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of Transportation
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Administration

Special Routing of Spent Fuel Shipments

Office of Research
and Development
Washington, DC 20590

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DOT/FRA/ORD-82/27

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16. Abstract

Special rail routing of spent fuel shipments from commercial nuclear power plants to Away-From-Reactor (AFR) storage and disposal sites has been proposed as one means of reducing the consequences and severity of radioactive materials accidents in areas of high population density. Whether or not special rail routing of spent fuel shipments does indeed decrease radiation exposure levels under normal and accident transportation conditions and at what incremental cost forms the basis of this study funded by the Federal Railroad Administration.

The study is divided into five areas: (1) developing analytical models for assessing the risks associated with both the normal and accident transport modes; (2) selecting representative origin to destination routing pairs using the normal transportation and accident risk models; (3) analyzing rail shipment costs for nuclear spent fuel; and (4) performing sensitivity analyses to identify parameters that critically affect the total exposure level.

The major findings resulting from this study are: (1) the risk over the seven example routes is relatively small for the normal transport mode; (2) the risk associated with an accident is at least an order of magnitude larger than the normal transport dose in all cases and as such is the overriding contribution to the total expected transport dose; and (3) no beneficial cost versus dose reduction relationship was found for any of the routes studied.

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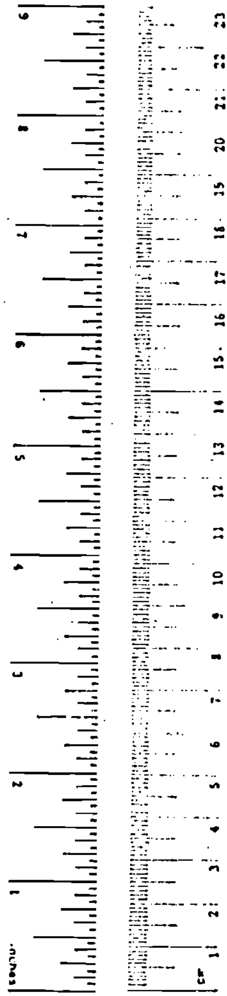
METRIC CONVERSION FACTORS

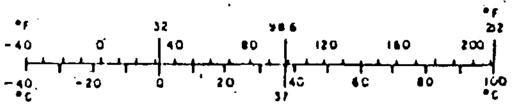
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

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1. EXECUTIVE SUMMARY

This program on risk and cost assessment of alternate routing of spent fuel was conducted under contract to the FRA, Office of Rail Safety Research (Contract No. DOT-FR-4463). The objective of this study was to develop a basic but effective methodology for estimating the incremental risks and costs associated with alternative rail routing of spent fuel shipments from commercial nuclear power plants to Away-From-Reactor (A-F-R) storage sites. For the purposes of this study, risk was defined as radiological dose. The project was functionally divided into three tasks.

In Task 1, analytical models and methodologies for assessing risks and costs associated with normal and accident transport modes for shipment of spent fuel were developed. The risk models identify the contribution to total dose from exposures of rail employees and the surrounding population. The total normal transportation exposure for a specific rail route depends on :

(1) radiation dose to the population along the rail route based on population density and train velocity;

(2) dose to the population due to shipment stops for switching and train makeup;

(3) dose to switchyard personnel; and

(4) dose to the train crew.

The accident transportation model is based upon the probability of an accident along a route and its consequences to estimate the total expected radiation dose to the population surrounding the accident site. The route cost shipping model utilizes daily cask rental costs and actual freight costs levied by rail carriers along specific routes.

Task 2 consisted of developing route selection criteria and then selecting seven origin to destination routing pairs, each having a primary and secondary route. Route selection was based on consideration of population density along a route, route length along each route segment (line identification code), specific railroad accident/incident histories and the number of rail interchanges required to go from a reactor facility to one of the three AFR storage sites. The following routing combinations were initially chosen for demonstrating the risk models because of the potentially significant risk differences between the alternate routes:

Route 1	Decatur, AL to Barnwell, SC
Route 2	Gaffney, SC to Barnwell, SC
Route 3	Mineral, VA to Barnwell, SC
Route 4	Seabrook, NH to West Valley, NY
Route 5	St. Clair Country, MI to Morris, IL

Route 6	Oak Harbor, OH to Morris, IL
Route 7	Hartsville, TN to Barnwell, SC

In Task 3, the normal and accident transportation risk models were implemented for evaluating the differences in population exposure and total costs for each route identified in Task 2. The risk levels associated with normal and accident transport modes for shipment of spent fuel are over these routes have the following ranges:

Normal Mode	15 to 46 milli man-rems
Accident Mode	540 to 19,470 milli man-rems

The total rail transport costs were found to range from $0.20 to $1.12 per ton mile.

A sensitivity analysis was performed on both risk models to assess impact of various parameters on total exposure levels. The most critical parameters in the normal transportation mode were (1) population in each of the urban, suburban and rural density zones and (2) distance traveled through each population class. The accident model was found to be extremely sensitive to variation in release fraction of the radioactive material as an indication of accident severity.

The major findings resulting from this study are:

(1) the risk associated with rail transportation of spent fuel over the seven example routes is relatively small for the normal transport mode, while the risk associated with an accident during the rail transportation of spent fuel is at least an order of magnitude larger than the normal transport dose in all cases studied and as such is the overriding contribution to the total expected transport dose; and

(2) Except for one case (6A and 6B) no beneficial cost versus dose reduction relationship was found for any of the routes studied. In all cases (except Routes 6A and 6B) the longer route was higher cost and also presented higher total expected population dose.

2. INTRODUCTION

Special rail routing of spent fuel shipments from commercial nuclear power plants to A-F-R storage and disposal sites has been proposed as one means of reducing the consequences and severity of radioactive material accidents in areas of high population density. The question of whether or not circuitous rail routing of spent fuel shipments does indeed decrease radiation exposure levels under normal and accident transportation conditions, and at what cost, is the crux of this FRA-funded study.

The study efforts were directed into five areas: (1) developing analytical models for assessing the incremental risks associated with both the normal and accident transport modes for nuclear spent fuel shipment by rail; (2) selecting origin to destination routing alternatives using demographic route selection criteria; (3) performing risk analyses of the selected routing alternatives using the normal transportation and accident risk models; (4) analyzing rail shipment costs for spent fuel; and (5) performing a sensitivity analysis on the analytical models to identify single parameters or combinations of parameters critical to the total risk exposure.

This report is structured as follows: Section 1. Executive Summary; Section 2. Introduction; Section 3. Risk/Cost Methodologies; Section 4. Reactor Site to A-F-R Site Route Selection; Section 5. Risk/Cost Analysis; Section 6. Conclusions and Recommendations; Section 7. Bibliography; and Appendices. Sections 1 and 2 give an overview of the report, highlighting methodologies and approaches, conclusions and recommendations. Section 3 presents the methodologies, assumptions and input data used in assessing the risks and costs involved in transporting spent fuel by rail from commercial reactors to A-F-R storage sites. Section 4 discusses the criteria and selection process for the seven routing combinations chosen for risk analysis and presents data on each primary and alternate route. Section 5 includes details of risk and cost analyses using the methodologies presented in Section 3 on each of the route pairs selected in Section 4. Section 6 provides observations and recommendations concerning rail routing of spent fuel shipments. Section 7 is a bibliography, listing the data sources used in the program. Two appendices follow: Appendix A contains data derived from studies conducted by Sandia Laboratory on the probability of railcar accidents and their severities; and Appendix B is comprised of a sample computer run used to perform one of several sensitivity analyses.

3. RISK/COST METHODOLOGIES

3.1 GENERAL

Mathematical models describing normal and accident transportation modes were developed in this study to determine the expected radiation dose levels from the rail transport of spent fuel. These models were designed specifically to identify the exposure risk of spent fuel rail shipments to rail employees and the surrounding population. For quantitative purposes, total risk for both normal and accident transportation modes has been expressed in the recognized form of population radiation exposure called the man-rem. Population dose in man-rems is the product of the average level of radiation received per individual multiplied by the number of people exposed. For this analysis, man-rem calculations were estimated per a standard rail shipment of a single spent fuel cask.

The first model that was developed estimates the total man-rem exposure to specific population groups along predetermined shipping routes as well as a route total exposure level for a shipment of spent fuel which is subject to normal rail transportation conditions (i.e., no accident, cask rupture or release). Total man-rem exposure for a specific rail route using this model depends on such input parameters as: (1) radiation doses to the public and railyard employees during shipment stops; (2) doses to the train crew and population segments exposed in transit; (3) route length; (4) population density along the route; (5) number of grade crossings; (6) stop time for switching and railyard operation for train makeup; (7) train velocity; (8) number of rail employees on the train and in the switchyard operations; and (9) placement of the spent fuel cask in the train.

The second risk model estimates the total man-rem exposure given a rail accident with possible ensuing cask rupture and release. This model uses a ground level puff release approximation for isotope dispersion into relatively unobstructed topographic features. In addition to the base parameters necessary to the normal transportation model, the accident model also utilizes: (1) isotopic dispersion as a function of weather stability; (2) isotope release levels as a function of accident severity; (3) presence or absence of fire involvement; and (4) route specific accident probability as a function of railroad accident/incident histories, track class, traffic density and switching accidents.

3.1.1 Population Density

A review of recent literature on risk analysis of the transport of radioactive materials indicated that a three segment population density structure (urban, suburban, and rural) was used in developing methodology. A similiar 3-segment approach was used in this study. A rural area is assumed to have a population density of less than 15 inhabitants per square mile; a suburban area, less than 1798 inhabitants per square mile; and an urban area greater than 1799 inhabitants per square mile. The Oak Ridge National Laboratory population grid cell data was used with the FRA 503 rail network superimposed on it. Pertinent information regarding the FRA 503 rail network as outlined in Final Standards, Classification and Designation of Class I Railroads in the U.S., was extracted using the graphic interactive computer system at Princeton University. The average population density per route segment was calculated and then grouped as rural, urban or suburban and then summed to give total route specific population density in each zone.

To illustrate the methodology used for calculating population density along each route, the following example examines the approach applied to each link on route 1A. It should be noted that a similar approach could be used for any link in the FRA rail network.

The population density along any link can be calculated by using the graphic interactive computer system at Princeton University. To identify the population density along each link, the endpoints (nodes) of each link and the railroad traversing the link must first be identified. The first link along route 1A for which population density was calculated is from Decatur, AL to Birmingham. AL. These two nodes are input into the computer system for calculating population density and can be designated either by entering the location's proper name (e.g., Decatur AL) or by designating it's assigned node identification number. After the nodes have been identified to the computer system, they are displayed on a video terminal. Associated with each of these nodes are the geographical coordinates (i.e., latitude and longitude) for each. These data are then stored in memory for future reference when calculating population density along a link.

The second step in calculating population density along a link is to identify the link by railroad. This is performed by inputting the identification number of the railroad which travels between the assigned nodes. After entering the railroad designation number into the system, the designated link along with it's two nodes are displayed on the video screen. This approach was useful for validating the authenticity of the routes in this study, because if a railroad did not travel between the identied nodes specified, no link would be displayed on the video screen.

The third step for identifying population density along the link is to retrieve the coordinates of the nodes for which the computer will overlay the coordinates of the endpoints on the geographically based population density grid cell system compiled by Oak Ridge National Laboratory. Further discussion of this population density data is given in Section 4.2.3. Both the FRA 503 Rail Network and the Oak Ridge population density grid cell system are integral components of the Princeton University computerized transportation information retrieval system. The link was then subdivided by the computer into half square mile (latitude and longitude) grid cells based on the Oak Ridge data with each cell having an assigned population density. The composite population density between the two nodes was then computer generated by summing the multiplied cell length by the cell's population density and dividing this value by the entire link length. These values were then added to values for the other links along route 1A resulting in a composite route population density.

3.1.2 Fire Incident Data

The number of railroad accidents with severe fire was needed to calculate the corrected release fraction for isotope fission gap products, since fire involvement causes greater dispersion of these products. FRA Accident/Incident Bulletins do not supply this data; the needed information was compiled from an in-house FRA report on railroad accidents of the FRA Office of Safety, Reports and Analysis Division. This document reported that on average 2.4% of all railroad accidents and incidents in 1978 and 1979 involved severe fire. This average value was used in calculating release fractions for some radioactive materials found in the spent fuel being transported.

3.1.3 Route Length

The lengths of the various rail route segments traveled were used as input in both the normal and accident transportation risk models. The procedure used to select each route and measure its length is presented in Section 4.3. The selected routes are described in detail in Section 4.4.

3.1.4 Train Velocity

The average velocity of a train traversing each rail route segment along each route was used as input data to the normal transportation risk model. Train velocity in conjunction with route length is needed to calculate the man-rem dose to the affected population and the train crew. Since 81% of the routing pairs in this study are comprised of class 4 track, an average velocity of 60 mph which is the maximum permitted freight train speed as indicated for class 4 track was assumed for all population density zones. (See Section 5.4.2.)

3.1.5 Grade Crossings

The number of grade crossings per route and the linear length of an average grade crossing were input to the normal transportation risk model. These data were important input to the model because at grade crossings, the general public is in closer proximity to the track than found in other situations associated with normal transportation. These data were compiled from the FRA/AAR Grade Crossing Inventory.

3.1.6 Stoptime

The number of hours a shipment is stopped in switchyards and other workyards as well as the population in these yards was a necessary input to the normal transportation risk model. Population density in a switchyard was found to vary from 100 to 300 employees per square mile. Stoptime and the average number of employees in the switchyard are major elements in calculating the total exposure risk to rail employees. This information was collected from testimony in public dockets of the ICC coupled with information from major rail carriers.

3.1.7 Number of Crew On Train

The average number of crew aboard the train together with their average linear distance from the spent fuel cask are significant factors in calculating the man-rem dose received by the railroad employees in normal transport operations. The average crew size for a shipment of spent fuel was identified as five (5) persons.

3.2 NORMAL TRANSPORTATION RISK MODEL

This model determines the risks associated with the normal transportation of spent fuel and consists of estimating the total dose to the population along the transportation route. Specifically, the total dose is a function of the following doses:

- o dose to population along rail route based on population density (D_{train})
- o dose to population due to shipment stops (D_{stop})
- o dose to maintenance personnel in switchyard (D_{switch})
- o dose to crew on train (D_{crew})

Mathematically, the total dose (D_{total}) during normal transportation can be expressed as follows:

$$D_{total} = D_{train} + D_{stop} + D_{switch} + D_{crew} \qquad (3\text{-}1)$$

3.2.1 Dose to Population Along Rail Route (D_{Train})

To derive the expression for dose, it is assumed the basic exposure relationship is given by the point source approximation

$$D(d) = \frac{Ke^{-\mu d} B(d)}{d^2} \qquad (3\text{-}2)$$

where: D(d) is the dose rate at distance, d (mrem/hr.)

μ is the absorption coefficient for air (.00118 ft.$^{-1}$)

B(d) is the dimensionless build-up factor in air (.0006 d +1)

K is the dose rate factor for the shipping cask which is specified to be less than 1000 mrem - ft.^{2}/hr.

The dose to the population in the vicinity of the train shipment can be approximated by dividing the population into three zones—rural, suburban and urban — a methodology used by the Nuclear Regulatory Commission in much of their research. The dose to the population along the rail route is given by

$$D_{train} = 4KL \left[\sum_{\ell} \left(\frac{f_{r\ell} \; PD_{r\ell}}{V_{r\ell}} \times I_r \right) + \sum_{\ell} \left(\frac{f_{s\ell} \; PD_{s\ell}}{V_{s\ell}} \times I_s \right) + \sum_{\ell} \left(\frac{f_{u\ell} \; PD_{u\ell}}{V_{u\ell}} \times I_u \right) \right]$$

where:

L	is the total trip length
$f_r\ell, f_s \ell f_u\ell$	represent fractions of rail segment distances the train travels in rural, suburban and urban population zones
$V_r\ell, V_s\ell, V_u\ell$	is the average train speed for each segment along the route
$PD_r \ell PD_s\ell, PD_u\ell$	are population densities for each rail segment
I_r, I_s, I_u	are integrals of the form $I = \int_{\min x}^{d} I(x)\, dx$ which serve to integrate the dose rate over the geometrical area in which the population is confined. I(x) has the exponential form shown in Equation 3-2. $I(x) = \int_{X}^{\infty} \frac{K e^{-d} B(d)}{d(d^2 - x^2)^{1/2}}$ Normally, the closest distance (min x) the population will be in relation to the railroad track is 100 ft., except at grade crossings. Due to the inverse square decrease in radiation level with distance, the farthest distance considered is d = 2600 ft.

Since at a grade crossing, the population can more closely approach the track, Equation 3-3 must be corrected to take this into account. In this case, the integral terms are modified as follows:

$$I \xrightarrow{\text{approaches}} I(f_o + k^1 f_1) \qquad (3\text{-}4)$$

where:

f_o is the fractional length of population zone not involving crossings
f_1 is the fractional length of population zone involving crossings
k^1 is the constant that accounts for the closer approach at crossings.

The constant k^1 is given by $k^1 = \dfrac{\int_{\min_{r,s,u}}^{d} I(x)\ dx}{\int_{\min_x}^{d} I(x)\ dx}$

where min x is the closest approach at crossings (30 ft.). The upper integration limit is taken as 2,600 ft. and the lower limits $\min_x$, $\min_s$, $\min_u$ = 100 ft. This leads to k^1 = 1.636. It is assumed that each crossing is 200 ft. in length.

Using the geometry of the population corridor and the basic dose rate expression given in Equation 3-2, I is found to be 2.42. Incorporating equations 3-2 and 3-4 into 3-3 leads to

$$D_{train} = 4KL\ (2.42) \left[\sum_{\ell} \left(\frac{f_{r\ell} PD_{r\ell}}{V_{r\ell}}\right) (f_{or} + 1.636\ f_{ir}) + \sum_{\ell} \left(\frac{f_{s\ell}\ PD_{s\ell}}{V_{s\ell}}\right) \right.$$
$$\left. (f_{os} + 1.636\ f_{is}) + \sum_{\ell} \left(\frac{f_{u\ell} PD_{u\ell}}{V_{u\ell}}\right) (f_{ou} + 1.636\ f_{iu}) \right] \quad (3\text{-}5)$$

This equation can be further refined by standardizing the population density (PD) along each rail segment in units of persons per square mile and velocity in miles per hour to yield the man-rem dose as follows:

$$D_{train} = 3.47 \times 10^{-10} \times KL \left[\sum_{\ell} \left(\frac{f_{r\ell} PD_{r\ell}}{V_{r\ell}}\right) (f_{or} + 1.636\ f_{ir}) + \sum_{\ell} \left(\frac{f_{s\ell}\ PD_{s\ell}}{V_{s\ell}}\right) \right.$$
$$\left. (f_{or} + 1.636\ f_{ir}) + \sum_{\ell} \left(\frac{f_{u\ell} PD_{u\ell}}{V_{u\ell}}\right) (f_{or} + 1.636\ f_{ir}) \right] \quad (3\text{-}6)$$

3.2.2 Dose to Population Due to Shipment Stops (D_{stop})

The dose received by persons when the spent fuel shipment is temporarily stopped in a given area along the route is given by

$$D_{stop} = K\ \Delta T\ \ PD \int_{\min r}^{d} 2\pi x \left(\frac{e^{-\mu x} B(x)}{x^2}\right) dx \quad (3\text{-}7)$$

where: ΔT is the stop time in hours

Assuming the closest approach distance (min r) for persons to the spent fuel cask is 10 ft., and the maximum sphere of influence is d = 2600 ft., leads to

$$D_{stop} = Q_1 \, K \, \Delta T \, PD \tag{3-8}$$

where:

$Q_1 = 2.54 \times 10^{-9}$ (rem-km^2/mrem - ft^2) is an appropriate integration constant based on the proximity of the persons to the spent fuel cask.

The time stopped along each route segment is categorized into population density groups in Equation 3-9, to give the total dose received by personnel due to shipment stops.

$$D_{stop} = Q_1 K \sum_{\ell} \left[\Delta T_{r\ell} \, PD_r + \Delta T_{s\ell} \, PD_{s\ell} + \Delta T_{u\ell} \, PD_{u\ell} \right] \tag{3-9}$$

3.2.3 Dose to Maintenance Personnel in Yard (D_{switch})

The dose absorbed by railroad maintenance personnel while the spent fuel shipment is being switched is given by

$$D_{switch} = Q_2 K \, \Delta T_{sy} \, PD_{sy} \tag{3-10}$$

where: $Q_2 = 2.77 \times 10^{-9}$ (rem-km^2/mrem - ft^2)is an integration constant based on the distance that personnel in the switching yard come in proximity to the spent fuel shipment; the closest approach is assumed to be 5 ft. with all personnel within a maximum distance of 1000 ft. from the spent fuel shipment,

T_{sy} represents time elapsed in switching,

PD_{sy} represents population density in switching yard.

3.2.4 Dose to Crew on Train (D_{crew})

The dose absorbed by the train crew in transit can be expressed by

$$D_{crew} = Q_3 K N_c \, S \, \Delta T_{ship} \tag{3-11}$$

where: $Q_3 = 10^{-3}$, a conversion factor from rem to mrem

N_c represents number of crew on train

d represents average distance of train crew to spent fuel shipment

ΔT_{ship} = duration of shipment which is given by

$$\sum_{\ell} \frac{L_{r\ell}}{V_{r\ell}} + \frac{L_{s\ell}}{V_{s\ell}} + \frac{L_{u\ell}}{V_{u\ell}}$$

$\bar{S} = \frac{e^{-\mu d}}{d^2} B(d)$, is the integration constant based on the distance of the crew from the spent fuel.

3.2.5 Mathematical Formula for Computing the Total Normal Transportation Dose

Combining equations 3-6, 3-9, 3-10, and 3-11 gives the total man-rem dose attributable to the normal rail transportation of spent fuel and this is given in Equation 3-12 (next page). The values for trip length, L, are expressed in miles and the train velocity, V, in miles per hour to generate the total dose in man-rems.

3.3 ACCIDENT RISK MODEL

The model for estimating the level of risk resulting from an accident involving a spent fuel rail cask involves calculating the total expected radiation dose to the population surrounding the accident site. The probability of an accident of severity, P_i along a route, together with its consequences, C_i can be used to derive the expression for risk, R_i. Mathematically, this can be stated as:

$$R_i = P_i C_i \tag{3-13}$$

As before, the consequences of an accident are expressed as exposure dose in man-rems. Consequently, the total risk of an accident is the product of the probability of each accident class (i) occuring and each related radiological dose, D_i. Mathematically, this relationship is expressed as

$$RT = DT = \sum_i P_i D_i \tag{3-14}$$

where RT represents total risk, and

DT represents total dosage.

$$D_{Total} = \overbrace{3.47 \times 10^{-7} \sum_{\ell} \left[\frac{L_{r\ell} PD_{r\ell}}{V_{r\ell}} (f_{or} + 1.636\ f_{ir}) + \frac{L_{s\ell} PD_{s\ell}}{V_{s\ell}} (f_{os} + 1.636\ f_{is}) + \frac{L_{u\ell} PD_{u\ell}}{V_{u\ell}} (f_{ou} + 1.636\ f_{iu}) \right]}^{D_{train}}$$

$$+ \underbrace{2.54 \times 10^{-6} \sum_{\ell} \left[\Delta T_{r\ell} PD_{r\ell} + \Delta T_{s\ell} PD_{s\ell} + \Delta T_{u\ell} PD_{u\ell} \right]}_{D_{stop}} + \underbrace{2.72 \times 10^{-6} \left[\Delta T_{sy} PD_{sy} \right]}_{D_{switch}} + \underbrace{D_c \bar{S} \sum_{\ell} \left[\frac{L_{r\ell}}{V_{r\ell}} + \frac{L_{s\ell}}{V_{s\ell}} + \frac{L_{u\ell}}{V_{u\ell}} \right]}_{D_{crew}} \text{man-rem}$$

Equation 3-12

EXPRESSION FOR TOTAL DOSE DUE TO NORMAL TRANSPORTATION OF SPENT FUEL SHIPMENT

The elements of the accident risk model include:

I determination of dose to the population surrounding an accident site; and

II the probability of occurrence of a particular accident.

I. Determination of Total Dose to the Population at the Accident Site

The total dose is calculated by:

(1) determining the quantity of each isotope in the fuel rod gaps of in the spent fuel cask;

(2) determining individual isotope doses based on dispersion of gases and particulates released for various weather stability classes; and

(3) summing individual isotope doses along isopleth (constant dose) areas to give total dose.

The expression for total dose is further refined:

(1) to account for multiple dose mechanisms, external and internal, for each individual isotope;

(2) to account for less than 100% release of radioactive material from a ruptured fuel cask; and

(3) to simplify the calculations by collapsing weather stability classes.

II. The Probability of Occurrence of an Accident

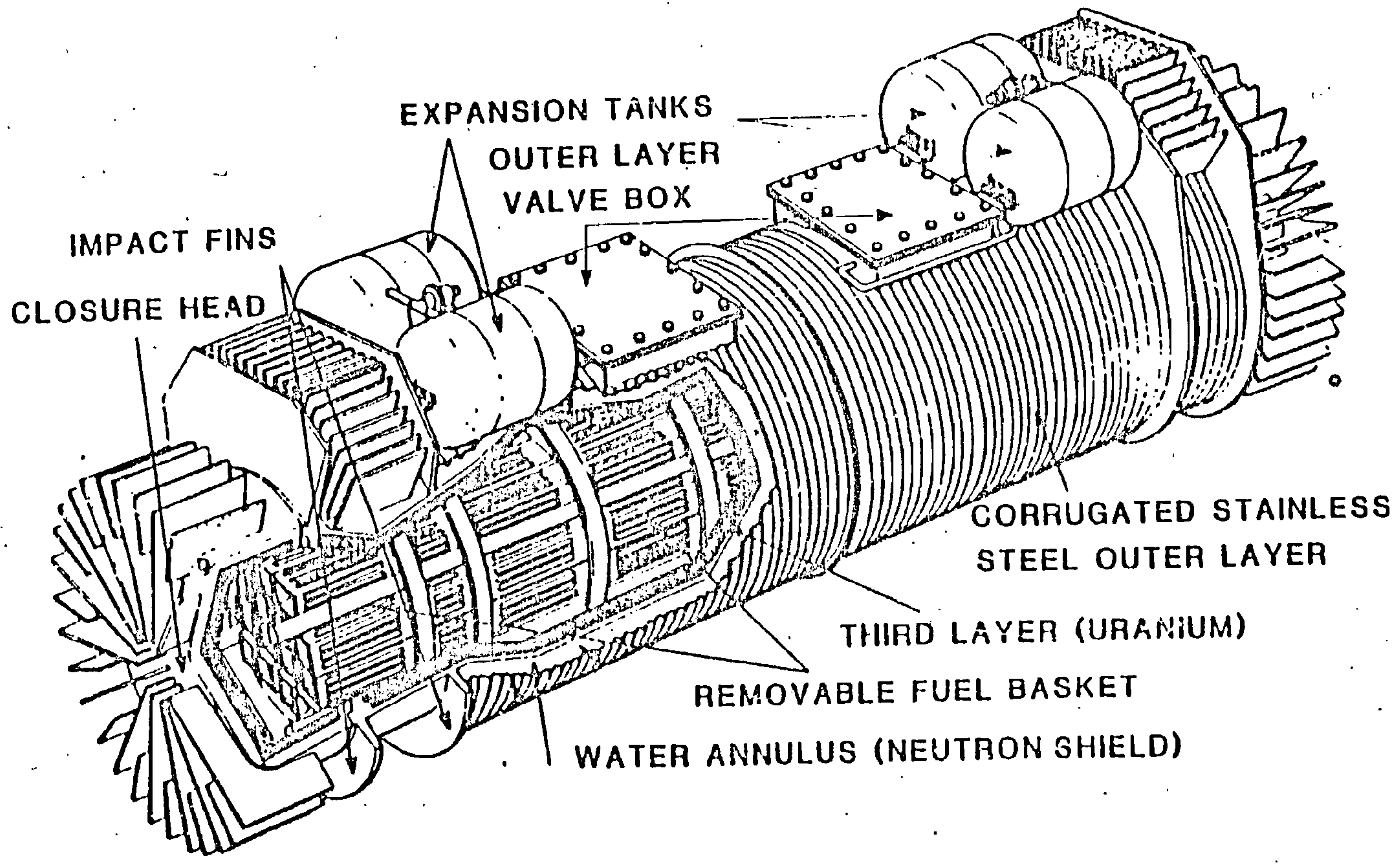
The probability of a release in an accident is the sum of products of the probabilities of occurrence per mile travelled in each population density zone times the number of miles traveled in each population zone. Therefore, total dose is the product of the dose in each population zone, the population density exposed, a release fraction factor, and the probability of an accident with that release fraction all summed for each isotope. The route specific accident probability per car-mile is dependent on railroad accident/incident history, class of track, traffic density and switching accidents.

3.3.1 Dose to Population at Accident Scene

To calculate the radiation dose to the population at an accident scene, the following information is used:

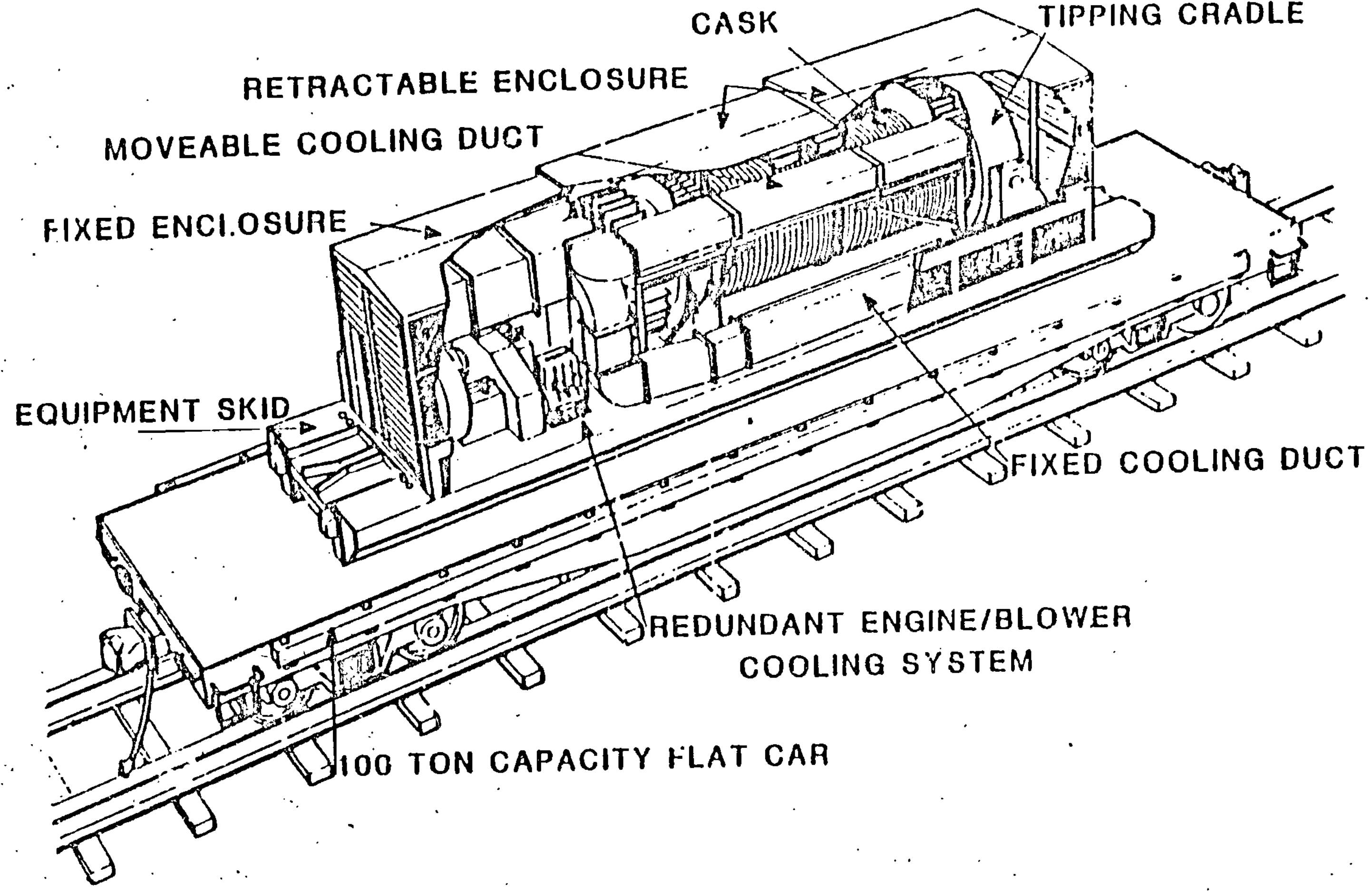
(1) The spent fuel rail cask (See Figures 1 and 2) is assumed to hold 3.2 metric tons of spent fuel, (approximately seven p.w.r. fuel assemblies), and to have a total loaded weight of 63.5 metric tons (70 tons).

(2) The estimated total fuel activity and gap activity for various isotopes in the spent fuel is based on results obtained in an Atomic Energy Commission (AEC) study entitled Environmental Survey of Transportation of Radioactive Materials To and From Nuclear Power Plans (WASH 1238).



Drawing courtesy of General Electric

FIGURE 1. GE IF 300 IRRADIATED FUEL SHIPPING CASK



Drawing courtesy of General Electric

FIGURE 2. GE IF 300 CASK AND CARRIER

(3) In a rail accident involving severe impact or fire where the transport cask may be breeched and the reactor fuel rods ruptured, it is assumed that all gases and volatiles in the gap will be released to the environment as well as a proportion of the solid fission products.

(4) For radioactive gas releases, the material is expected to be dispersed into the atmosphere following the Gaussian dispersion model.

3.3.1.1 Calculation of Fission Gap Activity

It should be noted that the AEC gap activities are based upon a six month decay of fuel at the nuclear power plant prior to transportation. This is conservative, since the fuel will probably have a longer cooling period. Radiation dose is due primarily to the following isotopes:

Kr^{85},
I^{131}, and
Fission Products

Since these isotopes are the major contributors to the dose level following a release, the accident risk model was formulated using these elements alone.

In a rail accident with cask rupture and release, 100% of the (Kr^{85}) and (I^{131}) will be dispersed. AEC report WASH-1238 indicates that approximately 1% of the gap fission products will be released into the atmosphere in a severe accident provided there is no fire involvement. An on-scene fire, however, will cause dispersion of approximately 10% of the gap fission products.

Since the entire gap activity for (Kr^{85}) and (I^{131}) is released in a rail accident, release fraction data from the AEC report was used. Because the dispersion rate for fission products is dependent upon fire involvement, this specific gap activity release fraction had to be calculated, as discussed below.

Fission products are largely particulates, and consequently, a large proportion of fission products remain in the cask or liquid coolant, rather than being dispersed in the aerosol cloud as the gases and volatiles are. To compute the gap activity release fraction for fission products, it was necessary to identify the number of train accidents/incidents with fire involvement. An in-house report by the FRA Office of Safety, Reports and Analysis Division indicated that on the average, 2.4% of all train accidents in 1978 and 1979 involved fires. Based on this accident data, fission product releases (FPR) can be calculated as:

$FPR = P_F D_F + (1 - P_F) D_{NF}$ x Fission Product Gap Activity

where:
P_F = percentage of rail accidents with fire
D_F = activity released during incident with fire
D_{NF} = activity released during incident with no fire

This leads to a fission product release of

$$FPR = 0.024 \times .10 + 0.976 \times .010 \times 1.4 \times 10^3$$
$$= 1.7 \times 10^1 \text{ curies}$$

Values for gap activities based on the AEC WASH 1238 study and the above calculations are shown in Table 1.

3.3.1.2 Calculation Dose Due to Dispersion of Isotopes

For a rail accident in which the fuel cask is ruptured, the conservative assumptions of a ground level puff release with no depletion from the cloud were made. The dose in rems caused by this exposure level can be expressed by

$$D = Q_o K \, \chi/Q \qquad (3\text{-}15)$$

where:
Q_o is the isotope release in curies,
K is the dose coefficient for specific isotopes, and
χ/Q is the dispersion coefficient which has been experimentally determined by tracer experiment dispersion studies

TABLE 1
GAP ACTIVITY FOR VARIOUS ISOTOPES AND FISSION PRODUCTS

ISOTOPE	Total Inventory (curies)	Percent Isotopes in gap	Activity in gap (curies)
Kr^{85}	3.5×10^4	30	1.1×10^4
I^{131}	6.9	2	1.4×10^{-1}
Fission Products (solids)	1.4×10^7	1×10^{-2}	1.7×10^1
Actinides	1.36×10^5	Nil	Nil
Xe^{131}	10.5	2	2.1×10^{-1}
I^{129}	6.4×10^{-3}	30	1.9×10^{-3}
H^3	2.2×10^3	1	2.2×10^1

Measure of Isopleth Areas

In the previously cited AEC report, isopleth areas were calculated for the assumptions detailed in Section 3.3.1. The isopleth or constant dose areas are deterimined for various dispersion conditions. With the input from each specific isotope and its associated release fraction, the isopleth areas subjected to various dose levels can be calculated. These dose levels vary based on the specific weather conditions existing during an accident. The isopleth area in square miles which would be impacted during an accident involving general types of radioactive materials is given in Table 2 along with the probability of occurrence of each weather stability class. It should be noted, however, that estimates of actual dose will vary as a function of the isotope used in the calculation.

TABLE 2

ISOPLETH AREAS FOR VARIOUS DOSE PARAMETERS* AND WEATHER CONDITIONS

Dose Parameter	Area in Mi^2/Stability Class TURBULENT ⟵						⟶ STABLE
D/Q_oK	A	B	C	D E	F	G	
10^{-1}	5.8×10^{-6}	5.8×10^{-6}	4.6×10^{-6}	3.8×10^{-6}	1.6×10^{-5}	3.8×10^{-5}	1.9×10^{-4}
10^{-2}	6.2×10^{-5}	6.2×10^{-5}	5.0×10^{-5}	4.2×10^{-5}	7.8×10^{-4}	5.8×10^{-4}	2.1×10^{-3}
10^{-3}	5.8×10^{-4}	5.4×10^{-4}	4.2×10^{-4}	4.2×10^{-4}	1.9×10^{-3}	5.4×10^{-3}	3.1×10^{-2}
10^{-4}	5.0×10^{-3}	5.4×10^{-3}	4.2×10^{-3}	5.8×10^{-3}	2.3×10^{-2}	7.3×10^{-2}	4.6×10^{-1}
10^{-5}	3.5×10^{-2}	4.6×10^{-2}	4.6×10^{-2}	7.7×10^{-2}	3.3×10^{-1}	1.5×10^{0}	1.9×10^{1}
10^{-6}	1.5×10^{-1}	3.1×10^{-1}	6.2×10^{-1}	1.2×10^{0}	7.7×10^{1}	7.7×10^{1}	3.9×10^{3}
(p) of weather conditions in each class (Pw)	.019	.081	.136	.44	.121	.122	.081

*These areas indicate the number of square miles subjected to the indicated or higher dose parameters.

Determination of Dose Bands And Average Dose Per Isotope

The isopleth areas of various dose parameters and weather conditions can be utilized to identify dose bands, the average dose in each band, and corresponding band areas. For example, from weather stability class "A" the average dose parameter band and the corresponding area in the band can be calculated as shown in Table 3.

TABLE 3

WEATHER STABILITY CLASS "A" DOSE BANDS AND BAND AREAS

Dose Band Index, i	D Dose Parameter Band	D_i' Average Dose in Band	A_{iw} Area in Parameter mi^2	Band
i=1	10^{-1} up		10^{-1}	5.8×10^{-6}
2	$10^{-2} - 10^{-1}$		5.5×10^{-2}	5.6×10^{-5}
3	$10^{-3} - 10^{-2}$		5.5×10^{-3}	5.2×10^{-4}
4	$10^{-4} - 10^{-3}$		5.5×10^{-4}	4.4×10^{-3}
5	$10^{-5} - 10^{-4}$		5.5×10^{-5}	3.0×10^{-2}
6	$10^{-6} - 10^{-5}$		5.5×10^{-6}	1.2×10^{-1}

The actual dose for a given isotope with dose coefficient K can be calculated from

$$\bar{D}_i = \bar{D}_i' \times Q_o \times K \qquad (3\text{-}16)$$

where $\bar{D}_i'$ represents the average isotope dose parameter in each band

K represents the dose coefficient for each isotope

Q_o represents the isotope release in curies.

Average dose parameters $\bar{D}_i'$ and areas A_{iw} could be calculated for all dose parameters bands, as exemplified in Table 3.

Using the doses determined from the previous calculations, the total dose associated with the release of a given isotope can be determined by using the population density in the areas surrounding the accident, as follows

$$D_T = PD_i \sum_{i=1}^{6} \bar{D}_i \sum_{w=A}^{G} P_w A_{iw} \qquad (3\text{-}17)$$

where D_T shows total dose in man-rems

PD shows population density (persons/mi^2)

P_w shows probability of weather per stability class

$\bar{D}_i$ shows average dose parameter in band

A_{iw} shows area encompassed by a specific dose level from isotope release during an incident

3.3.1.3 Total Dose Refined for Multiple Dose Mechanisms

Exposure of a number of isotopes to human organisms result in significant doses to internal organs such as the lung as well as external (skin) exposures. If fission products are released in a rail accident involving spent fuel, the total dose due to these products would be calculated by expanding the dose term in Equation 3-17 to account for both dose mechanisms

$$D_T = PD \left[\underbrace{\sum_{i=1}^{6} \bar{D}_i^{*} \sum_{w=Ay}^{G}}_{\text{whole body}} P_w A_{iw} + \sum_{i=1}^{6} \underbrace{\bar{D}_i^{**} \sum_{w=A}^{G}}_{\text{lung}} P_w A_{iw} \right] \qquad (3\text{-}18)$$

where D_i * is the isopleth dose due to whole body exposures, and

D_i ** is the dose due to lung exposures.

Total dose must be calculated for each isotope I released during a rail cask accident. Consequently, the population dose during an accident is expressed by

$$D_T = \sum_I PD \sum_{i=1}^{6} \bar{D}_i^{*} \sum_{w=A}^{G} P_w A_{iw} + \sum_{i=1}^{6} \bar{D}_i^{**} \sum_{w=A}^{G} P_w A_{iw} \qquad (3\text{-}19)$$

where $\sum_I$ represents the sum over each isotope

So far, we have assumed a 100% release of the fuel rod gap inventory which is not likely. A release of significantly less magnitude is more realistic and the actual release fraction value will depend on the accident severity.

3.3.1.4 Total Dose Refined for Less Than 100% Release

If (D_i) values in Equation 3-19 represent 100% release, then doses from any accident severity can be calculated by multiplying a release fraction factor as in Equation 3-20.

$$D_T = R_f \sum_I PD \left[\sum_{i=1}^{6} \bar{D}_i^{*} \sum_{w=A}^{G} P_w A_{iw} + \sum_{i=1}^{6} \bar{D}_i^{**} \sum_{w=A}^{G} P_w A_{iw} \right] \qquad (3\text{-}20)$$

where R_f is the release fraction, expressed as a percent of fuel rods ruptured.

3.3.1.5 Simplification of Total Dose Expression

To simplify the dose calculation in Equation 3-20, stability classes A through G identified in Table 2 were reduced to a single class by utilizing the probability distribution given in the AEC report. The area in square miles for all weather stability classes, A_i, was calculated by summing the probability of an accident occurring in all weather stability classes. When the areas were calculated by collapsing the stability classes, results were obtained for each dose parameter as shown in Table 4 below.

TABLE 4

COLLAPSED DOSE AND BAND AREAS FOR ALL WEATHER STABILITY CLASSES

Dose Parameter D/Q_oK	Area in mi^2 A_i
10^{-1}	2.48×10^{-5}
10^{-2}	2.94×10^{-4}
10^{-3}	3.70×10^{-3}
10^{-4}	5.26×10^{-2}
10^{-5}	1.81
10^{-6}	3.27×10^{2}

The dose and area bands for the collapsed weather stability classes were also formulated for the three major isotopes, I^{131}, Kr^{85} and fission products. Results of this analysis are shown in Table 5.

The specific isotope dose coefficients (K) and release activity (Q_o) from Table 1 were used in Equation 3-16 to calculate average dose for each isotope, assuming a 100% gap release for I^{131} and Kr^{85} and the combined gap activity for fission products of one percent release with no fire and 10 percent release with fire during a railcar accident. The area exposed will remain constant for each isotope while the dose levels exposed to the area will vary.

TABLE 5

COLLAPSED DOSE AND AREA BANDS FOR I^{131}, Kr^{85} AND FISSION PRODUCTS

Mean Dose Parameter D/Q_0K	Dose Parameter Bands D/Q_oK	Area (mi^2)
10^{-1}	10^{-1}	2.48×10^{-5}
5.5×10^{-2}	$10^{-2} - 10^{-1}$	2.69×10^{-4}
5.5×10^{-3}	$10^{-3} - 10^{-2}$	3.41×10^{-3}
5.5×10^{-4}	$10^{-4} - 10^{-3}$	4.89×10^{-2}
5.5×10^{-5}	$10^{-5} - 10^{-4}$	1.76
5.5×10^{-6}	$10^{-6} - 10^{-5}$	3.25×10^{2}

Tables 6 through 8 present these calculated dose levels which will be experienced in isopleth areas as a function of the specific isotope released.

Table 6 shows the dose to the population due to the release of I^{131} from the spent fuel shipment. The coefficient used to determine the radiation dose to the thyroid is an average of the combined doses to children and adults. The dose coefficient, $K_{Thyroid}$ for isotope I^{131} equals 4.0×10^2 rem.

TABLE 6

DOSE FROM RELEASE OF ISOTOPE I^{131}

$D_{Thyroid}$ (rem)	A_i Area (mi^2)
5.6	2.43×10^{-5}
3.1	2.69×10^{-4}
3.1×10^{-1}	3.41×10^{-3}
3.1×10^{-2}	4.89×10^{-2}
3.1×10^{-3}	1.76
3.1×10^{-4}	3.25×10^{2}

Table 7 presents dose levels to the population due to the isotope fission products. These calculated doses account for the average frequency of fire involvement in rail accidents. A disccusion of fission product release fraction as a function of fire involvement is found in Section 3.3.2. The dose coefficients for fission products are $K_{whole\ body} = 7.3 \times 10^2$ rem and $K_{lung} = 1.1 \times 10^2$ rem.

TABLE 7

DOSE LEVELS DUE TO THE RELEASE OF FISSION PRODUCTS

$D_{\text{whole body}}$ (rem)	D_{lung} (rem)	A_i Area (mi^2)
1.24×10^3	1.9×10^2	2.48×10^{-5}
6.8×10^2	1.0×10^1	2.69×10^{-4}
6.8×10^1	1.0	3.41×10^{-3}
6.8	1.0×10^{-1}	4.89×10^{-2}
6.8×10^{-1}	1.0×10^{-2}	1.76×10
6.8×10^{-2}	1.0×10^{-3}	3.25×10^2

Table 8 shows the population dose due to the release of isotope (Kr^{85}). The dose coefficient, K_{skin}, for Kr^{85} equals 5.3×10^{-2} rem.

TABLE 8

DOSE LEVELS TO THE RELEASE OF Kr^{85}

D_{Skin} (rem)	A_i Area (mi^2)
5.8×10^1	2.48×10^{-5}
3.2×10^1	2.69×10^{-4}
3.2	3.41×10^{-3}
3.2×10^{-1}	4.89×10^{-2}
3.2×10^{-2}	1.76
3.2×10^{-3}	3.25×10^2

Tables 6 through 8 provide the information needed to calculate total dose due to rail cask accidents, since for each isotope we have the area subjected to some average dose level. Using this simplification of the weather probability per stability class, the equation for dose, 3-20, reduces to

$$D_T = R_f \sum_I PD \left[\sum_{i=1}^{6} \bar{D}_i^{\,*} A_i + \sum_{i=1}^{6} \bar{D}_i^{\,**} A_i \right] \tag{3-21}$$

3.3.2 Probability of Release Fraction (R_f)

The total dose expression in equation (3-21) assumes a release fraction R_f during the accident. As indicated in section 3.1.1, calculation of the actual dose received during the accident must incorporate certain probabilities of the accident occurring. Thus, the actual total dose expression becomes

$$D_T = PA^r\left(R_f \times P(R_i) \times PD\, \Sigma I_i \sum_{i=1}^{6} D_i A_i\right) \qquad (3\text{-}22)$$

where	PA^r	is the route specific accident probability
	R_f	is the release fraction
	$P(R_f)$	is the probability of an accident with a release fraction R_f
	PD	is the population density
	$D_i A_i$	is the sum of the products of dose contributions and area impacted

The probability of any release fraction (R_f) during an accident for any route can be calculated using

$$P(R_f) = P\left[R_f(A)u\right] \times Lu + P\left[R_f(A)s\right] \times Ls + P\left[R_f(A)r\right] \times Lr \qquad (3\text{-}23)$$

where	$P(R_f(A))$	is the probability of a release fraction (R_f) during an accident of severity (A) per rail mile traveled in either an urban, suburban or rural population density zone
	L_u, L_s, L_r	represents the number of miles of track per population density zone

Accident probability data used in this model are route specific probabilities per rail car mile and are dependent on railroad specific accident histories, track class, traffic density and switching operations. Thus, the accident probability for each route can be expressed as:

$$PA^r = F\ (AH,\ TC,\ TD,\ SA) \qquad (3\text{-}24)$$

where	PA^r	is the route specific accident probability
	AH	is the railroad specific accident history
	TC	is class of track
	TD	is traffic density
	SA	is switching accidents

3.3.3 Calculation of Route Specific Railroad Accident History

The probability of an accident along each route, $PA^{r}{}_{AH}$ or P(AH), can be determined by the length of travel for each specific railroad and the railroad's accident probability P^{rxr}. This can be expressed as a summation over all railroads along each route:

$$PA^{r}_{AH} = {}_{rxr} \frac{P_{a}{}^{rxr} \text{ x } L_{rr}}{Lr} \qquad (3\text{-}25)$$

where Pa^{rxr} is the specific railroad accident history

L_{rxr} is the length of the route attributable to a railroad

L_{y} is the total route length

Input data for these calculations are the total number of freight car miles and the total number of accidents on a railroad specific basis for 1978. Accident data were obtained along with segment population density values from the computer graphics system at Princeton Unversity, these data were broken down into rural, urban and suburban segments which was particularly appropriate for this study. However, it is realized that a more statistically significant data base is needed and future efforts in this area ought to include additional accident data. Using this approach, route specific probabilities based on the accident histories of individual railroads was calculated and are presented in Table 9.

TABLE 9 ROUTE SPECIFIC RAILROAD ACCIDENT PROBABILITIES

Route	$PA^{r}{}_{AH} (x\ 10^{-6})$
1A	9.0
1B	1.3
2A	7.8
2B	1.7
3A	3.1
3B	4.6
4A	7.7
4B	2.1
5A	1.6
5B	7.6
6A	3.5
6B	1.5
7A	9.0
7B	1.0

3.3.4 Calculation of Accident Probability with Class of Track

Since the fractional accident severity breakdown was based on the Sandia work h does not consider class of track or traffic density, the route specific accident ies must be modified to give the accident probabilities for that route.

To incorporate track class effects into the route specific accident probability the following assumptions were made:

1) The Sandia severity analysis was based on U.S. wide average data which was not track class specific.

2) The majority of all freight car-miles traveled are on class 4 track based on data in the A.D. Little report, Event Probabilities and Impact Zones for Hazardous Materials Accidents on Railroads. This value is 81% for the seven pairs in this study.

3) The Sandia results are, therefore, based on an average track class of 3.94, which approximates class 4.

4) The probability of accidents/releases per track class per car-mile is the same as that for tank car releases versus track class per car-mile as found in "The Geographical Distribution of Risk Due to Hazardous Materials Tank Car Transportation in the U.S." It is important to note that accident severity has not been factored into this release probability data.

TRACK CLASS	1	2	3	4	5	6
RELEASE PROBABILITY ($\times 10^{-7}$)	91.3	6.6	5.4	1.3	1.3	33.1

Thus, the equation for route specific accident probability can be modified based on route specific track class as follows:

$$P(AH,TC) = PA^{r}_{AH} + \sum_{L_r} \left(\frac{PTC_i - PTC_4}{PTC_4} \right) \left(PA^{r}_{AH} \right) \left(\frac{L'_i}{L_r} \right) \quad (3\text{-}26)$$

where PTC_i is the release probability for track classes 1, 2, 3, and 6
PTC_4 is the release probability for track class 4 of 1.3×10^{-7}
L'_j is the length of each track class on a route
L_r is the total length of a route.

NOTE: No correction is needed for track class 4 or 5.

Table 10 presents the values for the route specific accident probability as a function of railroad specific accident histories and class of track.

TABLE 10
ACCIDENT PROBABILITY, P(AH,TC), BASED ON RAILROAD ACCIDENT HISTORIES AND CLASS OF TRACK

Route	Accident Probability (x 10^{-6})
1A	9.0
1B	13.0
2A	1.0
2B	17.0
3A	3.1
3B	6.6
4A	25.0
4B	2.4
5A	17.0
5B	36.0
6A	35.0
6B	37.0
7A	9.0
7B	31.0

3.3.5 Calculation of Accident Probability with Traffic Density

The next element needed to modify the accident probability is traffic density. Railroad accidents may be classed into two major categories: collisions and derailments.

A review of the A.D. Little report indicates that while the rate of railroad collisions will vary by the square of the traffic density, the rate of derailments does not vary on a traffic density basis.

To factor traffic density into the route accident probabilities, some assumptions concerning the Sandia event severity breakdowns which form the basis for the accident risk model are required:

1) The Sandia severity analysis was drawn from a U.S.-wide mean traffic density data base.

2) A mean route segment density was derived using DOT data.

The DOT analysis indicates that approximately 33 percent (about 60,000 route miles) of the rail system produces less than 2 percent of the traffic, on the equivalent of about one average-sized train per week. According to NUREG-0170, the average freight train is composed of approximately 70 cars. At the other extreme, 2/3 of the rail industry's total ton-miles are produced on approximately 1/5 (about 40,000 miles) of the system. The average annual gross traffic density of a mainline rail segment is 16.5 million tons.

By comparing route segment specific traffic density to a <u>derived</u> mean density, the route accident probability can be modified to account for traffic density effects.

Traffic density can be expressed by the following equation:

$$TD_r = \sum_{i=4}^{n} D_i \left(\frac{L_i}{L_r} \right) \tag{3-27}$$

where TD_r is average route traffic density
D_i is the route segment specific traffic density
L_i is the route segment length
L_r is the total length of the route.

TD_r can be calculated for each of the 14 route pairs. This yields a route specific traffic density which can be compared to the average route segment density of 10.15 x 10^6 gross ton-miles per year, which is in traffic density range 4. Since the A.D. Little study indicated that about 20 percent of rail accidents are collisions, the equation can for total route accident probability be expressed as:

$$PA^r = P(AH,TC) + \left(\frac{TD_r}{4} \right)^2 \left[(0.20)(P(AH,TC) \right] \tag{3-28}$$

Table 11 presents values for the accident probability including traffic density effects.

TABLE 11
ACCIDENT PROBABILITY INCLUDING TRAFFIC DENSITY P(TD) EFFECTS

Route	Accident Probability (x 10^{-6})
1A	11.0
1B	15.0
2A	12.0
2B	21.0
3A	3.8
3B	8.1
4A	32.0
4B	260.0
5A	19.0
5B	41.0
6A	4.9
6B	41.0
7A	11.0
7B	38.0

3.3.6 Calculation of Probability of Accident During Switching Operations

To calculate the probability of accidents along a route during switching operations, the total number of railroad specific yard switching miles for 1979 were used. The total number of yard switching accidents for 1979 was provided in the FRA Accident/Incident Bulletin. This value was used to determine the number of yard accidents attributable to each railroad. The percentage of accidents on a specific railroad per total 1979 train accidents was assumed proportional to the number of switching accidents each railroad represented as a percentage of the total switching accidents.

This number of switching accidents per mile of switching operation represents the probability of a switching accident for each railroad. Origin and destination points were not included, only railroad interchanges along each route.

The total route switching accidents probability can be calculated using the following:

$$P(SA) = \frac{\Sigma\ I_{rxr}}{L_R} \times PSA_{rxr} \qquad (3\text{-}29)$$

where $P(SA)$ is the probability of a switching accident along a route

I_{rxr} is the number of interchanges a railroad has along a route

PSA_{rxr} is the probability of a switching accident for a specific railroad

L_R total route length.

Table 12 gives the route specific switching accident probabilities.

3.3.7 Total Route Accident Probability

The total route accident probability can now be expressed as:

$$PA^r = P(AH,TC,TD) + P(SA) \qquad (3\text{-}30)$$

Table 13 presents the values for total route accident probabilities, PA^r.

TABLE 12

ROUTE SPECIFIC PROBABILITY OF ACCIDENTS DURING SWITCHING OPERATIONS

Route	Accident Probability (x 10^{-6})
1A	40.0
1B	18.5
2A	18.5
2B	18.5
3A	21.0
3B	21.0
4A	39.0
4B	99.0
5A	32.0
5B	86.0
6A	32.0
6B	100.0
7A	40.0
7B	40.0

TABLE 13

TOTAL ROUTE ACCIDENT PROBABILITY

Route	PA^r (x 10^{-6})
1A	51
1B	34
2A	31
2B	40
3A	25
3B	29
4A	42
4B	360
5A	51
5B	13
6A	81
6B	14
7A	51
7B	78

3.3.8 Calculation of Total Accident Dose

This can be accomplished using equation 3-21, viz

$$D_T = PA^r \left(R_f \times P(R_f) \times \Sigma D_I \sum_{i=1}^{6} \overline{D}_i A_i \right) \qquad (3\text{-}31)$$

The values of $D_i A_i$ are constant throughout any route with various population densities, release fractions and release fraction probabilities and can be calculated for Kr^{85}, I^{131} and fission products. Utilizing the sum over all isotopes yields

$$D_T = PA^r \left(S_I \times P_{(R_f)} \times R_f \times P_D \right) \qquad (3\text{-}32),$$

where S_I is the sum of $D_i A_i$ for all isotopes (rem-mi^2).

The appropriate values of $P_{(R_f)}$ and R_f per route mile for various population density zones are derived from data derived by Sandia Laboratory and can be found in Table A-3 in Appendix A. Therefore, if the number of miles in each population density zone is known for a specific route, the data can be expressed per mile for that route as follows:

$$\begin{aligned} D_T = PA^r \Big[& S_I \times R_{f_1} \ (P(R_{f_1})r \times L_r \times PD_r + (P(R_{f_1})s \times L_s \times PD_s) + (P(R_{f_1})u \times \\ & L_u \times PD_u) + S_I \times R_{f_2} \ (P(R_{f_2})r \times L_r \times PD_r) + (P(R_{f_2})s \times L_s \times PD_s) + \\ & (P(R_{f_2})_u \times L_u \times PD_u) + S_I \times R_{f_3} \ (P(R_{f_3})_r \times L_r \times PD_r) + (P(R_{f_3})_s * \\ & L_s \times PD_s) + (P(R_{f_3})_u \times L_u \times PD_u) \Big] \end{aligned} \qquad (3\text{-}33)$$

where	R_{f_1}, R_{f_2}, R_{f_3}	are release fractions found in Appendix A, Table A-3
	$P(R_{f_1})$, $P(R_{f_2})$, $P(R_{f_3})$	are accident probabilities per mile for each of the release fractions also found in Table A-3 for urban, suburban and rural zones.

This expression reduces to

$$D_T = PA^r \ C_r \times L_r + D_s \times L_s + C_u \times L_u \qquad (3\text{-}34),$$

where	C_r, C_s, C_u	are numerical constants calculated using the actual values of R_{f_1}, R_{f_2} and R_{f_3}; $P(R_{f_1})$, $P(R_{f_2})$ and (R_{f_3}); and the average population density in each zone.

3.4 ROUTE COST SHIPPING MODEL

A route cost shipping model was developed based on daily cask rental costs and freight costs levied by rail carriers for transporting spent fuel. Mathematically, this is expressed as

$$TT_c = C_{rc} + F_c \qquad (3\text{-}35),$$

where TT_c is the total transport cost per shipment

C_{rc} is the cask rental cost per shipment

F_c is the freight cost per shipment

3.4.1 Cask Rental Costs

Currently, there are three models of rail casks available to utilities for domestic shipments of spent fuel. They are:

Manufacturer/Supplier	Model Designation
Transnuclear Industries	TN-12
NL Industries	10/24
General Electric Co.	Series 300

Rental costs for the three available models of rail casks were obtained through contacts with representatives of the cask manufacturer/supply companies. It was learned that rail casks are rented to utilities on a per diem basis.

Typical daily cask rental costs are:

Cask Model	Rental Cost/day
TN-12	$5,500
NLI 10/24	$4,000
GE Series 300	$3,500

The total rental costs (C_{rc}) levied on utilities is time dependent and will increase linearly as a function of shipment distance, because rental charges will be based on total round trip length (miles), average train velocity (mph) plus stoptimes in switch and workyards (hours).

This relationship can be expressed as

$$C_{rc} = C_{rc_d} \left[\left(\frac{Lr}{Vr} + \frac{Ls}{Vs} + \frac{Lu}{Vu}\right) \times 2 + \left(ST_r + ST_s + ST_u\right)\right] /24 \qquad (3\text{-}36),$$

where C_{rc_d} = daily cask rental cost
L_r = length traveled in rural zone
L_s = length traveled in suburban zone
L_u = length traveled in urban zone
V_r = velocity traveled in rural zone
V_s = velocity traveled in suburban zone
V_u = velocity traveled in urban zone
ST_r = total stop time in rural zone
ST_s = total stop time in suburban zone
ST_u = total stop time in urban zone

3.4.2 Freight Cost

To identify the incremental freight rates that would be charged to utilities for transporting spent fuel along various routes, representatives of the Interstate Commerce Commission, originating rail carriers for the routes being examined and rail freight traffic associations were contacted.

Tariff rates published by the ICC are based on short-line routing and several of the routes being analyzed in this study are not short-line distances. Therefore, actual freight rates, levied by originating railroads on utilities, were relied upon.

Railroads surveyed indicated problems with rates for some of the alternate routes because prior agreed upon rates had not been established at the interchange points in some of the circuitous routes. However, where actual freight charges were provided, they were used and extrapolated to non-rated route segments. For routes with no unit cost data provided, the ICC Class 40 rates were applied along with the minimum weight requirements.

To calculate total freight handling costs for shipments of spent fuel, the following information was required:

- use of ICC approved rate per 100 lbs.;
- applicable minimum shipment weight (120 tons) or minimum number of cars accepted as indicated by the individual carrier;
- any special freight train charges as indicated by individual carriers;
- a standard load weight of 70 tons; and
- route length.

The total freight costs are then given by

$$C_F = 2\left[\left(C_{ICC} \times WS_{min}\right) + \left(SR \times L_R\right)\right] \qquad (3\text{-}37),$$

where	C_F	is the total freight costs in dollars for round trip
	C_{ICC}	is the ICC rate per 100 lbs
	WS_{min}	is 120 tons
	SR	are special freight train charges per mile
	L_R	is the route length.

The freight costs can then be further broken down as shown in Equation 3-31 to give an idea of cost of a specific route as a function of distance traveled and load. This will indicate costs per ton mile which will give a good comparative cost basis for evaluating routes:

$$C_{TM} = C_F \quad L_R \quad W_{LOAD} \tag{3-38}$$

where:	C_{TM}	is the cost per ton mile, and
	W_{LOAD}	is 70 tons.

3.4.3 Total Transportation Costs

The total transportation costs for a shipment of spent fuel along a specific route is the sum of the cask rental costs and the freight costs. This can be expressed as

$$\begin{aligned} TT_c = C_{rc_d} & \left[2\left(\frac{Lr}{Vr} + \frac{Ls}{Vs}\right) + \left(\frac{Lu}{Vu}\right) + \left(ST_r + ST_s + ST_u\right)\right] / 24 \\ & + 2 \times \left[\left(C_{ICC} \times WS_{min}\right) + \left(SR \times L_R\right)\right] \end{aligned} \tag{3-39}$$

4. REACTOR SITE TO A-F-R SITE ROUTE SELECTION

4.1 GENERAL

Seven routing combinations were selected from approximately 600 options for the risk analyses of transporting spent fuel. These seven-origin-to-destination routings each have a primary and secondary path. The routes were selected on the basis of routing alternatives available and potential risk levels from shipment of spent fuel through varying population density centers Figure 3 shows the geographic location of the more than 200 commercial nuclear power reactors in the U.S. and the three potential A-F-R storage sites selected as destination points in this study, Barnwell, SC; Morris, IL; and West Valley, NY.

In selecting routes suitable for risk analysis, a review was made of the number of rail interchanges required to ship spent fuel between the reactor facility and the AFR storage site. The total population density along the route, state-specific railroad accident histories and route lengths in each population density class were also considered. Trade-off between route length and population density was made in determining and selecting the alternate route pairs for risk analysis.

4.2 DEMOGRAPHIC ROUTE SELECTION METHODOLOGY

The route pairs were chosen for this analysis because of the potential risk differences between each alternate route based on variations in shipment frequency, population density along the route, the specific route lengths through varying population density classes, and state-specific railroad accident histories.

4.2.1 Selection of Generating Facilities

The first step in route selection was to identify the geographic location of each commercial nuclear power plant and A-F-R facility in the U.S. This was done using a U.S. Department of Energy map. Next, an analysis was conducted to identify specific geographic locations and power plants which currently represent a large fraction of the U.S. nuclear power production capacity. Department of Energy estimates that nuclear power production in 1990 will be roughly 186,620 Mw(e). The seven power plants chosen have a combined power capacity of 21,446 MW(e) or about 11 percent of the total projected U.S. production capacity. The names, locations, and estimated 1990 production capacities of the seven plants chosen are given in Table 14.

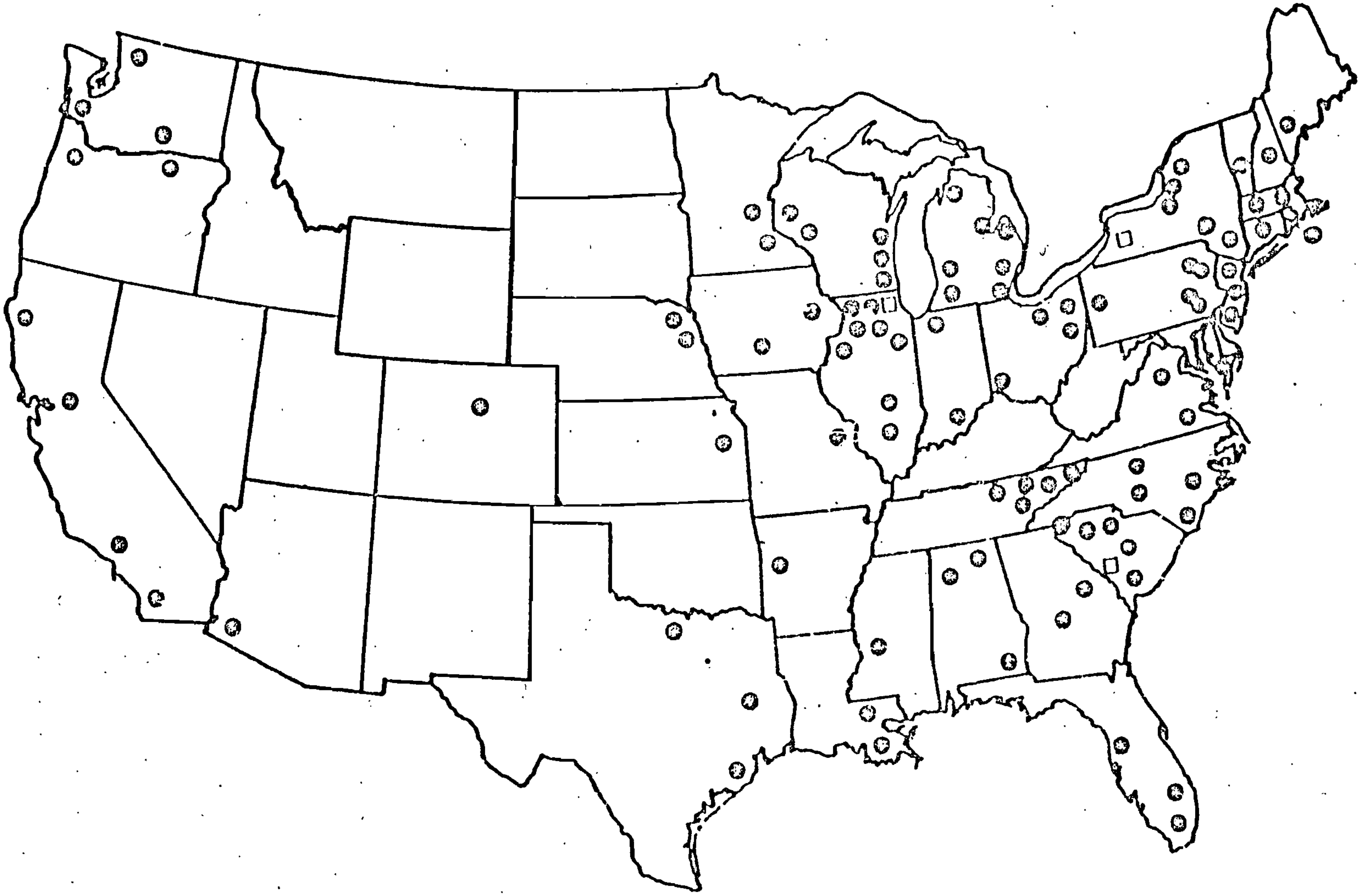


FIGURE 3. GEOGRAPHIC LOCATION OF NUCLEAR POWER PLANTS ● AND POTENTIAL AWAY-FROM-REACTOR (A-F-R) DISPOSAL SITES ☐

TABLE 14

NUCLEAR POWER PLANTS AND PROJECTED PRODUCTION CAPACITY

Power Facility	Geographic Location	Projected 1990 Production Capacity, MW(e)
Brown Ferry Nuclear* Power Station	Decatur, Alabama	3195
Cherokee Nuclear Station	Gaffney, So. Carolina	3840
North Anna Power* Station	Mineral, Virginia	3628
Seabrook Nuclear Station	Seabrook, New Hampshire	2400
Greenwood Energy Center	St. Clair County, Michigan	2528
Davis-Besse Nuclear* Power Station	Oak Harbor, Ohio	2718
Hartsville Nuclear Station	Hartsville, Tennessee	4932

*currently operating

The production capacities of these facilities were verified by contacting power plant officials.

4.2.2 Frequency of Spent Fuel Shipments

NRC estimates that some 300 nuclear reactors will be operational by the year 2000. Currently, there are approximately 80 reactors operational (Figure 3) at capacities of 1000 MW(e), each requiring biannual shipments of 100-200 metric tons of spent fuel. Spent fuel is currently stored primarily in on-site reactor storage pools because of controversy and adverse public reaction to transporting radioactive materials. Storage capacities at power facilities are being rapidly filled up and additional storage sites are needed. Thus, the transportation of spent fuel to distant storage sites will likely increase as additional storage sites become available, although current shipment quantities are still relatively low.

The following figures in Table 15 show the requirements for A-F-R storage capability through the year 1990.

TABLE 15. A-F-R STORAGE REQUIREMENTS

Years	Reactor Discharges (metric-tons)	A-F-R Requirement/ Transportation Requirement (metric-tons)	Cumulative A-F-R Requirement
1977 to 1980	7,704	730	730
1981 to 1985	14,403	3,522	4,252
1986 to 1990	24,504	14,687	18,939

4.2.3 Population Density Along the Route

Route specific population density data were required for both the normal transportation risk model and the accident risk model. Population density along each rail segment was determined by superimposing the FRA 503 network over the census enumeration districts in the U.S. The continental U.S. was subdivided into 1/2 mi.^{2} cells by Oak Ridge National Laboratories (0.0001^0 latitude and longitude). This grid cell composition provides specific 1970 population density data. The FRA rail segments were superimposed on the population cells and an average population density per route segment was calculated.

Once the population density was established for each route segment, the segments were categorized into the three population density classes; urban, suburban and rural and summed over each route for input into the model.

4.2.4 Route Lengths Through Population Zones

Route lengths traversing the various population density zones were measured in miles. Data on segment length were collected from the FRA publication, Final Standards Designation and Classification of Class I Railroads in the U.S. This document provides a series of state maps showing the configuration of the rail system in that area. Using the proper scale, rail segment length was determined by measuring the length of each with a divider and converting to the segment length in miles. The estimated route length was verified by using Princeton University's railroad data base, and refinements were made as needed.

4.2.5 State-Specific Railroad Accident Histories

State-specific railroad accidents were reviewed and enumerated using the hazardous materials incident file of the Materials Transportation Bureau of DOT and FRA's Accident/Incident Bulletins. These data were important in selecting routing alternatives which included a wide range of accident frequencies. Rail routes which traversed several states were often found to provide this range of accident frequencies. For this study, only rail routes east of the Mississippi River were considered since the majority of the nuclear power plant capacity and all of the A-F-R sites are east of the Mississippi. However, the methodologies developed can easily be applied to any route combination anywhere in the U.S.

4.2.5.1 Mode of Transportation Involved in Incident

The radioactive materials (RAM) incidents reported to the MTB for the years 1971 through 1979 were reviewed. A computer printout of these data shows a total of 512 incidents occurred. Although the rail mode accounted for only 11 incidents or 2.1% of the total, it does account for transporting large quantities of high level waste. Of the remaining incidents, 117 (22.9%) involved aircraft; 1 (0.2%) involved water transport vehicles; 380 (74.2%) involved highway carriers; and 3 (0.6%) involved other transport modes.

4.2.5.2 Number of Radioactive Incidents Per State

The RAM incidents on a state-by-state basis from the MTB data for the years 1971 through 1979 were also reviewed. Table 16 shows the total number of incidents per state and associated percentages of the total for those states east of the Mississippi River. It showed that of the total of 512 RAM incidents that occurred nationwide, a total of 369 incidents, representing 72.1% occurred in states east of the Mississippi River. Illinois, New York and South Carolina appear to have a disproportionately high number of RAM incidents which may be related to the presence of A-F-R sites in these states and not necessarily the safety of the railroads. Consequently, it is more meaningful to use the railroad accident/incident data to identify states with various ranges of accident history.

4.2.5.3 Railroad Accidents/Incidents by State

FRA accident/incident data for the years 1975 through 1979 were reviewed to identify the total number of rail accidents/incidents by state. Table 17 presents the total number of accidents/incidents reported to the FRA during this reporting period. A total of 58,400 accident/incidents occurred in states east of the Mississippi River, accounting for 59.4% of the national total of 98,000 accidents/incidents occurring during this period. Figure 4 shows the percentage contribution by state to the total number of rail accidents/incidents occurring east of the Mississippi River for this period 1975-1979.

These accident data were then used to determine the average annual number of accidents/incidents per 100 rail miles traveled. Table 18 and Figure 5 present this state-specific data which was used to identify states with various accident ranges for the purpose of route selection.

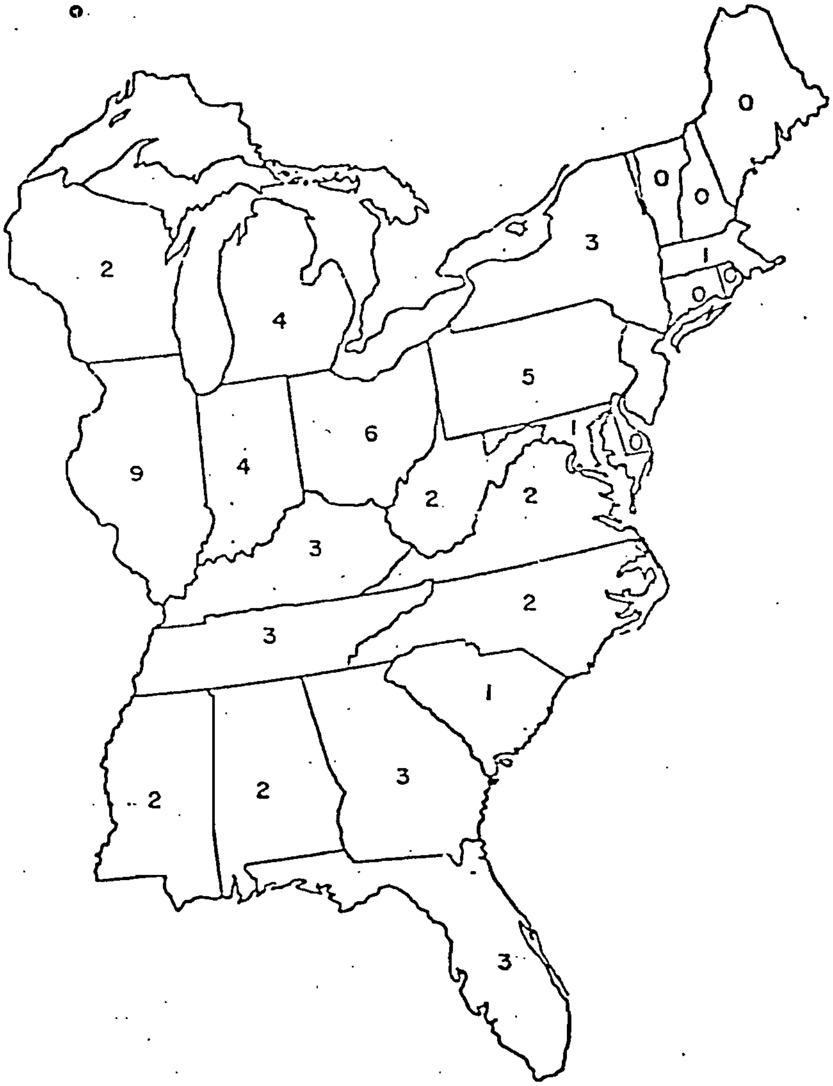
TABLE 16. NUMBER OF RAM INCIDENTS PER STATE
(MTB: 1971-1979)

STATE	NUMBER OF INCIDENTS	% OF TOTAL INCIDENTS
Alabama	3	0.6
Connecticut	4	0.8
Delaware	0	0.0
District of Columbia	8	1.5
Florida	8	1.5
Georgia	6	1.1
Illinois	49	9.3
Indiana	4	0.8
Kentucky	5	1.0
Louisiana	4	0.8
Maine	2	0.4
Maryland	4	0.8
Massachusetts	11	2.1
Michigan	6	1.1
Mississippi	0	0.0
New Hampshire	0	0.0
New Jersey	10	1.9
New York	23	4.4
North Carolina	9	1.7
Ohio	11	2.1
Pennsylvania	16	3.0
Rhode Island	0	0.0
South Carolina	172	32.8
Tennessee	15	2.9
Vermont	0	0.0
Virginia	4	0.8
West Virginia	3	0.6
Wisconsin	3	0.6
TOTAL	369	72.1

TABLE 17 ACCIDENTS/INCIDENTS BY STATE
CLASS I AND II RAILROADS
(1975-1979)

STATE	TOTAL ACCIDENTS/INCIDENTS	% OF TOTAL
Alabama	2309	2.4
Connecticut	234	0.2
Delaware	238	0.2
Florida	2569	2.6
Georgia	3357	3.4
Illinois	8997	9.1
Indiana	3661	3.7
Kentucky	2661	2.7
Louisiana	2274	2.3
Maine	424	0.4
Maryland	1300	1.3
Massachusetts	609	0.6
Michigan	3717	3.8
Mississippi	1537	1.6
New Hampshire	94	0.1
New Jersey	1134	1.2
New York	3304	3.4
North Carolina	1983	2.0
Ohio	5764	5.9
Pennsylvania	5127	5.2
Rhode Island	58	0.1
South Carolina	1092	1.1
Vermont	93	0.1
Virginia	1958	2.0
West Virginia	1516	1.5
Wisconsin	2404	2.5
TOTAL	58,400	59.4

Source: FRA Accident/Incident Bulletins



PERCENT OF TOTAL ANNUAL ACCIDENTS/INCIDENTS

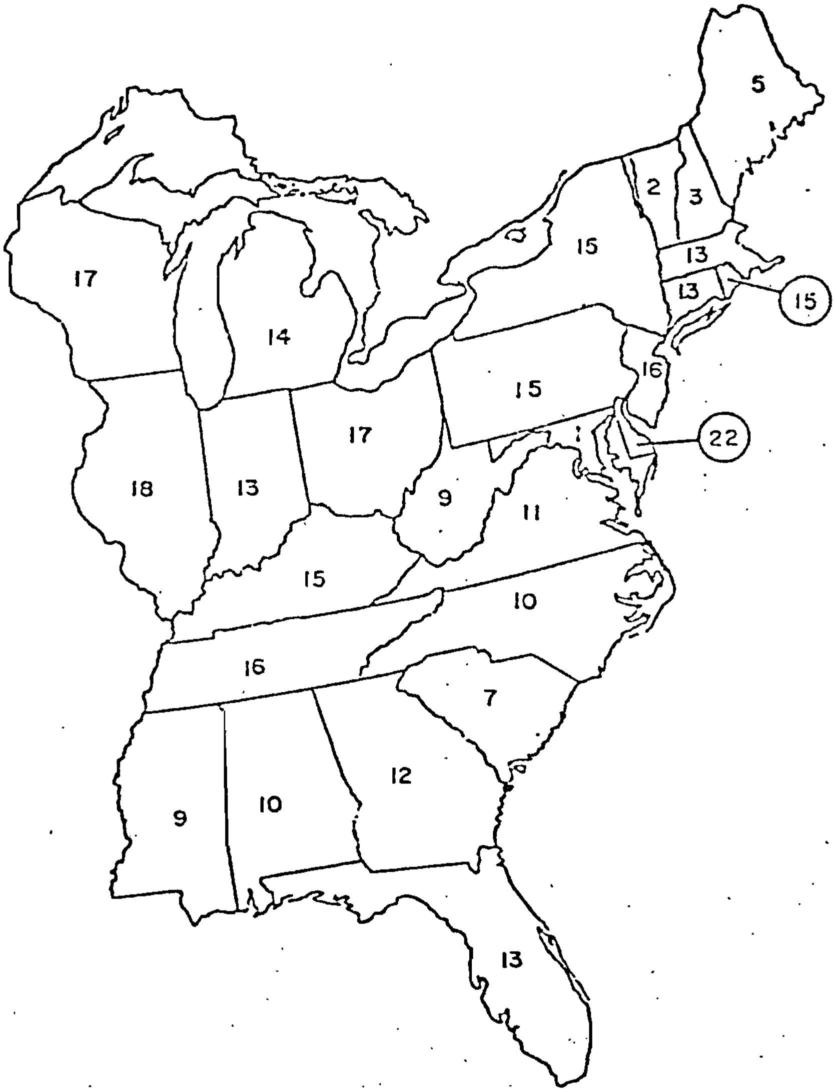
FIGURE 4

TABLE 18

STATE ACCIDENT DATA PER 100 LINE MILES

STATE	# OF ACCIDENTS 1975-1979	LINE MILES*	AVERAGE # OF ACCIDENTS/YR	# OF ACCIDENTS PER 100 LINE MILES PER YEAR
Florida	2569	4007	513.8	13
Mississippi	1537	3576	307.4	9
Alabama	2309	4437	461.8	10
Georgia	3357	5400	671.4	12
South Carolina	1092	2946	218.4	7
North Carolina	1983	4081	396.6	10
Tennessee	2461	3142	492.2	16
Kentucky	2661	3497	532.2	15
Ohio	5764	6775	1152.8	17
Wisconsin	2404	5669	480.8	8
Michigan	3717	5209	743.4	14
Indiana	3661	5496	732.2	13
Illinois	8997	10,203	1799.4	18
Virginia	1958	3716	391.6	11
West Virginia	1516	3450	303.2	9
Maryland	1300	766	260.0	34
Delaware	238	218	47.6	22
New Jersey	1134	1381	226.8	16
Pennsylvania	5127	6757	1025.4	15
New York	3304	4310	660.8	15
Connecticut	234	354	46.8	13
Rhode Island	58	78	11.6	15
Massachusetts	609	955	121.8	13
Vermont	93	775	18.6	2
Maine	424	1623	84.8	5
New Hampshire	94	637	18.8	3

*Source: Economics and Finance Department, American Association of Railroads.



NUMBER OF ANNUAL ACCIDENTS/INCIDENTS PER 100 LINE MILES

FIGURE 5

Using these data, routes between states having differing accident/incident frequencies were constructed.

4.2.6 Route Selection

Seven primary and seven alternate routes were chosen for the risk analysis using the information above for production capacity, location of A-F-R sites and state accident history. The seven origin to destination pairs are:

Decatur, AL to Barnwell, SC
Gaffney, SC to Barnwell, SC
Mineral, VA to Barnwell, SC
Seabrook, NH to West Valley, NY
St. Clair County, MI to Morris, IL
Oak Harbor, OH to Morris, IL
Hartsville, TN to Barnwell, SC

A detailed description of each route follows in the next section.

4.3 ROUTE DESCRIPTIONS

A description of each routing pair is discussed in this section. Route-specific information includes:

- length of each rail segment;
- total route length;
- average population density along each segment;
- route length for each population density zone;
- rail carriers active along each route;
- track class for each segment;
- traffic density for each segment;
- length of route travelled over each track class;
- and length travelled per traffic density class.

In the route description, the origin (nuclear power plant) is given first, followed by the destination (A-F-R). Figures 6 through 19 show the geography of the selected routing pairs.

4.3.1 Route 1: Decatur, AL to Barnwell, SC

4.3.1.1 Route 1A: Brown's Ferry Nuclear Station (Decatur, AL) to Barnwell, SC A-F-R

A. Origin	Destination	Railroad	Segment Miles Rural	Suburban	Urban	Total
Decatur AL	Birmingham AL	Family Lines	77	0	7	84
Birmingham AL	Atlanta GA	Southern	10	112	47	169
Atlanta GA	Barnwell GA	Family Lines	188	104	0	292
		TOTAL	275	216	54	545
		PERCENT	50	40	10	100

B. Mileage, Class of Track and Traffic Density for "503 Segments" on Route

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
Decatur AL	LN134	64	4	5
	LN135	10	4	5
	LN268	10	4	5
Birmingham AL	XX098	11	4	5
	S0354	57	4	5
	S0241	49	4	5
	S0097	35	4	5
	S0323	17	4	6
Atlanta, GA	GAR10	47	4	4
	GAR08	21	4	4
	GAR07	39	4	4
	GAR06	25	4	4
	GAR05	27	4	4
	GAR04	15	4	4

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
	SZ379	40	4	4
Barnwell SC	SZ166	27	4	4

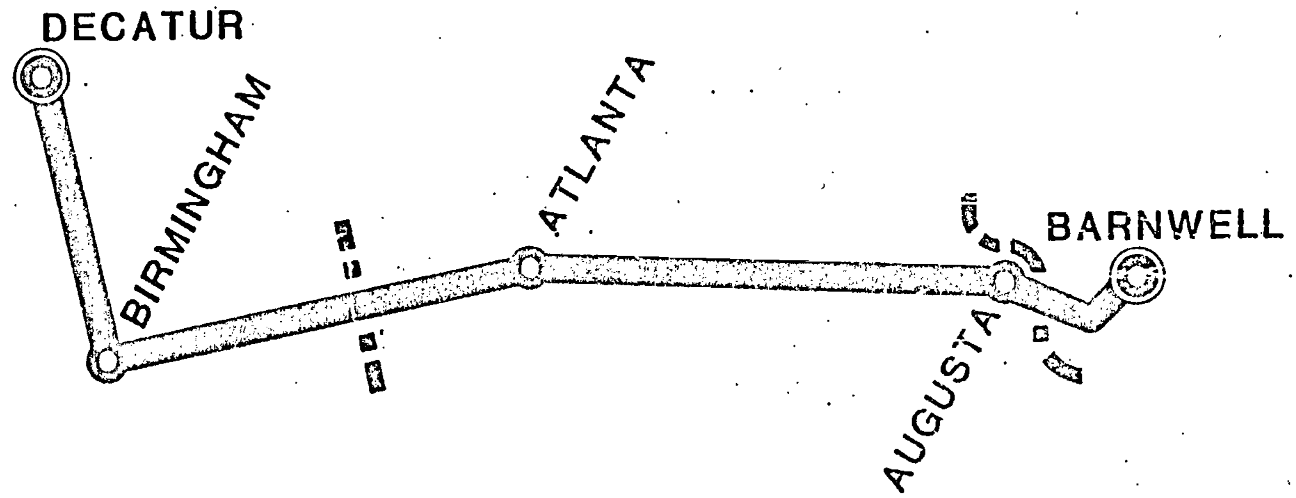
C.

	1	2	3	4	5	6
Miles in Track Class	0	0	0	545	0	0
Miles in Traffic Density	0	0	78	214	236	17

D. Average Route Population Density (persons/mi^2)

Rural = 1.114
Suburban = 391
Urban = 5,704

ROUTE 1: BROWNS FERRY NUCLEAR STATION
DECATUR (AL) TO BARNWELL (SC) A-F-R



ALTERNATE 1A – 545 MILES (872 KILOMETERS)

FIGURE 6.

4.3.1.2 Route 1B: Browns Ferry Nuclear Station (Decatur,AL) to Barnwell,SC A-F-R

A.

Origin	Destination	Railroad	Segment Miles Rural	Suburban	Urban	Total
Decatur AL	Huntsville AL	Southern	1	23	0	24
Huntsville AL	Barnwell SC	Family Lines	87	342	151	580
		TOTAL	88	365	151	604
		PERCENT	15	60	25	100

B. Mileage, Class of Track and Traffic Density for "503 Segments" on Route

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
Decatur AL	S0260	24	4	4
Huntsville AL	LN143	38	4	1
	LN151	32	4	1
	LN274	8	4	4
	LN148	12	4	4
	LN129	20	4	4
	LN267	26	4	1
Talladega AL	SZ429	50	4	4
	SZ333	28	4	4
	SZ099	26	4	4
	SZ101	6	4	4
	SZ102	56	4	6
	SZ388	32	4	6
	SZ387	54	4	2
	SZ083	30	4	2
	SZ076	64	4	3

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
Savannah GA	SZ385	16	4	5
	SZ080	32	4	3
	SZ170	6	4	4
	SZ169	24	4	4
Barnwell SC	SZ166	20	4	3

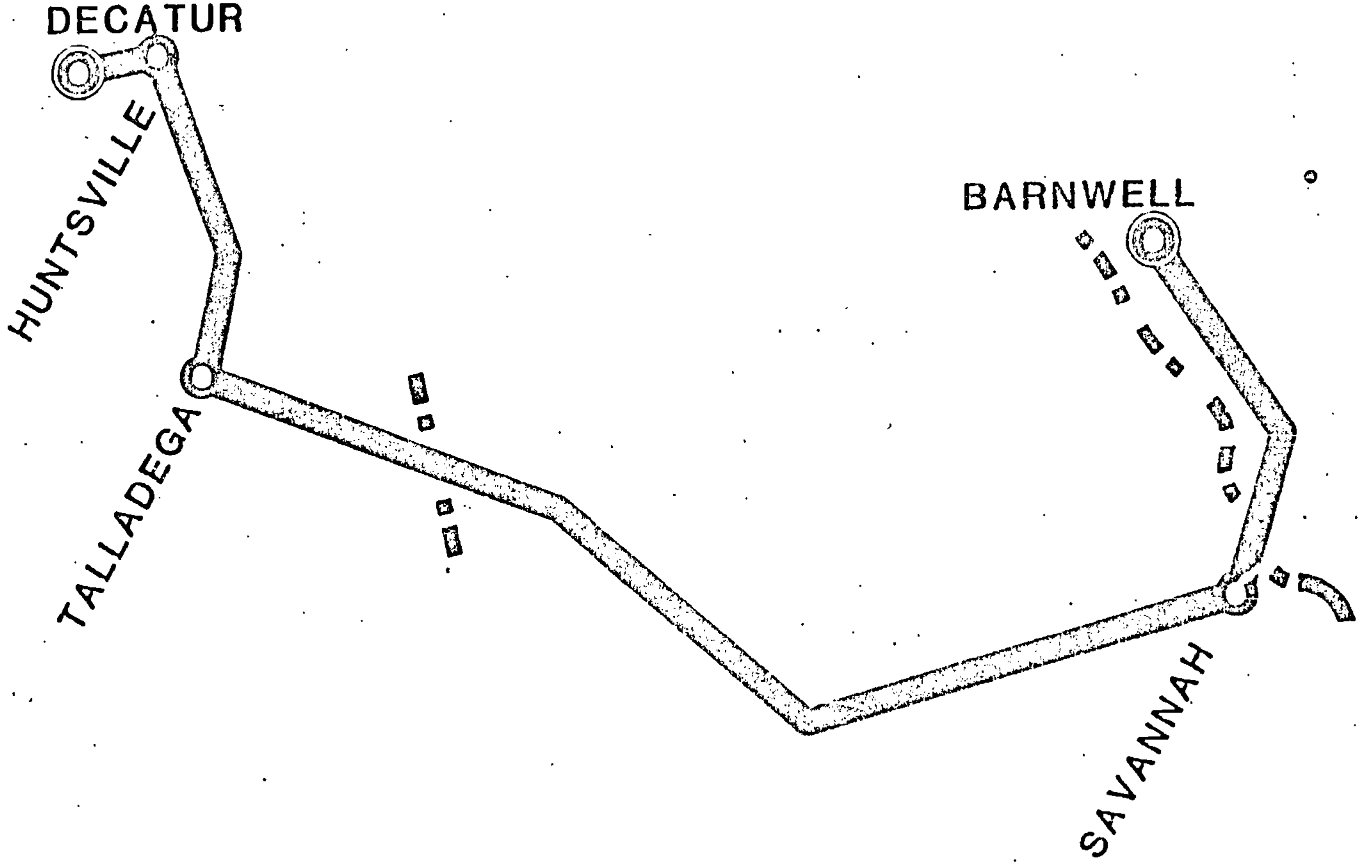
C.

	1	2	3	4	5	6
Miles in Track Class	0	0	0	604	0	0
Traffic Density	96	84	116	204	16	88

D. Average Route Population Density (persons/mi^2)

Rural = 0.000
Suburban = 288
Urban = 5,014

ROUTE 1: BROWNS FERRY NUCLEAR STATION
DECATUR (AL) TO BARNWELL (SC) A-F-R



ALTERNATE 1B - 604 MILES (966 KILOMETERS)

FIGURE 7.

4.3.2 Route 2: Cherokee Nuclear Station (Gaffney, SC) to Barnwell, SC A-F-R

4.3.2.1 Route 2A: Cherokee County Nuclear Station (Gaffney, SC) to Barnwell, SC A-F-R

A. Origin	Destination	Railroad	Segment Miles Rural	Suburban	Urban	Total
Gaffney SC	Macon GA	Southern	140	124	26	290
Macon GA	Barnwell SC	Family Lines	163	92	21	276
		TOTAL	303	216	47	566
		PERCENT	54	38	8	100

B. Mileage, Class of Track and Traffic Density for "503 Segments" on Route

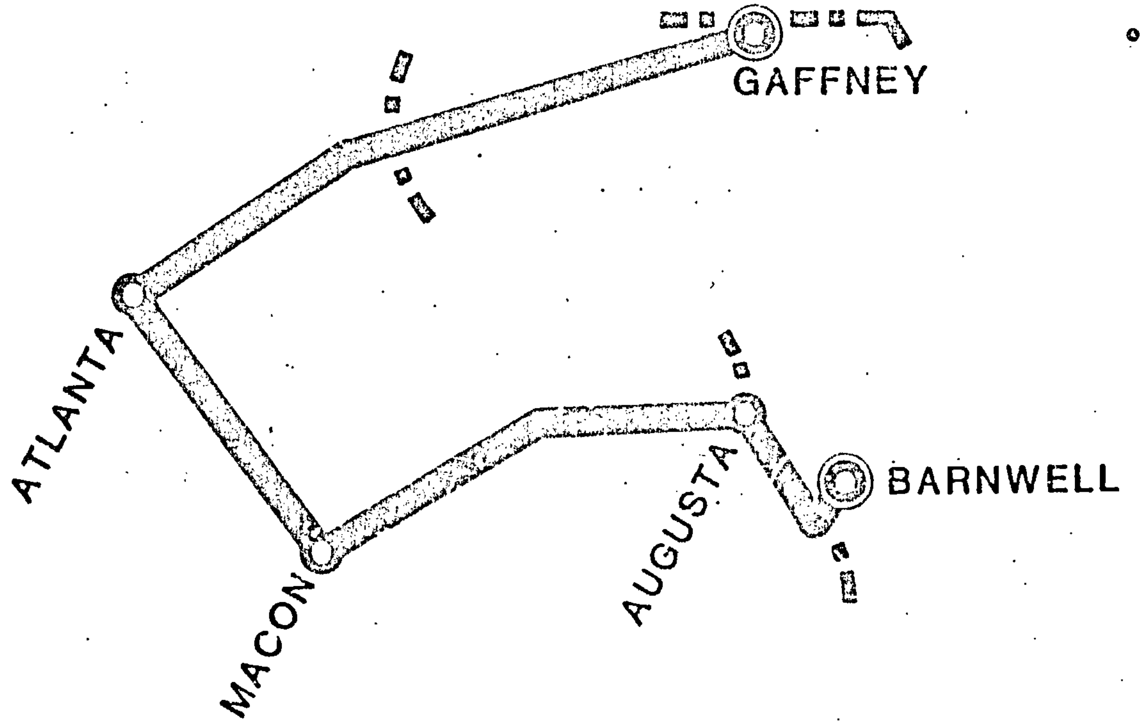
Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
Gaffney S.C.	S0310	37	4	5
	S0312	21	4	5
	S0317	13	4	5
	S0318	11	4	5
	S0157	29	4	5
	S0094	31	4	5
	S0095	18	4	5
	S0037	9	4	5
	S0324	48	4	5
Atlanta GA.	S0325	11	4	6
	S0192	12	4	6
	S0334	50	4	6
Macon GA.	GAR12	50	4	2
	GAR03	77	4	3
	GAR09	69	4	3
	SZ379	50	4	5
	SZ166	30	4	3

C.	1	2	3	4	5	6
Miles in Track Class	0	0	0	566	0	0
Miles in Traffic Density	0	50	176	0	267	73

D. Average Route Population Density (persons/mi^2)

Rural = 0.000
Suburban = 282
Urban = 5,993

ROUTE 2: CHEROKEE NUCLEAR STATION GAFFNEY (SC)
TO BARNWELL (SC) A-F-R



ALTERNATE 2A: – 566 MILES
(906 KILOMETERS)

FIGURE 8.

4.3.2.2 Route 2B: Cherokee County Nuclear Station (Gaffney, SC) to Barnwell, SC A-F-R

A.

Origin	Destination	Railroad	Segment Miles Rural	Suburban	Urban	Total
Gaffney SC	Lexington NC	Southern	33	58	29	120
Lexington NC	Wadesboro NC	Winston-Salem Southbound	29	35	5	69
Wadesboro NC	Barnwell SC	Family Lines	263	198	36	497
	TOTAL		325	291	70	686
	PERCENT		47	42	11	100

B. Mileage, Class of Track and Traffic Density for "503 Segments" on Route

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
Gaffney SC	S0310	50	4	5
	S0001	12	4	5
	S0065	40	4	5
	S0066	18	4	6
Lexington NC	WSS04	24	3	3
	WSS03	11	3	3
	WSS02	16	3	3
	WSS01	18	3	3
Wadesboro NC	SZ026	24	4	6
	SZ134	21	4	3
	SZ139	26	4	1
	SZ148	9	4	2
	SZ147	16	4	2
	SZ152	36	4	5
	SZ157	9	4	5

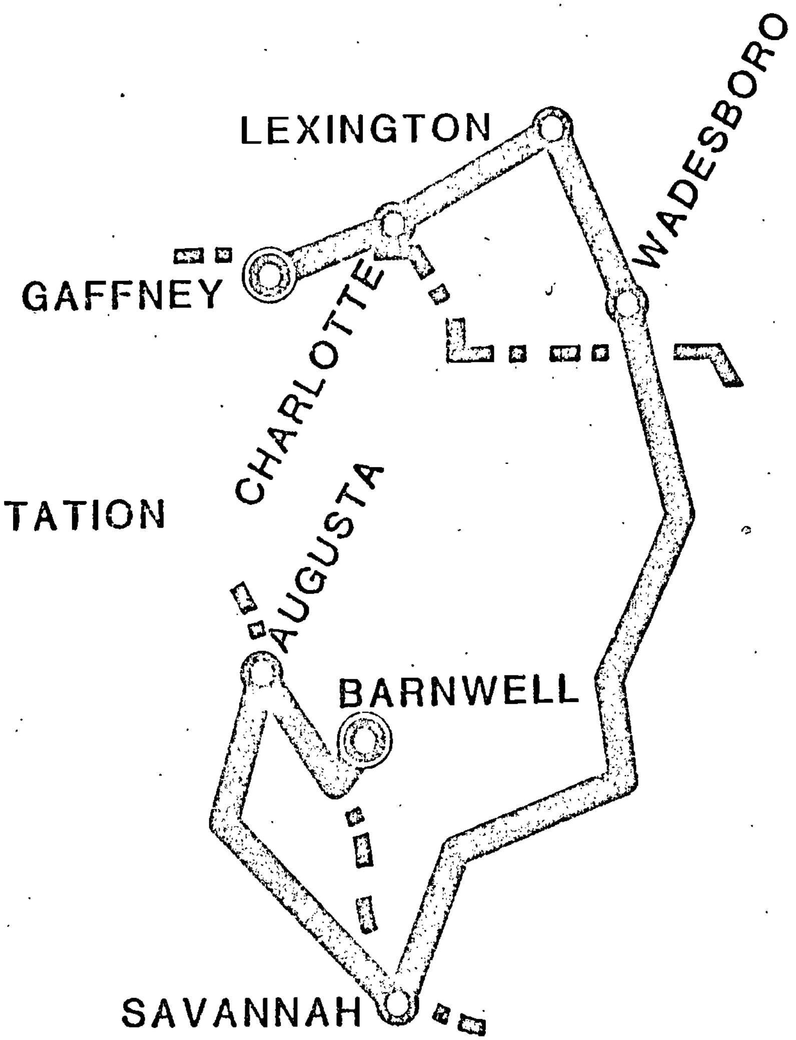
Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
Charleston SC	SZ432	52	4	5
	SZ159	13	4	5
	SZ053	29	4	5
	SZ174	27	4	5
	SZ054	15	4	2
	SZ383	42	4	2
Savannah GA	S0171	14	4	4
	S0170	26	4	4
	S0169	16	4	4
	S0168	22	4	4
	S0166	22	4	4
Augusta GA	S0328	28	4	4
	SZ379	30	4	4
Barnwell SC	SZ166	20	4	3

C.

	1	2	3	4	5	6
Miles in Track Class	0	0	69	617	0	0
Miles in Traffic Density	26	82	110	158	268	42

D. Average Route Population Density (persons/mi^2)

Rural = 0.000
Suburban = 554
Urban = 3,864



ROUTE 2:
CHEROKEE NUCLEAR STATION
GAFFNEY (SC) TO
BARNWELL (SC) A-F-R

ALTERNATE 2B - 686 MILES
(1098 KILOMETERS)

FIGURE 9.

4.3.3 Route 3: North Anna Power Station (Mineral, VA) to Barnwell, S.C. A-F-R

4.3.3.1 Route 3A: North Anna Nuclear Power Station (Mineral, VA) to Barnwell, SC A-F-R

A.

Origin	Destination	Railroad	Segment Miles Rural	Suburban	Urban	Total
Mineral VA	Charlottesville VA	Chessie	5	22	0	27
Charlottesville VA	Barnwell SC	Southern	143	200	92	435
		TOTAL	148	222	92	462
		PERCENT	32	48	20	100

B. Mileage, Class of Track and Traffic Density for "503 Segments" on Route

Origin/Destination Node	503 Segment	Class of Mileage	Track	Traffic Density
Mineral VA	CX094	18	4	1
	CX095	3	4	3
	CX091	6	4	3
Charlottesville VA	S0010	39	4	5
	S0276	16	4	5
	S0277	22	4	5
	S0115	42	4	5
	S0031	43	4	6
Greensboro NC	S0296	14	4	6
	S0070	6	4	6
	S0064	12	4	6
	S0066	16	4	6
	S0065	29	4	6
	S0295	12	4	6
	S0508	32	4	5
	S0309	50	4	3
Charlotte NC	S0305	38	4	3
	S0307	56	3	2

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
Barnwell SC	S0138	8	3	1

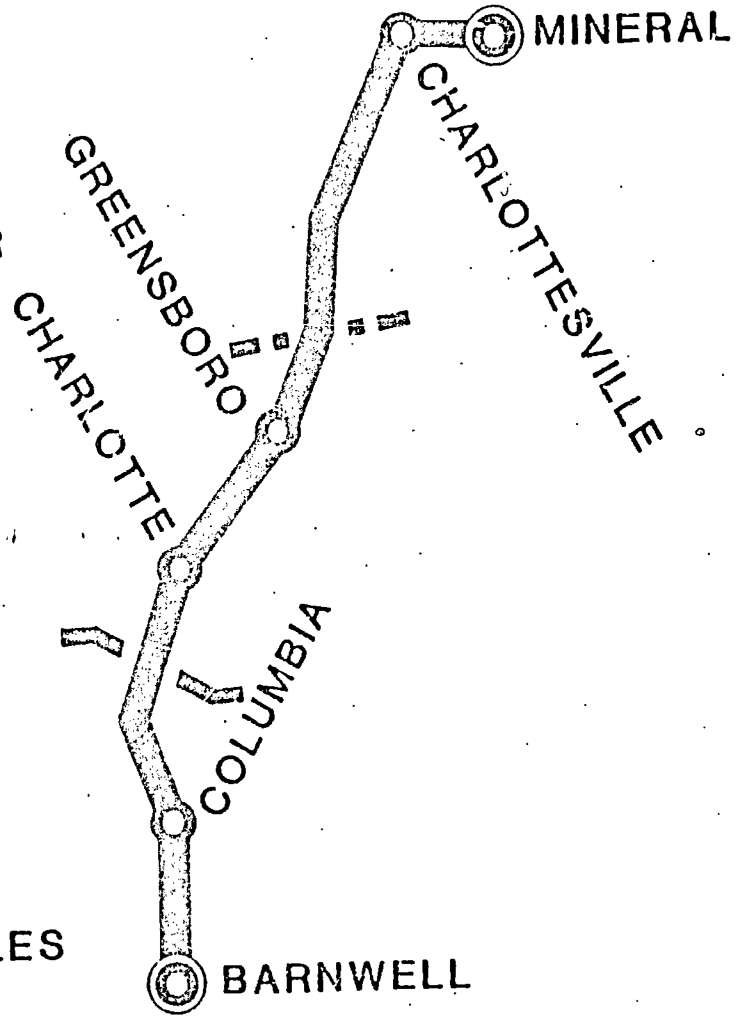
C.

	1	2	3	4	5	6
Miles in Track Class	0	0	64	398	0	0
Miles in Traffic Density	26	56	97	0	151	132

D. Average Route Population Density (persons/mi^2)

Rural = 0.000
Suburban = 472
Urban = 5,811

ROUTE 3:
NORTH ANNA NUCLEAR
STATION MINERAL (VA)
TO BARNWELL (SC) A-F-R



ALTERNATE 3A - 462 MILES
(739 KILOMETERS)

FIGURE 10

4.3.3.2 Route 3B: North Anna Power Station (Mineral, VA) to Barnwell, SC A-F-R

A.

Origin	Destination	Railroad	Segment Miles Rural	 Suburban	 Urban	 Total
Mineral VA	Richmond VA	Chessie	7	90	9	106
Richmond VA	Barnwell SC	Family Lines	147	212	50	409
		TOTAL	154	302	59	515
		PERCENT	30	59	11	100

B. Mileage, Class of Track and Traffic Density for "503 Segments" on Route

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
Mineral VA	CX094	64	4	1
	CX244	42	4	2
Richmond VA	SZ008	18	4	6
	SZ010	6	4	6
	SZ339	8	4	6
	SZ004	27	4	6
	SZ003	12	4	6
	SZ042	23	4	6
	SZ043	10	4	6
	SZ044	27	4	6
	SZ045	20	4	6
	SZ048	19	4	6
	SZ047	18	4	6
	SZ117	22	4	6
	SZ351	14	4	5
	SZ123	16	4	5
	SZ124	8	4	5

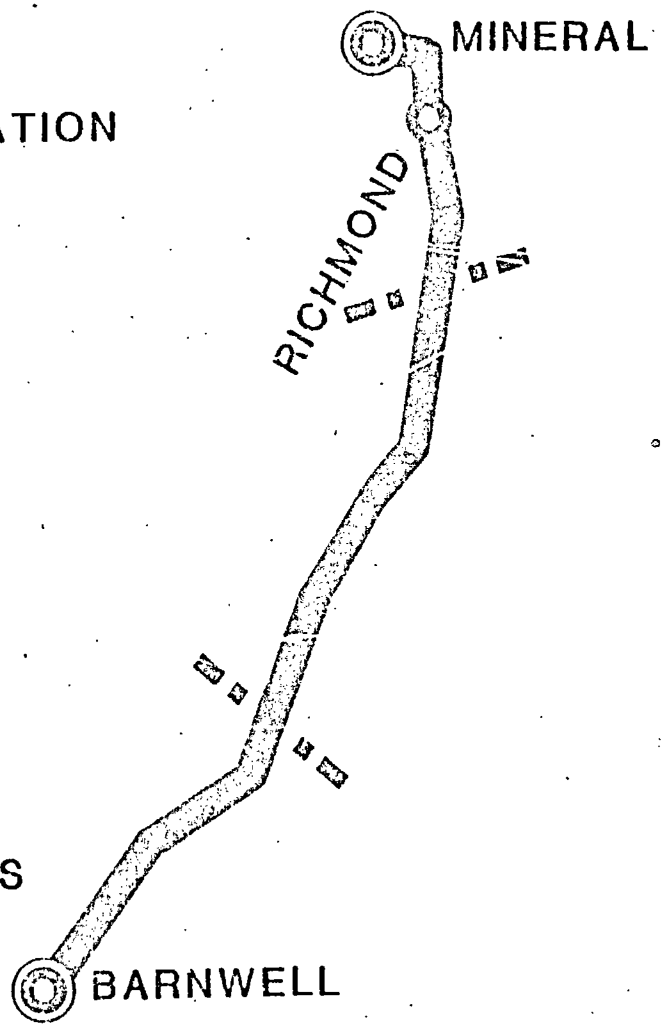
Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
	SZ141	16	4	5
	SZ145	18	4	6
	SZ356	16	4	6
	SZ149	34	4	3
	SZ354	21	4	3
	SZ164	21	4	3
	SZ357	19	4	3
Barnwell SC	SZ165	16	4	3

C.	1	2	3	4	5	6
Miles in Track Class	0	0	0	515	0	0
Miles in Traffic Density	64	42	111	0	54	244

D. <u>Average Route Population Density (persons/mi^2)</u>

Rural = 0.000
Suburban = 474
Urban = 5,351

ROUTE 3:
NORTH ANNA NUCLEAR STATION
MINERAL (VA) TO
BARNWELL (SC) A-F-R



ALTERNATE 3B - 515 MILES
(824 KILOMETERS)

FIGURE 11

4.3.4 Route 4: Seabrook Nuclear Station (Seabrook, NH) to West Valley, NY A-F-R

4.3.4.1 Route 4A: Seabrook Nuclear Station (Seabrook, NH) to West Valley, NY A-F-R

A.

Origin	Destination	Railroad	Segment Miles Rural	 Suburban	 Urban	 Total
Seabrook NH	Boston MA	Boston & Maine	11	30	29	70
Boston MA	Buffalo NY	Conrail	105	155	236	496
Buffalo NY	West Valley NY	Chessie	7	13	39	59
		TOTAL	123	198	304	625
		PERCENT	20	32	48	100

B. Mileage, Class of Track and Traffic Density for "503 Segments" on Route

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
Seabrook NH	BM030	15	1	1
	BM039	25	3	1
	BM040	5	3	1
	BM052	25	3	2
Boston MA	BM054	5	4	3
	BM050	10	4	1
	P0006	5	4	1
	P0008	5	4	2
	P0023	28	4	5
Worcester MA	P0022	3	4	5
	P0591	43	4	5
	P0889	13	4	5
	P0890	14	4	5
	P0887	13	4	6
	P0021	60	4	6
	P0884	19	4	6

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
	P0048	12	4	6
Albany NY	P0845	14	4	6
	P0609	3	4	6
	P0607	15	4	6
	P0931	21	4	6
	P0804	23	4	6
	P0805	10	4	6
	P0803	10	4	6
	P0809	10	4	6
	P0810	10	4	6
	P0811	5	4	6
	P0042	35	4	6
	P0816	5	4	6
Rochester NY	P0043	28	4	6
	P0612	10	4	6
	P0614	25	4	6
	P0615	32	4	6
Buffalo NY	P0624	10	4	1
West Valley NY	BX240	59	3	3

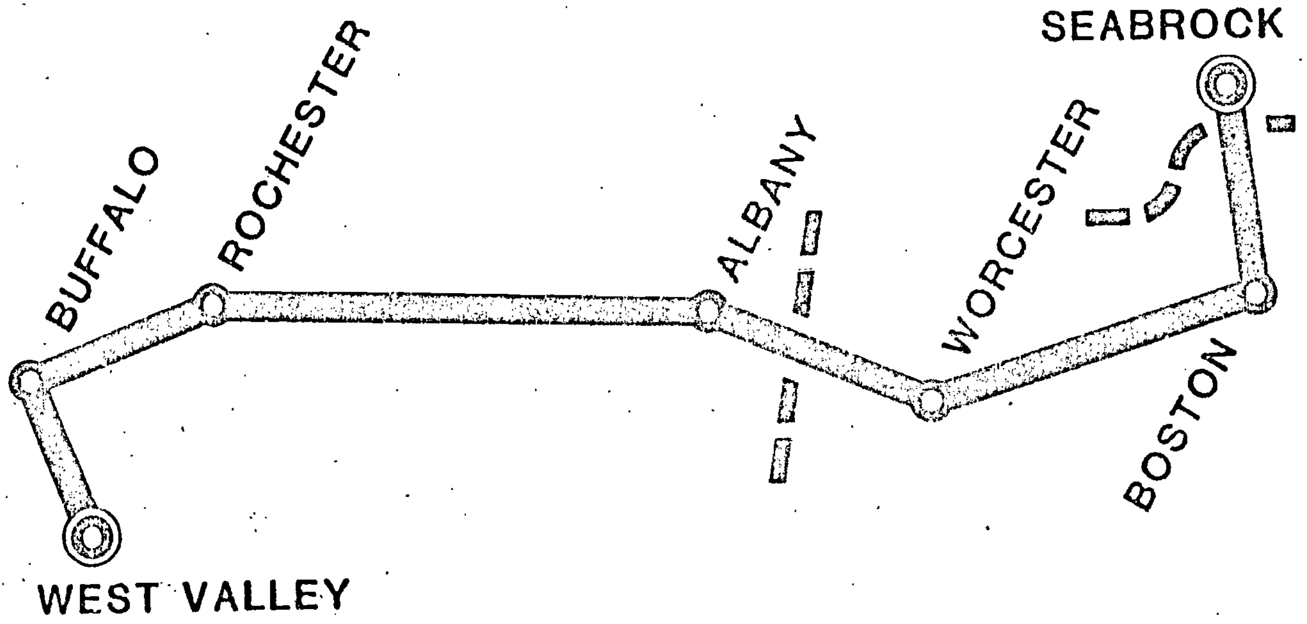
C.

	1	2	3	4	5	6
Miles in Track Class	15	0	114	496	0	0
Miles in Traffic Density	70	30	64	0	101	360

D. Average Route Population Density (persons/mi^2)

Rural = 0.000
Suburban = 1,059
Urban = 7,981

ROUTE 4: SEABROOK NUCLEAR STATION
SEABROOK (NH) TO WEST VALLEY (NY) A-F-R



ALTERNATE 4A - 625 MILES (1000 KILOMETERS)

FIGURE 12.

4.3.4.2 Route 4B: Seabrook Nuclear Station (Seabrook, NH) to West Valley, NY A-F-R

A. Origin	Destination	Railroad	Segment Miles Rural	Suburban	Urban	Total
Seabrook NH	White River Jct. VT	Boston & Maine	31	114	85	230
White River Jct. VT	Burlington VT	Central VT	49	46	0	95
Burlington VT	Rutland VT	Vermont	60	0	0	60
Rutland VT	Schenectady NY	Delaware & Hudson	35	48	14	97
Schenectady NY	West Valley NY	Conrail	97	219	319	635
		TOTAL	272	427	418	1117
		PERCENT	24	38	38	100

b. Mileage, Class of Track and Traffic Density for "503 Segments" on Route

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
Seabrook NH	BM030	39	1	1
	BM004	62	2	1
	BM022	32	2	2
	BM017	97	2	1
White River Jct.VT	CV005	52	2	3
	CV004	33	2	3
	CV018	10	2	2
Burlington VT	VTR06	50	3	-
	VTR04	10	3	-
Rutland VT	DH003	15	1	2
	DH008	13	1	2
	DH010	3	1	4
	DH011	17	1	4

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
	DH037	21	1	-
Schenectady NY	P0607	9	4	6
Albany NY	P0609	11	4	6
	P0846	10	4	4
	P0049	45	4	3
Newburgh NY	P0853	15	4	5
	EL146	25	4	1
	LHR01	40	4	1
	LHR06	20	4	1
	LHR02	20	4	1
	EL079	14	4	2
	EL094	5	4	2
	EL076	21	4	2
	EL080	19	4	1
	LV029	10	4	1
	LV031	7	4	1
Bethlehem PA	LV032	6	4	1
	LV036	6	4	1
Allentown PA	RDG37	4	4	6
	RDG38	6	4	6
	RDG31	10	4	6
	RDG79	9	4	6
	RDG34	2	4	5
	RDG33	9	4	6
	RDG71	10	4	5
	RDG74	15	4	6

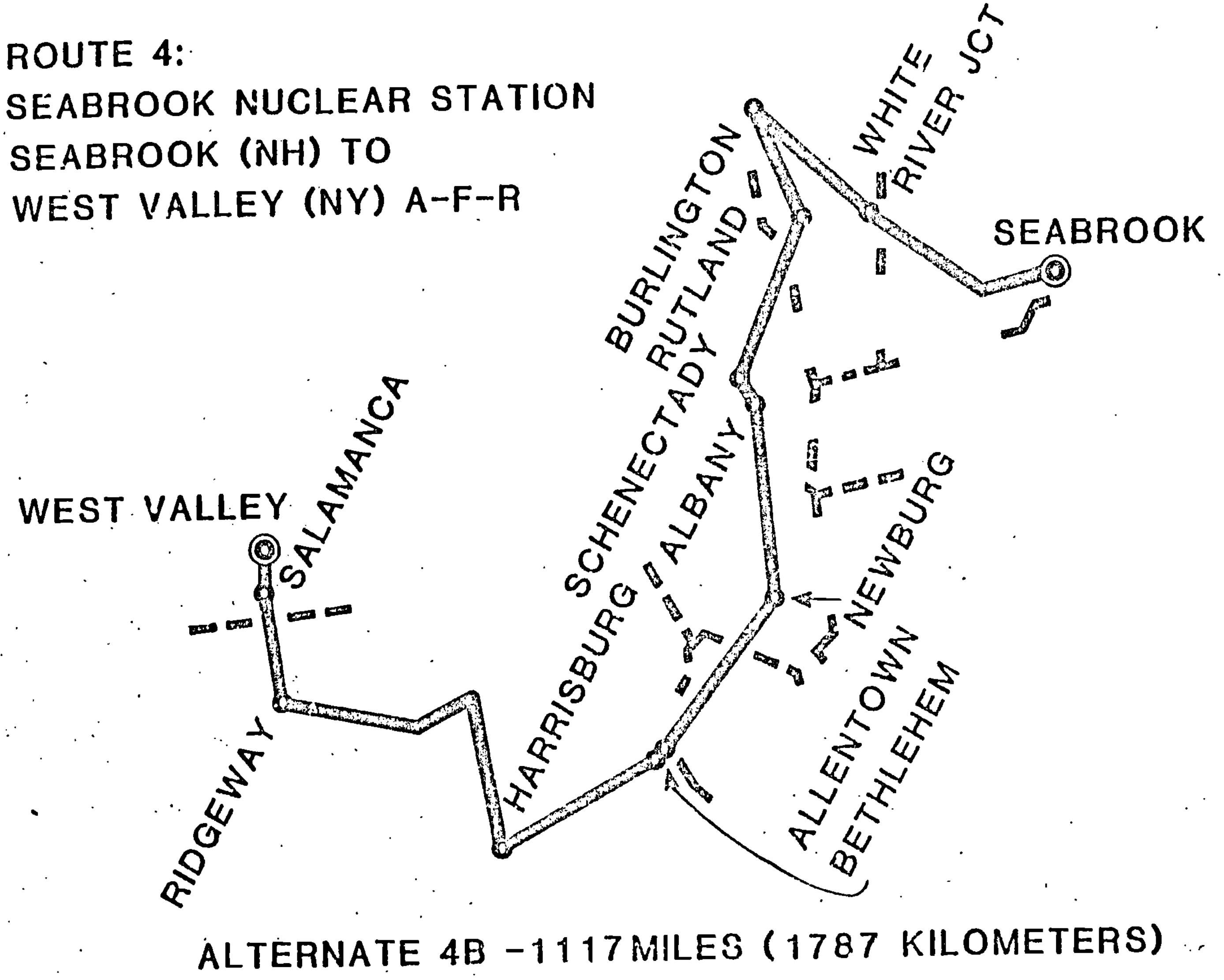
Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
	RDG55	15	4	6
Harrisburg PA	P0183	6	3	6
	P0179	8	3	5
	P0189	25	3	5
	P0188	6	3	5
	P0634	15	3	5
	P0636	6	3	5
	RDG49	11	3	1
	P0770	17	3	5
	P0769	13	3	3
	P0067	4	3	3
	P0066	6	3	5
	P0785	25	3	6
	P0784	14	3	5
	P0783	14	3	5
	P0781	25	3	2
Ridgway PA	EL102	18	3	4
	BX007	25	3	3
	EL021	5	3	3
	EL02[illegible]	6	3	4
Salamanca NY	EL143	5	3	4
West Vailey NY	P0618	18	3	5

C.

	1	2	3	4	5	6	Unknown
Miles in Track Class	136	286	332	363	0	0	0
Miles in Traffic Density	362	135	177	87	165	110	81

D. Average Route Population Density (persons/mi^2)

Rural = 1.269
Suburban = 363
Urban = 1,962



ROUTE 4:
SEABROOK NUCLEAR STATION
SEABROOK (NH) TO
WEST VALLEY (NY) A-F-R

ALTERNATE 4B -1117 MILES (1787 KILOMETERS)

FIGURE 13.

4.3.5 Route 5: Greenwood Energy Center (St. Clair, MI) to Morris, IL. A-F-R

4.3.5.1 Route 5A: Greenwood Energy Center, (St. Clair County, MI) to Morris, IL. A-F-R

A. Origin	Destination	Railroad	Segment Miles Rural	Suburban	Urban	Total
St. Clair MI	Detroit MI	Grand Trunk Western	1	8	6	15
Detroit MI	Chicago IL	Conrail	0	143	153	296
Chicago IL	Morris IL	Burlington Northern	7	16	91	114
		TOTAL	8	167	250	425
		PERCENT	2	39	59	100

B. Mileage, Class of Track and Traffic Density for "503 Segments" on Route

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
St. Clair MI	GTW16	15	4	3
Detroit MI	P0546	12	4	3
	P0543	12	4	3
Ann Arbor MI	PI010	49	4	3
	P0542	36	4	3
	P0537	18	4	3
	P0538	36	4	1
	P0519	21	4	1
	P0518	15	4	1
	P0469	61	4	1
	UBN01	36	4	1
Chicago IL	BNC04	36	4	6
	BN002	10	4	6
	CH005	13	4	2
	CH025	26	4	6
	CH026	16	4	6

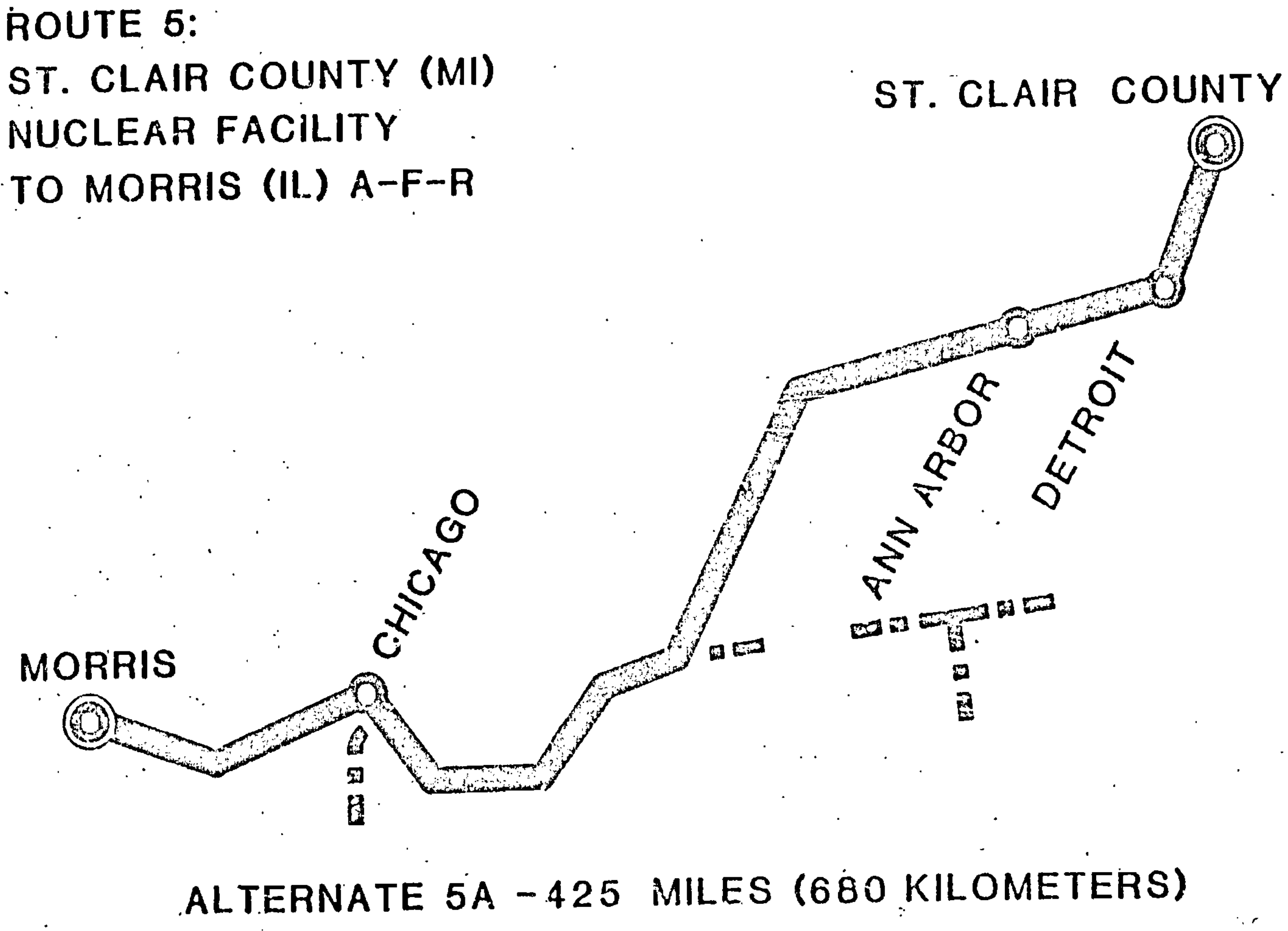
Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
	BN549	5	2	5
Morris IL	BN010	8	2	5

C.

	1	2	3	4	5	6
Miles in Track Class	0	8	0	417	0	0
Miles in Traffic Density	169	13	142	0	13	88

D. Average Route Population Density (persons/mi^2)

Rural = 1.225
Suburban = 647
Urban = 9,068



ROUTE 5:
ST. CLAIR COUNTY (MI)
NUCLEAR FACILITY
TO MORRIS (IL) A-F-R

ALTERNATE 5A -425 MILES (680 KILOMETERS)

FIGURE 14.

4.3.5.2 Route 5B: Greenwood Energy Center (St. Clair, MI) to Morris, IL. A-F-R

A.

Origin	Destination	Railroad	Segment Miles Rural	Suburban	Urban	Total
St. Clair MI	Durand MI	Grand Trunk Western	9	45	16	70
Durand MI	Ann Arbor MI	Ann Arbor	12	18	22	52
Ann Arbor MI	Ft. Wayne IN	Conrail	3	95	107	205
Ft. Wayne IN	Logansport IN	Norfolk & Western	17	30	25	72
Logansport IN	El Paso IL	Toledo, Peoria, & Western	6	37	98	141
El Paso IL	Mendota IL	Illinois Central Gulf	25	21	11	57
Mendota IL	Morris IL	Burlington Northern	8	17	78	103
		TOTAL	80	263	357	700
		PERCENT	11	38	51	100

B. Mileage, Class of Track and Traffic Density for "503 Segments" on Route

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
St. Clair MI	GTW16	15	4	3
	GTW15	10	4	3
	GTW13	15	4	1
	GTW14	8	4	1
	GTW10	11	4	4
	GTW29	11	4	4
Durand MI	AA009	24	2	1
	AA008	8	2	1
	AA007	20	2	1
Ann Arbor MI	PI010	49	4	3

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
	PI011	70	4	3
	P0530	14	4	1
	P0531	27	4	1
	P0393	10	4	1
	P0398	10	4	2
	P0403	25	4	2
Ft. Wayne IN	NW062	28	4	5
	NW054	21	4	5
	NW365	23	4	6
Logansport IN	P0408	5	4	4
	TPW25	15	4	3
	TPW24	6	4	3
	TPW22	33	4	3
	TPW23	7	4	3
	TPW12	5	4	3
	TPW13	6	4	3
	TPW20	13	4	3
	TPW14	20	4	4
	TPW15	6	4	3
	TPW16	10	4	3
El Paso IL	IC029	12	2	2
	IC027	6	2	2
	IC028	8	2	2
	IC025	18	2	2
	IC290	16	2	2
Mendota, IL	BN592	11	2	6

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
	BN277	29	2	6
	BN278	4	2	6
	BN273	38	2	5
	BN274	5	2	5
	BN549	5	2	5
Morris IL	BN010	8	2	5

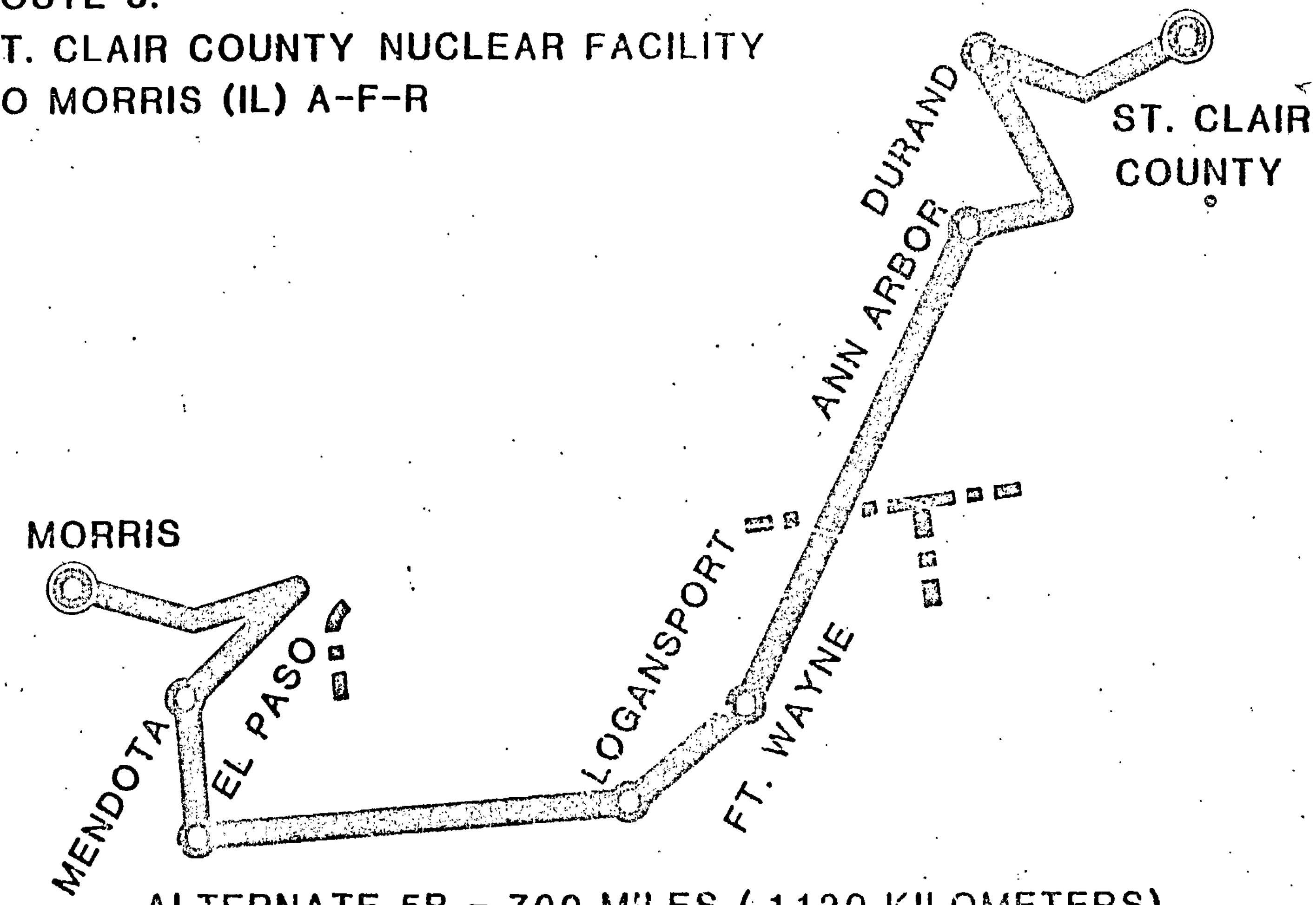
C.

	1	2	3	4	5	6
Miles in Track Class	0	212	0	488	0	0
Miles in Traffic Density	126	95	260	47	105	67

D. Average Route Population Density (persons/mi^2)

Rural = 0.131
Suburban = 797
Urban = 9,152

ROUTE 5:
ST. CLAIR COUNTY NUCLEAR FACILITY
TO MORRIS (IL) A-F-R



ALTERNATE 5B – 700 MILES (1120 KILOMETERS)

FIGURE 15.

4.3.6 Route 6: Davis-Besse Nuclear Power Station (Oak Harbor, OH) to Morris, IL A-F-R

4.3.6.1 Route 6A: Davis Besse Nuclear Power Station (Oak Harbor, OH) to Morris, IL A-F-R

A. Origin	Destination	Railroad	Segment Miles Rural	 Suburban	 Urban	 Total
Oak Harbor OH	South Bend IN	Conrail	16	16	206	238
South Bend IL	Chicago IL	Grand Trunk Western	18	16	208	242
Chicago IL	Morris IL	Burlington Northern	7	6	92	105
		TOTAL	41	38	506	585
		PERCENT	7	6	87	100

B. Mileage, Class of Track and Traffic Density for "503 Segments" on Route

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
Oak Harbor OH	P0378	5	4	6
	P0380	3	4	6
Toledo OH	P0382	44	4	6
	P0396	72	4	6
	P0395	36	4	6
	P0394	34	4	6
	P0391	16	4	6
	P0978	28	4	6
South Bend IN	GTW02	36	4	5
	GTW01	20	4	5
	GTW38	16	4	5
	GTW03	134	4	5
Gary IN	UBN01	36	4	1
Chicago IL	BN004	36	4	6
	BN002	10	4	6

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
	BN003	3	4	6
	BN273	38	4	5
	BN274	5	4	5
	BN549	5	4	5
Morris IL	BN010	8	4	5

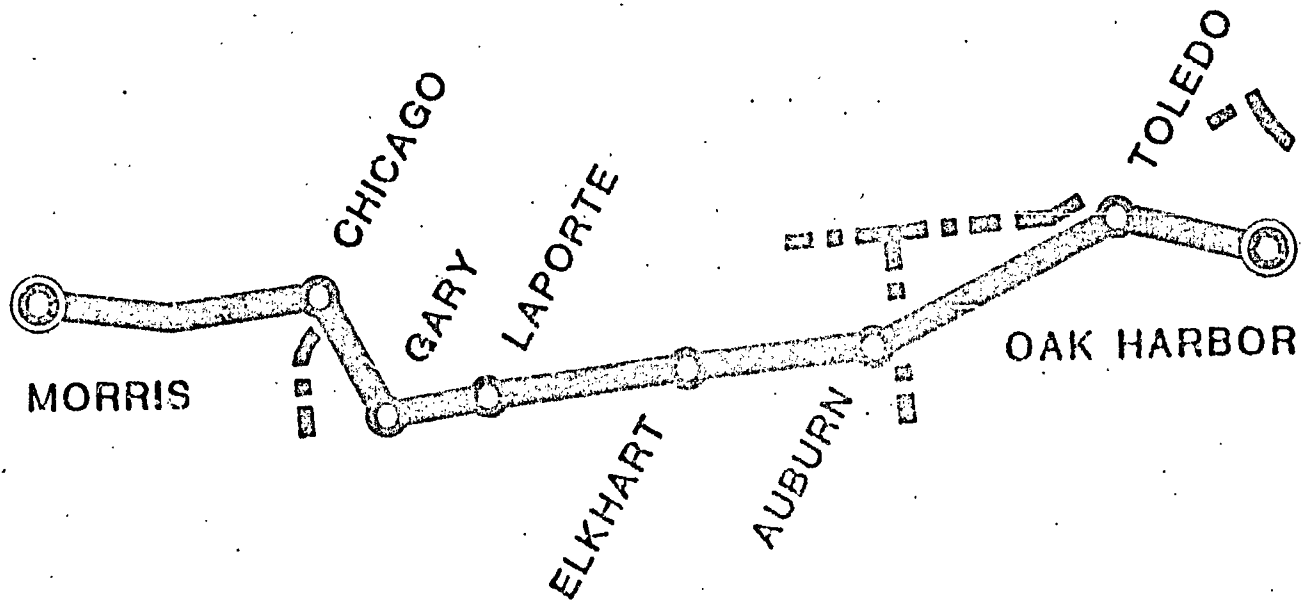
C.

	1	2	3	4	5	6
Miles in Track Class	0	0	0	585	0	0
Miles in Traffic Density	36	0	0	0	262	323

D. Average Route Population Density (persons/mi^2)

Rural = 0.000
Suburban = 189
Urban = 11,130

ROUTE 6:
OAK HARBOR (OH) NUCLEAR GENERATING FACILITY
TO MORRIS (IL) A-F-R



ALTERNATE 6A - 585 MILES (936 KILOMETERS)

FIGURE 16.

4.3.6.2 Route 6B: Davis-Besse Nuclear Station (Oak Harbor,OH) to Morris, IL A-F-R

A.

Origin	Destination	Railroad	Segment Miles Rural	Suburban	Urban	Total
Oak Harbor OH	Toledo OH	Conrail	0	0	8	8
Toledo OH	Lima OH	Chessie	10	27	37	74
Lima OH	Guion IN	Norfolk & Western	39	143	32	214
Guion IN	Decatur IL	Chessie	26	45	17	88
Decatur IL	Mendota IL	Illinois Central Gulf	66	39	28	133
Mendota IL	Morris IL	Burlington Northern	8	17	78	103
		TOTAL	149	271	200	620
		PERCENT	24	44	32	100

B. Mileage, Class of Track and Traffic Density for "503 Segments" on Route

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
Oak Harbor OH	P0378	5	4	6
	P0380	3	4	6
Toledo OH	BX133	18	3	6
	BX134	19	3	6
	BX136	8	3	6
	BX277	16	3	6
	BX278	13	3	6
Lima OH	EL160	36	4	1
	NW371	16	4	1
	NW370	19	4	1
	NW060	43	4	1

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
	NW060	43	4	1
	NW055	34	4	1
	NW368	36	4	1
	NW367	16	4	3
	NW075	14	4	3
Guion IN	LN021	7	4	3
	LN022	9	4	3
	BX151	22	3	2
	BX150	5	3	2
	BX155	7	3	2
	BX156	4	3	2
	BX288	13	3	2
	BX287	21	3	2
Decatur IL	IC307	16	3	2
	IC128	9	3	2
	IC316	27	3	2
	IC087	20	3	2
	IC029	12	3	2
	IC027	3	3	2
	IC028	8	3	2
	IC025	20	3	2
	IC026	3	3	2
	IC290	15	3	2
Mendota IL	BN592	11	4	6
	BN277	32	4	6
	BN278	6	4	6

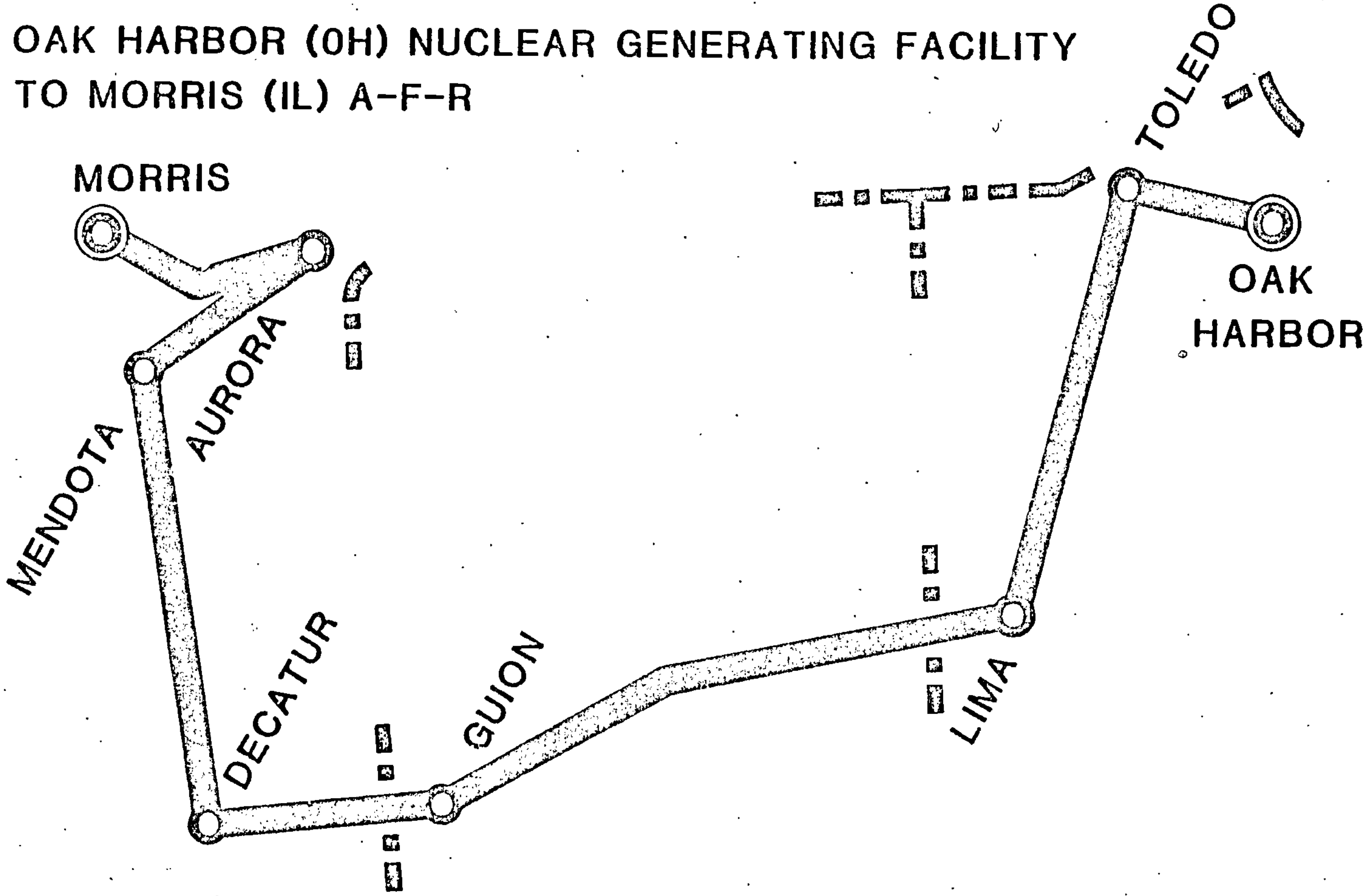
Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
Aurora IL	BN273	31	4	5
	BN274	10	4	5
Morris IL	BN010	13	4	5

C.	1	2	3	4	5	6
Miles in Track Class	0	0	279	341	0	0
Miles in Traffic Density	184	205	46	0	54	131

D. Average Route Population Density (persons/mi^2)

Rural = 0.070
Suburban = 588
Urban = 12,626

ROUTE 6:
OAK HARBOR (0H) NUCLEAR GENERATING FACILITY
TO MORRIS (IL) A-F-R



ALTERNATE 6B - 620 MILES (992 KILOMETERS)

FIGURE 17.

4.3.7 Route 7: Hartsville Nuclear Station (Hartsville, TN) to Barnwell, SC A-F-R

4.3.7.1 Route 7A: Hartsville Nuclear Station (Hartsville, TN) to Barnwell, SC A-F-R

A.

Origin	Destination	Railroad	Rural	Segment Miles Suburban	Urban	Total
Hartsville TN	Nashville TN	Family Lines	34	0	3	37
Nashville TN	Atlanta GA	Southern	38	184	33	255
Atlanta GA	Barnwell SC	Family Lines	188	104	0	292
		TOTAL	260	288	36	601
		PERCENT	45	49	6	100

B. Mileage, Class of Track and Traffic Density for "503 Segments" on Route

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
Hartsville TN	LN213	22	4	5
	LN252	15	4	6
Nashville TN	LN216	8	4	2
	LN218	26	4	2
	S0380	50	4	1
	S0137	5	4	4
	S0045	8	4	4
	S0044	5	4	4
	S0042	5	4	4
	S0289	10	4	5
Knoxville TN	S0041	25	4	5
	S0136	10	4	5
	S0135	5	4	5
	S0373	10	4	3
	S0371	10	4	6
	S0036	28	4	6

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
	S0322	13	4	6
	S0321	20	4	6
	S0323	17	4	6
Atlanta GA	GAR10	47	4	4
	GAR08	21	4	4
	GAR07	39	4	4
	GAR06	25	4	4
	GAR05	27	4	4
	GAR04	15	4	4
	GAR09	51	4	3
Augusta GA	SZ379	40	4	4
Barnwell SC	SZ166	27	4	3

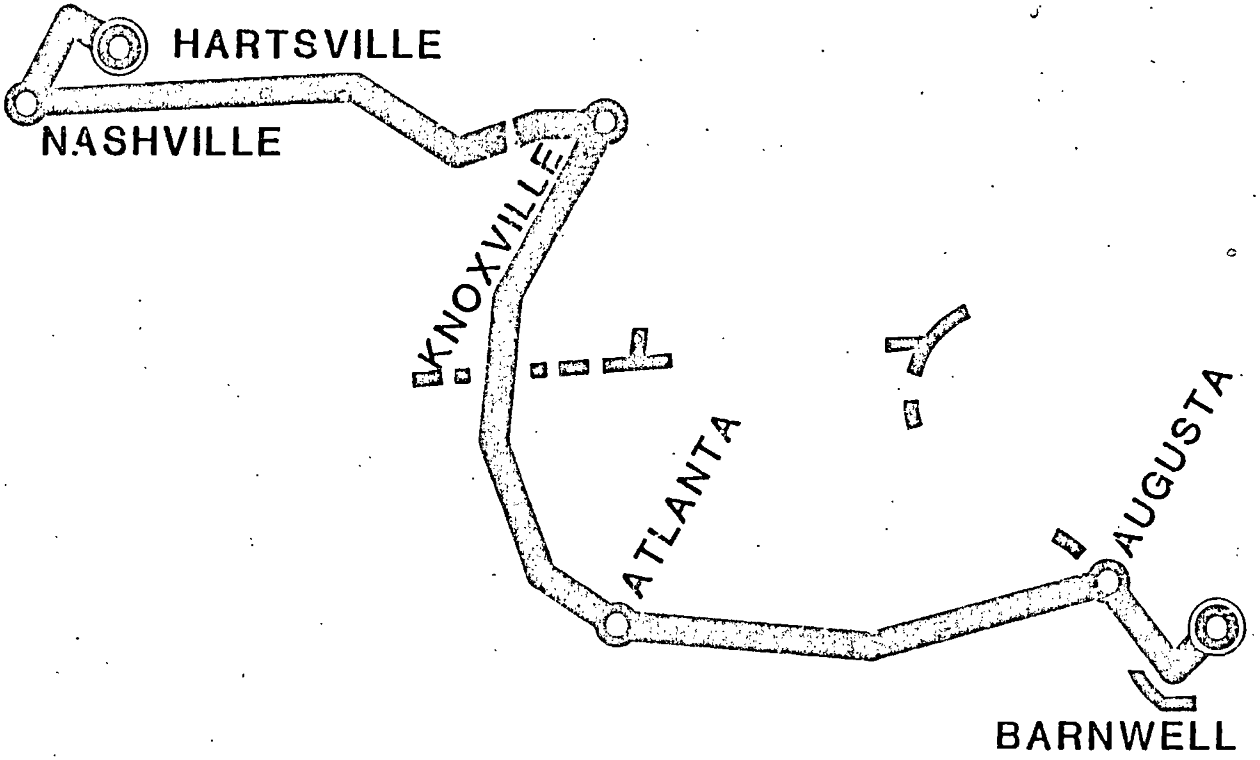
C.

	1	2	3	4	5	6
Miles in Track Class	0	0	0	601	0	0
Miles in Traffic Density	54	34	88	237	85	103

D. Average Route Population Density (persons/mi^2)

Rural = 1.709
Suburban = 311
Urban = 6,721

ROUTE 7: HARTSVILLE (TN) NUCLEAR PLANT TO BARNWELL (SC) A-F-R



ALTERNATE 7A - 601 MILES (962 KILOMETERS)

FIGURE 18.

4.3.7.2 Route 7B: Hartsville, TN Nuclear Station to Barnwell, SC A-F-R

A.

Origin	Destination	Railroad	Segment Miles Rural	Suburban	Urban	Total
Hartsville TN	Birmingham AL	Family Lines	191	62	13	266
Birmingham AL	Atlanta GA	Southern	10	112	47	169
Atlanta GA	Barnwell SC	Family Lines	188	104	0	292
		TOTAL	389	278	60	727
		PERCENT	54	38	8	100

B. Mileage, Class of Track and Traffic Density for "503 Segments" on Route

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
Hartsville TN	LN213	22	1	5
	LN252	15	4	6
Nashville TN	LN214	7	4	5
	LN205	36	4	4
	LN144	58	4	1
	LN145	22	4	5
	LN134	80	4	5
	LN268	13	4	5
Birmingham AL	XX098	15	4	5
	S0354	50	4	5
	S0241	46	4	5
	S0097	36	4	5
	S0323	22	4	6
Atlanta GA	SZ377	82	4	5
	SZ378	38	4	5
	SZ073	15	4	5

Origin/Destination Node	503 Segment	Mileage	Class of Track	Traffic Density
	SZ074	47	4	4
	SZ379	39	4	4
Barnwell SC	SZ166	25	4	3

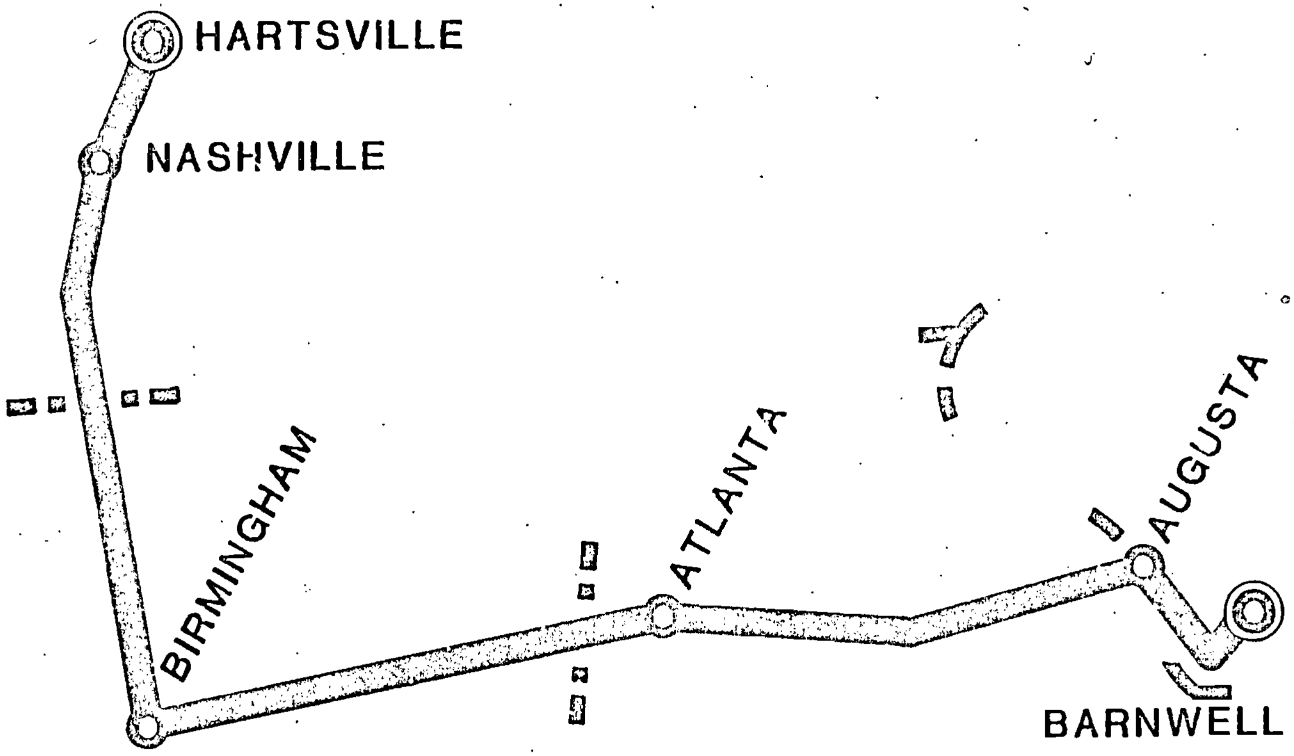
C.

	1	2	3	4	5	6
Miles in Track Class	22	0	0	705	0	0
Miles in Traffic Density	104	0	25	122	439	37

D. Average Route Population Density (persons/mi^2)

Rural = 2.359
Suburban = 380
Urban = 7,098

ROUTE 7: HARTSVILLE (TN) NUCLEAR PLANT
TO BARNWELL (SC) A-F-R



ALTERNATE 7B - 727 MILES (1163 KILOMETERS)

FIGURE 19.

5. RISK/COST ANALYSIS

5.1 GENERAL

In this section, the risk and cost analysis methodologies developed in Section 3 are applied to the routes selected in Section 4. The specific issues addressed include:

- the risks associated with the normal rail transportation of spent fuel;
- the risks associated with an accident involving rupture of a spent fuel rail cask with accompanying release of radioactive material;
- the costs associated with normal transportation of spent fuel; and
- an analysis of the sensitivity of risk with respect to certain parameters.

As discussed earlier, risk in this study is expressed as radiological exposure, with costs expressed in dollars.

5.2 ANALYSIS OF THE RISKS ASSOCIATED WITH THE NORMAL TRANSPORTATION OF SPENT FUEL

The risk associated with the normal transportation of spent fuel via the selected routing alternatives was calculated. The risk values in milli man-rems for the various routing alternatives are given in Table 19. The percentages of route length in rural, urban and suburban areas are also included.

The totals for the routes analyzed range from 15 to 46 milli man-rems. It is felt that these levels pose no serious threat to public health or the environment since the dose levels produced in these normal transportation modes are less than the average individual background exposure of approximately 100 millirem/yr. Since the U.S. population consists of approximately 200 million people, the annual population dose due to background radiation alone is 2.0×10^{10} milli man-rems, which is about 18 orders of magnitude larger than the dose calculated for the normal transport of spent fuel by rail.

5.3 ANALYSIS OF THE RISKS OCCURRING FROM AN ACCIDENT INVOLVING SPENT FUEL RELEASE

The risk levels associated with release of radioactive material in a rail accident occurring on each of the routing combinations were calculated by implementing the transportation accident risk model discussed in Section 3.3. Route specific input data as well as release probability data derived by Sandia Laboratory were used and the resultant route specific man-rem exposure levels were calculated.

TABLE 19. NORMAL TRANSPORT MAN-REM DOSE FOR EACH ROUTE

ROUTE NAME	ROUTE NUMBER	% OF TOTAL ROUTE LENGTH IMPACTING RURAL	SUBURBAN	URBAN	DOSE IN MILLI MAN-REMS
Decatur, AL - Barnwell, SC	1A	50	40	10	15
" "	1B	15	60	25	18
Gaffney, SC - Barnwell, SC	2A	54	38	8	15
" "	2B	47	42	11	16
Mineral.VA - Barnwell, SC	3A	32	48	20	17
" "	3B	30	59	11	16
Seabrook, NH - West Valley, NY	4A	20	32	48	28
" "	4B	24	38	38	19
St. Clair, MI - Morris, IL	5A	2	39	59	27
" "	5B	11	38	51	33
Oak Harbor, OH - Morris, IL	6A	7	6	87	46
" "	6B	24	44	32	29
Hartsville, TN - Barnwell, SC	7A	45	49	6	15
" "	7B	54	38	8	16

5.3.1 Dose Released and Adjacent Area Contaminated

To identify the dose released and adjacent area contaminated in a potential accident, the values shown in Tables 6 through 8 were condensed as discussed in Section 3. The accident dose levels in areas along any route, irrespective of population density and release probabilities, will be 1.13 rem-mi^2 for (Kr^{85}), 1.09×10^{-1} rem-mi^2 for (I^{131}), and 2.76×10^{1} rem-mi^2 for fission products. The total dose released by these isotopes is 28.8 rem-mi^2.

As shown in Section 3, route specific doses with various release fractions and population densities, are used to determine probabilistic expected doses as

$$D = PA^{r}\left[28.8 \text{ rem-mi}^{2} \text{ x}Pr\text{x}Rf\text{x}PD\right] \qquad (5\text{-}1)$$

where	PA^r	is the route specific accident probability
	Pr	is the probability of release
	Rf	is the release function for a certain severity of accident
	PD	is the population density along the route

Values for Pr, Rf and PD for rural, suburban and urban environments are given in Tables A-3 of Appendix A. These values are based on values derived by Sandia Laboratory and can be used to calculate the probability of release for a specific route by mulitplying the respective releases probabilities with release fraction and the number of miles in the population density zone Values for PA^r are given in Table 13. The equation is stated mathematically as follows:

$$\begin{aligned} DT = PA^r \ 28.8 \text{ rem-mi}^2 \text{ x } & (1.05\text{x}10^{-3}\text{xLrxPDr}) + (5.73\text{x}10^{-4}\text{x Ls x PDs}) + \\ & (3.79\text{x}10^{-4}\text{xLuxPDu}) + 2.88 \text{ rem-mi}^2 \text{ x } (5.4\text{x}10^{-3}\text{xLrxPDr}) + (7.33 \text{ x}10^{-3} \\ & \text{xLsxPDs}) + (5.4\text{x}10^{-3}*\text{LuxPDu}) + .288 \text{ rem-mi}^2 \text{ x } (5.4\text{x}10^{-2}\text{xLrxPDr}) + \\ & (7.33\text{x}10^{-2} \text{ xLsxPDs}) + (5.4\text{x}10^{-2}\text{xLuxPDu}) \end{aligned} \qquad (5\text{-}2)$$

The average population densities in rural, urban and suburban zones for each route were utilized in equation (5-2) to calculate total dose for each route.

5.3.2 Accident Doses for Various Routes

The accident doses in milli man-rems for the primary and alternate rail routes have been calculated using equation 5-2 and are given in Table 20.

From Table 20, the difference in milli man-rem dose that would be experienced from transporting spent fuel via the primary versus the alternate route can be calculated. Table 21 shows these differences.

TABLE 20. ACCIDENT DOSE ASSOCIATED WITH THE VARIOUS ROUTES

ROUTE	ACCIDENT DOSE (milli man-rems)
1A	920
1B	1,290
2A	620
2B	640
3A	540
3B	830
4A	4,790
4B	15,670
5A	5,180
5B	19,470
6A	19,220
6B	16,180
7A	790
7B	1,880

TABLE 21

VARIATION IN ACCIDENT DOSE BETWEEN ALTERNATE ROUTES

ROUTE	DIFFERENCE IN DOSE (milli man-rems)	ROUTE HAVING HIGHER MAN-REM DOSE
1A 1B	370	1B
2A 2B	20	2B
3A 3B	290	3B
4A 4B	10,880	4B
5A 5B	14,290	5B
6A 6B	3,040	6A
7A 7B	1,090	7B

5.3.3 Comparison of Normal Transportation Dose and Accident Dose

Table 22 presents the normal transportation and accident dose levels for a shipment of spent nuclear fuel via each of the primary and alternate route pairs. The last column shows the sum of the normal and accident doses. This represents the true total risk for a shipment, since the total risk exposure must include both normal and accident components.

The man-rem exposure to individuals as a result of spent fuel cask accidents is higher than the expocure during normal transportation. Risk associated with the accident situation exceeds normal transportation risk by at least an order of magnitude for all routes. Route 6A poses the highest normal transport risk (46 milli man-rem) while Route 5B poses the highest exposure (19,470 milli man-rem), in an accident situation. Routes showing higher risk levels in the normal transportation cycle (6A, 5B, 6B, 4A, 5A, 4B) traverse the area of highest total average population density as well as traveling greater distances (in terms of percentage of total route length) in urban and surburban population density zones. The normal transportation dose is population dependent and the magnitude of each route dose from 46 to 15 milli man-rems corresponds to a decreasing total average population affected as well as decreasing percent of route length in rural and suburban density zones. Route 6A traverses 87 percent of its 585 mile length in urban density zones, affecting a total average population of 5.7 million persons. Route 5B while totaling 700 miles travels 51 percent of its length in urban density zones, affecting a total average population of 3.5 million persons. This trend continues with no anomalies for all 14 routing pairs.

The accident risk levels represented by the routing alternatives vary from 540 (Route 3A) to 19,470 (Route 5B) milli man-rems. Total risk levels for the route combinations range from 557 to 19,503 milli man-rems.

The accident dose for the various routes follow the same general patterns as the normal transportation dose. In general, the routes with higher total average population affected and higher percentage of total route length in urban and suburban density zones have higher accident doses. However, the accident model is probabilistic and other factors such as railroad accident history, track class and switching accidents represent significant contributions to route specific accident probability and thus to the overall dose. For example, Route 5B and 6A have the highest accident doses, 19,470 and 19,220 milli man-rem, respectively. Both, these routes have more than 50 percent of their length in urban density zones at 9,000 persons/mi.^{2}. Route 5B is 700 miles long, has more switches than any other route, 30 percent of its route on less than class 4 track and 51 percent of its length in urban zones affecting 3.3 million persons. Route 6A, on the

TABLE 22

ROUTE SPECIFIC RISK LEVELS

ROUTE NAME	ROUTE NUMBER	NORMAL TRANSPORTATION DOSE (milli man-rems)	ACCIDENT DOSE (milli man-rems)	TOTAL DOSE (milli man-rems)
Decatur, AL - Barnwell, SC	1A	15	920	935
Decatur, AL - Barnwell, SC	1B	18	1,290	1,308
Gaffney, SC - Barnwell, SC	2A	15	620	635
Gaffney, SC - Barnwell, SC	2B	16	640	656
Mineral, VA - Barnwell, SC	3A	17	540	557
Mineral, VA - Barnwell, SC	3B	16	830	846
Seabrook, NH - West Valley, NY	4A	28	4,790	4,818
Seabrook, NH - West Valley, NY	4B	19	15,670	15,689
St. Clair, MI - Morris, IL	5A	27	5,180	5,207
St. Clair, MI - Morris, IL	5B	33	19,470	19,503
Oak Harbor, OH - Morris, IL	6A	46	19,220	19,266
Oak Harbor, OH - Morris, IL	6B	29	16.180	16,209
Hartsville, TN - Barnwell, SC	7A	15	790	805
Hartsville, TN - Barnwell, SC	7B	16	1,880	1,896

other hand, travels only on class 4 track, has only two interchange points, is 585 miles long, with 87 percent of its length in urban density zones, affecting 5.7 million persons. Thus, these two routes which have the highest accident doses have differing contributions from the various inputs to the model and point up the interaction and interdependence of the functional elements comprising the accident model.

5.4 COST-BENEFIT ANALYSIS ASSOCIATED WITH ALTERNATE ROUTING OF SPENT FUEL IN NORMAL TRANSPORTATION

5.4.1 General

The relationship between transport costs for spent fuel shipments and radiation dose levels via primary and alternate rail routes are evaluated in this section. The incremental costs for rail shipments of spent fuel along specified routes are calculated and evaluated in terms of variation in exposure levels. Route specific freight cost data were obtained from the originating rail carrier or from published ICC Class 40 rates. In cases where the data were not available, ICC rates were extrapolated based on actual route mileage and 120-ton minimum weight limitation in order to give an expected total transport cost, cost per ton mile and cost per man-rem dose for each route. Cask rental costs were obtained through personal contact with cask manufacturers.

5.4.2 Route Specific Total Transport Costs

The cost methodology developed in Section 3.3 was used to determine total transport costs along each route. The first step was to determine rail cask rental costs on a per-trip basis. The total shipping time from reactor facility to AFR was estimated for each route. Total shipment time in hours was calculated by summing each route segment length (miles traveled in each population density), divided by the estimated train velocity in each zone plus stop times. Mathematically, this is expressed as

$$T = \left[\left(\frac{Lr}{Vr}\right) + 24 + \frac{Ls}{Vs} + \frac{Lu}{Vu}\right] \qquad (5\text{-}4)$$

where the stoptimes have been assumed as rural = 24 hours, suburban and urban = 0 hours. Using the following velocity data: rural = 60 mph, suburban = 60 mph and urban = 60 mph, together with route lengths given in section 4.3 lead to route transit times as shown in Table 23. An average train velocity of 60 mph was assumed in all population density zones because approximately 81 percent of the routes in this study are composed of class 4 track, with a maximum permitted freight train speed of 60 mph (49 CFR Sec. 213.9).

The cask rental costs can be calculated by doubling the one-way transit times of Table 23 and using a daily cash rental of $3,500 (Section 3.4). The freight rates for the various routes were obtained by contacting the originating railroads on the lines and supplementing them with ICC Class 40 rates where applicable. The railroads quote two types of rates, one which applies to shipment of regular materials and one which involves special rates which the railroads often apply to materials such as nuclear spent fuel. Table 24 shows the total rail transport costs (i.e., cask rental costs + freight rates) for the various routes.

TABLE 23. ROUTE TRANSIT TIMES (HOURS)

ROUTE	TRANSIT TIME
1A	33.1
1B	34.1
2A	35.4
2B	33.4
3A	31.7
3B	32.6
4A	34.4
4B	42.6
5A	31.1
5B	35.7
6A	33.8
6B	34.3
7A	34.0
7B	36.1

TABLE 24. TOTAL RAIL TRANSPORT COSTS (DOLLARS)

ROUTE	CASK RENTAL	FREIGHT RATES	TOTAL COST WITHOUT SPECIAL FREIGHT RATES	SPECIAL FREIGHT RATES	TOTAL COST WITH SPECIAL FREIGHT RATES
1A	4826.97	10,776	15,602.97	14,527.56	30,130.53
1B	4972.80	10,776	15,748.80	17,440.40	33,189.20
2A	4870.72	6,864	11,734.72	13,449.80	25,184.52
2B	5162.38	6,864	12,026.38	18,770.60	30,797.73
3A	4622.81	9,648	14,270.81	14,700.00	28,970.81
3B	4754.06	9,648	14,402.06	15,000.00	29,402.06
4A	5016.55	9,648	14,664.55	17,100.00	31,764.55
4B	6212.36	9,648	15,860.36	26,250.00	42,110.36
5A	4535.31	9,648	14,183.31	13,650.00	27,833.36
5B	5206.13	9,648	14,854.13	19,650.00	34,504.13
6A	4893.75	22,565	27,458.75	27,708.00	55,166.75
6B	4978.33	Unavailable	Unavailable	Unavailable	49,848.33
7A	4958.22	11,472	16,430.22	18,163.44	34,593.66
7B	5264.46	11,472	16,736.46	18,163.44	34,399.90

5.4.3 Unit Costs Shipment

Table 25 presents total transport costs on a per rail-mile basis and on a per ton-mile basis using a standard of 70-tons for the loaded cask weight.

5.4.4 Incremental Cost of Reducing Exposure Through Alternative Routing

The differences in total transport cost and dose levels between the routing pairs were analyzed to assess the cost of reducing radiation dose to the population through alternative routing. These are shown in Tables 26 and 27. The incremental dose reduction using alternative routing ranges from 29 to 15,111 milli man-rems. The increments in total transportation costs for the various routing pairs range from approximately $130 to $20,000 based on normal freight rates. To compare benefits to incremental costs, it is necessary to assign a monetary value to a unit dose reduction. For purposes of this assessment, the official NRC estimate of $1,000 per man-rem as designated in Section 20 of Appendix I to 10 CFR Part 50, "Licensing of Production and Utilization Facilities" is used.

Examination of the cost differences versus reduction in dose between each routing pair shows that the route with the highest dose is also more expensive. Therefore, no cost-benefit relationship exists in terms of a trade-off between a higher cost route versus one having a higher risk. In all cases except Routes 6A and 6B, the longer more circuitous route was more expensive and had a higher total expected transportation dose. In the case of Routes 6A and 6B, the shorter route (6A, 585 miles) travels through much greater population density, giving a higher total expected dose than 6B (620 miles long). However, costs provided for Route 6B included special rates with no specific itemizing of the cost component which made up the total route costs.

It must be pointed out that costs for rail shipments of spent fuel are a point of much controversy in the rail industry. As such, a uniform approach to costing might be necessary to make a more detailed and systematic analysis of costs versus dose reduction afforded by special routing. At this time, however, the shorter route in all cases (except 6A and B) is less costly and poses less transportation risk.

TABLE 25
COST PER TON-MILE AND COST PER RAIL-MILE

ROUTE	TOTAL COST WITHOUT SPECIAL FREIGHT RATES (DOLLARS)	TOTAL COST WITH SPECIAL FREIGHT RATES (DOLLARS)	TOTAL ROUTE DISTANCE MILES	COST PER TON-MILE WITH SPECIAL FREIGHT RATES (DOLLARS)	COST PER TON-MILE WITHOUT SPECIAL FREIGHT RATES (DOLLARS)	COST PER RAIL-MILE WITH SPECIAL FREIGHT RATES (DOLLARS)	COST PER RAIL-MILE WITHOUT SPECIAL FREIGHT RATES (DOLLARS)
1A	15,602.97	30,130.53	545	0.79	0.41	55.29	28.63
1B	15,748.80	33,189.20	604	0.78	0.37	54.95	26.07
2A	11,734.72	25,184.52	566	0.64	0.25	44.89	17.53
2B	12,026.38	30,797,73	686	0.64	0.30	44.50	20.73
3A	14,270.06	28,970.81	462	0.90	0.44	62.71	30.89
3B	14,402.06	29,402.06	515	0.82	0.40	57.09	27.97
4A	14,664.55	31,764.55	625	0.73	0.34	50.82	23,46
4B	15,860.36	42,110.36	1117	0.54	0.20	37.70	14.20
5A	14,183.31	27,883.37	425	0.94	0.48	65.61	33.37
5B	14,854.13	34,504.13	700	0.70	0.30	49.29	21.22
6A	27,494.05	55,166.75	585	1.35	0.67	94.36	47.00
6B	unavailable	49,848.33	620	1.15	unavailable	80.40	unavailable
7A	16,430.22	34,593.66	601	0.82	0.39	57.56	27.34
7B	16,736.46	34,899.90	727	0.69	0.33	48.00	23.02

TABLE 26
COST-BENEFIT ANALYSIS OF SPECIAL ROUTING

ROUTE	TRANSPORT COSTS WITHOUT SPECIAL FREIGHT RATES (DOLLARS)	DIFFERENCE IN COST (DOLLARS)	TOTAL TRANSPORTATION DOSE (man-rems)	DIFFERENCE IN DOSE BETWEEN ROUTING PAIRS	COST PER MAN-REM (DOLLARS)
1A	15,602.97	145.83	0.935	0.373	*
1B	15,748.80		1.308		
2A	11,734.72	291.66	0.635	0.021	*
2B	12,026.38		0.656		
3A	14,270.81	131.25	0.557	0.289	*
3B	14,402.06		0.846		
4A	14,664.55	1,195.81	4.818	10.871	*
4B	15,860.36		15.689		
5A	14,183.31	670.82	5.209	10.871	*
5B	14,854.13		19.503		
6A	27,458.75	unavailable	19.266	3.0572	unavailable
6B	unavailable	unavailable	16.209		
7A	16,430.22	306.24	0.805	.091	*
7B	16,736.46		1.896		

* In this case, the more expensive route also presents a higher total expected man-rem dose yielding no cost versus dose reduction relationship.

TABLE 27
COST BENEFIT ANALYSIS OF SPECIAL ROUTING
(Based On Special Freight Rates)

ROUTE	TRANSPORT COSTS WITH SPECIAL FREIGHT RATES (DOLLARS)	DIFFERENCE IN COST (DOLLARS)	TOTAL TRANSPORTATION DOSE (man-rems)	DIFFERENCE IN DOSE BETWEEN ROUTING PAIRS	COST PER MANREM (dollars)
1A	30,130.53	3,058.67	0.935	0.373	*
1B	33,189.20		1.308		
2A	25,184.52	5,613.21	0.635	0.021	*
2B	30,797.73		0.656		
3A	28,970.81	431.25	0.557	0.289	*
3B	29,402.06		0.846		
4A	31,764.55	10,345.81	4.818	10.871	*
4B	42,110.36		15.689		
5A	27,883.31	6,620.82	5.204	14.296	*
5B	34,504.13		19.503		
6A	55,166.75	5,318.42	19.266	3.0572	1,740.00
6B	49,848.33		16.209		
7A	34,593.66	306.24	0.805	1.091	*
7B	34,899.90		1.8969		

*In this case, the more expensive route also presents a higher total expected man-rem dose yielding no cost versus dose reduction relationship.

5.5 SENSITIVITY ANALYSIS OF NORMAL TRANSPORTATION RISK

An analysis of the normal transportation and accident risk models were run to identify those parameters critical to the dose level for each route. This sensitivity analysis was conducted using sample input data for route 1A and entailed single parameter variation as well as simultaneous variation of more than one parameter. Parameters examined for effect on the man-rem exposure associated with the normal transportation risk model for route 1A include:

- stop times in rural, suburban and urban density zones;
- switchyard population density;
- miles traveled in rural, suburban and urban density zones; and
- velocity in rural, suburban and urban density zones.

Some parameters were also varied in concert to assess their interrelationship as well as their effect on man-rem exposure. The following were analyzed:

- the relationship between rural, suburban and urban population density, velocity (mph) and man-rem exposure; and
- the relationship between stop times in switchyards within rural, suburban and urban population densities, switchyard population density, and man-rem exposure.

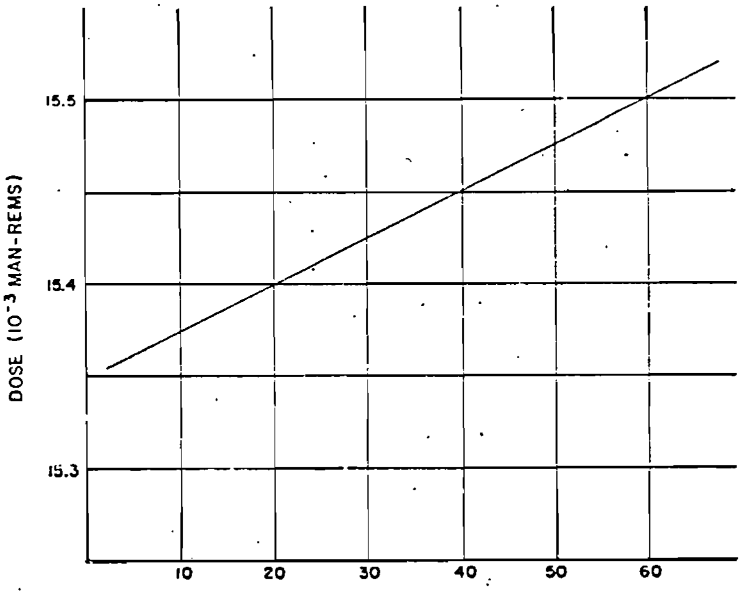
5.5.1 Single-Variable Sensitivity Analysis

5.5.1.1 Variation in Stop Times

The sensitivity of total risk to variations in stop time in a rural zone was explored. Rural stop times were varied from zero to 60 hours. As would be expected, increase in stop time increased the total man-rem exposure. Figure 20 shows this linear relationship between stop time and man-rem dose in rural zones.

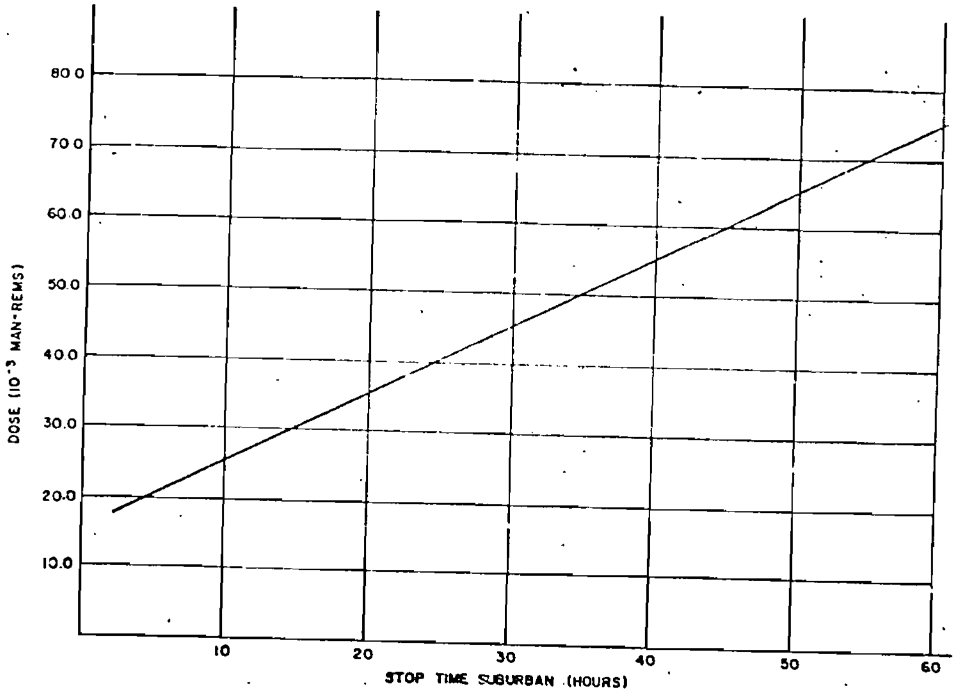
A similar analysis of stop time variation was also conducted for suburban and urban density zones. Figures 21 and 22 show the relationship between stop time and man-rem dose in suburban and urban zones, respectively.

Table 28 summarizes the change in dose as a function of stop time in the various zones.



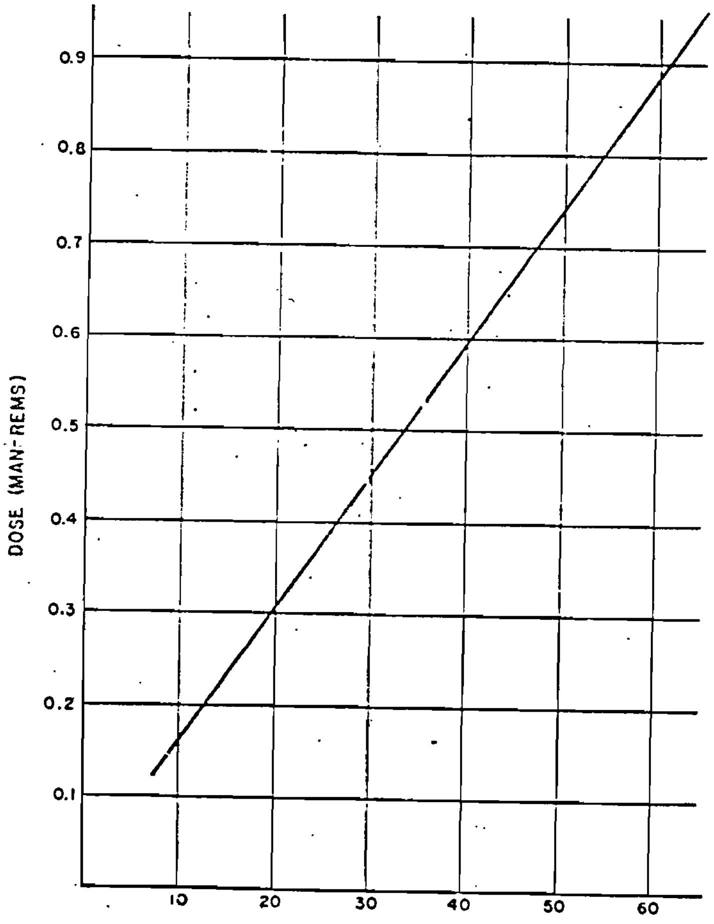
DOSE VS. STOP TIME RURAL

FIGURE 20



DOSE VS. STOP TIME SUBURBAN

FIGURE 21



DOSE VS. STOP TIME URBAN

FIGURE 22

TABLE 28

VARIATION IN MAN-REM DOSE AS A FUNCTION OF STOP TIME

	INCREASE IN DOSE (MILLI MAN-REMS)		
STOP TIME IN HOURS	RURAL	SUBURBAN	URBAN
10	15.37	25	160
20	15.39	35	305
30	15.42	45	450
40	15.45	55	595
50	15.48	65	740
60	15.50	75	885

This table shows that stop time is much more critical in urban and suburban areas than in rural. Increments of 10 hours stop time add between 0.02 and 0.03 milli man-rems to dose in rural zones and 145 milli man-rems in urban population zones. A stop time of 10 hours in a suburban zone gives a man-rem exposure an order of magnitude greater than a total stop time of 60 hours in a rural zone.

5.5.1.2 Variations in Switchyard Population Density

A sensitivity analysis was performed to assess the impact that varying switchyard population density has on man-rem exposure. Switchyard population density was varied from 25 to 300 rail employees per square mile. These values were indicated by rail carriers to be representative of probable switchyard population density during switching of a spent fuel shipment. Table 29 shows the effect that variations in switchyard population density have upon total exposure. Increases in switchyard population density uniformly increase total man-rem exposure. Each increment of 25 employees increases total dose by 1.6 milli man-rem. In terms of the overall percentage change of total dose the critical areas impacted are the 25 to 100 employee range. Dose increases from 40 percent going from 25 to 50 employees to 20 percent going from 75 to 100 employees.

TABLE 29

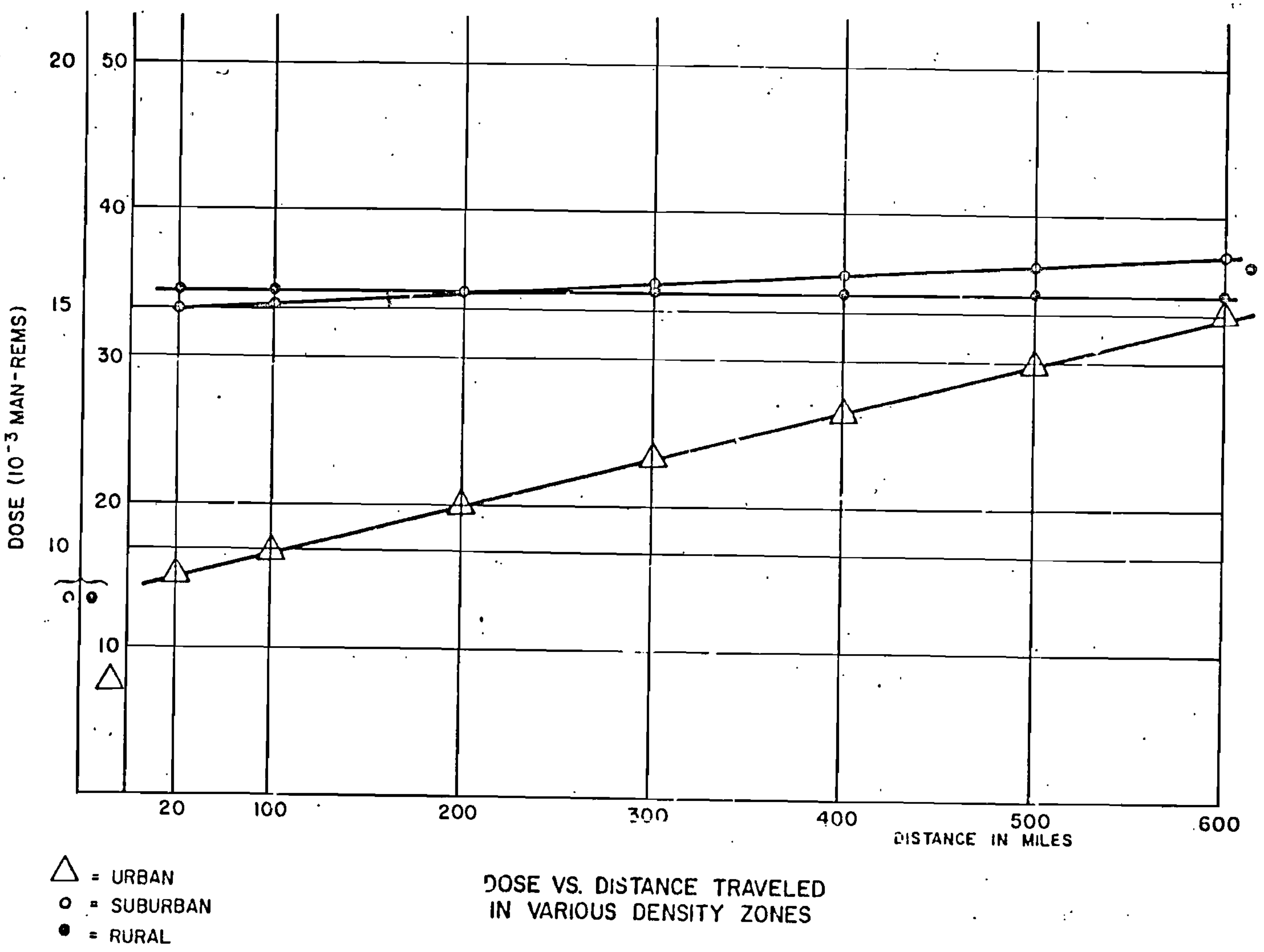
EFFORT OF SWITCHYARD POPULATION ON TOTAL DOSE (MILLI MAN-REMS)

SWITCHYARD POPULATION DENSITY (persons/mi^2)	$D_{(SWITCH)}$ (milli man-rems)	TOTAL DOSE (milli man-rems)
25	1.63	3.99
50	3.26	5.62
75	4.90	7.25
100	6.53	8.88
125	8.16	10.5
150	9.79	12.1
175	11.4	13.8
200	13.1	15.4
225	14.7	17.0
250	16.3	18.7
275	18.0	20.3
300	19.6	21.9

5.5.1.3 Variations in Distance Traveled in Density Zones

Distance traveled in various population density zones was varied from 50 to 450 miles. Figure 23 shows the relationship between miles traveled in a rural density zone and its effect upon total exposure. This relationship is linear; total distance traveled in rural zone is directly proportional to the total exposure.

Distances traveled in suburban and urban density zones were also varied to analyze the impact on total man-rem exposure. A similiar relationship holds between total distance traveled in each zone and man-rem exposure; that is, exposure increases in direct proportion to increases in total distance traveled in either zone. Table 30 shows the relationship between distance traveled in all three density zones and exposure. The exposure to individuals from shipping spent fuel a minimum of 100 miles through urban areas exceeds the exposure for shipments of spent fuel traveling 450 miles in rural and suburban areas. Total exposure in both rural and suburban zones is relatively insensitive to variations in distance traveled.



DOSE VS. DISTANCE TRAVELED IN VARIOUS DENSITY ZONES

FIGURE 23

TABLE 30

NORMAL TRANSPORTATION DOSE AS A FUNCTION OF DISTANCES TRAVELLED IN VARIOUS ZONES

(milli man-rems)

MILES TRAVELED IN ZONE	RURAL	SUBURBAN	URBAN
50	15.403	15.029	15.278
100	15.405	15.144	16.934
150	15.406	15.259	18.591
200	15.408	15.373	20.248
250	15.409	15.488	21.905
300	15.411	15.603	23.562
350	15.412	15.718	25.219
400	15.414	15.832	26.876
450	15.415	15.947	28.533

5.5.1.4 Variations in Velocity Traveled in Various Density Zones

The effect of changes in train velocity on total exposure for Route 1A was assessed. Velocities ranging from 5 to 75 mph were examined for rural, suburban and urban population density zones at increments of five miles per hour. Table 31 presents the data calculated in the sensitivity analysis.

TABLE 31

NORMAL TRANSPORTATION DOSE AS A FUNCTION OF TRAIN VELOCITY IN VARIOUS ZONES

(milli man-rems)

VELOCITY (MPH)	RURAL	SUBURBAN	URBAN
5	15.50	20.86	35.09
10	15.45	17.89	24.44
15	15.43	16.90	20.78
20	15.43	16.40	18.99
25	15.42	16.10	17.92
30	15.42	15.91	17.20
35	15.42	15.76	16.69
40	15.41	15.66	16.30
45	15.41	15.58	16.01
50	15.41	15.51	15.77
55	15.41	15.46	15.57
60	15.41	15.41	15.41
65	15.41	15.37	15.27
70	15.41	15.34	15.15
75	15.41	15.31	15.05

An inversely proportional relationship exists between train velocity and exposure. As train velocity through the population density zone increases, actual exposure decreases. Total dose is not strongly sensitive to changes in train velocity in the rural zone. For a train traveling at 5 to 20 mph, the greatest exposure is indicated in urban areas. However, at speeds in excess of 20 mph, the doses for rural and suburban density zones are similiar and the dose in rural zones actually becomes greater than both urban and suburban population zones at speeds of 60 mph and higher. Total exposure in rural areas appears to be less critically linked to train velocity than in urban and suburban areas because of the smaller number of individuals per square mile exposed to the radiation source which decreases the importance of speed and travel time. Initial increase in velocity causes large decreases (10 to 50 percent) in total dose in urban and suburban zones but this effect levels off at about 30 mph.

5.5.2 Multi-Parameter Sensitivity Analysis

5.5.2.1 Relationship Between Exposure, Population Density and Velocity

The impact of simultaneous variation of population density and train velocity upon exposure levels was analyzed. This analysis was conducted separately for rural, suburban and urban zones.

The effect that variations in speed from 1 to 40 mph, and population density from 1 to 11 individuals per square mile produced upon risk levels in the rural population density zone were measured. The rural population density was divided into segments of one, six, and 11 inhabitants per square mile, and while the population density was held constant, the velocity traveled in the rural zone was varied incrementally. Once dose was calculated for velocity variations in a specific rural population density, the population density was increased and risks associated with the velocity increments were recalculated. Table 32 shows the sensitivity of exposure levels to changes in population density and train velocity. As speed increases in a rural density zone, the exposure level decreases slightly. Variations in population density and velocity reveal that as velocity increases, exposure decreases slightly while increases in population density give slightly higher exposure levels. Risk level increases due to higher population density are proportional to the incremental increases in population density for each velocity variation. The risk associated with higher rural population densities parallels the risk for lower population densities at an incrementally higher level.

Suburban population densities from 100 to 1,000 individuals per square mile and train velocities from 10 to 80 mph were then input to determine sensitivity of the model to variation in these parameters. The methodology used was the same as for rural population density and the results were similiar. Risk decreased slightly as velocity was increased and risk increased as population density was increased.

The analysis of urban population density variations (1,500 to 10,000 inhabitants per square mile) and velocity increments resulted in the same results as for the rural and suburban zones. Tables 33 and 34 show dose values in varying suburban and urban population density zones, respectively, for velocities ranging from 10 to 80 mph. The data indicate that in all cases the effect of velocity on exposure is the most pronounced at higher population densities.

TABLE 32
NORMAL TRANSPORTATION DOSE AS A FUNCTION OF POPULATION DENSITY AND VELOCITY IN RURAL ZONES

RURAL POPULATION DENSITY (persons/mi^2)	VELOCITY (mph)	DOSE (milli man-rem)
1	10	15.45
1	20	15.43
1	30	15.42
1	40	15.41
6	10	15.80
6	20	15.75
6	30	15.74
6	40	15.73
11	10	16.14
11	20	16.08
11	30	16.06
11	40	16.05

TABLE 33
NORMAL TRANSPORTATION DOSE AS A FUNCTION OF VELOCITY AND POPULATION DENSITY IN SUBURBAN ZONES

SUBURBAN POPULATION DENSITY (persons/mi^2)	VELOCITY (mph)	DOSE (milli man-rem)
200	10	3.39
	20	2.63
	40	2.24
	60	2.11
	80	2.05
400	10	4.90
	20	3.38
	40	2.62
	60	2.37
	80	2.24
600	10	6.4
	20	4.13
	40	2.99
	60	2.62
	80	2.43
800	10	7.91
	20	4.88
	40	3.37
	60	2.87
	80	2.61
1,000	10	9.41
	20	5.64
	40	3.75
	60	3.12
	80	2.80

TABLE 34
NORMAL TRANSPORTATION DOSE AS A FUNCTION OF VELOCITY AND POPULATION DENSITY IN URBAN ZONES

URBAN POPULATION DENSITY (persons/mi^2)	VELOCITY (mph)	DOSE (milli man-rem)
1,500	10	3.39
	20	1.98
	40	1.27
	60	1.04
	80	0.92
3,000	10	6.22
	20	3.39
	40	1.98
	60	1.51
	80	1.27
4,500	10	9.04
	20	4.80
	40	2.68
	60	1.98
	80	1.62
6,000	10	11.86
	20	6.21
	40	3.39
	60	2.45
	80	1.98
7,500	10	14.68
	20	7.62
	40	4.09
	60	2.92
	80	2.33
9,000	10	17.50
	20	9.03
	40	4.80
	60	3.39
	80	2.68
10,000	10	19.38
	20	9.97
	40	5.27
	60	3.70

5.5.2.2 Relationship Between Total Exposure, Switchyard Population Density and Stop Times in Switchyards

The impact of switchyard population density and stop times in switchyards on total exposure was assessed. Switchyard stop times were increased to a maximum of 100 hours while switchyard population density was varied from zero to 300 rail employees.

For all three population zones, increasing switchyard population density increased dose. Varying stop times in conjuction with varying switchyard population density increased dose at an even greater rate.

5.5.3 Sensitivity Analysis of Accident Risk Model

A sensitivity analysis of the accident risk model was conducted on Route 1A to identify single parameters which are critical to total accident dose. The parameters which were considered included:

- weather stability at accident sites; and
- release fraction associated with various accident severities.

5.5.3.1 Variation of Weather Stability at Accident Site on Dose

In Section 3, the dependence of atmospheric dispersion of spent fuel in an accident upon weather stability was discussed. This section describes the analysis performed to determine the sensitivity of exposure levels to changes in weather stability.

Table 2 presents the distribution of weather conditions assumed for the dose-area calculations in Section 3. This distribution was designed to represent a typical accident site. Thus, if an accident occurred in an area having weather stability other than that expected, the accident dose would vary.

To measure the magnitude of the impact that weather conditions have upon accident dose, a weather stability distribution model consisting of more stable conditions than that used in the analytical accident risk model was postulated. This distribution is shown below:

WEATHER CLASS	A	B	C	D	E	F	G
PROBABILITY OF OCCURRENCE	0	.05	.10	.45	.15	.15	.10

These values provide modified dose bands, as found in Table 35.

TABLE 35

MODIFIED DOSE BANDS RESULTING FROM CHANGE IN WEATHER STABILITY

Dose Parameter Band (D/Q_oK)	Dose Parameter Area (mi^2)
10^{-1}	3.0×10^{-5}
$10^{-2} - 10^{-1}$	4.1×10^{-4}
$10^{-3} - 10^{-2}$	4.1×10^{-3}
$10^{-4} - 10^{-3}$	6.0×10^{-2}
$10^{-5} - 10^{-4}$	2.1
$10^{-6} - 10^{-5}$	406

Table 35 was developed using the following information:

Kr^{85}, D_iA_i = 1.41 rems-mi^2

I^{131}, D_iA_i = 1.36×10^{-1} rems-mi^2, and

fission products, D_iA_i = 3.44×10^{1} rems-mi^2

It can be seen that the combined isotope area dose level is 35.9 rems-mi^2.

Total accident dose for Route 1A was recalculated using the modified weather conditions to give:

$$D_T = 1{,}140 \text{ milli man-rems}$$

Comparing the modified accident dose to the original calculation (D_T for Route 1A = 920 milli man-rems), it appears that a moderate shift in assumed weather conditions to more stable atmospheric stability classes, resulted in a 24 percent increase in accident radiation exposure level.

Thus, while a change in weather distribution does affect the population dose, the accident risk model does not appear to be critically sensitive to changes in weather conditions.

5.5.3.2 Variation of Release Fraction and Accident Severity

Release fraction as a function of accident severity was the other parameter assessed for sensitivity in the accident risk model. The assumptions used in this analysis can be found in Table A-3 of Appendix A.

Impact testing of rail cask cars has shown that spent fuel cask design is sufficient to withstand severe impact, crush and fire damage without release of spent fuel contents. Limited crash testing by Sandia Laboratory confirms these design objectives. Therefore, data on release fractions developed in the Sandia work were used in the accident model. Further impact testing is necessary to validate these original impact data. However, since there is no significant accident history or accident data base compiled, uncertainties in the assumptions may be considered.

If the assumption is made that an accident of severity class III or worse results in 100% release of the isotopic products, the accident probabilities in Table A-4 of Appendix A become:

Release Fraction	Fractional Release Probability (per mile) Rural	 Suburban	 Urban
1.0	6.05×10^{-2}	8.1×10^{-2}	5.98×10^{-2}

Using this probability, the specific accident dose for Route 1A was recalculated to give:

$$D_T = 4{,}122 \text{ milli man-rems}$$

This value is 45 times greater than the accident model dose for Route 1A assuming the Sandia severity categories. Consequently, as expected, the accident severity and how it affects release fraction is critical to dose.

6. CONCLUSIONS AND RECOMMENDATIONS

Several observations were drawn using the risk analysis methodologies developed in this study. It should be noted that this analysis is an initial attempt to estimate the incremental risks and costs in transporting spent fuel by rail and a more in-depth and detailed assessment of alternative rail routing will be required to confirm the trends discussed here. However, this study is useful as a baseline study of routing alternative analyses.

Major observations resulting from this study include:

- The risk associated with normal transportation of spent fuel along routes is relatively small, .015 to .046 man-rems. Variations in normal transportation risk between alternate routes is extremely small, from .001 to .017 man-rems.
- The dose experienced by the population as a result of a rail car accident is at least one order of magnitude higher than that for normal transportation shipments for all of the routing alternatives considered.
- The risk associated with rail accidents involving spent fuel shipments ranges from 0.54 to 19.5 man-rems. The variation between routing alternatives is only 0.28 to 4.29 man-rems or less.
- The total risk, taking into account normal transportation and an accident, ranges from 0.56 to 19.8 man-rems for the routes studied.
- Use of population dose appears to be useful measure of risk from spent fuel transport.
- In terms of shipping costs, the routes with higher costs also showed higher expected exposure levels. In all but one case, the shorter route in terms of miles traveled had a lower dose and less cost. The one anomaly in terms of route length is Route pair 6, with the shorter route (6A) showing the higher dose level and higher cost. The cost data supplied for 6B has special rates built in with no itemizing of normal freight costs for the purposes of route cost comparison. However, in looking at the comparison of costs with special values, it apears that rail 6A with higher costs had the greater exposure level.

- The parameters of most significance to the normal transportation risk appear to be: (1) percent of population in urban, rural and suburban density zones; and (2) length traveled in each of the three population density zones.
- For the accident situation, the release fraction assumption is critical to the total dose received by the population.

The largest difference in population dose during normal transportation occurs between routing combinations 6A (585 miles in total length) and 6B (620 miles in total length). Route 6A has a risk level almost double that associated with Route 6B. The most significant difference between these routes lies in the population levels in different population density zones. Route 6A has 87 percent of its length in urban zones (at 11,130 persons/mi^2) while route 6B has only 32 percent in urban zones (at 12,626 persons/mi^2). Thus the total population along a route coupled with the percentage of that population in certain density zones are parameters which in combination can be more critical to total risk than the total route length in miles.

The largest difference in accident dose is between route combinations 5A and 5B. Route 5A with lower total population (24 million versus 5.7 million persons for route 5B) and higher percentage of its length population in urban density zones (59% for 5A and 51% for Route 5B), has a much smaller accident dose (5.2 man-rems) than route 5B (19.5 man-rems). The only apparent difference is the total route length (5A is 425 miles and 5B is 700 miles). Closer review shows, however, that Route 5B travels more actual miles (357) through urban zones than 5A (250 miles), and this coupled with its longer length in suburban and rural zones contributes to the larger total accident dose. Route 5B also has contributions to dose from track class considerations (30% of length on class 2 track) and from the number of severities required along the route (6). Route 5A has only 2% of its length on class 2 track and only two switching operations necessary.

In examining the effect of population density and route length, both are important parameters in determining risk for both normal and accident transport modes. In general, increases in population density and route length increase risk but as to which has the overriding effect depends on the percent of that population or route length in the higher population density zones. In other words, the route with the higher percentage of its length through higher population density zones will have larger risk levels associated with it. Therefore, choice of a longer route with less total population alone does not guarantee a reduction in risk.

It is recommended that further effort be directed to the following areas:

1. Expansion and improvement of the railroad specific accident per car-mile data base to include a more statistically significant sample as imput to the accident model;
2. Analysis of additional routing pairs to cover the entire continental U.S. spent fuel shipment picture; and
3. Additional effort to improve data on accident severity by track class for imput to the accident model.

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APPENDIX A

PROBABILITY OF RAIL CAR ACCIDENTS OF VARIOUS SEVERITIES

The probability of rail car accidents of various severities was presented in a U.S. Nuclear Regulatory Commission Report entitled, "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes" (NUREG-0170). This study presented a fractional distribution for train accidents by accident severity and population density zone. These results are used in our analysis:

Fractional Occurrences for Train Accidents By Accident Severity Category and Population Density Zone

Accident Severity Category	Fractional Occurrences	Fractional Occurrences According to Population Density Zones		
		Low	Medium	High
I	.50	.1	.1	.8
II	.30	.1	.1	.8
III	.18	.3	.4	.3
IV	.018	.3	.4	.3
V	.0018	.5	.3	.2
VI	1.3×10^{-4}	.7	.2	.1
VII	6.0×10^{-5}	.8	.1	.1
VIII	1.0×10^{-5}	.9	.05	.05

Low Population density = rural
Medium population density = suburban
High population density = urban

This report also presents what fraction of the contained fuel rods will be ruptured for an accident of various severities (Table A-2).

TABLE A-2
RELEASE FRACTIONS

Severity Category	Release From Casl
I	0
II	0
III	0.01
IV	0.1
V	1.0
VI	1.0
VII	1.0
VIII	1.0

Tables A-2 and A-3 can be combined to give the probability of various release fractions for the different population densities as shown in Table A-3.

TABLE A-3
RELEASE FRACTIONS FOR POPULATION DENSITIES

RELEASE FRACTION	ACCIDENT PROBABILITY (per mile) Rural	Suburban	Urban
.01	5.4×10^{-2}	7.33×10^{-2}	5.4×10^{-2}
.1	5.4×10^{-3}	7.33×10^{-3}	5.4×10^{-3}
1.0	1.05×10^{-3}	5.73×10^{-4}	3.79×10^{-4}

APPENDIX B

COMPUTER PRINTOUT OF SENSITIVITY ANALYSIS SHOWING RAIL YARD POPULATION DENSITY, EXPECTED DOSE TO RAIL YARD PERSONNEL AND EXPECTED DOSE TO THE TOTAL ROUTE POPULATION

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MAN-REM VARIATION IN RAIL YARD POPULATION DENNSITY
RAILYARD           EXPECTED DOSE    EXPECTED DOSE
POPULAT.           TO RAILYARD      TO THE TOTAL
DENSITY            PERSONNEL        ROUTE POPULAT.
 25                 1.632E-03        3.9861E-03
 30                 1.9584E-03       4.3125E-03
 35                 2.2848E-03       4.6387E-03
 40                 2.6112E-03       4.9653E-03
 45                 2.9376E-03       5.2917E-03
 50                 3.264E-03        5.6181E-03
 55                 3.5904E-03       5.9445E-03
 60                 3.9168E-03       6.2709E-03
 65                 4.2432E-03       6.5973E-03
 70                 4.5696E-03       6.9237E-03
 75                 4.896E-03        7.25009E-03
 80                 5.2224E-03       7.5765E-03
 85                 5.5488E-03       7.9029E-03
 90                 5.8752E-03       8.2293E-03
 95                 6.2016E-03       8.5557E-03
 100                6.528E-03        8.8821E-03
 105                6.8544E-03       9.2085E-03
 110                7.1808E-03       9.5349E-03
 115                7.5072E-03       9.8613E-03
 120                7.8336E-03       .0101877
 125                8.16E-03         .0105141
 130                8.4864E-03       .0108405
 135                8.8128E-03       .0111669
 140                9.1392E-03       .0114933
 145                9.4656E-03       .0118197
 150                9.792E-03        .0121461
 155                .0101184         .0124725
 160                .0104448         .0127989
 165                .0107712         .0131253
 170                .0110976         .0134517
 175                .011424          .0137781
 180                .0117504         .0141045
 185                .0120768         .0144309
 190                .0124032         .0147573
 195                .0127296         .0150837
 200                .013056          .0154101
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 205                .0133824          .0157365
 210                .0137088          .0160629
 215                .0140352          .0163893
 220                .0143616          .0167157
 225                .014688           .0170421
 230                .0150144          .0173685
 235                .0153408          .0176949
 240                .0156672          .0180213
 245                .0159936          .0183477
 250                .01632            .0186741
 255                .0166464          .0190005
 260                .0169728          .0193269
 265                .0172992          .0196533
 270                .0176256          .0199797
 275                .017952           .0203061
 280                .0182784          .0206325
 285                .0186049          .0209589
 290                .0189312          .0212853
 295                .0192576          .0216117
 300                .019584           .0219381
10 A=275
20 B=216
30 C=54
40 D=60
50 E=60
60 F=60
70 G=1
80 H=391
90 I=5704
100 J=.994
110 K=.006
120 P=24
130 Q=0
140 R=0
150 S=24
160 U=5
170 LPRINT "MAN-REM VARIATION IN RAIL YARD POPULATION DENNSITY"
180 LPRINT "RAILYARD","EXPECTED DOSE","EXPECTED DOSE"
190 LPRINT "POPULAT.","TO RAILYARD  ","TO THE TOTAL "
200 LPRINT "DENSITY ","PERSONNEL    ","ROUTE POPULAT."
210 FOR T=25 TO 300 STEP 5
220 V=3.47E-07*((A*G/D)*(J+1.636*K)+(B*H/E)*(J+1.636*K)+(C*I/F)*(J+1.636*K))
230 W=2.72E-06*S*T
240 X=2.54E-06*(P*G+Q*H+R*I)
250 Y=U*2.88E-07*(A/D+B/E+C/F)
260 Z=V+W+X+Y
270 LPRINT T,W,Z
280 NEXT T
```