. Prob. (Ac. Rate)		Seg. Econ. Risk
1	(179.8	+	28.1)	÷	290	=	.717	x	.003	=	.002
2	(77.6	+	9.5)	÷	70	=	1.24	x	.0007	=	.0009
3	(215.5	+	13.0)	÷	30	=	7.62	x	.0006	=	.005
4	(35.5	+	7.6)	÷	100	=	.431	x	.0007	=	.0003
									ROUTE TOTAL	=	.0082

[1] Based on Economic Consequence Measure Weight Factor Table (3.2-3).

WORKSHEET 3 ROUTE A SHEET 2 of 2

WORKSHEET FOR ECONOMIC RISK COMPARISON FACTOR
(5 - 10 Mile Band)

Land Use Type	Segment 1 Area		Weight[1]		Weighted Total	Segment 2 Area		Weight[1]		Weighted Total
Farmland	2400	x	.0002	=	0.48	560	x	.0002	=	0.11
Single Family Residential	150	x	0.04	=	6.0	60	x	0.04	=	2.4
Multi-Family Residential	80	x	0.20	=	16.0	30	x	0.20	=	6.0
Commercial	160	x	0.01	=	1.6	30	x	0.01	=	0.3
Parks	50	x	0.02	=	1.0	10	x	0.02	=	0.2
Public Areas	60	x	0.05	=	3.0	10	x	0.05	=	0.5
	WEIGHTED TOTAL			=	28.1	WEIGHTED TOTAL			=	9.5

Land Use Type	Segment 3 Area		Weight[1]		Weighted Total	Segment 4 Area		Weight[1]		Weighted Total
Farmland	20	x	.0002	=	0	860	x	.0002	=	0.17
Single Family Residential	60	x	0.04	=	2.4	40	x	0.04	=	1.6
Multi-Family Residential	30	x	0.20	=	6.0	20	x	0.20	=	4.0
Commercial	100	x	0.01	=	1.0	40	x	0.01	=	0.4
Parks	30	x	0.02	=	0.6	20	x	0.02	=	0.4
Public Areas	60	x	0.05	=	3.0	20	x	0.05	=	1.0
	WEIGHTED TOTAL			=	13.0	WEIGHTED TOTAL			=	7.6

---

1 Based on Economic Consequence Measure Weight Table (Table 3.2-3)

WORKSHEET 4 ROUTE B SHEET 1 of 1

WORKSHEET FOR NORMAL RADIATION EXPOSURE COMPARISON FACTOR

$$D = (PL/v)*C_1 + (LT/v^2)*C_2 + (LT^2/v^3)*C_3 + L/v$$

Segment 1 (0 - 5 Mile Band)

P = 9/sq. mi. = (28,000/3,200)

L = 320 mi.

v = 40 mph

T = 1042 veh. / hr. = (25,000/24)

$C_1 = 6.8 \times 10^{-5}$

Avg. Dist. Opposing Lanes = 50 ft.

C_2 (Table 3.2-1) = 9.4×10^{-4}

Avg. Veh. Separation Dist. = 203 ft.

C_3 (Table 3.2-1) = 1.3×10^{-5}

D = 8.27

Segment ___ (0 - 5 Mile Band)

P =

L =

v =

T =

$C_1 = 6.8 \times 10^{-5}$

Avg. Dist. Opposing Lanes =

C_2 (Table 3.2-1) =

Avg. Veh. Separation Dist. =

C_3 (Table 3.2-1) =

D = ____

Segment ___ (0 - 5 Mile Band)

P =

L =

v =

T =

$C_1 = 6.8 \times 10^{-5}$

Avg. Dist. Opposing Lanes =

C_2 (Table 3.2-1) =

Avg. Veh. Separation Dist. =

C_3 (Table 3.2-1) =

D = ____

ROUTE TOTAL = 8.27

WORKSHEET 5 ROUTE B SHEET 1 of 1

WORKSHEET FOR PUBLIC HEALTH RISK COMPARISON FACTOR

Segment Release Consequences

	(0 - 5 Mile Band)					(5 - 10 Mile Band)				
Segment	Pop. Count		Multiplier		Total	Pop. Count		Multiplier		Total
1	28	x	.75	=	21	7	x	.25	=	1.75
2		x	.75	=			x	.25	=	
3		x	.75	=			x	.25	=	
4		x	.75	=			x	.25	=	

Health Risk Calculations

Segment	0 - 5 Mile Total		10 Mile Total		Segment Length		Pub. Hlth. Conseq. Factor		Acc. Prob. (Ac. Rate)		Seg. Health Risk
1	(21	+	1.75)	÷	320	=	.071	x	.006	=	.0004
2	(	+	)	÷		=		x		=	
3	(	+	)	÷		=		x		=	
4	(	+	)	÷		=		x		=	
									ROUTE TOTAL	=	.0004

WORKSHEET 6 ROUTE B SHEET 1 of 2

WORKSHEET FOR ECONOMIC RISK COMPARISON FACTOR
(0-5 Mile Band)

Land Use Type	Segment 1 Area		Weight[1]		Weighted Total	Segment ___ Area		Weight[1]		Weighted Total
Farmland	2900	x	0.002	=	5.8		x	0.002	=	
Single Family Residential	120	x	0.10	=	12.0		x	0.10	=	
Multi-Family Residential	10	x	2.0	=	20.0		x	2.0	=	
Commercial	120	x	0.20	=	24.0		x	0.20	=	
Parks	20	x	0.03	=	0.6		x	0.03	=	
Public Areas	30	x	0.50	=	15.0		x	0.50	=	
	WEIGHTED TOTAL			=	77.4	WEIGHTED TOTAL			=	

Land Use Type	Segment Area		Weight[1]		Weighted Total	Segment Area		Weight[1]		Weighted Total
Farmland		x	0.002	=			x	0.002	=	
Single Family Residential		x	0.10	=			x	0.10	=	
Multi-Family Residential		x	2.0	=			x	2.0	=	
Commercial		x	0.20	=			x	0.20	=	
Parks		x	0.03	=			x	0.03	=	
Public Areas		x	0.50	=			x	0.50	=	
	WEIGHTED TOTAL			=		WEIGHTED TOTAL			=	

Economic Risk calculations

Segment	0-5 Mile Wt. Tot.		5-10 Mile Wt. Tot.		Segment Length		Econ. Conseq. Factor		Econ. Prob. (Ac. Rate)		Seg. Econ. Risk
1	(77.4	+	5.0)	÷	320	=	.257	x	.006	=	.0015
2	(	+	)	÷		=		x		=	
3	(	+	)	÷		=		x		=	
4	(	+	)	÷		=		x		=	

ROUTE TOTAL = .0015

---

1 Based on Economic Consequence Measure Weight Table (Table 3.2-3)

WORKSHEET 6 ROUTE B SHEET 2 of 2

WORKSHEET FOR ECONOMIC RISK COMPARISON FACTOR
(5 - 10 Mile Band)

	Segment 1					Segment ___				
Land Use Type	Area		Weight[1]		Weighted Total	Area		Weight[1]		Weighted Total
Farmland	3070	x	.0002	=	0.6	___	x	.0002	=	___
Single Family Residential	50	x	0.04	=	2.0	___	x	0.04	=	___
Multi-Family Residential	4	x	0.20	=	0.8	___	x	0.20	=	___
Commercial	50	x	0.01	=	0.5	___	x	0.01	=	___
Parks	6	x	0.02	=	0.1	___	x	0.02	=	___
Public Areas	20	x	0.05	=	1.0	___	x	0.05	=	___
	WEIGHTED TOTAL			=	5.0	WEIGHTED TOTAL			=	___

	Segment ___					Segment ___				
Land Use Type	Area		Weight[1]		Weighted Total	Area		Weight[1]		Weighted Total
Farmland	___	x	.0002	=	___	___	x	.0002	=	___
Single Family Residential	___	x	0.04	=	___	___	x	0.04	=	___
Multi-Family Residential	___	x	0.20	=	___	___	x	0.20	=	___
Commercial	___	x	0.01	=	___	___	x	0.01	=	___
Parks	___	x	0.02	=	___	___	x	0.02	=	___
Public Areas	___	x	0.05	=	___	___	x	0.05	=	___
	WEIGHTED TOTAL			=	___	WEIGHTED TOTAL			=	___

---

1 Based on Economic Consequence Measure Weight Table (Table 3.2-3)

WORKSHEET 7 ROUTE A SHEET 1 of 1

WORKSHEET FOR EMERGENCY RESPONSE and EVACUATION
COMPARISON FACTORS (Area in 0 - 5 Mile Band)

EMERGENCY RESPONSE CALCULATIONS

Land Use Type	Seg 1		Seg 2		Seg 3		Seg 4		Total	Route Fraction		Weight[1]		Weighted Total
Rural	2300	+	500	+	0	+	820	=	3620	0.74	x	12	=	8.88
Suburban[2]	103	+	102	+	65	+	53	=	323	0.07	x	10	=	0.70
Urban[2]	97	+	58	+	85	+	27	=	267	0.05	x	7	=	0.35
Commercial/ Industrial	400	+	40	+	150	+	100	=	690	0.14	x	6	=	0.84
										(Total) Comparison Factor			=	10.77

EVACUATION CALCULATIONS

Land Use Type	Seg 1		Seg 2		Seg 3		Seg 4		Total	Route Fraction		Weight[3]		Weighted Total
Rural	2300	+	500	+	0	+	820	=	3620	0.74	x	11	=	8.14
Suburban[2]	103	+	102	+	65	+	53	=	323	0.07	x	13	=	0.91
Urban[2]	97	+	58	+	85	+	27	=	267	0.05	x	28	=	1.40
Commercial/ Industrial	400	+	40	+	150	+	100	=	690	0.14	x	17	=	2.38
										(Total) Comparison Factor			=	12.83

[1] Based on Sample Emergency Response Parameter Scaling System (Table 3.2-4)

[2] Includes Parks and Public Areas

[3] Based on Sample Evacuation Parameter Scaling System (Table 3.2-5)

WORKSHEET 8 ROUTE A SHEET 1 of 1

WORKSHEET FOR SPECIAL FACILITIES COMPARISON FACTOR

Special Facility	Number of Facilities		Weight Factor (Table 3.2-6)		Total
Children's Hospital		X		=	
Hospital	18	X	11	=	198
Prison		X		=	
Nursing Home		X		=	
School	36	X	9	=	324
Church	54	X	5	=	270
Stadium		X		=	
Shopping Center	18	X	5	=	90
Theater		X		=	
Factory		X		=	
			(Total) Comparison Factor	=	882

WORKSHEET 9 ROUTE A SHEET 1 of 1

WORKSHEET FOR TRAFFIC FATALITIES/INJURIES COMPARISON FACTOR

Accident Unit of Measure: Truck Accident Fatalities (Mil Tr Mi.)

Segment	Segment Accident Rate		Segment Length		Total
1	0.01	X	290	=	2.9
2	0.01	X	70	=	0.7
3	0.02	X	30	=	0.6
4	0.007	X	100	=	0.7
			(Total) Comparison Factor	=	4.9

WORKSHEET 10 ROUTE B SHEET 1 of 1

WORKSHEET FOR EMERGENCY RESPONSE and EVACUATION COMPARISON FACTORS (Area in 0 - 5 Mile Band)

EMERGENCY RESPONSE CALCULATIONS

Land Use Type	Seg 1		Seg 2		Seg 3		Seg 4		Total	Route Fraction		Weight[1]		Weighted Total
Rural	2900	+		+		+		=	2900	0.91	x	12	=	10.92
Suburban[2]	103	+		+		+		=	103	0.03	x	10	=	0.30
Urban[2]	77	+		+		+		=	77	0.02	x	7	=	0.14
Commercial/ Industrial	120	+		+		+		=	120	0.04	x	6	=	0.24

(Total) Comparison Factor = 11.60

EVACUATION CALCULATIONS

Land Use Type	Seg 1		Seg 2		Seg 3		Seg 4		Total	Route Fraction		Weight[3]		Weighted Total
Rural	2900	+		+		+		=	2900	0.91	x	11	=	10.01
Suburban	103	+		+		+		=	103	0.03	x	13	=	0.39
Urban	77	+		+		+		=	77	0.02	x	28	=	0.56
Commercial/ Industrial	120	+		+		+		=	120	0.04	x	17	=	0.68

(Total) Comparison Factor = 11.64

---

1 Based on Sample Emergency Response Parameter Scaling System (Table 3.2-4)

2 Includes Parks and Public Areas

3 Based on Sample Evacuation Parameter Scaling System (Table 3.2-5)

WORKSHEET 11 ROUTE B SHEET 1 of 1

WORKSHEET FOR SPECIAL FACILITIES COMPARISON FACTOR

Special Facility	Number of Facilities		Weight Factor (Table 3.2-6)		Total
Children's Hospital		X		=	
Hospital	3	X	11	=	33
Prison		X		=	
Nursing Home		X		=	
School	6	X	9	=	54
Church	9	X	5	=	45
Stadium		X		=	
Shopping Center	1	X	5	=	5
Theater		X		=	
Factory		X		=	
			(Total) Comparison Factor	=	137

WORKSHEET 12 ROUTE B SHEET 1 of 1

WORKSHEET FOR TRAFFIC FATALITIES/INJURIES COMPARISON FACTOR

Accident Unit of Measure: Truck Accident Fatalities (Mil Tr Mi.)

Segment	Segment Accident Rate		Segment Length		Total
1	0.02	X	320	=	6.4
		X		=	
		X		=	
		X		=	
			(Total) Comparison Factor	=	6.4

WORKSHEET 13

SHEET 1 of 1

ROUTE COMPARISONS

PRIMARY FACTORS	TOTAL FACTOR VALUES Rte.A	TOTAL FACTOR VALUES Rte.B	FACTOR VALUES	NORMALIZED VALUES Rte.A	NORMALIZED VALUES Rte.B
Normal Radiation Exposure	11.01	8.27	19.28	0.57	0.43
Public Health Risk from Accidents	.0078	.0004	.0082	0.94	0.05
Economic Risk from Accidents	.0082	.0015	.0097	0.85	0.15
			Route Totals (FIGURE OF MERIT)	2.36	0.63

SECONDARY FACTORS	TOTAL FACTOR VALUES Rte.A	TOTAL FACTOR VALUES Rte.B	FACTOR VALUES	NORMALIZED VALUES Rte.A	NORMALIZED VALUES Rte.B
Emergency Response	10.77	11.60	22.37	0.48	0.52
Evacuation	12.83	11.64	24.47	0.52	0.48
Special Facilities	882	137	1019	0.87	0.13
Traffic Fatalities and Injuries	4.8	6.4	11.3	0.43	0.57

APPENDIX A

DERIVATION OF NORMAL RADIATION EXPOSURE COMPARISON FACTOR

The method for determining the normal radiation exposure factor for use in the route selection process was developed from a transportation radiation exposure model used in a previous Battelle study (Greenborg, et. al., 1980) of the routine radiation exposure from spent fuel shipments. In this model, radiation exposure from truck shipments is divided into six population groups. These groups include:

- Persons residing along the shipping route
- Travelers in the opposite direction
- Travelers going in the same direction as the shipment
- The truck crew
- People at truck stops
- Personnel handling the shipments at origin and destination.

For purposes of comparing routes, the latter category can be neglected, because it does not change with the shipping route used. The dose comparison factor for each route then becomes:

$$D = \begin{array}{c}\text{dose to persons}\\ \text{along route}\end{array} + \begin{array}{c}\text{dose to passengers}\\ \text{in vehicles}\\ \text{traveling in}\\ \text{opposite direction}\end{array} + \begin{array}{c}\text{dose to passengers}\\ \text{in vehicles}\\ \text{traveling in same}\\ \text{direction}\end{array} + \begin{array}{c}\text{dose to}\\ \text{truck crew}\end{array} + \begin{array}{c}\text{dose to people at}\\ \text{truck stops}\end{array} \quad (1)$$

Doses to each of these groups will be referred to as ID_1 through ID_5, respectively for the remainder of the discussion.

The dose to persons residing along the transport route (ID_1) is given by the following equation:

$$ID_1 = \sum_{i=1}^{n} \frac{4P_iL_ikI_2(d)}{V_i} \quad (2)$$

where the summation is over the number of segments that the route has been divided into for purposes of the analysis. Route segments are generally selected to correspond to significant changes in population densities. Other factors in the equation are defined as follows:

$P =$ population density (people/m^2)

$L =$ route segment length (m)

$k =$ dose conversion factor (mR • m^2/hr)

$v =$ truck velocity (m/hr)

$I_2(d) =$ an integral that estimates the dose at a given point from a moving source.

Note unit abbreviations: mR = millirems; m = meters

The dose factor, k, is dependent on the characteristics of the material being shipped and the particular shipping container being used. For route comparison purposes, a representative value can be used for this parameter because it will not change from one route to another. A value of 28 mR • m^2/hr was used, corresponding to the dose factor for a shipment of one-year-old spent fuel in a current generation legal-weight truck cask (Greenborg et al., 1980, Table B.2).

$I_2(d)$ is a function of the distance (d) from the truck carrying the radioactive shipment to the area along the route normally occupied by people. It corresponds roughly to the right of way for the highway segment being analyzed. $I_2(d)$ is plotted as a function of d in Figure A.1. The plot shows that $I_2(d)$ is a slowly varying function of d. For purposes of this analysis, a representative value of $I_2(d)$, 4, was chosen, corresponding to a distance of 10 meters (about 40 ft) from the vehicle traffic lane to the edge of the normally-populated zone along the road.

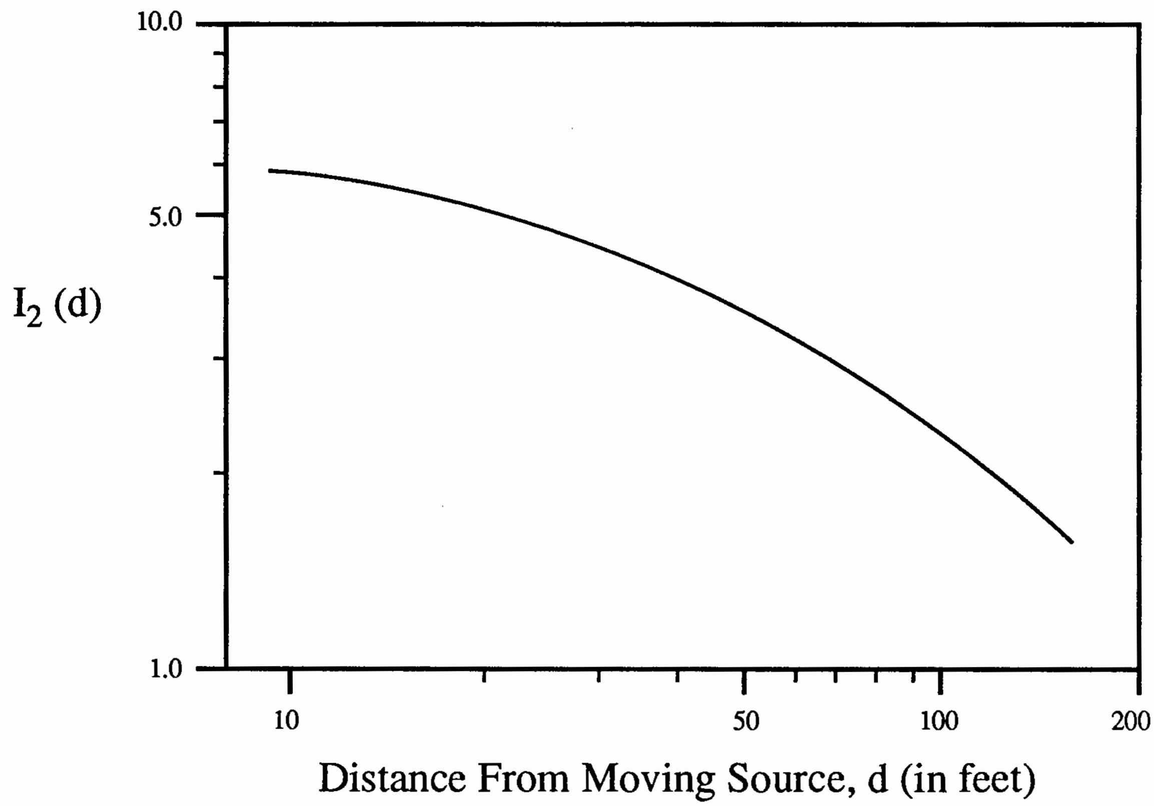

Figure A-1. $I_2(d)$ as a function of d

Substituting these values into equation (2), and assuming that only one route segment is being analyzed,[3]

$$ID_1 = 448 \frac{PL}{v}$$

Converting P, L, and v to more convenient units for use in the route selection process,

$$ID_1 = 1.7 \times 10^{-4} \frac{PL}{v}$$

where P has units of people/mi^2, L has units of miles, and v is given in mph. The constant 1.7×10^{-4} has the units of mR • $mile^2$/hr.

The dose to travelers in the opposite direction to the radioactive material shipment (ID_2) is given by the expression:

$$ID_2 = \frac{k \bullet L \bullet N \bullet T}{v^2} I_1(y) \qquad (3)$$

where k = dose conversion factor (mR • m^2/hr)

L = route length (m)

N = average number people/vehicle

T = traffic count (vehicle/hr)

v = truck velocity (m/hr)

$I_1(y)$ = an integral that estimates the dose to a moving target from a moving source.

$I_1(y)$ is a function of the distance (y) from the source to the target. This distance corresponds to the distance from the center of one lane of traffic to the center of the lane of traffic moving in the opposite direction. $I_1(y)$ is plotted as a function of y in Figure A-2.

The dose factor, k, in this equation (3) is identical to the dose factor used in ID_1 and is again assigned a value of 28 mR • m^2/hr. A representative value of N can also be used, because this tends to not vary significantly

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[3] This assumption will be adopted for the remainder of the derivation, in the interest of simplicity and clarity.

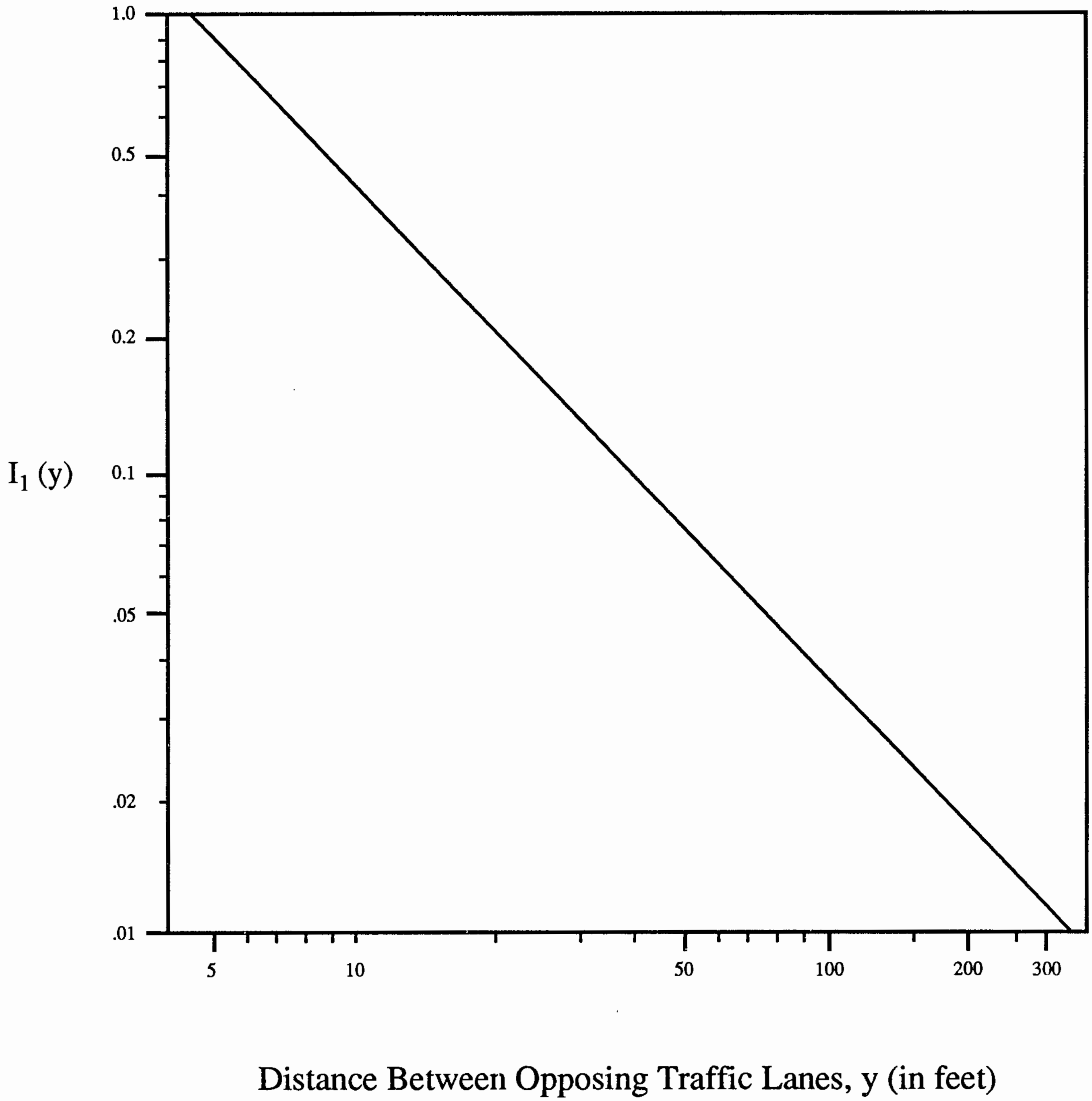

Figure A-2. $I_1(y)$ as a function of y

between routes. A value of 1.4 passengers/vehicle was selected. This is a national average for vehicles on freeways. Converting v and L to more convenient units, equation (3) then becomes:

$$ID_2 = 2.4 \times 10^{-2} \frac{LT}{v^2} I_1(y)$$

where L is in miles, T in vehicles/hr and v in mph. $I_1(y)$ has the units of meter^{-1} and the constant, 2.4×10^{-2} has the units of mR • people • meter^2/(vehicle • hour).

The dose to travelers in the same direction as the radioactive material shipment (ID_3) is given by the expression:

$$ID_3 = \frac{2kLT^2}{v^3} F(s) \tag{4}$$

where k, L, N, T and v are defined as before and F(s) is a function F that estimates the dose to passengers in all vehicles near the truck carrying the radioactive cargo. F is a function of the average vehicle separation distance (s) on the route segment. The vehicle separation distance, s, is equal to the average vehicle speed on the route, divided by the traffic count. F(s) is plotted as a function of s in Figure A-3. Substituting for N and k, and again converting units, equation (4) becomes:

$$ID_3 = 3 \times 10^{-5} \frac{LT^2}{v^3} F(s)$$

where L is in miles, T is in vehicle/hr and v is in mph. The constant, 3.0×10^{-5}, has the units of mR • people • mile^2/(hour • vehicle) and F(s) has the units vehicle^{-1}.

The dose to the truck crew (ID_4) is given by the following equation:

$$ID_4 = 2R_1 \frac{L}{v} \tag{5}$$

where L and v are defined as before, and R_1 is the dose rate (mR/hr) in the truck cab. It has been assumed that there are 2 drivers in the truck. A representative value of R_1 of 1 mR/hr has been used in this analysis because R_1 will not change from one route to another. (The maximum dose permitted in

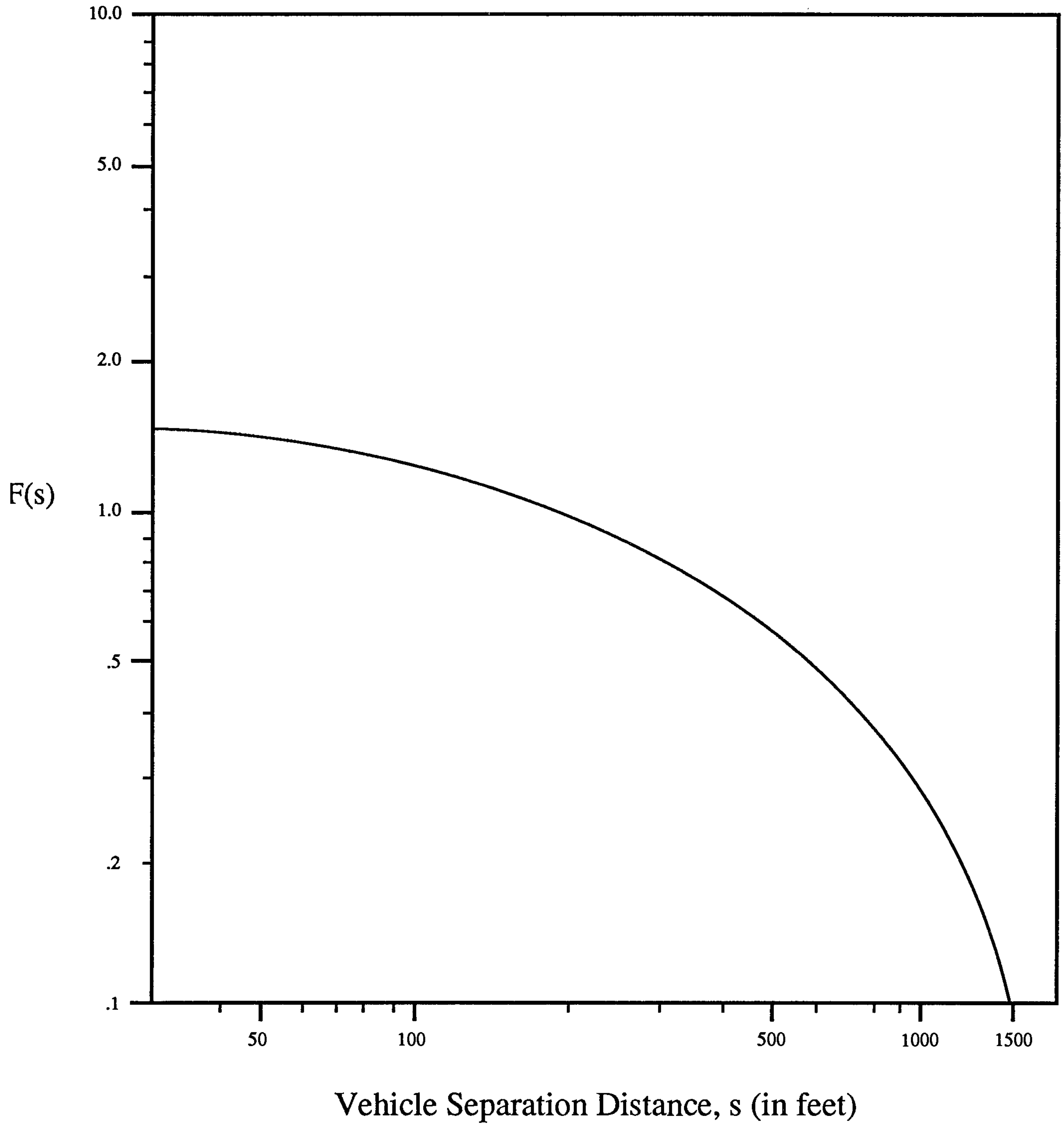

Figure A-3. F(s) as a function of s

the cab by DOT regulations is 2 mR/hr. Typical values are much less than this.) Equation (5) then becomes:

$$ID_4 = \frac{2L}{v}$$

where L is in miles and v in mph.

The dose to people at truck stops (ID_5) is given by the expression

$$ID_5 = \left(\frac{R_2}{4} + 9.1 \times 10^{-2}\ k_1\right) \bullet \text{integer} \bullet \frac{L}{4v} \qquad (6)$$

where R_2 is the dose at 10 ft from the package of radioactive material, k_1 is another dose conversion factor and L and v are defined as before. R_2 is used to estimate the dose to service station attendants, who are assumed to be in the vicinity of the truck for about 15 minutes at each stop. A representative value for R_2 of 2 mR/hr was used for this analysis. R_2 is a function of the shipment characteristics, and not of the route used. The dose conversion factor, k_1, is used in estimating the dose to other people at the truck stop. This would include, for example, people eating in a restaurant at the stop. The value of k_1 used in this analysis was 18 mR m^2/hr. The integer expression estimates the number of stops made by the truck in traveling a route of length L. It is assumed that refueling and crew comfort stops are made every four hours. To simplify the expression for the route selection process, the integer part of the equation has been ignored. This has the effect of discounting fractional stops, but should not significantly affect the route comparison process. Equation (6) then becomes:

$$ID_5 = \frac{0.5L}{v}$$

where L is in miles and v in mph.

Substituting these expressions for ID_1 through ID_5 into equation (1).

$$D = 1.7 \times 10^{-4}\ \frac{PL}{v} + 2.4 \times 10^{-2}\ \frac{LT}{v^2}\ I_1\ (y) + 3.0 \times 10^{-5}\ \frac{LT^2}{v^3}\ F(s) + 2.5\ \frac{L}{v}$$

Because D needs to be only proportional to the normal radiation exposure on each route, constants can be factored out to simplify the expression.

Factoring out 2.5 gives

$$D = C_1 \frac{PL}{v} + C_2 \frac{LT}{v^2} + C_3 \frac{LT^2}{v^3} + \frac{L}{v}$$

where, $C_1 = 6.8 \times 10^{-5}$ mR • mile^2/hr

$C_2 = 9.6 \times 10^{-3}\ I_1\ (y)$ mR • people • mile/(vehicle • hour)

$C_3 = 1.2 \times 10^{-5}\ F(s)$ mR • people • mile^2/(vehicle^2 • hour)

Values for C_2 and C_3 as a function of y and s are given in Table A-1.

TABLE A-1

Conversion Factors for Use in Estimating Routine Radiation Exposure Factor

Distance Between Opposing Traffic Lanes (ft)	C_2	Vehicle Separation Distance = $\frac{v}{T}$ (ft)	C_3
10	4.9×10^{-3}	10	1.8×10^{-5}
20	2.5×10^{-3}	50	1.6×10^{-5}
30	1.5×10^{-3}	100	1.3×10^{-5}
40	1.1×10^{-3}	200	1.3×10^{-5}
50	9.4×10^{-4}	300	1.0×10^{-5}
60	7.5×10^{-4}	400	8.6×10^{-6}
70	6.5×10^{-4}	500	7.3×10^{-6}
80	5.7×10^{-4}	600	6.0×10^{-6}
90	4.9×10^{-4}	700	5.0×10^{-6}
100	4.1×10^{-4}	800	4.0×10^{-6}
150	2.6×10^{-4}	900	3.3×10^{-6}
200	1.9×10^{-4}	1000	3.0×10^{-6}
300	1.0×10^{-4}	1200	1.3×10^{-6}

APPENDIX B

DERIVATION OF RELEASE CONSEQUENCE ESTIMATE

Release Consequences

In this analysis, the estimation of the consequence of an accidental release of radioactive material is based upon a linear relationship between dose and health effects. The health effects estimated in this analysis are latent cancer fatalities due to short duration exposure to airborne radionuclides. A reasonable estimate of health effects can be made by determining the inhalation dose received over the duration of the release (A.L. Franklin, 1980). Estimates of the inhalation dose can be made by applying a standard atmospheric dispersion model to various atmospheric conditions and radioactive material release rates (D.B. Turner, 1970). Because this routing decision analysis is concerned with identifying a route preference, exact determination of the health effects is not necessary. This allows the methodology to be generalized somewhat. It will not be necessary to identify the specific material being shipped and which organs are most sensitive to that material. Also the conversion of dose to health effect will not be necessary since the same material will be shipped over each route and no physical differences are expected in the populations along the pathway. With these simplifying assumptions, exact calculation of health effects can be reduced to calculating the dose to the general public. The dose to the general public will be directly related to the quantity of material inhaled. The quantity of material that can be inhaled by a group of individuals will primarily depend upon their orientation with respect to the release site and wind direction. Figure B.1 shows several possible orientations for individuals near a release of radioactive material.

The isopleths, shown in Figure B.1, are lines of constant atmospheric concentration. Isopleth 1 identifies a line of higher concentration than isopleths 2 or 3. Isopleth 3 is a lower concentration than isopleth 2 and may represent the lower limit of exposure consideration. Past isopleth 3 the material may be considered as totally dispersed (below hazardous

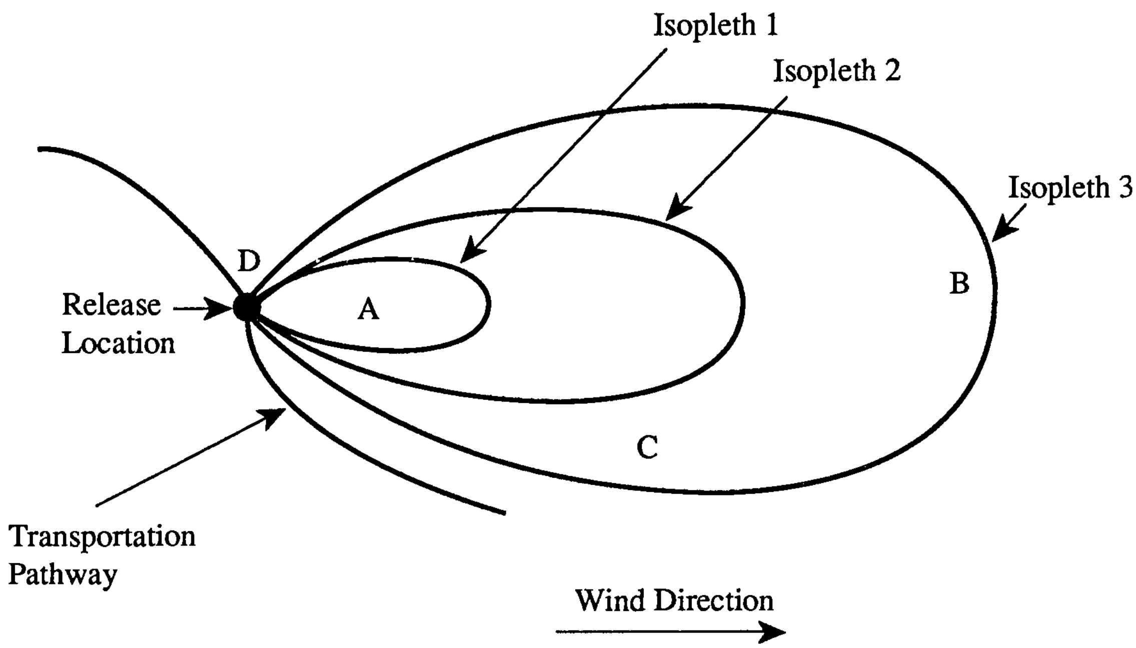

Figure B.1
Dispersion Isopleths

concentrations). Four individuals, A, B, C, and D, are presented in Figure B.1. Individual A is standing directly downwind from the release and will receive an inhalation dose proportional to the airborne concentration of radioactive material at that point. Individual B is also standing directly downwind but will receive a smaller dose than A because his distance from the release location is greater. This allows the material to disperse more before reaching B. Individual C is closer to the release location than B but will receive a dose similar to B because he is not standing directly downwind. Finally, individual D is closer to the release location than any of the other individuals but will receive essentially no exposure because the isopleths converge on the release location. This person is not standing in the dispersion pattern.

Figure B.2 demonstrates that the determination of inhalation dose is highly dependent upon the wind direction and the distance from the release location. To apply this dispersion pattern to a general population along a transportation pathway, the position dependent concentrations need to be combined with the number of persons at each position. This was done by dividing the isopleths into a grid pattern. The average airborne concentration in each cell is multiplied by the area of the cell to yield a two-dimensional exposure parameter. This parameter is summed along the crosswind direction of the isopleths to produce an exposure parameter that is a function of downwind distance alone. Possible wind direction orientations with respect to the pathway are accounted for by repeating this process for 16 evenly spaced wind directions. Each direction is considered to be equally probable. These 16 calculations are then combined to yield a probabilistically weighted parameter that is proportional to the anticipated inhalation dose at any point along the transportation route. This curve is shown in Figure B.3.

The data in Figure B.3 have been normalized to show the fraction of the total inhalation dose received by the public as a function of distance from the pathway. The data on the curve is cumulative along the downwind distance so that eventually, as x increases, 100% of the inhalation dose is accounted for. The curve stops at 10 miles and 0% of the total dose lies beyond this distance.

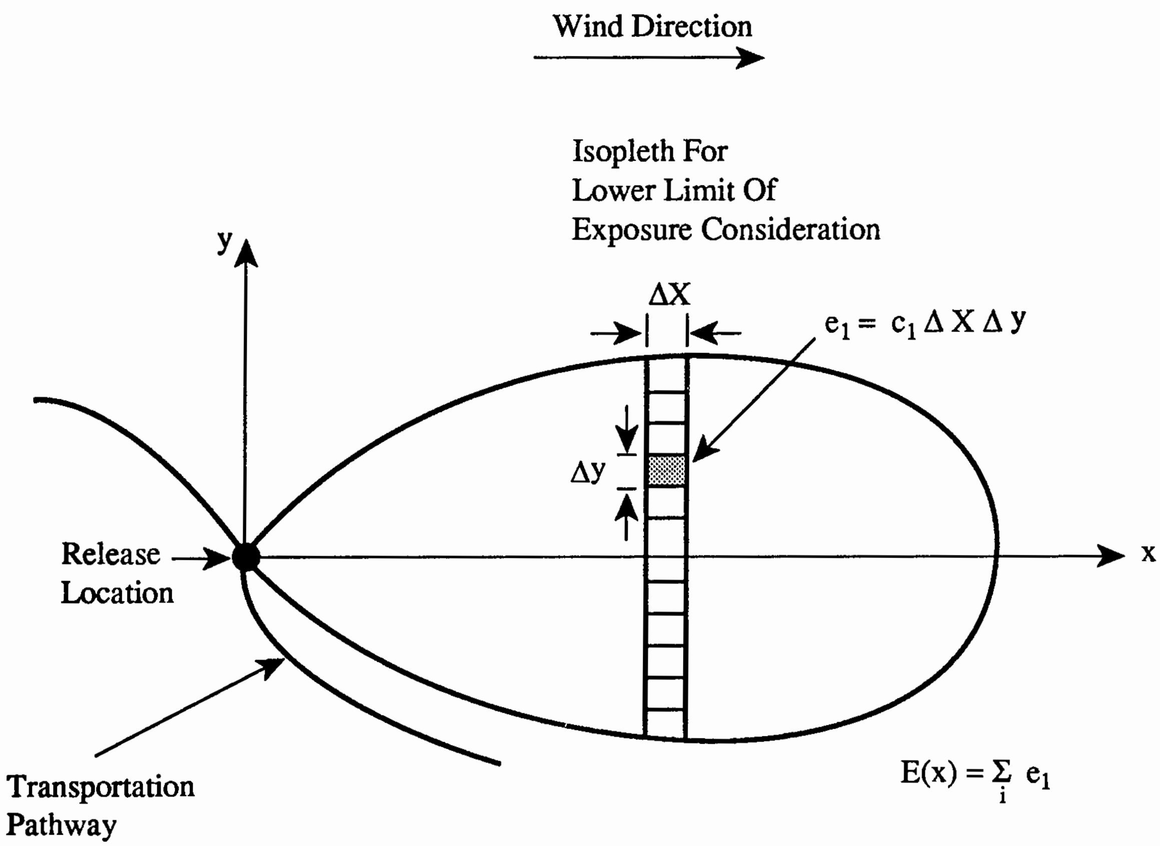

Figure B.2
Determination of the Exposure Parameter, E(x), as a Function of Downward Distance

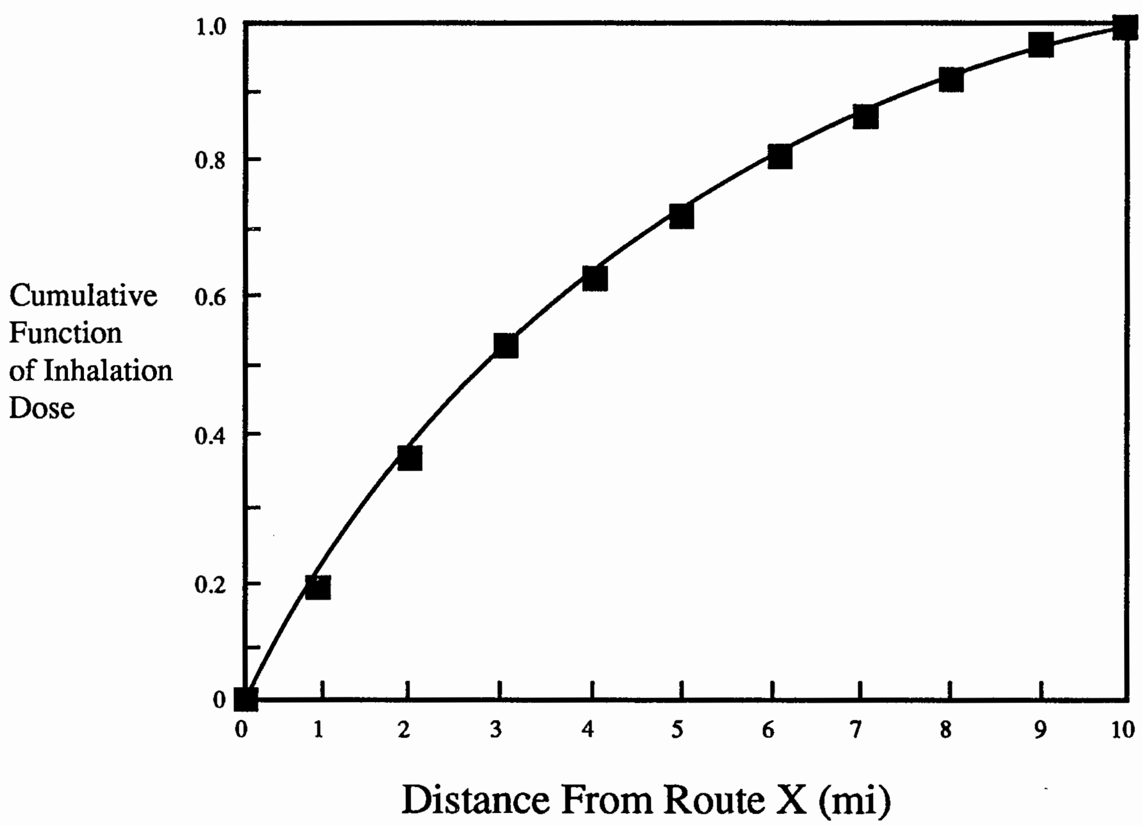

Figure B.3
Dose Contribution

The boundary, dividing the 10 mi. exposure distance into two bands, is chosen to be at 5 mi. This distance is relatively small yet represents the 75% point on the exposure curve. The band boundaries and their incremental contributions to public dose are given in Table B.1. The incremental contributions can be used as multipliers to produce a figure of merit that will be proportional to the anticipated public health consequence of an accidental release of radioactive material.

TABLE B.1

Health Consequence Band Multipliers

Population Band Boundary	Health Consequences Band Multipliers
0 - 5 mi	0.75
5 - 10 mi	0.25

To apply this consequence evaluation method, the number of persons within each of the population bands in the table is determined from maps, census data, or other available information. Counting by thousands or tens of thousands will not affect the results provided each of the routes under consideration is counted in the same way. (Note that the bands cover the indicated distance on either side of the highway, i.e., the first band is 10 miles wide, centered on the highway.) In many applications of the route selection methodology, the number of people in each band can be determined by adding the population of cities, towns, and villages that lie within the band. The population in rural areas would be neglected, but this is not expected to significantly affect the results of the route comparison. This method will usually be appropriate when relatively long routes are being compared that pass through or near a number of population centers of various sizes. More detailed data, using census districts, for example, may be required when comparing shorter routes. This type of analysis would generally be associated with comparisons of through routes with possible bypass routes for a major city.

As mentioned on page 16 of this document, a complete derivation of the method used to calculate the public health risk comparison factor will be given here. In the complete treatment, the number of people in each band is divided by the segment area, and multiplied by the appropriate weighting factor to obtain a figure known as the weighted population density. These values for the 0-5 mile and 5-10 mile bands of each segment are added, and then multiplied by the area assumed to be affected by the accident. The area potentially affected in the event of an accident is difficult to predict with any degree of accuracy, being dependent on the particular event scenario and meteorological conditions at the time and location of the accident. As described in Appendix B, a teardrop-shaped area of impact is predicted, with 75% of the health effects occurring within 5 miles of the accident and 100% within 10 miles. The wind direction at the time of release will determine the direction in which the dispersion pattern is oriented, and this could be in any direction, i.e., 360 degrees relative to the source. As this is a comparative risk analysis, however, an exact area of effect is not critical, because the term will be the same for all calculations. This is further multiplied by the number of accidents per mile and the number of miles per segment to yield a segment public health risk. These values are summed for a final public health risk factor for the route.

It can be seen, however, that in a comparative assessment of the public health risk for two different routes, there are several factors shared in common. First is the factor of band width which appears as a divisor. In the complete mathematical treatment, the band area (length x width) is divided into population count to obtain population density. As the band width is 10 miles for all routes compared, this will cancel out of the final equation. Another factor that is shared in common in formulations of public health risk is the area affected by the accident. Hence in a ratio of public health risks for two routes, this area of effect also cancels. This leaves an expression for public health risk that is composed of the sum of the population counts for both 0-5 and 5-10 mile bands (after each has been multiplied by the appropriate weighting factor of .75 and .25, respectively), divided by the length of the segment, and finally multiplied by the accident rate (in number of accidents per segment) to yield the final public health risk value.

APPENDIX C

DERIVATION OF ECONOMIC RISK COMPARISON FACTOR

If radioactive materials are released in a severe transportation accident, property in the vicinity of the accident could become contaminated with radioactive materials. When contamination exceeds safe levels, it would have to be removed or otherwise reduced to safe levels before the property could be returned to normal use. The expenses associated with decontamination are expected to be the primary economic impact of a transportation accident that releases radioactive materials.

Decontamination costs vary with the type of property being decontaminated (Reactor Safety Study, 1975 (i.e., Wash 1400, 1975 Report)). The decontamination costs for several land development types are given in Table C.1. Costs are presented for two levels of decontamination that are assumed to be required following a release. A decontamination factor (DF) is defined as the starting contamination level divided by the reduced contamination level following decontamination activities.

TABLE C.1

Average Land Use Decontamination Costs

Land Use Type	DF=20	DF=2
Farmland	\$230/acre	\$23/acre
Single Family Dwelling	\$9,000/dwelling	\$5,000/dwelling
Multiple Family Dwelling	\$280/capita	\$30/capita
Commercial	\$315/capita	\$21/capita
Parks	\$38/capita	\$30/capita
Public Areas	\$420/capita	\$40/capita

The values shown in Table C.1 are chosen to be representative of the ranges of the values listed in the Reactor Safety Studies document. Representative values were used rather than the ranges given to make the routing evaluation methodology easier to apply. To further simplify the methodology application, the values were converted to cost per square mile. This required making several assumptions concerning the number of persons per structure and the number of structures per acre. These assumptions were based upon the descriptions of the development types given in the Reactor Safety Studies document. The results of this conversion are given in Table C.2. To make the economic consequences comparison factor a conveniently sized number, the values were further modified to represent millions of dollars per hundred square miles.

TABLE C-2

Decontamination Costs ($K/mi^2)

Land Use Type	DF=20	DF=2
Farmland	150	15
Residential		
Single-Family	11,210	3,600
Multi-Family	205,000	22,000
Commercial	20,000	1,300
Parks	3,200	1,900
Public Areas	50,000	4,700

To apply the economic consequence methodology to the routing decision analysis, the decontamination factors need to be interpreted into a measurable distance from the pathway. The "DF equals 20" region will lie closer to the pathway than the "DF equals 2" region. This is due to higher deposition rates of airborne radioactive material, resulting from higher airborne concentrations, near the release location. The boundaries for these regions have been selected to coincide with the bands for the public health consequence evaluation. A decontamination factor of 20 will be assumed to be required to return land in the 0-5 mile band to normal use after an accident. A decontamination factor of 2 will be assumed for the 5-10 mile band. It is assumed that no decontamination will be required past 10 miles from the shipping route. With these last simplifying assumptions, the economic consequence multipliers take on the value given in Table C.3.

TABLE C-3

Economic Consequence Multipliers

Land Use Types	0 - 5 Mile Band	5 - 10 Mile Band
Farmland	0.002	0.0002
Residential		
Single-Family	0.1	0.04
Multi-Family	2.0	0.2
Commercial	0.2	0.01
Parks	0.03	0.02
Public Areas	0.5	0.05

A complete derivation of the economic risk factor calculation will now be given. This treatment parallels that for the public health risk given on page B-6. As in that case, factors common to economic risk expressions for two different routes, when placed in the ratio form of a comparative assessment, cancel each other out. A simplified expression for economic risk results and is utilized in the text portion of the Guidelines and in the worksheets for purposes of calculating economic risk.

Specifically the complete expression for economic risk (in simplified form that closely parallels that for the public health risk) when given in the form of a word equation is:

ER = ((Weighted totals of land use types$_{0-5}$/segment area$_{0-5}$) + (Weighted totals of land use types$_{5-10}$/segment area$_{5-10}$)) x (area affected by accident) x (number of accidents/segment).

In a ratio of two economic risk factors from two different routes, the factors of band width (recall that segment area is band width multiplied by length of segment) and area affected by the accident are common to both, and hence cancel. This leaves the simplified expression:

ER = [((Weighted totals of land use types$_{0-5}$) + (Weighted totals of land use types$_{5-10}$)) ÷ (segment length)] x (number of accidents/segment).

APPENDIX D

DERIVATION OF EVACUATION COMPARISON FACTOR

Public health consequences from accidents involving radioactive materials are due to mechanical forces generated by the accident and exposures of populations to ionizing radiation if a release of material occurs. Accident forces are the only effects with potential for immediate public health impacts. Public exposure to radiation during a transportation accident would not result in immediate fatalities due to the relatively low individual doses that would be produced. Public dose can be further reduced, moreover, through evacuation of persons in the affected areas.

Factors contributing to an effective evacuation include the type of area to be evacuated (i.e., residential, industrial, etc.), means of egress, implementation of plans by authorities and the nature of the threat. Little research has been done to measure the effect of these parameters on evacuation results. Evacuation results can be measured in terms of the number of persons who choose not to evacuate, time required to evacuate, and impacts on the evacuating population. A study by EPA (Hans and Sell, 1974) was used in this project to gain insight on evacuation mechanisms.

Hans and Sell gathered all available historic data on evacuations. This included information on planned evacuations for civil defense, natural disasters, special facility evacuations and precautionary evacuations in response to potential threats. Several conclusions were developed on public behavior during an evacuation. First, the frequency of death or injury is approximated by motor vehicle accident statistics because 99% of all evacuations were made using motor vehicles. Second, a state of panic does not exist. Low speeds and orderly movement of vehicles were observed. Third, evacuation planning is essential to identify potential problems. Fourth, special facilities such as schools, hospitals, and penal institutions require specific plans for their evacuation. Fifth, evacuation times vary with population density. Areas of lower density required longer to evacuate. Finally, even when faced with a threat, an average of 6% of the people refuse to evacuate. Much higher refusal rates were observed for situations where the threat was not apparent. Radioactivity is not detectable by human senses, hence evacuations to avoid exposure may be met with resistance without adequate communication from officials.

Persons who refuse to evacuate should be encouraged to take measures to improve the protection afforded by their homes. Studies of toxic gas infiltration for typical homes in the Netherlands (Directorate-General of Labour, Netherlands) indicate that concentrations inside are about 1/3 of those outside for 0.5 hours following gas contact with the house. When makeshift seals were installed, this time was extended to 2.5 hours.

Data from Hans and Sell was used in a study of chlorine risks (Andrews et al., 1980) to predict evacuation times as a function of population density. Descriptions of evacuations for nine transportation accidents were used to develop the following relationship:

$$\log(\text{evacuation time in hours}) = -0.16 \log(\text{persons/km}^2) + 0.94$$

Rural areas averaging 50 persons/km^2 are predicted by this relationship to require 5 hours for evacuation. Evacuation times are reduced to 3 hours for urban areas with population densities of 1000 persons/km^2.

APPENDIX E

WORKSHEETS AND WORKSHEET INSTRUCTIONS

The following instructions guide the user through the steps necessary to fill in the data correctly on the route selection worksheets that are illustrated in Chapter 4, the Sample Problem. If proper data collection is done, then most of the work to use the worksheets correctly entails only that one fill in the blanks correctly. Almost all of the calculations necessary are on the worksheet to assist the user in coming up with Route Comparison Factors. Blank, reproducible worksheets are included with this Appendix to illustrate the instructions, and so that they can be used for real cases.

Route Choice and Segmentation - The first step, prior to the use of any worksheet, is to define the alternative routes for analysis, and then break them into segments that will make applying the route selection methodology meaningful. Segments many times bound areas with differing land use types or population densities. Frequently, segments are made to encompass a road type, like an Interstate, or a change of road type, from county road to state road to take advantage of changes in data collection frequency and accuracy.

Data - The first worksheet is the Route Identification Chart. Using county, state, and any other municipality land use maps, census data, and traffic count and accident rate data, this worksheet should be filled in first. The data should be filled in on a segment basis, using the segments decided on in the alternative route selection process. Distances between opposing lanes should be in feet; lengths of segments should be in miles. The number of special facilities for each route segment should be for the 0-5 mile Band only. Once all data has been filled in, the Route Comparison Factors can be calculated.

Normal Radiation Exposure Comparison Factor - First, the values of segment length L, average speed v, and distance between opposing lanes can be filled in for each route segment. The population density, P, is calculated using the population count for the 0-5 mile band and dividing by the area (10 x length of the segment). The hourly traffic count, T, is calculated by dividing the daily traffic count by 24. The vehicle separation distance is calculated for each segment by first converting v from mph to fph (by multiplying v by 5280 ft.), then dividing by the hourly traffic count, T. C_2 and C_3 values come from Table 3.2-1. Using the expression on the worksheet for D, route segment D's are calculated. The Normal Radiation Exposure Comparison Factor is then the sum of all the segment D values.

<u>Public Health Risk Comparison Factor</u> - First, populations within the 0-5 mile band and the 5-10 mile band can be filled in, using the actual count, or another convenient count, provided that all routes are treated equally. That is, all population counts can be divided by 1000 to make calculations easier. The result will not be affected as long as all populations for all segments and routes are treated the same. Then these population figures are multiplied by the public health multipliers for the bands. These values for the two bands are summed, and then divided by the segment length (in miles) to arrive at a segment health consequence. These consequences are multiplied by the Accident Probability to arrive at Segment Health Risks. The sum of all of the segment Health Risks gives the Health Risk Comparison Factor.

Accident Probability can be simply the accident rate obtained in data collection, or it can be converted into other meaningful probability numbers. For instance, if the accident rate for route segments is given as truck accidents per million truck miles, multiplying the accidents per million truck miles by the segment length and by one thousand leaves an Accident Probability of accident rates per 1000 shipments. Any measure of probability, expressed in a relationship to the accident rate can be used, provided that every route and route segment is figured the same way.

<u>Economic Risk Comparison Factor</u> - The areas for each land use type in each of the two area bands (0-5 mile band and 5-10 mile band) are entered on the worksheet. These areas are then multiplied by the economic consequence measures derived in Appendix C. These are summed, and divided by the segment length (in miles) to arrive at a measure of the segment economic consequence. This number is then multiplied by its respective accident probability just used in the calculation of the Public Health Risk Comparison Factor. The

result is the Economic Risk for each segment. These are all summed to obtain the Economic Risk Comparison Factor for the Route in question.

Emergency Response and Evacuation Comparison Factors - These two comparison factors are combined on one worksheet, for most of the calculations are the same for the two factors. First, the Band areas for the land use types for the 0-5 Mile Band only are entered for every segment. These are totaled to give a Route total. Then these are transposed into percentages of the total area under consideration. Then the Route percentages are multiplied by the route-specific Emergency Response Land Use Parameter and the Evacuation Land Use Parameter from the Scaling Systems, to arrive at Land Use Totals. Route-specific emergency response weighting factors and evacuation weighting factors can be derived by completing the appended parameter scaling tables. The land use totals are summed over the four land use categories to arrive at the Route Totals.

Special Facilities Comparison Factor - The number of different special facilities within the 0-5 Mile Band is entered and multiplied by the Special Facility Factor which can be determined from the route-specific special facilities scaling system table. The results are summed to obtain the Special Facilities Comparison Factor for the Route.

Traffic Fatalities/Injuries Comparison Factor - For each segment, the segment length and accident rate are entered and multiplied. These products are summed up to give the Traffic Fatalities/Injuries Comparison Factor.

Route Comparison Worksheets - The Route Comparison Worksheets should be filled in with the respective Route Comparison Factors for every Route. The Route Comparison Factors are normalized and the total of the three Primary Route Comparison Factors, known as the "figure of merit," is calculated. Normalized values must be used to prevent attempting to arrive at decisions when comparing large numbers with small numbers. The normalized values allow the decision-making to be carried out on equal scale, where % differences are compared. (Normalizing involves dividing the Comparison Factor for one Route by the total for all Routes of that Route Comparison Factor. Summing the Normalized Route Comparison Factor for all routes should total 1). More specific comparative effects (e.g., the percentage increase in normal radiation exposure) resulting from selecting one route over another can be determined by calculating the percentage difference between the specific normalized route comparison factors (e.g., normal radiation dose).

WORKSHEETS FOR APPLYING ROUTING GUIDELINES

Route Identification Chart

Normal Radiation Exposure Comparison Factor

Public Health Risk Comparison Factor

Economic Risk Comparison Factor

Route Specific Emergency Response Parameter Scaling System

Route Specific Evacuation Parameter Scaling System

Emergency Response and Evacuation Comparison Factors

Route-Specific Special Facility Scaling System

Special Facilities Comparison Factor

Traffic Fatalities/Injuries Comparison Factor

Route Comparison Worksheet

ROUTE IDENTIFICATION CHART

ROUTE IDENTIFICATION: ______________________

TOTAL DISTANCE: ____________________________

Accident Unit: __________________________________

Segment	Segment End-Points	Segment Length	Average Speed	Distance Between Opposing Lanes	Pop. Count 0-5 Mile	Pop. Count 5-10 Mile	Daily Traffic Count	Daily Truck Count	Annual No. of Deaths	Accident Rate per Mil Tk-Mi	Accident Rate per Thou Shipments
1											
2											
3											
4											

ROUTE ___ SHEET ___ of ___

WORKSHEET FOR NORMAL RADIATION EXPOSURE COMPARISON FACTOR

$$D = (PL/v)*C_1 + (LT/v^2)*C_2 + (LT^2/v^3)*C_3 + L/v$$

Segment _1_ (0 - 5 Mile Band)

P = $C_1 = 6.8 \times 10^{-5}$

L = Avg. Dist. Opposing Lanes =

v = C_2 (Table 3.2-1) =

T = Avg. Veh. Separation Dist. =

C_3 (Table 3.2-1) =

D = ____

Segment _2_ (0 - 5 Mile Band)

P = $C_1 = 6.8 \times 10^{-5}$

L = Avg. Dist. Opposing Lanes =

v = C_2 (Table 3.2-1) =

T = Avg. Veh. Separation Dist. =

C_3 (Table 3.2-1) =

D = ____

Segment _3_ (0 - 5 Mile Band)

P = $C_1 = 6.8 \times 10^{-5}$

L = Avg. Dist. Opposing Lanes =

v = C_2 (Table 3.2-1) =

T = Avg. Veh. Separation Dist. =

C_3 (Table 3.2-1) =

D = ____

ROUTE TOTAL = ____________

ROUTE ___ SHEET ___ of ___

WORKSHEET FOR PUBLIC HEALTH RISK COMPARISON FACTOR

Segment Release Consequences

	(0 - 5 Mile Band)			(5 - 10 Mile Band)		
Segment	Pop. Count	Multiplier	Total	Pop. Count	Multiplier	Total
1	___	x .75 =	___	___	x .25 =	___
2	___	x .75 =	___	___	x .25 =	___
3	___	x .75 =	___	___	x .25 =	___
4	___	x .75 =	___	___	x .25 =	___

Health Risk Calculations

Segment	0-5 Mile Total		5-10 Mile Total		Segment Length		Pub. Hlth. Conseq. Factor		Acc. Prob. (Ac. Rate)		Seg. Health Risk
1	(___	+	___)	÷	___	=	___	x	___	=	___
2	(___	+	___)	÷	___	=	___	x	___	=	___
3	(___	+	___)	÷	___	=	___	x	___	=	___
4	(___	+	___)	÷	___	=	___	x	___	=	___

ROUTE TOTAL = ___

ROUTE ___ SHEET ___ of ___

WORKSHEET FOR ECONOMIC RISK COMPARISON FACTOR

Segment

	(0-5 Mile Band)				(5-10 Mile Band)			
Land Use Type	Area	Weight[1]		Weighted Total	Area	Weight[1]		Weighted Total
Farmland	____	x 0.002	=	_____	____	x 0.0002	=	_____
Single Family Residential	____	x 0.10	=	_____	____	x 0.04	=	_____
Multi-Family Residential	____	x 2.0	=	_____	____	x 0.20	=	_____
Commercial	____	x 0.20	=	_____	____	x 0.01	=	_____
Parks	____	x 0.03	=	_____	____	x 0.02	=	_____
Public Areas	____	x 0.50	=	_____	____	x 0.05	=	_____
	WEIGHTED TOTAL		=	_____	WEIGHTED TOTAL		=	_____

Segment

	(0-5 Mile Band)				(5-10 Mile Band)			
Land Use Type	Area	Weight[1]		Total	Area	Weight[1]		Weighted Total
Farmland	____	x 0.002	=	_____	____	x 0.0002	=	_____
Single Family Residential	____	x 0.10	=	_____	____	x 0.04	=	_____
Multi-Family Residential	____	x 2.0	=	_____	____	x 0.20	=	_____
Commercial	____	x 0.20	=	_____	____	x 0.01	=	_____
Parks	____	x 0.03	=	_____	____	x 0.02	=	_____
Public Areas	____	x 0.50	=	_____	____	x 0.05	=	_____
	WEIGHTED TOTAL		=		WEIGHTED TOTAL		=	

Economic Risk calculations

Segment		0-5 Mile Wt. Tot.		5-10 Mile Wt. Tot.			Segment Length		Econ. Conseq. Factor		Econ. Prob. (Ac. Rate)		Seg. Econ. Risk
_____	(	_____	+	_____	)	÷		=	_____	x	_____	=	___
_____	(	_____	+	_____	)	÷		=	_____	x	_____	=	___
_____	(	_____	+	_____	)	÷		=	_____	x	_____	=	___
_____	(	_____	+	_____	)	÷		=	_____	x	_____	=	___

ROUTE TOTAL = __

1 Based on Economic Consequence Measure Weight Table (Table 3.2-3)

Route Specific Emergency Response Parameter Scaling System

Land Use Type	Response Time	Equipment Availability	Personnel Hazardous Material Training	Manpower Availability	Land Use Emergency Response Weight Factor
Rural					
Suburban					
Urban					
Commercial/ Industrial					

Route Specific Evacuation Parameter Scaling System

Land Use Type	Population Density	Egress Availability	Manpower and Equipment Availability	Evacuation Time	Evacuation Impacts	Land Use Evacuation Weight Factor
Rural						
Suburban						
Urban						
Commercial/ Industrial						

ROUTE ___ SHEET ___ of ___

WORKSHEET FOR EMERGENCY RESPONSE and EVACUATION COMPARISON FACTORS (Area in 0 - 5 Mile Band)

EMERGENCY RESPONSE CALCULATIONS

Land Use Type	Seg 1		Seg 2		Seg 3		Seg 4		Total	Route Fraction		Weight[1]		Weighted Total
Rural	___	+	___	+	___	+	___	=	___	___	x	___	=	___
Suburban[2]	___	+	___	+	___	+	___	=	___	___	x	___	=	___
Urban[2]	___	+	___	+	___	+	___	=	___	___	x	___	=	___
Commercial/ Industrial	___	+	___	+	___	+	___	=	___	___	x	___	=	___

(Total) Comparison Factor = ___

EVACUATION CALCULATIONS

Land Use Type	Seg 1		Seg 2		Seg 3		Seg 4		Total	Route Fraction		Weight[3]		Weighted Total
Rural	___	+	___	+	___	+	___	=	___	___	x	___	=	___
Suburban	___	+	___	+	___	+	___	=	___	___	x	___	=	___
Urban	___	+	___	+	___	+	___	=	___	___	x	___	=	___
Commercial/ Industrial	___	+	___	+	___	+	___	=	___	___	x	___	=	___

(Total) Comparison Factor = ___

---

1 Based on Sample Emergency Response Parameter Scaling System (Table 3.2-4)

2 Includes Parks and Public Areas

3 Based on Sample Evacuation Parameter Scaling System (Table 3.2-5)

Route Specific Special Facility Scaling System

	Dose Response	Accident Evaluation	Economics	Facility Factor
Children's Hospital				
Hospital				
Prison				
Nursing Home				
School				
Churches				
Stadium				
Shopping Center				
Theaters				
Factory				

ROUTE A

WORKSHEET FOR SPECIAL FACILITIES COMPARISON FACTOR

Special Facility	Number of Facilities		Weight Factor		Total
Children's Hospital	______	X	______	=	______
Hospital	______	X	______	=	______
Prison	______	X	______	=	______
Nursing Home	______	X	______	=	______
School	______	X	______	=	______
Church	______	X	______	=	______
Stadium	______	X	______	=	______
Shopping Center	______	X	______	=	______
Theater	______	X	______	=	______
Factory	______	X	______	=	______
			ROUTE TOTAL	=	______

ROUTE ___ SHEET ___ of ___

WORKSHEET FOR TRAFFIC FATALITIES/INJURIES COMPARISON FACTOR

Accident Unit of Measure: ______________________

Segment	Segment Accident Rate		Segment Length (L)		Segment Total
1	______	X	______	=	______
2	______	X	______	=	______
3	______	X	______	=	______
4	______	X	______	=	______
			ROUTE TOTAL	=	______

SHEET ___ of ___

ROUTE COMPARISON WORKSHEETS
(page 1 of 2)

FACTOR VALUES

PRIMARY FACTORS	Route A	Route B	Route C	Route D	TOTALS
Normal Radiation Exposure	___	___	___	___	___
Public Health Risks	___	___	___	___	___
Economic Risks	___	___	___	___	___
SECONDARY FACTORS					
Emergency Response	___	___	___	___	___
Evacuation	___	___	___	___	___
Special Facilities	___	___	___	___	___
Traffic Fatal./Inj.	___	___	___	___	___

SHEET ___ of ___

ROUTE COMPARISON WORKSHEETS
(page 2 of 2)

NORMALIZED FACTOR VALUES

PRIMARY FACTORS	Route A	Route B	Route C	Route D
Normal Radiation Exposure	______	______	______	______
Public Health Risks	______	______	______	______
Economic Risks	______	______	______	______
Route Totals	______	______	______	______
(FIGURE OF MERIT)				

SECONDARY FACTORS				
Emergency Response	______	______	______	______
Evacuation	______	______	______	______
Special Facilities	______	______	______	______
Traffic Fatal./Inj.	______	______	______	______

APPENDIX F

BIBLIOGRAPHY AND REFERENCES

A listing of reference materials that may be useful to state officials in applying the guidelines and in presenting the results of the route selection process to the public is presented below. Most reports contained in this list are available through the National Technical Information Services (NTIS), 5285 Port Royal Road, Springfield, VA 22151.

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