- Two transportation casks are being transported in the same hold on each cargo vessel.

The per shipment incident-free impact on the port workers would be identical to that calculated for the basic implementation of Management Alternative 1. None of the assumptions used to generate the per shipment information change. The 168 shipments required to meet the needs of this subalternative would result in a reduction in the total (program) impacts by approximately 77 percent. The total population exposure would range from 7.0 person-rem (for the breakbulk vessel with two intermediate port calls) to 1.9 person-rem (for the container vessel with no intermediate port stops). This corresponds to an incident-free risk of 0.0028 to 0.00076 LCFs (i.e., a chance of between three-in-a-thousand and seven-in-ten thousand of incurring one LCF).

Implementation Subalternative 2a of Management Alternative 1 – Acceptance of Foreign Research Reactor Spent Nuclear Fuel for 5 Year Policy Duration: As stated above, this implementation subalternative would result in the shipment of 586 transportation casks of foreign research reactor spent nuclear fuel. The assumptions used previously for incident-free port impact have been used in the analysis of this subalternative. This implementation subalternative has been analyzed using the "exclusive use" regulatory limit transportation cask external dose rates. To compare this implementation subalternative to the basic implementation of Management Alternative 1, it is only necessary to perform the analysis using one external dose rate.

Included in the assumptions that have not changed in this analysis are the following:

- The worker exposure times and distances from the transportation cask are as detailed in Tables D-8 through D-10.
- The intermediate port stops are considered for the breakbulk vessel but not for the container vessel.
- Two transportation casks are being shipped in the same hold of each cargo vessel.

The per shipment incident-free impact on the port workers would be identical to that calculated for the basic implementation of Management Alternative 1. Therefore, none of the assumptions used to generate the per shipment information change. The 586 shipments required to meet the needs of this implementation subalternative would result in a reduction in the total (program) impacts to approximately 81 percent of the impacts associated with the basic implementation of Management Alternative 1. The total population exposure would be 25 person-rem (for the breakbulk vessel with two intermediate port calls) to 6.7 person-rem (for the container vessel with no intermediate port stops). This corresponds to an incident-free risk of 0.0098 to 0.0027 LCFs (i.e., a chance of between one-in-a-hundred and three-in-a-thousand of incurring one LCF).

Management Alternative 2, Subalternative 1b – Overseas Reprocessing with Shipment of the Vitrified Waste to a U.S. Storage Facility: In this subalternative under Management Alternative 2, the foreign research reactor spent nuclear fuel would be processed overseas (most probably in Great Britain or France) and the waste products are contained within several vitrified waste logs. This high-level waste may be brought to the United States for storage in one of the storage facilities evaluated under this EIS. Under these conditions, up to eight transportation casks containing vitrified waste would be shipped from Europe to the United States. This analysis addresses the incident-free port risks associated with transporting these eight casks of vitrified waste from Europe to the United States.

As with the shipment of foreign research reactor spent nuclear fuel as spent nuclear fuel, the primary incident-free port impacts of shipping vitrified waste would be upon the workers in the ports. The assumptions used in the analysis of the incident-free port impact of the basic implementation of Management Alternative 1 have been used in the analysis of this subalternative. Differences between the foreign research reactor spent nuclear fuel transportation casks and the vitrified waste transportation casks are not expected to significantly alter the work requirements in port. For the purposes of this analysis, it has been assumed that the vitrified waste would be transported on a chartered vessel, and there would be no intermediate port calls.

This alternative has been analyzed using the regulatory limit transportation cask external dose rates. Little information is available on the casks to be used to transport the vitrified waste. No attempt was made to extrapolate limited historical data to determine the port worker incident-free impacts from any other exposure rate other than the limit set forth in NRC and DOE regulations.

Included in the assumptions that have not changed in this analysis are the following:

- The worker exposure times and distances from the transportation cask are as detailed in Tables D-8 through D-10.
- The intermediate port stops are not considered for the container vessel.
- Two transportation casks are being transported in the same hold of the cargo vessels.

The per shipment incident-free impact on the port workers would be identical to that calculated for the basic implementation of Management Alternative 1. None of the assumptions used to generate the per shipment information change. The eight shipments required to meet the needs of this subalternative would result in a reduction in the total (program) impacts by a factor of approximately one hundred. The total population exposure would be 0.0091 person-rem for the container vessel with no intermediate port stops. [illegible] incident-free risk of 0.0000036 LCFs (i.e., a chance of approximately [illegible]

four-in-a-million of incurring one LCF).

Hybrid Alternative – Acceptance of Foreign Research Reactor Spent Nuclear Fuel From Countries Without High Level Waste Disposal Capability: As stated above, this hybrid alternative results in the population exposure would be 19 person-rem (for regularly scheduled commercial vessel with two intermediate port calls) to 5.1 person-rem (for the chartered vessel with no intermediate port calls). This corresponds to an incident-free risk of 0.0076 to 0.0021 LCFs (i.e., a chance of between approximately one-in-five hundred to less than one-in-a-hundred of incurring one LCF).

D.5 Accident Impacts: Methods and Results

D.5.1 Introduction

This section describes the approach used to assess the risks associated with in-port accidents that could result in a release of radioactive material from the transportation cask containing foreign research reactor spent nuclear fuel. The discussion addresses both the accident risk assessment methodology and the results of the analyses. The risk assessment results are presented in terms of a per-shipment accident risk and the total port-accident risks associated with various alternative under the proposed action.

Spent nuclear fuel shipments could occur via any of four types of vessels, container ships, roll-on/roll-off vessels, breakbulk vessels, and purpose-built (dedicated) vessels. In the incident-free analysis, only breakbulk vessels and container vessels were studied, since these two provide a bounding assessment of the risks associated with port activities. Under the assumptions used in the port accident analysis, the type of vessel used to transport the foreign research reactor spent nuclear fuel would not impact the result of the analysis.

All radiologically-related impacts are calculated in terms of committed dose and associated health effects in the exposed populations. The radiation dose calculated is the total effective dose equivalent, which is the sum of the effective dose equivalent (EDE) from the external radiation exposure and the 50 year committed effective dose equivalent from internal radiation exposure. Radiation doses are presented in units of person-rem for collective population and rem or mrem for individuals. The impacts are further expressed as health risks, specifically in terms of LCF. The health risk conversion factors were derived from International Commission on Radiological Protection Publication 60 (ICRP, 1991). See Chapter 4 for a more complete explanation of radiation measurement and health risks.

D.5.1.1 Accident Risks

Risk (R) is the product of the magnitude (M) of an unfavorable consequence and the probability of occurrence (P) of that consequence. Thus,

$$R = PM.$$

For accidents that happen during the transportation of radioactive materials, the unfavorable consequences of the accident may include exposure of people to radiation emitted by the radioactive materials released to the atmosphere by the accident and the occurrence of radiation induced health effects that the exposure may cause. The magnitude of these consequences depends on the amount of radioactivity released to the atmosphere, the degree to which the radioactive materials are diluted during downwind transport, and the size of the population that is exposed to radiation from the passing plume or from materials deposited on the ground or in the water from the plume. The amount of dilution experienced by a plume during downwind transport depends principally on atmospheric stability and windspeed. The size of the exposed population is determined by the direction the wind is blowing at the time of the accident and the number of people in that direction. Thus, the probability that a given consequence occurs is given by the following product,

$$P = P_{st}P_{w}P_{p}$$

where P_{st} is the probability of the source term (the amount of radioactive material released), P_{w} is the probability of the prevailing weather conditions, and P_{p} is the exposure probability of the population that is exposed to radiation, given the direction that the wind is blowing at the time of the accident.

D.5.1.2 Ship Accident Risks

The total risk caused by transporting foreign research reactor spent fuel to and within the United States is the sum of the risks for transport by land and by ship. Thus,

$$R_{total} = R_{land} + R_{ship}$$

For ships, the risk is given by:

$$R_{ship} = R_{sea} + R_{coast} + R_{port}$$

where R_{sea}, R_{coast}, and R_{port} are the risk while at sea, while sailing in coastal waters, and while in the port (R_{sea} and R_{coast} were addressed in Appendix C). Each risk term has an incident-free and an accident contribution, so

$$R_{port} = R_{port\text{-}incident\text{-}free} + R_{port\text{-}accident}$$

The accident risks associated with the foreign research reactor spent nuclear fuel while it is on a ship in the port, $R_{port\text{-}accident}$, is the subject of this section. $R_{port\text{-}incident\text{-}free}$ was covered in D.4 of this appendix.

The only port accidents considered are those where the ship carrying the spent nuclear fuel is struck by another ship. Accidents where the spent nuclear fuel transport ship rams a fixed structure (a bridge or a dock), rams another ship (a collision where the spent nuclear fuel ship is the striking ship), or runs aground are neglected for the following reasons.

First, ship accident data show that when a ship rams a fixed structure or collides with another ship, damage to the striking ship is confined to its prow and to the forwardmost hold. Even in these cases, the forces exerted on cargo in the forward hold are less than the forces exerted on cargo in the case where a striking ship impacts the cargo hold.

Second, because keel structures are massive and very sturdy, groundings rarely lead to significant damage to cargo, although monetary losses due to sinking of cargo or the ship can be significant. Immersion to the

If a ship transporting spent nuclear fuel is struck by another ship, and the collision leads to the failure of the spent fuel cask, the prevailing winds would transport the radioactive gases and aerosols in the plume released to the atmosphere during the accident away from the accident scene. During transport by the prevailing winds, downwind populations would likely be exposed to radiation, and land, buildings, and crops located below the plume trajectory might be contaminated by the radioactive materials deposited from the plume. Estimation of the range and probability of the health effects induced by the radiation exposures, and of the economic costs and losses that would result from any contamination of land, buildings, and crops is the objective of a MACCS accident consequence analysis.

MACCS calculations require the following accident and site data:

The radioactive inventory of the cask at the time of the accident for those radionuclides important for the calculation of accident consequences.

Release fractions and probability of release for the source term caused by the accident.

Plume characteristics for the radioactivity released to the atmosphere by the accident, the sensible heat content and the release time and duration.

Meteorological data characteristic of the region where the port is located, usually one year of hourly readings of windspeed, atmospheric stability, and rainfall.

The population distribution about the port where the accident occurs.

Emergency response assumptions, such as evacuation time and average speed; building shielding factors and the time when people take shelter if nearby populations are instructed to take shelter.

Land usage (habitable land fractions and farmland fractions) for the region surrounding the port.

Given these data, MACCS predicts:

The downwind transport, dispersion, and deposition of the radioactive materials released from the failed spent fuel cask.

The radiation doses received by the exposed populations via direct (cloudshine, inhalation, groundshine, resuspension) and indirect (ingestion) exposure pathways.

The mitigation of these doses by emergency response actions (evacuation, sheltering, and post-accident relocation of people).

Health effects that might occur in the population exposed to radiation as a result of the accident, both LCF and acute injuries (if short-term exposures are large).

The potential costs of emergency response actions, and of the decontamination, temporary interdiction, and condemnation of milk, crops, land, and buildings located in the region around the port, if necessary.

D.5.3 MACCS Input Data

D.5.3.1 Source Terms

MACCS source terms are specified by five input quantities: the probability (P_{st}) of the accident that leads to the release; the time (t) and duration (delta t) of the release (for ship accidents there may be both a mechanical release following the collision and a later thermal release if the accident progression leads to a fire); and the accident release fraction (f_i) and cask inventory (I_i) of each radionuclide (i) important for the calculation of accident consequences.

D.5.3.1.1 Source Term Probabilities

In the Environmental Assessment for the Urgent Relief Acceptance of Foreign Research Reactor Spent Nuclear Fuel (DOE, 1994d), accident risks were estimated using six categories of accident severity. To facilitate comparison of the risk estimates developed for this EIS to those developed for the Environmental [illegible] EIS [illegible] the six categories of accidents. Table D-21 presents the six categories of

Table D-21 Accident Severity Categories Used in the EIS

Accident Severity Category	Accident Conditions	Conditional Probabilities	Radionuclide Release Fractions[a]
1	Conditions do not exceed those for a Type B package; no release of contents.	0.603	Co 0 Kr 0 Cs 0 Ru 0 Part 0
2	Conditions equal to those for Type B certification tests; no release of contents.	0.395	Co 0 Kr 0 Cs 0 Ru 0 Particulate 0
3	Seal damage creates leak path, but fuel undamaged; only corrosion deposits, if present, released from package.	0.002	Co 0.012 Kr 0 Cs 0 Ru 0 Particulate 0
4	Impact damage great enough to cause damage to spent fuel; fuel particulates and fission gases may be released.	0.0004	Co 0.012 Kr 0.010 Cs 0.00000001 Ru 0.00000001 Particulate 0.00000001
5	Impact damage to seals plus fire severe enough to cause the cask to leak with release of fission gases, volatiles, and particulates.	0.0004	Co 0.012 Kr 0.100 Cs 0.0009 Ru 0.000001 Particulate 0.00000005
6	Severe impact damage plus fire severe enough to oxidize fuel with release of greater amounts of volatiles than Category 5.	0.0004	Co 0.012 Kr 0.100 Cs 0.00098 Ru 0.000042 Particulate 0.00000005

[a]*No credit was taken for the deposition of fission product vapors or aerosols released from a failed cask onto surfaces of the ship or cargo.*

Table D-22 Event Sequence for a Severe Ship Accident

Event	Event Probability
Collision between large ships	$P_{collision}$
Foreign research reactor spent nuclear fuel hold struck	P_{hold}
Foreign research reactor spent nuclear fuel hold penetrated (the cask and fuel are subjected to impact forces)	P_{impact}
Cargo compression (the cask is subjected to crush forces)	P_{crush}
Severe fire ensues	$P_{severe\ fire}$
Fire engulfs the cask (heat loads are sufficient to vaporize cesium)	$P_{engulfing\ fire}$
Convective flow of air through cask causes ruthenium to oxidize	$P_{convection}$

Attachment D4, using the methods of Minorsky (Minorsky, 1959) and results from previous studies of ship accidents (ORI, 1981b). $P_{convection}$ was estimated by review of data on fires and on the temperatures required to oxidize ruthenium to RuO_4, which is necessary to yield the higher ruthenium release fractions.

Table D-23 EIS Source Term Probability Expressions

Accident Severity Category	*Probability*
4	$P_{st} = P_{collision}P_{hold}(P_{impact} + P_{crush})$
5	$P_{st} = P_{collision}P_{hold}(P_{impact} + P_{crush})P_{severe\ fire}P_{engulfing\ fire}$
6	$P_{st} = P_{collision}P_{hold}(P_{impact} + P_{crush})P_{severe\ fire}P_{engulfing\ fire}P_{convection}$

D.5.3.1.3 Probabilities Developed From Accident Data

Fifteen years of Lloyd's casualty data (Lloyds, 1991) and previous studies of ship accidents (Warwick, 1976; SRI, 1978; ORI, 1981a; Abkowitz, 1985) were reviewed to develop (1) the probability of a severe collision ($P_{collision}$) between large ships that occurs dockside in ports or while sailing in port channels, and (2) the probability that such a collision leads to a severe fire (P_{fire}).

Collision Probability

Ship accident casualty data for the years 1978 through 1993 and U.S. port call data for the years 1992 and 1993 were obtained from Lloyd's Maritime Information Services, Inc. Searches of the port call data for the 2-year period 1992-1993 identified the number of port calls made in U.S. ports by all ships, all dry [illegible] and all dry cargo ships of deadweight 10 to 20 thousand long tons (equivalent to

Only 17 of the 391 collisions in the Abkowitz and Galarraga study (Abkowitz, 1985) led to fires of any severity. Thus, the probability that a collision leads to a fire of any severity is 17/391 = 0.044. SRI data suggest that about five percent of all ship fires involve an entire hold (SRI, 1978). Thus, the chance that a ship fire on a cargo ship will involve an entire hold is about 0.05. Combining these last two results allows the probability that a cargo ship collision leads to a severe fire to be estimated as follows:

$$\textit{(fires per collision)} \times \textit{(fires involving an entire hold per fire)} =$$

$$(4.4 \times 10^{-2}) \times (0.05) = 0.0022 \textit{ severe fires per collision}$$

Fires on cargo ships were reviewed by several countries for the International Maritime Organization. The [illegible] International Maritime Organization developed data for 599 cargo

D.5.3.1.5 Probabilities Developed From Ship Design Data

Two probabilities can be derived from the general ship design data, P_{hold} and $P_{engulfing\ fire}$. The first of these probabilities addresses the likelihood that the collision results in damage to the hold in which the spent nuclear fuel cask resides. (If the cask is stowed in an aft hold and the collision results in damage to a forward hold, no cask damage would be expected.) The second probability addresses the likelihood that the severe fire resulting from the accident (see Section D.5.3.1.3) is located in the same hold and on the same deck as the cask of spent nuclear fuel.

If foreign research reactor spent fuel casks were shipped one at a time, as is assumed here, then P_{hold}, the probability that the hold that contains the cask is the hold that is struck, can be approximated by $1/N_{hold}$, where N_{hold} is the number of holds in the ship transporting the spent nuclear fuel cask. The representative breakbulk freighter used in the impact and crush analyses described below has seven holds. Therefore, for this prototypic ship, $P_{hold} = 1/7 = 0.143$.

The total cargo area of this typical breakbulk freighter is about 3,066 m^2 (33,000 ft^2). Each hold includes two, three, or four decks. Together, the seven holds encompass 21 decks. Thus, the area of each deck is about 3,066/21 = 146 m^2 (33,000/21 = 1,600 ft^2). The Pegase cask used as a prototype in this study has a 2.1-m by 3-m (7-ft by 10-ft) base. This cask should be completely engulfed by a pool fire that has a diameter of 9.1 m (30 ft), provided that the fire occurs in the same hold and on the same deck that the cask is stored on. Since a pool fire of diameter 9.1 m (30 ft) occupies about 65 m^2 (700 ft^2), any engulfing fire will probably involve an entire deck in a hold. If a collision can lead to a fire on any deck in the hold, the $P_{engulfing\ fire} = 1/21$. Limiting the location of the fire to the struck hold or an adjacent hold reduces the number of decks on which the fire could occur. In this case, the number of holds of interest is approximately ten, and therefore, $P_{engulfing\ fire} = 1/10$. Using the larger estimate gives $P_{engulfing\ fire} = 0.1$.

D.5.3.1.6 Probability of Convective Flow Through the Failed Cask

Nonuniform heating of the cask during engulfing fires is expected to produce substantial flow of gases through the cask if two or more small holes or one medium hole have been produced in the cask by the ship collision. Because transportation cask bottoms and lid seats are welded to the cylindrical shell of the cask using full-penetration welds that are as strong or stronger than the parent material, when the cask shell is subjected to a severe stress (e.g., high impact or crush forces), the cask shell should yield before the welds fail. In fact, extra-regulatory 97 km/hr (60 mph) drop tests produced large plastic strains in the cylindrical shell of the test cask without failing its welds (Ludwigsen and Ammerman, 1995). Thus, during a ship collision, crush forces should collapse the cask walls inward without producing catastrophic failure of the lid, its seat, or the welds that attach the seat or the bottom of the cask to the cask walls. Therefore, an unusual configuration of cargo and/or deformed ship structures must be produced during the ship collision in order to subject the cask to forces that will produce failures substantially worse than failure of the lid seal. Either the lid seat must be bent significantly, or at least two penetrations must break, or the cask walls must be sheared or punctured. Although data for such failures is lacking, because cask designs normally do not fail by these mechanisms, the probability that a failure substantially worse than seal failure occurs is conservatively assumed to be no larger than 0.1, therefore $P_{convection} = 0.1$.

D.5.3.1.7 Source Term Probability Values

Table D-24 summarizes the estimates developed for the probabilities that enter the EIS source term probability expressions presented in Table D-23.

Table D-24 Estimated Values for Probabilities in Source Term Probability Expressions

Severity Category	*Probability*	*Estimated Value*[a]
	$P_{collision}$	0.0001
	P_{hold}	0.143
	P_{impact}	0.0
	P_{crush}	0.40
	$P_{severe\ fire}$	0.01
	$P_{engulfing\ fire}$	0.1
	$P_{convection}$	0.1
4	$P_{st} = P_{collision}P_{hold}(P_{impact} + P_{crush})$	0.000006
5	$P_{ST} = P_{collision}P_{hold}(P_{impact} + P_{crush})P_{severe\ fire}P_{engulfing\ fire}$	5×10^{-9}
6	$P_{ST} = P_{collision}P_{hold}(P_{impact} + P_{crush})P_{severe\ fire}P_{engulfing\ fire}\ P_{convection}$	6×10^{-10}

[a]*Severity category 6 is a subset of severity category 5, which in turn is a subset of severity category 4. Therefore, the final estimated value for each P was adjusted to account for this.*

D.5.3.1.8 Source Term Magnitudes

In MACCS, source term magnitudes (M_{sti}) are given by the product of the inventory (I_i) of radionuclides (i) available for release and the fraction (f_i) of that inventory that is released during the accident being examined. Therefore,

$$M_{sti} = I_i f_i.$$

Cask radionuclide inventories were developed for three types of research reactor fuel — Training, Research, Isotope, General Atomic (TRIGA), RHF, and BR2 — for use in the port accident analysis (see Appendix B). Table D-25 presents these inventories. Because it is partly metallic, the TRIGA fuel may undergo exothermic oxidation if exposed to air while at elevated temperatures during an accident involving an enveloping fire.

Because of the large number of casks that might be used to transport foreign research reactor spent nuclear fuel, analyses could not be performed for all possible cask/inventory combinations. Since the size of the cask, rather than the details of its construction, determines the size of the cask's inventory, construction details were obtained for one typical spent nuclear fuel transportation cask, and these construction data were the basis for analyses that depended on cask properties. See Appendix B for description and figures of transportation casks.

For base case analyses, the values for the release fractions (f_i) for the five representative elements, cobalt,

Table D-25 Curie Content of Fully Loaded Transportation Casks for Three Representative Fuel Types

Nuclide	Fuel		
	BR-2	RHF	TRIGA
Hydrogen-3	8.6	37	13
Krypton-85	2,470	1,070	363
Strontium-89	40,800	17,600	275
Strontium-Yttrium-90	20,800	8,930	3,160
Yttrium-91	73,000	31,400	4,560
Zirconium-95	107,000	46,300	6,480
Niobium-95	220,000	94,900	12,800
Ruthenium-103, Rh-103m	8,900	3,770	844
Ruthenium-106, Rh-106m	21,500	9,160	2,540
Tin-123	427	184	27
Antimony-125	890	381	119
Tellurium-125m	212	91	29
Tellurium-127m	887	382	56
Tellurium-129m	189	80	23
Cesium-134	16,400	4,000	1,160
Cesium-137	20,600	8,870	3,190
Cerium-141	5,740	2,440	697
Cerium-144	312,000	135,000	25,500
Promethium-147	48,300	24,600	7,020
Promethium-148m	75	29	47
Europium-154	620	163	42
Europium-155	130	46	23
Uranium-234	0.0009	0.0004	0.0001
Uranium-235	0.014	0.01	0.008
Uranium-238	0.0003	0.0002	0.007
Plutonium-238	64	10	3
Plutonium-239	1.8	0.09	0.6
Plutonium-240	1.2	0.4	2
Plutonium-241	284	68	213
Americium-241	0.4	0.1	0.4
Americium-242m	0.001	0.0001	0.009
Americium-243	0.004	0.004	0.0004
Curium-244	1.3	0.009	0.007
Curium-242	1.8	0.1	3

corrosion product are released in a category 3 accident, and only minor amounts of corrosion product deposits form on research reactor spent nuclear fuel. To examine the possible impacts of corrosion products release, during the sensitivity studies, one category 3 accident calculation was performed during which 350 Ci of Co-60 was the only nuclide released, and one calculation was performed that added the same amount of Co-60 to the base case calculation.

D.5.3.1.9 Source Term Timing and Sensible Heat

Ship accident source terms may have both a puff (an immediate release of most material) and a tail (a gradual release of the material over an extended time), where the puff follows the mechanical failure of the cask due to the collision forces, and the tail is produced by the slow heating of the cask contents by an ensuing fire. Because ship collisions are short duration events, if the collision causes a mechanical release, it should be of relatively short duration and the gases released from the cask should be cold (no significant sensible heat content) and thus not subject to plume rise. Conversely, because a substantial engulfing fire that burns for approximately an hour is required to heat both the cask and the spent nuclear fuel elements in the cask to temperatures where cesium compounds (for example, CsOH) vaporize to a significant extent, thermal releases will be delayed (release won't occur until about one hour after the collision) and will not take place rapidly (release duration of about one hour). Of course, if cask failure is caused by thermal rather than mechanical loads, any radioactivity released inside of the cask by the collision will not be released from the cask until the cask fails due to those thermal loads. Moreover, if heat loads cause the fuel elements in the cask to fail at essentially the same time that the cask seals fail due to thermal stress, a delayed short duration release could occur. Thus, ship accident source terms can have four release patterns: (1) a single short (15 minute) release caused by the mechanical forces engendered by the collision; (2) a single short (15 minute) release caused by the mechanical forces engendered by the collision followed by a longer (60 minute) release caused by the thermal loads produced by an ensuing fire; (3) a single long duration (60 minute) release caused by thermal loads on the cask if the collision does not lead to failure but an ensuing fire does; and (4) a single delayed short (15 minute) duration release if cask failure and burst rupture of fuel elements occur together.

Because a substantial engulfing fire of significant duration is required to cause a thermal release, for such thermal releases the radioactivity released from the failed cask will be assumed to be released into the fire plume, which typically will have a bulk gas temperature of about 1,200°K (1,700°F). Therefore, the sensible heat content of that plume will be 100 kilowatts for severity category 5 releases and 150 kilowatts for severity category 6 releases.

The start time and duration of the four release patterns described above are presented in Table D-26. For base case calculations, the first release pattern will be assumed for severity Category 4 accidents and the second pattern for severity Category 5 and 6 accidents. The third and forth release patterns will be examined by sensitivity studies.

Table D-26 Release Timing Patterns

Pattern	*Puff*		*Tail*	
	Release Start (min)	*Release Duration (min)*	*Release Start (min)*	*Release Duration (min)*
1	0	10		
2	0	10	60	60
3			60	60
4			90	10

D.5.3.2 Population Distributions

[illegible] specific weather conditions. The [illegible]

Table D-27 Ports Analyzed

Coast	High Population	Medium Population	Low Population
East	Philadelphia, PA New York, NY	Hampton Roads, VA Jacksonville, FL	Charleston, SC MOTSU, NC Savannah, GA Wilmington, NC
West	Long Beach, CA	Concord NWS, CA Portland, OR Tacoma, WA	
Gulf			Galveston, TX

Two accident locations were considered for each port, one at dockside and one channel location near the population center where a major ship collision would be possible. Two exceptions were made for ports able to share the same channel accident location due to their close proximity to each other. T

Table D-28 Accident Location Map Coordinates

			Coordinates	

Although MACCS calculations can use constant meteorology, one year of hourly meteorological data is preferred because adverse results are often the result of meteorological sequences that involve changing meteorological conditions. MACCS uses an importance sampling method to find these less probable sequences that yield adverse results. The sampling method examines all of the 8,760 weather sequences in

one year of hourly data and selects the start times of the approximately 100 weather sequences that are used during a variable meteorology calculation. The impact of using constant versus variable meteorology is the subject of one of the sensitivity calculations.

D.5.4 MACCS Calculations

All of the MACCS calculations performed during this study used a source term probability of one. Thus, the consequence estimates generated and the probabilities associated with those estimates are conditional on the release of the source term (i.e., the estimates are conditional on the accident having occurred).

For any source term, a MACCS calculation generates results for all possible combinations of a representative set of weather sequences and a representative set of exposed downwind populations. Since the probability of occurrence of each weather sequence and the exposure probability of each population distribution is known, the variability of consequences due to weather and population conditional on the

- of using release fractions developed for the Programmatic SNF&INEL Final EIS (DOE, 1995) for truck and rail accidents,
- of adding the harbor work force population to the residential population distribution,
- of modeling extremely high temperature effects on aluminum-based and TRIGA fuels release fractions,
- of modeling accidents that lead to severe fires using a puff and a tail (two segment release) rather than only a puff, and
- [illegible]

[illegible]

The results of these sensitivity calculations are presented in Section D.5.4.3.

Both the variable meteorology and the constant meteorology MACCS calculations performed for this study consist of a large number of individual trials (about 1,750 trials for each variable meteorology calculation; about 1,150 trials for each constant meteorology calculation). By accumulating the results of [illegible]

Table D-30 Sample Output from MACCS

SITE=NEW LOC=CHANNEL INV=BR-2 ST=EA4 VAR MET=NYC

		PROB NON-ZERO	MEAN	QUANTILES 50TH	90TH	95TH	99TH	99.9TH	PEAK CONS	PEAK PROB	PEAK TRIAL
EARLY + CHRONIC RESULTS											
HEALTH EFFECTS CASES											
CAN FAT/TOTAL	0-1.6 KM	0.5675	4.16E-05	2.43E-07	1.30E-04	2.15E-04	4.38E-04	8.02E-04	1.13E-03	2.50E-04	73
CAN FAT/TOTAL	0-80.5 KM	1.0000	1.64E-04	7.15E-05	4.38E-04	6.29E-04	9.89E-04	1.29E-03	1.50E-03	2.50E-04	73
POPULATION DOSE (SV)											
EDEWBODY TOT LIF	0-1.6 KM	0.5675	9.45E-04	5.56E-06	2.90E-03	4.96E-03	1.03E-02	1.56E-02	2.56E-02	2.50E-04	73
EDEWBODY TOT LIF	0-8.1 KM	0.8016	2.42E-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Health Effect Cases. The first health effect considered is the number of cancer fatalities expected to occur among the population located within 1.6 km (1 mi) of the accident location. For this population group, the table shows:

- that the probability of getting a nonzero result is 0.6818 which means that not even a fractional cancer fatality was predicted to occur in this population group for 31.82 percent of the approximately 1,750 trials run during this calculation (conversely, at least a fractional cancer death was predicted to occur in 68.18 percent of the trials);
- that the expected (mean) number of cancer fatalities for this population group is 0.098;
- that the 90th and 99th quantiles of the Complementary Cumulative Distribution Function of cancer fatalities for this population group have values of 0.0271 and 2.60; and

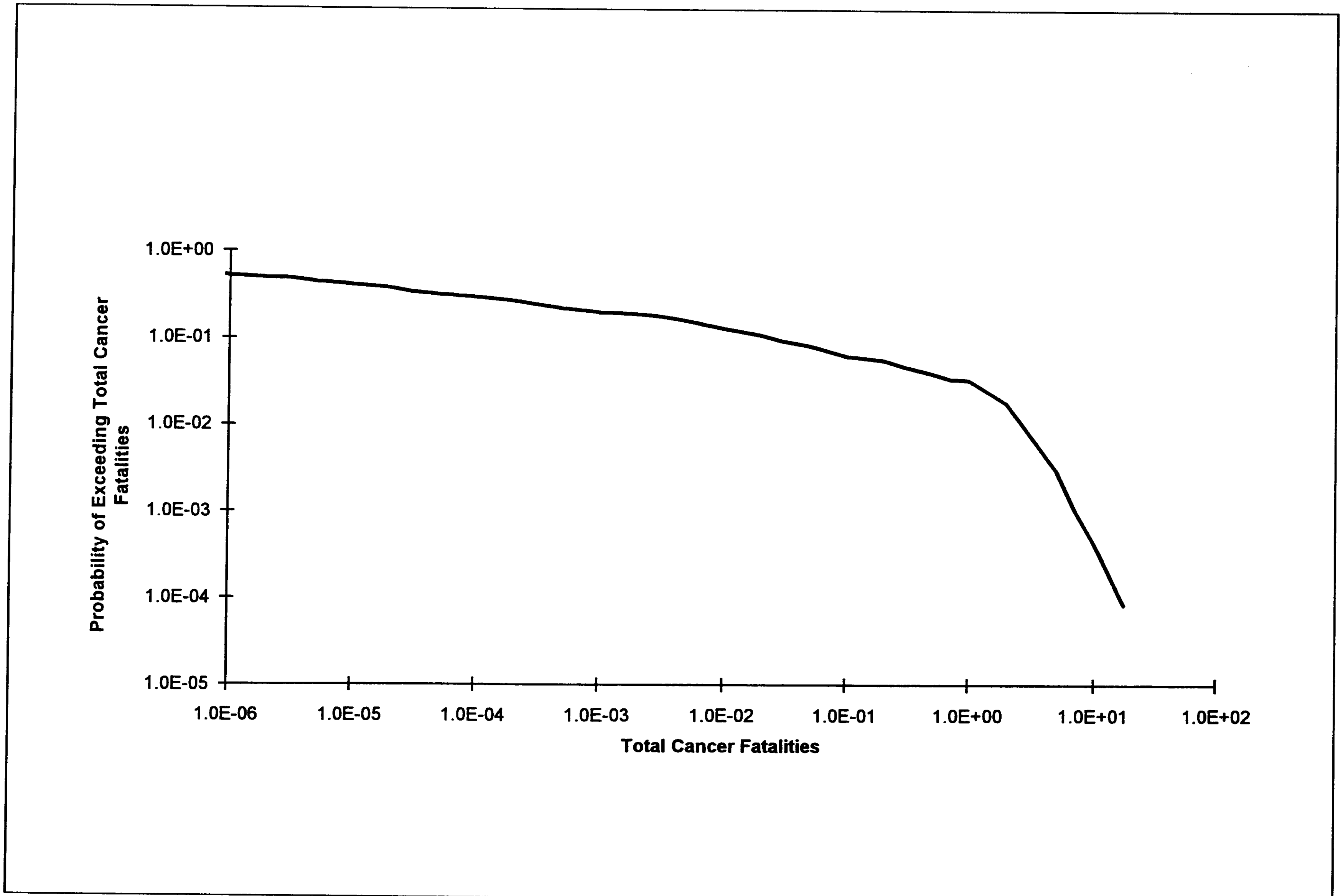


Figure D-54 Total Cancer Fatalities, 0-1.6 km (0-1 mi), Elizabeth Channel, Variable Meteorology, BR-2 Inventory, Severity Category 5

D-30 also shows that the economic losses (costs) caused by the accident are very small (expected value of $18.00; peak value of $5,640) and are entirely attributable to the disposal of contaminated crops and milk by farms located close to the accident site (the largest disposal distance found was 1.6 km or 1 mi). This also is typical of the MACCS output for all accidents analyzed.

The values of mean (expected) centerline dose (D_{cl}) (not shown in Table D-30) for severity category 5 release fractions are plotted versus distance (d) in Figure D-55. The figure shows that on a log-log plot dose decreases linearly with distance with a slope very close to minus one. Therefore, as one would expect, individual centerline dose is inversely proportional to distance ($D_{C1} \propto 1/d$).

Table D-30 presents a breakdown of long-term population dose (calculated as a wholebody dose by the Effective Dose Equivalent method and thus labeled EDEWBODY POP. DOSE) by exposure pathways. Inspection of this breakdown and comparison of the total long-term pathway dose to the total population dose for release category 5, mean results, in the 0-80.5 km (0-50 mi) ranges shows:

- that the total population dose 6,930 rem (69.3 Sv), is almost entirely due to the 6,920 rem (69.2 Sv) dose delivered by long-term exposure pathways;
- that short-term (acute) pathways deliver only a minor dose of 10 rem (0.1 Sv), which is the difference between the 69.3 Sv and the 69.2 Sv;
- that the long-term dose of 6,920 rem (69.2 Sv) is caused mainly by direct exposure pathways [6,750 rem (67.5 Sv)] and only secondarily by ingestion pathways [170 rem (1.7 Sv)];
- that groundshine [6,720 rem (67.2 Sv)] causes almost all of the long-term direct dose; resuspension (external direct exposure to radiation emitted by radionuclides resuspended from the ground) causes the rest of the long-term pathway dose, 30 rem (0.3 Sv);
- that the dose from radioactivity deposited directly on food crops [125 rem (1.25 Sv)] or on grass consumed by milk cows [30 rem (0.30 Sv)] accounts for most ingestion dose; and
- that the rest of the ingestion dose is caused by root uptake [to food crops, 10 rem (0.10 Sv); to grass and fodder crops, 4 rem (0.04 Sv)] with drinking of contaminated water causing only a very small dose of 1 rem (0.01 Sv).

D.5.4.2.2 Principal Base Case Consequence Results

Accident consequence mean (expected) values for whole body population dose and total cancer fatalities for the distance range 0-80.5 km (0-50 mi), and individual centerline dose and individual centerline cancer risk for the distance range 0-1.6 km (0-1 mi) are presented in Table D-31. Table D-32 provides 99.9th quantile values for whole body population dose and total cancer fatalities for the range 0-80.5 km (0-50 mi). Table D-33 presents the largest (peak) result calculated for individual centerline dose and cancer risk in the range 0-1.6 km or 0-1 mi. Table D-34 presents probabilities of the largest results calculated.

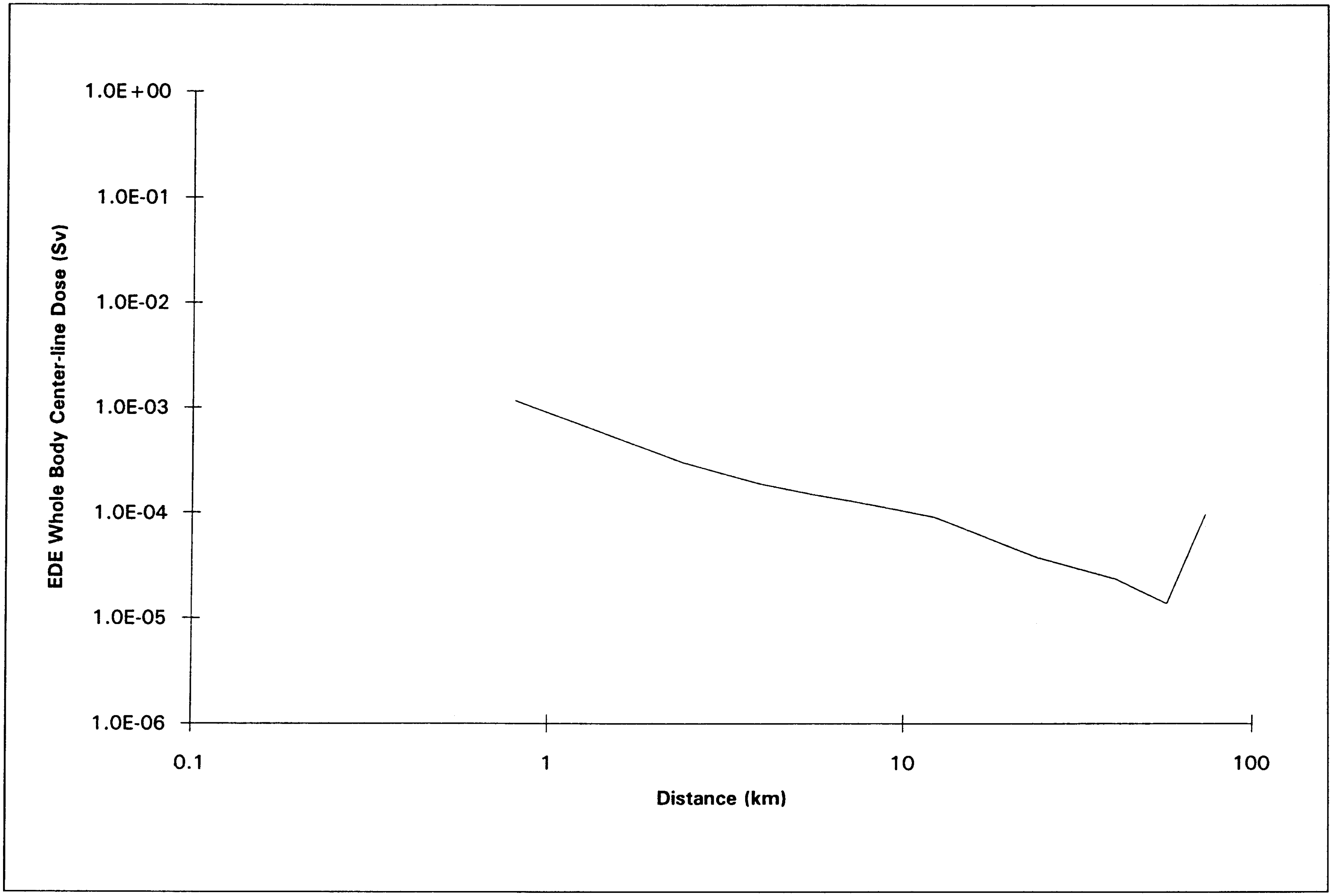


Figure D-55 Mean Effective Dose Equivalent Whole Body Center-Line Dose (Sv) vs Distance, Elizabeth Channel, Variable Meteorology, BR-2 Inventory, Severity Category 5

Table D-31 Mean Results, Variable Meteorology

EDE Whole Body Population Dose, 0-80 KM (SV)

Site/Loc	BR-2 EA4	BR-2 EA5	BR-2 EA6	RHF EA4	RHF EA5	RHF EA6	TRIGA EA4	TRIGA EA5	TRIGA EA6
CHA-D	2.40E-04	4.15E+00	4.13E+00	9.55E-05	1.54E+00	1.53E+00	2.97E-05	5.32E-01	5.26E-01
CHA-C	3.78E-04	4.18E+00	4.21E+00	1.51E-04	1.55E+00	1.56E+00	4.58E-05	5.35E-01	5.37E-01
CNC-D	4.40E-04	2.07E+01	2.21E+01	1.76E-04	7.97E+00	8.51E+00	5.43E-05	2.78E+00	2.97E+00
CNC-C	9.44E-04	3.31E+01	3.40E+01	3.77E-04	1.29E+01	1.32E+01	1.13E-04	4.52E+00	4.63E+00
GAL-D	7.26E-04	1.44E+01	1.58E+01	2.90E-04	5.45E+00	6.00E+00	8.94E-05	1.90E+00	2.08E+00
GAL-C	3.23E-04	1.42E+01	1.55E+01	1.29E-04	5.36E+00	5.89E+00	4.13E-05	1.86E+00	2.04E+00
JAC-D	2.79E-04	6.82E+00	6.76E+00	1.11E-04	2.55E+00	2.52E+00	3.48E-05	8.84E-01	8.71E-01
JAC-C	2.58E-04	5.33E+00	5.45E+00	1.03E-04	1.99E+00	2.03E+00	3.22E-05	6.87E-01	6.99E-01
LOS-D	2.13E-03	4.71E+01	4.82E+01	8.52E-04	1.85E+01	1.89E+01	2.54E-04	6.49E+00	6.62E+00
LOS-C	8.09E-04	4.26E+01	4.40E+01	3.23E-04	1.67E+01	1.73E+01	9.72E-05	5.86E+00	6.05E+00
MOT-D	7.24E-05	2.08E+00	2.21E+00	2.88E-05	7.45E-01	7.91E-01	9.72E-06	2.54E-01	2.70E-01
NEW-D	2.33E-03	6.55E+01	6.51E+01	9.30E-04	2.58E+01	2.56E+01	2.77E-04	9.07E+00	9.00E+00
NEW-C	3.76E-03	6.93E+01	6.77E+01	1.50E-03	2.73E+01	2.67E+01	4.46E-04	9.60E+00	9.37E+00
NOR-D	5.52E-04	8.54E+00	8.32E+00	2.20E-04	3.25E+00	3.15E+00	6.69E-05	1.13E+00	1.09E+00
NOR-C	3.02E-04	6.65E+00	6.64E+00	1.21E-04	2.51E+00	2.50E+00	3.70E-05	8.73E-01	8.67E-01
PHI-D	1.77E-03	2.81E+01	2.78E+01	7.08E-04	1.10E+01	1.08E+01	2.11E-04	3.84E+00	3.79E+00
PHI-C	8.48E-04	2.74E+01	2.81E+01	3.39E-04	1.07E+01	1.09E+01	1.02E-04	3.74E+00	3.83E+00
POR-D	7.70E-04	1.17E+01	1.19E+01	3.07E-04	4.45E+00	4.50E+00	9.32E-05	1.55E+00	1.56E+00
POR-C	5.33E-04	1.12E+01	1.15E+01	2.13E-04	4.26E+00	4.36E+00	6.52E-05	1.48E+00	1.51E+00
SAV-D	5.60E-04	4.91E+00	5.01E+00	2.23E-04	1.80E+00	1.83E+00	6.82E-05	6.18E-01	6.28E-01
SAV-C	1.34E-04	3.82E+00	3.93E+00	5.32E-05	1.38E+00	1.42E+00	1.75E-05	4.74E-01	4.86E-01
SEA-C	1.31E-04	7.54E+00	8.29E+00	5.21E-05	2.84E+00	3.12E+00	1.68E-05	9.86E-01	1.08E+00
TAC-D	5.55E-04	1.73E+01	1.83E+01	2.21E-04	6.67E+00	7.02E+00	6.81E-05	2.33E+00	2.45E+00
TAC-C	3.87E-04	1.43E+01	1.50E+01	1.55E-04	5.50E+00	5.73E+00	4.75E-05	1.92E+00	2.00E+00
WIL-D	3.80E-04	4.82E+00	5.02E+00	1.51E-04	1.79E+00	1.86E+00	4.66E-05	6.19E-01	6.43E-01
WIL-C	9.65E-05	2.07E+00	2.20E+00	3.84E-05	7.47E-01	7.96E-01	1.24E-05	2.56E-01	2.72E-01
CHN-D	1.67E-04	4.76E+00	4.74E+00	6.63E-05	1.76E+00	1.77E+00	2.13E-05	6.09E-01	6.08E-01

Total Cancer Fatalities, 0-80 KM

Site/Loc	BR-2 EA4	BR-2 EA5	BR-2 EA6	RHF EA4	RHF EA5	RHF EA6	TRIGA EA4	TRIGA EA5	TRIGA EA6
CHA-D	1.05E-05	1.89E-01	1.90E-01	4.20E-06	6.97E-02	6.95E-02	1.24E-06	2.40E-02	2.39E-02
CHA-C	1.66E-05	1.90E-01	1.93E-01	6.65E-06	7.01E-02	7.08E-02	1.90E-06	2.41E-02	2.43E-02
CNC-D	1.91E-05	8.96E-01	9.57E-01	7.63E-06	3.44E-01	3.67E-01	2.23E-06	1.20E-01	1.28E-01
CNC-C	4.10E-05	1.41E+00	1.45E+00	1.65E-05	5.48E-01	5.62E-01	4.63E-06	1.92E-01	1.97E-01
GAL-D	3.17E-05	6.39E-01	7.02E-01	1.27E-05	2.41E-01	2.65E-01	3.70E-06	8.35E-02	9.17E-02
GAL-C	1.39E-05	6.30E-01	6.92E-01	5.57E-06	2.37E-01	2.60E-01	1.71E-06	8.20E-02	9.01E-02
JAC-D	1.22E-05	3.07E-01	3.06E-01	4.88E-06	1.14E-01	1.13E-01	1.45E-06	3.94E-02	3.91E-02
JAC-C	1.13E-05	2.42E-01	2.49E-01	4.51E-06	8.95E-02	9.16E-02	1.34E-06	3.09E-02	3.15E-02
LOS-D	9.32E-05	1.99E+00	2.04E+00	3.75E-05	7.79E-01	7.97E-01	1.04E-05	2.73E-01	2.79E-01
LOS-C	3.51E-05	1.80E+00	1.86E+00	1.41E-05	7.05E-01	7.28E-01	3.96E-06	2.47E-01	2.55E-01
MOT-D	3.16E-06	9.94E-02	1.06E-01	1.25E-06	3.53E-02	3.76E-02	4.13E-07	1.20E-02	1.28E-02
NEW-D	1.02E-04	2.75E+00	2.73E+00	4.09E-05	1.08E+00	1.07E+00	1.13E-05	3.80E-01	3.77E-01
NEW-C	1.64E-04	2.90E+00	2.84E+00	6.62E-05	1.14E+00	1.12E+00	1.83E-05	4.01E-01	3.92E-01
NOR-D	2.42E-05	3.77E-01	3.70E-01	9.71E-06	1.42E-01	1.39E-01	2.76E-06	4.94E-02	4.82E-02
NOR-C	1.32E-05	2.96E-01	2.97E-01	5.30E-06	1.11E-01	1.11E-01	1.53E-06	3.85E-02	3.84E-02

Table D-31 Mean Results, Variable Meteorology (Continued)

Individual Center-line EDE Whole Body Dose, 0-1.6 KM (SV)

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	8.60E-07	6.83E-04	7.10E-04	3.44E-07	2.70E-04	2.81E-04	9.71E-08	9.51E-05	9.88E-05
CHA-C	8.60E-07	6.83E-04	7.10E-04	3.44E-07	2.70E-04	2.81E-04	9.71E-08	9.51E-05	9.88E-05
CNC-D	1.07E-06	2.28E-04	2.17E-04	4.29E-07	9.01E-05	8.59E-05	1.21E-07	3.17E-05	3.02E-05
CNC-C	1.07E-06	2.28E-04	2.17E-04	4.29E-07	9.01E-05	8.59E-05	1.21E-07	3.17E-05	3.02E-05
GAL-D	9.29E-07	6.52E-04	6.91E-04	3.71E-07	2.58E-04	2.74E-04	1.05E-07	9.08E-05	9.62E-05
GAL-C	9.29E-07	6.52E-04	6.91E-04	3.71E-07	2.58E-04	2.74E-04	1.05E-07	9.08E-05	9.62E-05
JAC-D	8.60E-07	6.83E-04	7.10E-04	3.44E-07	2.70E-04	2.81E-04	9.71E-08	9.51E-05	9.88E-05
JAC-C	8.60E-07	6.83E-04	7.10E-04	3.44E-07	2.70E-04	2.81E-04	9.71E-08	9.51E-05	9.88E-05
LOS-D	1.07E-06	2.28E-04	2.17E-04	4.29E-07	9.01E-05	8.59E-05	1.21E-07	3.17E-05	3.02E-05
LOS-C	1.07E-06	2.28E-04	2.17E-04	4.29E-07	9.01E-05	8.59E-05	1.21E-07	3.17E-05	3.02E-05
MOT-D	5.32E-07	6.24E-04	5.51E-04	2.12E-07	2.47E-04	2.18E-04	6.04E-08	8.69E-05	7.67E-05
NEW-D	5.98E-07	1.17E-03	9.53E-04	2.39E-07	4.63E-04	3.77E-04	6.81E-08	1.63E-04	1.33E-04
NEW-C	5.98E-07	1.17E-03	9.53E-04	2.39E-07	4.63E-04	3.77E-04	6.81E-08	1.63E-04	1.33E-04
NOR-D	5.32E-07	6.24E-04	5.51E-04	2.12E-07	2.47E-04	2.18E-04	6.04E-08	8.69E-05	7.67E-05
NOR-C	5.32E-07	6.24E-04	5.51E-04	2.12E-07	2.47E-04	2.18E-04	6.04E-08	8.69E-05	7.67E-05
PHI-D	1.01E-06	6.31E-04	6.59E-04	4.02E-07	2.50E-04	2.61E-04	1.14E-07	8.78E-05	9.16E-05
PHI-C	1.01E-06	6.31E-04	6.59E-04	4.02E-07	2.50E-04	2.61E-04	1.14E-07	8.78E-05	9.16E-05
POR-D	7.54E-07	7.56E-04	7.97E-04	3.01E-07	2.99E-04	3.15E-04	8.57E-08	1.05E-04	1.11E-04
POR-C	7.54E-07	7.56E-04	7.97E-04	3.01E-07	2.99E-04	3.15E-04	8.57E-08	1.05E-04	1.11E-04
SAV-D	8.60E-07	6.83E-04	7.10E-04	3.44E-07	2.70E-04	2.81E-04	9.71E-08	9.51E-05	9.88E-05
SAV-C	8.60E-07	6.83E-04	7.10E-04	3.44E-07	2.70E-04	2.81E-04	9.71E-08	9.51E-05	9.88E-05
SEA-C	7.54E-07	7.56E-04	7.97E-04	3.01E-07	2.99E-04	3.15E-04	8.57E-08	1.05E-04	1.11E-04
TAC-D	7.54E-07	7.56E-04	7.97E-04	3.01E-07	2.99E-04	3.15E-04	8.57E-08	1.05E-04	1.11E-04
TAC-C	7.54E-07	7.56E-04	7.97E-04	3.01E-07	2.99E-04	3.15E-04	8.57E-08	1.05E-04	1.11E-04
WIL-D	5.32E-07	6.24E-04	5.51E-04	2.12E-07	2.47E-04	2.18E-04	6.04E-08	8.69E-05	7.67E-05
WIL-C	5.32E-07	6.24E-04	5.51E-04	2.12E-07	2.47E-04	2.18E-04	6.04E-08	8.69E-05	7.67E-05
CHN-D	8.60E-07	6.83E-04	7.10E-04	3.44E-07	2.70E-04	2.81E-04	9.71E-08	9.51E-05	9.88E-05

Individual Center-line Cancer Risk, 0-1.6 KM

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	4.10E-08	2.85E-05	2.96E-05	1.66E-08	1.13E-05	1.17E-05	4.29E-09	3.96E-06	4.11E-06
CHA-C	4.10E-08	2.85E-05	2.96E-05	1.66E-08	1.13E-05	1.17E-05	4.29E-09	3.96E-06	4.11E-06
CNC-D	5.12E-08	9.50E-06	9.06E-06	2.08E-08	3.75E-06	3.58E-06	5.36E-09	1.32E-06	1.26E-06
CNC-C	5.12E-08	9.50E-06	9.06E-06	2.08E-08	3.75E-06	3.58E-06	5.36E-09	1.32E-06	1.26E-06
GAL-D	4.43E-08	2.72E-05	2.88E-05	1.80E-08	1.08E-05	1.14E-05	4.63E-09	3.78E-06	4.01E-06
GAL-C	4.43E-08	2.72E-05	2.88E-05	1.80E-08	1.08E-05	1.14E-05	4.63E-09	3.78E-06	4.01E-06
JAC-D	4.10E-08	2.85E-05	2.96E-05	1.66E-08	1.13E-05	1.17E-05	4.29E-09	3.96E-06	4.11E-06
JAC-C	4.10E-08	2.85E-05	2.96E-05	1.66E-08	1.13E-05	1.17E-05	4.29E-09	3.96E-06	4.11E-06
LOS-D	5.12E-08	9.50E-06	9.06E-06	2.08E-08	3.75E-06	3.58E-06	5.36E-09	1.32E-06	1.26E-06
LOS-C	5.12E-08	9.50E-06	9.06E-06	2.08E-08	3.75E-06	3.58E-06	5.36E-09	1.32E-06	1.26E-06
MOT-D	2.51E-08	2.60E-05	2.30E-05	1.02E-08	1.03E-05	9.08E-06	2.64E-09	3.62E-06	3.19E-06
NEW-D	2.80E-08	4.88E-05	3.97E-05	1.14E-08	1.93E-05	1.57E-05	2.96E-09	6.78E-06	5.52E-06
NEW-C	2.80E-08	4.88E-05	3.97E-05	1.14E-08	1.93E-05	1.57E-05	2.96E-09	6.78E-06	5.52E-06
NOR-D	2.51E-08	2.60E-05	2.30E-05	1.02E-08	1.03E-05	9.08E-06	2.64E-09	3.62E-06	3.19E-06
NOR-C	2.51E-08	2.60E-05	2.30E-05	1.02E-08	1.03E-05	9.08E-06	2.64E-09	3.62E-06	3.19E-06
PHI-D	4.80E-08	2.63E-05	2.75E-05	1.95E-08	1.04E-05	1.09E-05	5.01E-09	3.66E-06	3.82E-06

Table D-32 99.9th Quantile Results, Variable Meteorology

EDE Whole Body Population Dose, 0-80 KM (SV)

Site/Loc	BR-2 EA4	BR-2 EA5	BR-2 EA6	RHF EA4	RHF EA5	RHF EA6	TRIGA EA4	TRIGA EA5	TRIGA EA6
CHA-D	1.20E-03	4.63E+01	5.26E+01	3.82E-04	1.71E+01	2.04E+01	1.30E-04	6.21E+00	7.13E+00
CHA-C	3.40E-03	9.03E+01	9.75E+01	1.23E-03	3.70E+01	4.13E+01	3.98E-04	1.22E+01	1.37E+01
CNC-D	3.31E-03	9.47E+01	1.02E+02	1.29E-03	3.41E+01	3.56E+01	3.87E-04	1.17E+01	1.22E+01
CNC-C	1.06E-02	1.55E+02	1.73E+02	3.77E-03	5.55E+01	5.20E+01	1.17E-03	1.91E+01	1.97E+01
GAL-D	5.03E-03	1.33E+02	1.38E+02	2.01E-03	4.90E+01	4.92E+01	5.35E-04	1.66E+01	1.92E+01
GAL-C	1.37E-03	8.70E+01	1.16E+02	6.77E-04	3.72E+01	3.93E+01	2.01E-04	1.30E+01	1.38E+01
JAC-D	1.29E-03	7.23E+01	7.86E+01	5.59E-04	2.78E+01	3.07E+01	1.45E-04	1.01E+01	1.05E+01
JAC-C	1.26E-03	6.40E+01	6.77E+01	5.28E-04	2.45E+01	2.69E+01	1.55E-04	8.55E+00	9.22E+00
LOS-D	NOT-FOUND	2.67E+02	2.70E+02	NOT-FOUND	1.02E+02	1.04E+02	NOT-FOUND	3.32E+01	3.64E+01
LOS-C	3.66E-03	2.19E+02	2.41E+02	1.38E-03	9.72E+01	9.84E+01	5.13E-04	3.14E+01	3.12E+01
MOT-D	5.03E-04	2.46E+01	2.63E+01	1.80E-04	8.87E+00	9.48E+00	6.25E-05	2.90E+00	2.95E+00
NEW-D	1.20E-02	5.87E+02	6.37E+02	4.24E-03	2.42E+02	2.52E+02	1.34E-03	8.29E+01	8.68E+01
NEW-C	3.13E-02	9.41E+02	1.08E+03	1.19E-02	3.86E+02	3.99E+02	3.52E-03	1.33E+02	1.42E+02
NOR-D	3.40E-03	1.03E+02	1.10E+02	1.40E-03	4.04E+01	4.41E+01	4.59E-04	1.30E+01	1.39E+01
NOR-C	1.62E-03	9.02E+01	1.00E+02	7.13E-04	3.35E+01	3.56E+01	2.06E-04	1.16E+01	1.24E+01
PHI-D	8.45E-03	3.10E+02	3.32E+02	3.45E-03	1.15E+02	1.18E+02	1.00E-03	4.65E+01	5.03E+01
PHI-C	5.07E-03	2.86E+02	2.98E+02	2.03E-03	1.05E+02	1.08E+02	6.95E-04	4.13E+01	4.63E+01

Table D-33 Peak Results, Variable Meteorology

EDE Whole Body Population Dose, 0-80 KM (SV)

		BR-2			RHF			TRIGA	
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	2.82E-03	1.04E+02	1.10E+02	1.12E-03	4.07E+01	4.32E+01	3.41E-04	1.43E+01	1.51E+01
CHA-C	4.41E-03	2.12E+02	2.31E+02	1.76E-03	8.56E+01	9.34E+01	5.23E-04	3.00E+01	3.27E+01
CNC-D	3.35E-03	1.02E+02	1.11E+02	1.33E-03	4.03E+01	4.40E+01	4.00E-04	1.42E+01	1.55E+01
CNC-C	1.42E-02	6.71E+02	7.27E+02	5.70E-03	2.66E+02	2.88E+02	1.72E-03	9.34E+01	1.01E+02
GAL-D	5.60E-03	2.33E+02	2.54E+02	2.22E-03	9.59E+01	1.05E+02	6.69E-04	3.36E+01	3.66E+01
GAL-C	2.09E-03	1.85E+02	2.02E+02	8.28E-04	7.23E+01	7.89E+01	2.56E-04	2.53E+01	2.76E+01
JAC-D	2.15E-03	1.10E+02	1.20E+02	8.53E-04	4.28E+01	4.66E+01	2.61E-04	1.50E+01	1.63E+01
JAC-C	1.90E-03	1.12E+02	1.23E+02	7.52E-04	4.59E+01	5.01E+01	2.31E-04	1.61E+01	1.76E+01
LOS-D	1.30E-02	3.94E+02	4.29E+02	5.20E-03	1.56E+02	1.70E+02	1.54E-03	5.49E+01	5.98E+01
LOS-C	5.97E-03	3.47E+02	3.76E+02	2.39E-03	1.37E+02	1.49E+02	7.21E-04	4.83E+01	5.23E+01
MOT-D	7.72E-04	4.61E+01	5.03E+01	2.98E-04	1.71E+01	1.86E+01	9.74E-05	5.88E+00	6.42E+00
NEW-D	1.86E-02	1.13E+03	1.24E+03	7.44E-03	4.48E+02	4.89E+02	2.24E-03	1.58E+02	1.72E+02
NEW-C	3.41E-02	1.33E+03	1.45E+03	1.36E-02	5.25E+02	5.73E+02	4.01E-03	1.85E+02	2.02E+02
NOR-D	4.29E-03	1.66E+02	1.81E+02	1.71E-03	6.49E+01	7.06E+01	5.08E-04	2.27E+01	2.47E+01
NOR-C	2.78E-03	1.64E+02	1.78E+02	1.11E-03	6.44E+01	7.00E+01	3.36E-04	2.26E+01	2.45E+01
PHI-D	1.13E-02	7.15E+02	7.80E+02	4.52E-03	2.82E+02	3.08E+02	1.36E-03	9.91E+01	1.08E+02
PHI-C	8.77E-03	4.87E+02	5.31E+02	3.50E-03	1.92E+02	2.10E+02	1.06E-03	6.75E+01	7.36E+01
POR-D	3.85E-03	1.69E+02	1.85E+02	1.54E-03	6.69E+01	7.30E+01	4.64E-04	2.35E+01	2.57E+01
POR-C	3.94E-03	1.70E+02	1.85E+02	1.57E-03	6.66E+01	7.27E+01	4.67E-04	2.34E+01	2.55E+01
SAV-D	6.18E-03	2.39E+02	2.60E+02	2.46E-03	9.64E+01	1.05E+02	7.32E-04	3.38E+01	3.69E+01
SAV-C	1.43E-03	7.65E+01	8.00E+01	5.66E-04	2.94E+01	3.07E+01	1.75E-04	1.03E+01	1.07E+01
SEA-C	9.93E-04	5.62E+01	6.13E+01	3.93E-04	2.14E+01	2.33E+01	1.22E-04	7.44E+00	8.11E+00
TAC-D	2.67E-03	1.18E+02	1.29E+02	1.06E-03	4.66E+01	5.09E+01	3.23E-04	1.64E+01	1.79E+01
TAC-C	3.13E-03	1.70E+02	1.85E+02	1.25E-03	6.64E+01	7.25E+01	3.78E-04	2.33E+01	2.54E+01
WIL-D	5.50E-03	1.49E+02	1.63E+02	2.20E-03	5.91E+01	6.44E+01	6.51E-04	2.08E+01	2.27E+01
WIL-C	1.18E-03	3.28E+01	3.58E+01	4.71E-04	1.29E+01	1.41E+01	1.41E-04	4.57E+00	4.99E+00
CHN-D	1.76E-03	6.83E+01	7.43E+01	6.97E-04	2.64E+01	2.87E+01	2.14E-04	9.20E+00	1.00E+01

Total Cancer Fatalities, 0-80 KM

		BR-2			RHF			TRIGA	
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	1.20E-04	4.41E+00	4.69E+00	4.80E-05	1.72E+00	1.83E+00	1.37E-05	6.02E-01	6.39E-01
CHA-C	1.95E-04	8.90E+00	9.71E+00	7.83E-05	3.60E+00	3.93E+00	2.17E-05	1.26E+00	1.38E+00
CNC-D	1.49E-04	4.31E+00	4.68E+00	5.96E-05	1.68E+00	1.83E+00	1.68E-05	5.90E-01	6.44E-01
CNC-C	6.01E-04	2.80E+01	3.03E+01	2.42E-04	1.11E+01	1.20E+01	6.84E-05	3.89E+00	4.22E+00
GAL-D	2.48E-04	9.97E+00	1.09E+01	9.90E-05	4.08E+00	4.45E+00	2.79E-05	1.43E+00	1.55E+00
GAL-C	9.02E-05	7.89E+00	8.61E+00	3.57E-05	3.07E+00	3.35E+00	1.05E-05	1.07E+00	1.17E+00
JAC-D	9.25E-05	4.71E+00	5.12E+00	3.68E-05	1.82E+00	1.98E+00	1.07E-05	6.37E-01	6.93E-01
JAC-C	8.20E-05	4.71E+00	5.13E+00	3.26E-05	1.93E+00	2.11E+00	9.47E-06	6.77E-01	7.38E-01
LOS-D	5.75E-04	1.64E+01	1.79E+01	2.31E-04	6.50E+00	7.08E+00	6.37E-05	2.29E+00	2.49E+00
LOS-C	2.52E-04	1.45E+01	1.57E+01	1.01E-04	5.73E+00	6.20E+00	2.87E-05	2.01E+00	2.18E+00
MOT-D	3.49E-05	2.10E+00	2.29E+00	1.34E-05	7.69E-01	8.39E-01	4.24E-06	2.65E-01	2.88E-01
NEW-D	7.88E-04	4.72E+01	5.16E+01	3.17E-04	1.87E+01	2.04E+01	8.94E-05	6.56E+00	7.16E+00
NEW-C	1.50E-03	5.53E+01	6.04E+01	6.06E-04	2.19E+01	2.39E+01	1.66E-04	7.69E+00	8.39E+00
NOR-D	1.89E-04	7.09E+00	7.71E+00	7.62E-05	2.75E+00	2.99E+00	2.10E-05	9.63E-01	1.05E+00
NOR-C	1.19E-04	6.92E+00	7.52E+00	4.75E-05	2.71E+00	2.94E+00	1.35E-05	9.50E-01	1.03E+00
PHI-D	4.79E-04	2.99E+01	3.26E+01	1.93E-04	1.18E+01	1.29E+01	5.44E-05	4.14E+00	4.52E+00
PHI-C	3.71E-04	2.04E+01	2.23E+01	1.49E-04	8.03E+00	8.77E+00	4.23E-05	2.82E+00	3.08E+00
POR-D	1.68E-04	7.05E+00	7.70E+00	6.74E-05	2.79E+00	3.04E+00	1.87E-05	9.80E-01	1.07E+00
POR-C	1.74E-04	7.18E+00	7.84E+00	7.00E-05	2.81E+00	3.06E+00	1.94E-05	9.84E-01	1.07E+00
SAV-D	2.74E-04	1.00E+01	1.09E+01	1.10E-04	4.07E+00	4.44E+00	3.04E-05	1.43E+00	1.55E+00
SAV-C	6.15E-05	3.32E+00	3.48E+00	2.44E-05	1.27E+00	1.33E+00	7.14E-06	4.42E-01	4.62E-01
SEA-C	4.27E-05	2.47E+00	2.69E+00	1.69E-05	9.33E-01	1.02E+00	4.99E-06	3.24E-01	3.53E-01
TAC-D	1.14E-04	5.03E+00	5.49E+00	4.54E-05	1.95E+00	2.12E+00	1.31E-05	6.83E-01	7.45E-01
TAC-C	1.33E-04	7.18E+00	7.84E+00	5.34E-05	2.80E+00	3.06E+00	1.51E-05	9.82E-01	1.07E+00
WIL-D	2.43E-04	6.24E+00	6.80E+00	9.80E-05	2.46E+00	2.69E+00	2.69E-05	8.70E-01	9.48E-01
WIL-C	5.22E-05	1.41E+00	1.54E+00	2.10E-05	5.42E-01	5.92E-01	5.94E-06	1.93E-01	2.10E-01
CHN-D	7.30E-05	2.95E+00	3.21E+00	2.90E-05	1.13E+00	1.23E+00	8.51E-06	3.95E-01	4.29E-01

CHA = Charleston (Wando Terminal), SC; CNC = Concord, CA; GAL = Galveston, TX; JAC = Jacksonville, FL; LOS = Long Beach, CA; MOT = MOTSU, SC; NEW = Elizabeth, NJ; NOR = Norfolk, VA; PHI = Philadelphia, PA; POR = Portland, OR; SAV = Savannah, GA; SEA = Seattle, WA; TAC = Tacoma, WA; WIL = Wilmington, NC; CHN = NWS Charleston, SC

Table D-33 Peak Results, Variable Meteorology (Continued)

Individual Center-line EDE Whole Body Dose, 0-1.6 KM (SV)

Site/Loc	BR-2 EA4	BR-2 EA5	BR-2 EA6	RHF EA4	RHF EA5	RHF EA6	TRIGA EA4	TRIGA EA5	TRIGA EA6
CHA-D	3.66E-06	5.85E-02	6.39E-02	1.46E-06	2.32E-02	2.53E-02	4.06E-07	8.15E-03	8.89E-03
CHA-C	3.66E-06	5.85E-02	6.39E-02	1.46E-06	2.32E-02	2.53E-02	4.06E-07	8.15E-03	8.89E-03
CNC-D	3.66E-06	2.51E-02	2.74E-02	1.46E-06	9.94E-03	1.08E-02	4.06E-07	3.50E-03	3.81E-03
CNC-C	3.66E-06	2.51E-02	2.74E-02	1.46E-06	9.94E-03	1.08E-02	4.06E-07	3.50E-03	3.81E-03
GAL-D	3.66E-06	5.34E-02	5.82E-02	1.46E-06	2.11E-02	2.31E-02	4.06E-07	7.43E-03	8.10E-03
GAL-C	3.66E-06	5.34E-02	5.82E-02	1.46E-06	2.11E-02	2.31E-02	4.06E-07	7.43E-03	8.10E-03
JAC-D	3.66E-06	5.85E-02	6.39E-02	1.46E-06	2.32E-02	2.53E-02	4.06E-07	8.15E-03	8.89E-03
JAC-C	3.66E-06	5.85E-02	6.39E-02	1.46E-06	2.32E-02	2.53E-02	4.06E-07	8.15E-03	8.89E-03
LOS-D	3.66E-06	2.51E-02	2.74E-02	1.46E-06	9.94E-03	1.08E-02	4.06E-07	3.50E-03	3.81E-03
LOS-C	3.66E-06	2.51E-02	2.74E-02	1.46E-06	9.94E-03	1.08E-02	4.06E-07	3.50E-03	3.81E-03
MOT-D	3.66E-06	5.96E-02	6.50E-02	1.46E-06	2.36E-02	2.57E-02	4.06E-07	8.29E-03	9.04E-03
NEW-D	3.66E-06	4.12E-02	4.50E-02	1.46E-06	1.63E-02	1.78E-02	4.06E-07	5.74E-03	6.26E-03
NEW-C	3.66E-06	4.12E-02	4.50E-02	1.46E-06	1.63E-02	1.78E-02	4.06E-07	5.74E-03	6.26E-03
NOR-D	3.66E-06	5.96E-02	6.50E-02	1.46E-06	2.36E-02	2.57E-02	4.06E-07	8.29E-03	9.04E-03
NOR-C	3.66E-06	5.96E-02	6.50E-02	1.46E-06	2.36E-02	2.57E-02	4.06E-07	8.29E-03	9.04E-03
PHI-D	3.66E-06	6.06E-02	6.61E-02	1.46E-06	2.40E-02	2.62E-02	4.06E-07	8.43E-03	9.20E-03
PHI-C	3.66E-06	6.06E-02	6.61E-02	1.46E-06	2.40E-02	2.62E-02	4.06E-07	8.43E-03	9.20E-03
POR-D	3.66E-06	5.64E-02	6.15E-02	1.46E-06	2.23E-02	2.43E-02	4.06E-07	7.85E-03	8.56E-03
POR-C	3.66E-06	5.64E-02	6.15E-02	1.46E-06	2.23E-02	2.43E-02	4.06E-07	7.85E-03	8.56E-03
SAV-D	3.66E-06	5.85E-02	6.39E-02	1.46E-06	2.32E-02	2.53E-02	4.06E-07	8.15E-03	8.89E-03
SAV-C	3.66E-06	5.85E-02	6.39E-02	1.46E-06	2.32E-02	2.53E-02	4.06E-07	8.15E-03	8.89E-03
SEA-C	3.66E-06	5.64E-02	6.15E-02	1.46E-06	2.23E-02	2.43E-02	4.06E-07	7.85E-03	8.56E-03
TAC-D	3.66E-06	5.64E-02	6.15E-02	1.46E-06	2.23E-02	2.43E-02	4.06E-07	7.85E-03	8.56E-03
TAC-C	3.66E-06	5.64E-02	6.15E-02	1.46E-06	2.23E-02	2.43E-02	4.06E-07	7.85E-03	8.56E-03
WIL-D	3.66E-06	5.96E-02	6.50E-02	1.46E-06	2.36E-02	2.57E-02	4.06E-07	8.29E-03	9.04E-03
WIL-C	3.66E-06	5.96E-02	6.50E-02	1.46E-06	2.36E-02	2.57E-02	4.06E-07	8.29E-03	9.04E-03
CHN-D	3.66E-06	5.85E-02	6.39E-02	1.46E-06	2.32E-02	2.53E-02	4.06E-07	8.15E-03	8.89E-03

Individual Center-line Cancer Risk, 0-1.6 KM

Site/Loc	BR-2 EA4	BR-2 EA5	BR-2 EA6	RHF EA4	RHF EA5	RHF EA6	TRIGA EA4	TRIGA EA5	TRIGA EA6
CHA-D	1.79E-07	2.44E-03	2.66E-03	7.29E-08	9.65E-04	1.05E-03	1.84E-08	3.39E-04	3.70E-04
CHA-C	1.79E-07	2.44E-03	2.66E-03	7.29E-08	9.65E-04	1.05E-03	1.84E-08	3.39E-04	3.70E-04
CNC-D	1.79E-07	1.05E-03	1.14E-03	7.29E-08	4.14E-04	4.52E-04	1.84E-08	1.46E-04	1.59E-04
CNC-C	1.79E-07	1.05E-03	1.14E-03	7.29E-08	4.14E-04	4.52E-04	1.84E-08	1.46E-04	1.59E-04
GAL-D	1.79E-07	2.23E-03	2.43E-03	7.29E-08	8.80E-04	9.60E-04	1.84E-08	3.09E-04	3.37E-04
GAL-C	1.79E-07	2.23E-03	2.43E-03	7.29E-08	8.80E-04	9.60E-04	1.84E-08	3.09E-04	3.37E-04
JAC-D	1.79E-07	2.44E-03	2.66E-03	7.29E-08	9.65E-04	1.05E-03	1.84E-08	3.39E-04	3.70E-04
JAC-C	1.79E-07	2.44E-03	2.66E-03	7.29E-08	9.65E-04	1.05E-03	1.84E-08	3.39E-04	3.70E-04
LOS-D	1.79E-07	1.05E-03	1.14E-03	7.29E-08	4.14E-04	4.52E-04	1.84E-08	1.46E-04	1.59E-04
LOS-C	1.79E-07	1.05E-03	1.14E-03	7.29E-08	4.14E-04	4.52E-04	1.84E-08	1.46E-04	1.59E-04
MOT-D	1.79E-07	2.48E-03	2.71E-03	7.29E-08	9.82E-04	1.07E-03	1.84E-08	3.45E-04	3.77E-04
NEW-D	1.79E-07	1.72E-03	1.88E-03	7.29E-08	6.80E-04	7.42E-04	1.84E-08	2.39E-04	2.61E-04
NEW-C	1.79E-07	1.72E-03	1.88E-03	7.29E-08	6.80E-04	7.42E-04	1.84E-08	2.39E-04	2.61E-04
NOR-D	1.79E-07	2.48E-03	2.71E-03	7.29E-08	9.82E-04	1.07E-03	1.84E-08	3.45E-04	3.77E-04
NOR-C	1.79E-07	2.48E-03	2.71E-03	7.29E-08	9.82E-04	1.07E-03	1.84E-08	3.45E-04	3.77E-04
PHI-D	1.79E-07	2.53E-03	2.76E-03	7.29E-08	9.98E-04	1.09E-03	1.84E-08	3.51E-04	3.83E-04
PHI-C	1.79E-07	2.53E-03	2.76E-03	7.29E-08	9.98E-04	1.09E-03	1.84E-08	3.51E-04	3.83E-04
POR-D	1.79E-07	2.35E-03	2.57E-03	7.29E-08	9.29E-04	1.01E-03	1.84E-08	3.27E-04	3.56E-04
POR-C	1.79E-07	2.35E-03	2.57E-03	7.29E-08	9.29E-04	1.01E-03	1.84E-08	3.27E-04	3.56E-04
SAV-D	1.79E-07	2.44E-03	2.66E-03	7.29E-08	9.65E-04	1.05E-03	1.84E-08	3.39E-04	3.70E-04
SAV-C	1.79E-07	2.44E-03	2.66E-03	7.29E-08	9.65E-04	1.05E-03	1.84E-08	3.39E-04	3.70E-04
SEA-C	1.79E-07	2.35E-03	2.57E-03	7.29E-08	9.29E-04	1.01E-03	1.84E-08	3.27E-04	3.56E-04
TAC-D	1.79E-07	2.35E-03	2.57E-03	7.29E-08	9.29E-04	1.01E-03	1.84E-08	3.27E-04	3.56E-04
TAC-C	1.79E-07	2.35E-03	2.57E-03	7.29E-08	9.29E-04	1.01E-03	1.84E-08	3.27E-04	3.56E-04
WIL-D	1.79E-07	2.48E-03	2.71E-03	7.29E-08	9.82E-04	1.07E-03	1.84E-08	3.45E-04	3.77E-04
WIL-C	1.79E-07	2.48E-03	2.71E-03	7.29E-08	9.82E-04	1.07E-03	1.84E-08	3.45E-04	3.77E-04
CHN-D	1.79E-07	2.44E-03	2.66E-03	7.29E-08	9.65E-04	1.05E-03	1.84E-08	3.39E-04	3.70E-04

CHA = Charleston (Wando Terminal), SC; CNC = Concord, CA; GAL = Galveston, TX; JAC = Jacksonville, FL; LOS = Long Beach, CA; MOT = MOTSU, SC; NEW = Elizabeth, NJ; NOR = Norfolk, VA; PHI = Philadelphia, PA; POR = Portland, OR; SAV = Savannah, GA; SEA = Seattle, WA; TAC = Tacoma, WA; WIL = Wilmington, NC; CHN = NWS Charleston, SC

Table D-34 Probability of Peak Results, Variable Meteorology

EDE Whole Body Population Dose, 0-80 KM (SV)

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05
CHA-C	7.77E-06	4.44E-06	4.44E-06	7.77E-06	4.44E-06	4.44E-06	7.77E-06	4.44E-06	4.44E-06
CNC-D	8.47E-04	1.18E-05	1.18E-05	8.47E-04	1.18E-05	1.18E-05	8.47E-04	1.18E-05	1.18E-05
CNC-C	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06
GAL-D	7.80E-06	9.75E-06	9.75E-06	7.80E-06	7.80E-06	7.80E-06	7.80E-06	7.80E-06	7.80E-06
GAL-C	7.80E-06	9.75E-06	9.75E-06	7.80E-06	9.75E-06	9.75E-06	7.80E-06	9.75E-06	9.75E-06
JAC-D	6.03E-06	6.03E-06	6.03E-06	6.03E-06	6.03E-06	6.03E-06	6.03E-06	6.03E-06	6.03E-06
JAC-C	6.08E-06	8.06E-06	8.06E-06	6.08E-06	8.06E-06	8.06E-06	6.08E-06	8.06E-06	8.06E-06
LOS-D	1.83E-03	3.42E-06	3.42E-06	1.83E-03	3.42E-06	3.42E-06	1.83E-03	3.42E-06	3.42E-06
LOS-C	4.91E-06	2.81E-06	2.81E-06	4.91E-06	2.81E-06	2.81E-06	4.91E-06	2.81E-06	2.81E-06
MOT-D	1.67E-05	2.76E-05	2.76E-05	1.67E-05	2.76E-05	2.76E-05	1.67E-05	2.76E-05	2.76E-05
NEW-D	2.03E-05	2.03E-05	2.03E-05	2.03E-05	2.03E-05	2.03E-05	2.03E-05	2.03E-05	2.03E-05
NEW-C	2.50E-04	7.65E-05	7.65E-05	2.50E-04	7.65E-05	7.65E-05	2.50E-04	7.65E-05	7.65E-05
NOR-D	3.51E-04	9.62E-06	9.62E-06	3.51E-04	9.62E-06	9.62E-06	3.51E-04	9.62E-06	9.62E-06
NOR-C	1.07E-05	1.61E-05	1.61E-05	1.07E-05	1.61E-05	1.61E-05	1.07E-05	1.61E-05	1.61E-05
PHI-D	3.17E-06	3.17E-06	3.17E-06	3.17E-06	3.17E-06	3.17E-06	3.17E-06	3.17E-06	3.17E-06
PHI-C	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05	2.44E-05
POR-D	1.26E-05	1.09E-05	1.09E-05	1.26E-05	1.09E-05	1.09E-05	1.26E-05	1.09E-05	1.09E-05
POR-C	3.19E-04	1.09E-05	1.09E-05	3.19E-04	1.09E-05	1.09E-05	3.19E-04	1.09E-05	1.09E-05
SAV-D	1.13E-05	6.22E-06	6.22E-06	1.13E-05	6.22E-06	6.22E-06	1.13E-05	6.22E-06	6.22E-06
SAV-C	1.30E-05	1.14E-05	1.14E-05	1.30E-05	1.14E-05	1.14E-05	1.30E-05	1.14E-05	1.14E-05
SEA-C	1.36E-04	6.79E-04	6.79E-04	1.36E-04	6.79E-04	6.79E-04	1.36E-04	9.80E-04	9.80E-04
TAC-D	5.33E-06	1.14E-05	1.14E-05	5.33E-06	1.14E-05	1.14E-05	5.33E-06	1.14E-05	1.14E-05
TAC-C	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05	1.08E-05
WIL-D	3.26E-04	1.16E-04	1.16E-04	3.26E-04	1.16E-04	1.16E-04	3.26E-04	1.16E-04	1.16E-04
WIL-C	3.04E-04	1.08E-04	1.08E-04	3.04E-04	1.08E-04	1.08E-04	3.04E-04	1.08E-04	1.08E-04
CHN-D	6.27E-06	3.89E-06	3.89E-06	6.27E-06	3.89E-06	3.89E-06	6.27E-06	3.89E-06	3.89E-06

Total Cancer Fatalities, 0-80 KM

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05	1.01E-05
CHA-C	7.77E-06	4.44E-06	4.44E-06	7.77E-06	4.44E-06	4.44E-06	7.77E-06	4.44E-06	4.44E-06
CNC-D	8.47E-04	5.08E-04	5.08E-04	8.47E-04	1.18E-05	1.18E-05	8.47E-04	1.18E-05	1.18E-05
CNC-C	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06	7.58E-06
GAL-D	7.80E-06	9.75E-06	9.75E-06	7.80E-06	7.80E-06	7.80E-06	7.80E-06	7.80E-06	7.80E-06
GAL-C	7.80E-06	9.75E-06	9.75E-06	7.80E-06	9.75E-06	9.75E-06	7.80E-06	9.75E-06	9.75E-06

Table D-34 Probability of Peak Results, Variable Meteorology (Continued)

Individual Center-line EDE Whole Body Dose, 0-1.6 KM (SV)

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
CHA-C	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
CNC-D	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
CNC-C	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
GAL-D	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03
GAL-C	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03
JAC-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
JAC-C	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
LOS-D	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
LOS-C	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
MOT-D	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
NEW-D	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03
NEW-C	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03
NOR-D	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
NOR-C	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
PHI-D	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04
PHI-C	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04
POR-D	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
POR-C	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
SAV-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
SAV-C	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
SEA-C	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
TAC-D	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
TAC-C	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
WIL-D	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
WIL-C	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
CHN-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03

Individual Center-line Cancer Risk, 0-1.6 KM

	BR-2			RHF			TRIGA		
Site/Loc	EA4	EA5	EA6	EA4	EA5	EA6	EA4	EA5	EA6
CHA-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
CHA-C	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
CNC-D	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
CNC-C	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
GAL-D	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03
GAL-C	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03	3.73E-02	1.57E-03	1.57E-03
JAC-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
JAC-C	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
LOS-D	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
LOS-C	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04	1.22E-01	2.00E-04	2.00E-04
MOT-D	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
NEW-D	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03
NEW-C	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03	3.45E-03	1.06E-03	1.06E-03
NOR-D	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
NOR-C	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
PHI-D	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04
PHI-C	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04	7.89E-02	5.14E-04	5.14E-04
POR-D	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
POR-C	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
SAV-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
SAV-C	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03
SEA-C	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
TAC-D	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
TAC-C	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04	2.91E-02	4.00E-04	4.00E-04
WIL-D	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
WIL-C	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03	8.16E-03	1.46E-03	1.46E-03
CHN-D	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03	2.36E-02	1.66E-03	1.66E-03

CHA = Charleston (Wando Terminal), SC; CNC = Concord, CA; GAL = Galveston, TX; JAC = Jacksonville, FL; LOS = Long Beach, CA; MOT = MOTSU, SC; NEW = Elizabeth, NJ; NOR = Norfolk, VA; PHI = Philadelphia, PA; POR = Portland, OR; SAV = Savannah, GA; SEA = Seattle, WA; TAC = Tacoma, WA; WIL = Wilmington, NC; CHN = NWS Charleston, SC

population within 80.5 km (50 mi) of the Elizabeth channel accident location is about 16 million people and typical plumes are about two compass sectors wide, a typical accident plume might expose about two million people to radiation. Thus, for the largest mean result obtained, an average 50-year individual dose over the total exposed populations is about 6,900 person-rem/2,000,000 people = 0.0035 rem per person, which is 5,300 times smaller than the average dose (15 rem) people normally receive from natural, medical, and occupational exposures during the same period of time (BEIR, 1990).

Due to variable weather conditions, the calculated accident consequences vary over a range of values of approximately two orders of magnitude. Quantile values are one means used to indicate how much variation exists among the quantified consequences. The 99.9th quantile values presented in Table D-32 represent the accident consequences that are expected no more than 0.1 percent of the time, that is 99.9 percent of the time the accident consequences will be less than the values presented here. The 99.9th quantile values range from 0.00625 rem (at the MOTSU dock, TRIGA fuel, release category 4) to 108,000 rem (at the Elizabeth channel, BR-2 fuel, release category 6). These results are about three orders of magnitude less likely than the mean, but are less than two orders of magnitude higher than the mean results. (In some cases a 99.9th quantile value is listed as "NOT FOUND." In these instances the peak values, discussed in the following paragraph, occur with a probability of greater than 0.001).

Table D-33 shows that the largest value (peak result) calculated for population dose within 80.5 km (50 mi) of the accident location was 145,000 person-rem (1,450 person-Sv) and that this result was obtained for the Elizabeth channel calculation that used the BR-2 inventory, severity category 6 (EA6) release fractions, and New York City weather. Dividing by the two million people exposed by the accident gives an average 50-year individual dose over the exposed population of about 73 mrem, which is still 250 times smaller than a normal annual individual dose from background and medical exposure over

Table D-31 shows that the mean number of cancer deaths predicted to occur during the decades after the accident, among the populations located within 80.5 km (50 mi) of the accident site at the time of the accident, ranges from 0.00000041 for the MOTSU dock calculation that used the TRIGA inventory, severity category 4 (EA4) release fractions, and mean Cape Hatteras weather to 2.9 for the Elizabeth channel calculation that used the BR-2 inventory, severity category 5 (EA5) release fractions, and mean New York City weather. If all three of the cancer deaths predicted to occur as a result of the accident at the Elizabeth site should happen to occur in the same year, then the death rate among the two million people exposed to radiation by this accident would be 3/2,000,000 = 0.0000015 deaths per person year. Since the normal death rate due to all types of cancer is about 150 deaths per 100,000 people per year (World Almanac, 1992) or 0.0015 deaths per person year, the largest mean (expected) death rate for any base case calculation is 1,000 times smaller than the normal death rate due to cancer. Table D-33 shows that the largest number of cancer deaths obtained for any weather trial in any base case calculation was 60 and that this result was obtained for the Elizabeth channel calculation that used the BR-2 inventory, severity category 6 (EA6) release fractions, and New York City weather. Again, if all of these deaths were to occur in the same year in the future (a very improbable outcome), the death rate during that year among the population exposed to radiation by the accident would be 0.00003 or 50 times lower than the normal death rate due to cancer among this population. Table D-34 shows that the probability of this result is 0.000077 conditional on the occurrence of the accident or less than 1×10^{-10} per port call. Thus, even the worst case number of cancer deaths would be wholly undetectable in the exposed population by the best of epidemiological studies.

Figures D-56 and D-57 present Complementary Cumulative Distribution Functions for population dose and cancer fatalities among the population located within 80.5 km (50 mi) of the accident site for seven of the thirteen ports studied. Only seven were plotted to simplify the figure; these seven provide the full range of results. The figures display the range and probability (conditional on the occurrence of the accident) of these two consequence measures. Figure D-56 shows that any large accident (severity category 5 with the BR-2 inventory is a severe ship collision and fire accident) will lead to a population dose of 10 person-rem, that the values of the 99th quantile (probability of 0.01) range from about 2,000 person-rem to about 40,000 person-rem, and that the largest (peak) result calculated ranges from about 4,600 rem (MOTSU) to about 110,000 rem (Elizabeth). Figure D-57 shows that a large accident has about one chance in 10 (range of 0.002 to 0.6) of causing at least one cancer death among the exposed population in future years, that the values of the 99.9th quantile range from 1 cancer fatality to about 25 cancer deaths, and that the largest (peak) result calculated ranges from 2.1 to 47 deaths due to cancer during the years after the accident.

Figure D-58 presents an example of Complementary Cumulative Distribution Functions for population dose and cancer fatalities for the distance range 0 to 80.5 km (0 to 50 mi) for both the dock and channel locations at Charleston. This figure shows that the dock and channel Complementary Cumulative Distribution Functions for both population dose and cancer fatalities are quite similar, which is typical for all of the ports examined. This suggests that moving the coordinates of the origin of a population distribution a small distance (a few kilometers) has little effect on population dose or cancer fatalities among population located within 80.5 km (50 mi) of the accident location for severe accidents (Table D-28 lists the coordinates of the origins of the polar coordinate population distributions used in these calculations).

), Select
eases

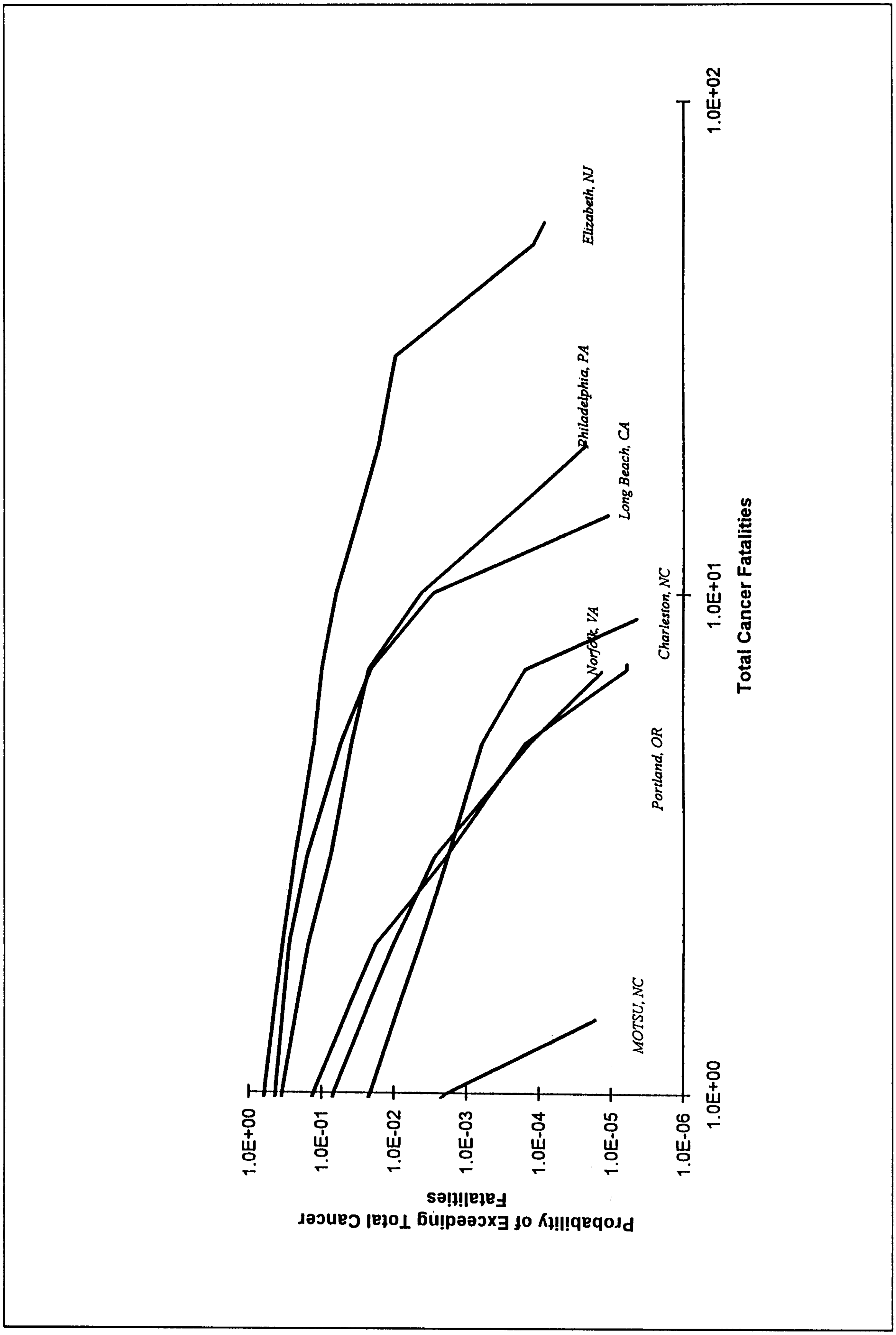


Figure D-57 Total Latent Cancer Fatalities, 0-80 km (0-50 mi), Select Ports (in the Channel), Variable Meteorology, BR-2 Inventory, Severity Category 5 Release

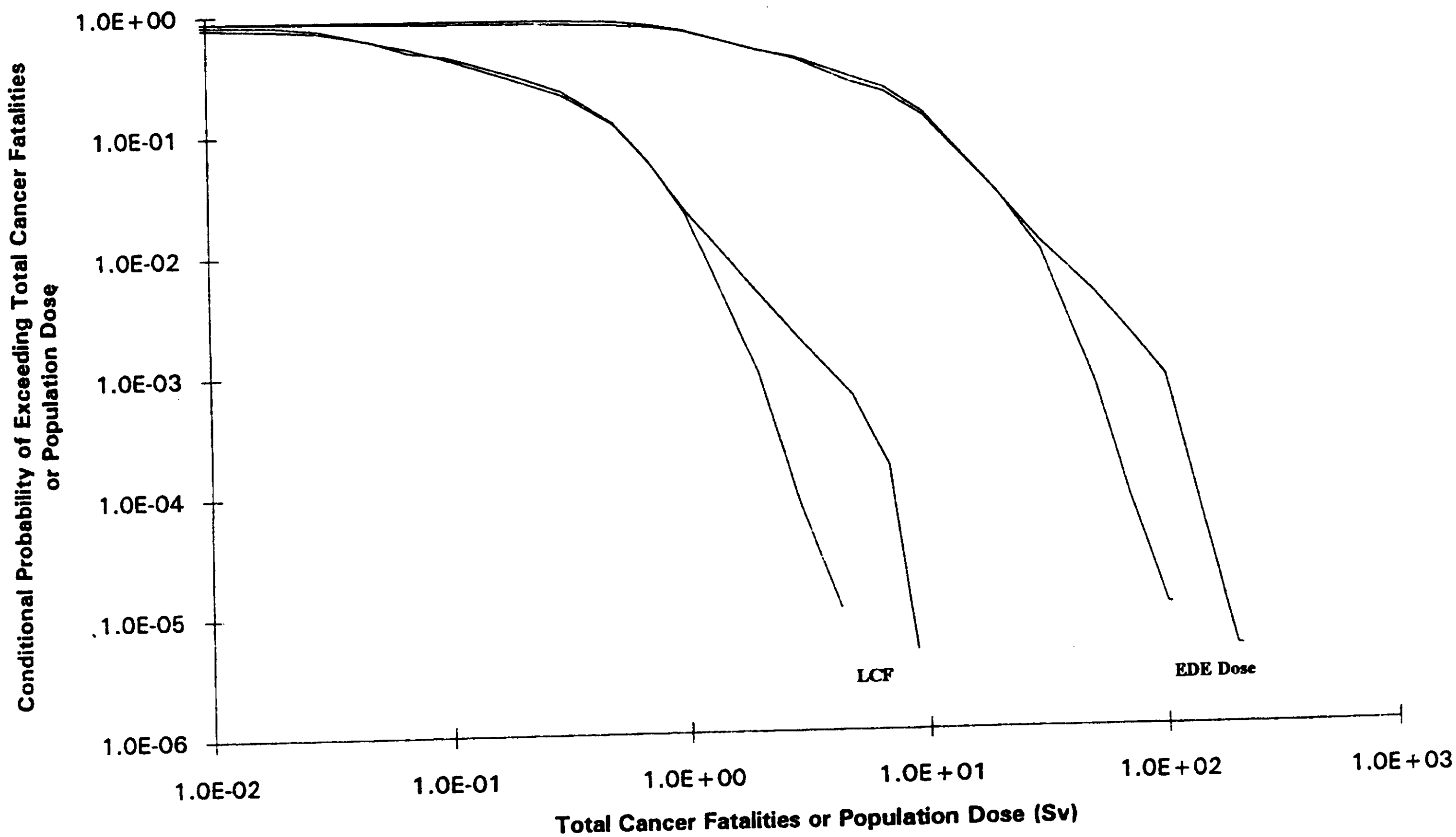


Figure D-58 Effective Equivalent Dose Whole Body Population Dose (Person-Sv) and Total Latent Cancer Fatalities, 0-80 km (0-50 mi), Charleston Dock and Channel Locations, Variable Meteorology, BR-2 Inventory, Severity Category 5 Release

D.5.4.3 Sensitivity Calculations

Two principal sensitivity calculations were performed to determine the sensitivity of the results to key parameters. First, the effect of using local less detailed meteorological data versus meteorological data recorded at a National Weather Service station located some distance from the port was evaluated. Second, the results of exceptionally high spent nuclear fuel temperatures were examined. Additionally, the sensitivity of changes in plume buoyancy, the size of the nuclide set, modal study release fractions, corrosion products release, and work force population were examined. The meteorological sensitivity calculations compared results obtained using variable meteorology recorded at a National Weather Service station away from the port to results obtained using constant meteorology recorded at the port. All other sensitivity calculations except the work force calculations were performed by modifying the Elizabeth base case channel calculation as was appropriate in order to examine the parameter of interest. The work force calculations were based on the Elizabeth dock site. All of the sensitivity calculations used the BR-2

Table D-35 1988-92 Summary Joint Frequency Table for Charleston, SC Port

A Stability

Wind Directions (Blowing Toward)

Wind Speed (mph)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1- 3	.0003	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0003	.0003	.0002	.0003	.0001	.0002	.0001	.0001
4- 7	.0005	.0003	.0005	.0004	.0004	.0006	.0003	.0003	.0006	.0004	.0004	.0002	.0002	.0001	.0002	.0003
8-12	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
13-18	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
19-24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
>24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

B Stability

Wind Directions (Blowing Toward)

Wind Speed (mph)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1- 3	.0008	.0003	.0006	.0007	.0005	.0007	.0008	.0005	.0011	.0006	.0010	.0007	.0007	.0006	.0004	.0005
4- 7	.0018	.0013	.0017	.0019	.0023	.0020	.0017	.0013	.0031	.0016	.0023	.0017	.0018	.0011	.0013	.0007
8-12	.0021	.0013	.0021	.0025	.0025	.0014	.0013	.0008	.0016	.0013	.0013	.0010	.0013	.0012	.0016	.0012
13-18	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
19-24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
>24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

C Stability

Wind Directions (Blowing Toward)

Wind Speed (mph)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1- 3	.0002	.0002	.0003	.0003	.0003	.0003	.0003	.0003	.0004	.0003	.0005	.0005	.0003	.0002	.0001	.0001
4- 7	.0015	.0014	.0016	.0022	.0026	.0021	.0019	.0020	.0026	.0021	.0035	.0021	.0014	.0010	.0014	.0012
8-12	.0081	.0038	.0061	.0072	.0090	.0049	.0037	.0031	.0057	.0051	.0062	.0042	.0034	.0043	.0042	.0049
13-18	.0017	.0012	.0021	.0020	.0021	.0014	.0006	.0005	.0006	.0005	.0005	.0004	.0008	.0005	.0008	.0007
19-24	.0000	.0000	.0000	.0001	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
>24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

D Stability

Wind Directions (Blowing Toward)

Wind Speed (mph)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1- 3	.0009	.0005	.0005	.0007	.0006	.0005	.0004	.0008	.0013	.0012	.0013	.0012	.0007	.0007	.0004	.0004
4- 7	.0045	.0030	.0037	.0027	.0028	.0026	.0022	.0044	.0094	.0079	.0093	.0056	.0042	.0039	.0026	.0022
8-12	.0196	.0151	.0165	.0112	.0108	.0070	.0047	.0061	.0168	.0216	.0201	.0124	.0108	.0075	.0066	.0083
13-18	.0140	.0179	.0145	.0082	.0133	.0096	.0058	.0058	.0084	.0080	.0057	.0047	.0051	.0035	.0034	.0036
19-24	.0009	.0019	.0020	.0007	.0020	.0023	.0010	.0004	.0003	.0000	.0000	.0001	.0001	.0001	.0001	.0000
>24	.0002	.0005	.0002	.0001	.0003	.0003	.0001	.0000	.0000	.0001	.0000	.0000	.0000	.0000	.0000	.0000

E Stability

Wind Directions (Blowing Toward)

Wind Speed (mph)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1- 3	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
4- 7	.0127	.0071	.0088	.0047	.0033	.0023	.0021	.0025	.0050	.0061	.0094	.0066	.0052	.0049	.0036	.0051
8-12	.0063	.0072	.0085	.0059	.0067	.0058	.0032	.0030	.0038	.0066	.0043	.0021	.0019	.0013	.0011	.0016
13-18	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
19-24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
>24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

F Stability

Wind Directions (Blowing Toward)

Wind Speed (mph)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
1- 3	.0090	.0076	.0081	.0059	.0052	.0039	.0035	.0057	.0086	.0076	.0101	.0054	.0054	.0036	.0032	.0035
4- 7	.0122	.0088	.0112	.0074	.0063	.0051	.0044	.0059	.0095	.0104	.0122	.0057	.0044	.0044	.0029	.0039
8-12	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
13-18	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
19-24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
>24	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

Table D-36 Wind Rose Table for Select Ports

1988-92 Summary Wind Rose Table For Charleston, SC Port
Wind Directions (Blowing Toward)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
.0974	.0796	.0892	.0650	.0712	.0530	.0380	.0436	.0790	.0817	.0882	.0549	.0479	.0389	.0341	.0385

1988-92 Summary Wind Rose Table For Long Beach, CA Port
Wind Directions (Blowing Toward)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
.0246	.0171	.0602	.3093	.1804	.0157	.0177	.0229	.0331	.0227	.0271	.0475	.1115	.0601	.0348	.0154

1988-92 Summary Wind Rose Table For Newark, NJ Port
Wind Directions (Blowing Toward)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
.0784	.0725	.1015	.0871	.0854	.0639	.0788	.0559	.0832	.0786	.0442	.0273	.0231	.0304	.0452	.0447

1988-92 Summary Wind Rose Table For Norfolk, VA Port
Wind Directions (Blowing Toward)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
.1078	.0963	.1021	.0647	.0562	.0456	.0344	.0285	.0940	.0665	.0860	.0573	.0470	.0321	.0358	.0458

1988-92 Summary Wind Rose Table For Philadelphia, PA Port
Wind Directions (Blowing Toward)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
.0682	.0440	.0950	.1118	.1281	.0913	.0715	.0568	.0669	.0266	.0275	.0639	.0545	.0284	.0278	.0378

1988-92 Summary Wind Rose Table For Portland, OR Port
Wind Directions (Blowing Toward)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
.0936	.0551	.0337	.0315	.0756	.0956	.1163	.1054	.0704	.0187	.0171	.0225	.0638	.1126	.0576	.0304

1988-92 Summary Wind Rose Table For Wilmington, NC Port
Wind Directions (Blowing Toward)

N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW
.0744	.0804	.0994	.0798	.0747	.0378	.0417	.0435	.0955	.0780	.0699	.0488	.0549	.0351	.0411	.0451

Table D-37 Rainfall Data, Select Ports

Rainfall Data for the Charleston, SC Port 1988-1992 Data

Stab Class	Avg Rate (in/hr)	Fraction Time
A	0.05000	0.00264
B	0.22400	0.00371
C	0.16322	0.00771
D	0.13860	0.11099
E	0.14740	0.01099
F	0.07941	0.00125

Rainfall Data for the Long Beach, CA Port 1988-1992 Data

Stab Class	Avg Rate (in/hr)	Fraction Time
A	0.00000	0.00000
B	0.00000	0.00000
C	0.14375	0.00233
D	0.07837	0.03648
E	0.06596	0.00809
F	0.07083	0.00115

Rainfall Data for the Newark, NJ Port 1988-1992 Data

Stab Class	Avg Rate (in/hr)	Fraction Time
A	0.00000	0.00000
B	0.05000	0.00059
C	0.08571	0.00648
D	0.08577	0.12139
E	0.08968	0.00971
F	0.05000	0.00153

Rainfall Data for the Norfolk, VA Port 1988-1992 Data

Stab Class	Avg Rate (in/hr)	Fraction Time
A	0.00000	0.00000
B	0.09167	0.00371
C	0.10921	0.00771
D	0.47136	0.11099
E	0.12574	0.01099
F	0.05000	0.00125

Rainfall Data for the Philadelphia, PA Port 1988-1992 Data

Stab Class	Avg Rate (in/hr)	Fraction Time
A	0.00000	0.00000
B	0.17500	0.00089
C	0.11250	0.00431
D	0.07520	0.12101
E	0.10682	0.00649
F	0.17500	0.00035

Rainfall Data for the Portland, OR Port 1988-1992 Data

Stab Class	Avg Rate (in/hr)	Fraction Time
A	0.00000	0.00000
B	0.11250	0.00139
C	0.08125	0.01245
D	0.06172	0.15220
E	0.06493	0.01428
F	0.05000	0.00087

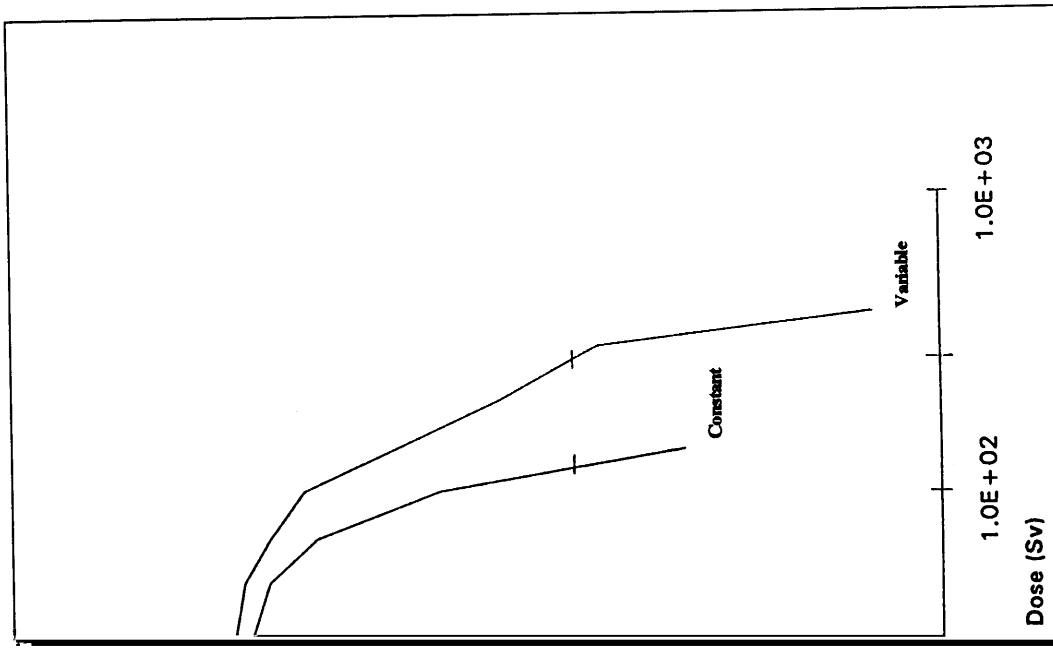
Rainfall Data for the Wilmington, NC Port 1988-1992 Data

Stab Class	Avg Rate (in/hr)	Fraction Time
A	0.00000	0.00000
B	0.18235	0.00718
C	0.17500	0.01937
D	0.15048	0.12490
E	0.16295	0.02310
F	0.08571	0.00244

Table D-38 Comparison of Population Dose and Selected Ports Using Variable vs. Constant Meteorology for Category Accident of a BR-2 Fuel Cask

Site/Loc	EDE Whole Body Population Dose, 0-80 KM (Sv)				Total Cancer Fatalities, 0-80 KM			
	Mean		99.9th Quantile		Mean		99.9th Quantile	
	Var	Const	Var	Const	Var	Const	Var	Const
CHA-D	4.15E+00	3.06E+00	4.63E+01	2.13E+01	1.89E-01	1.29E-01	1.98E+00	8.43E-01
CHA-C	4.18E+00	3.41E+00	9.03E+01	3.71E+01	1.90E-01	1.43E-01	3.96E+00	2.01E+00
LOS-D	4.71E+01	3.44E+01	2.67E+02	1.19E+02	1.99E+00	1.44E+00	1.03E+01	5.35E+00
LOS-C	4.26E+01	3.31E+01	2.19E+02	8.16E+01	1.80E+00	1.38E+00	9.81E+00	3.43E+00
NEW-D	6.55E+01	5.47E+01	5.87E+02	2.32E+02	2.75E+00	2.28E+00	2.46E+01	9.54E+00
NEW-C	6.93E+01	5.89E+01	9.41E+02	NOT-FOUND	2.90E+00	2.46E+00	3.89E+01	NOT-FOUND
NOR-D	8.54E+00	8.88E+00	1.03E+02	7.26E+01	3.77E-01	3.72E-01	4.23E+00	3.07E+00
NOR-C	6.65E+00	6.76E+00	9.02E+01	3.51E+01	2.96E-01	2.83E-01	3.59E+00	1.34E+00
PHI-D	2.81E+01	2.53E+01	3.10E+02	NOT-FOUND	1.20E+00	1.06E+00	1.18E+01	1.34E+00
PHI-C	2.74E+01	2.01E+01	2.86E+02	5.91E+01	1.17E+00	8.40E-01	1.22E+01	2.45E+00
POR-D	1.17E+01	1.08E+01	1.09E+02	7.76E+01	5.18E-01	4.54E-01	4.90E+00	3.29E+00
POR-C	1.12E+01	8.76E+00	1.01E+02	3.88E+01	4.97E-01	3.68E-01	3.78E+00	1.51E+00
MOT-D	2.08E+00	1.02E+00	2.46E+01	NOT-FOUND	9.94E-02	4.37E-02	1.22E+00	1.51E+00
WIL-C	2.07E+00	1.05E+00	2.25E+01	5.47E+00	9.76E-02	4.49E-02	1.04E+00	2.22E-01

Table D-38 compares for seven ports the expected (mean) and 99.9th quantile values of population dose and cancer fatalities for the distance range 0 to 80.5 km (0-50 mi) obtained using variable meteorology to the values obtained using constant meteorology. Inspection of the table shows that the mean values for constant meteorology are quite similar to mean values for variable meteorology. For example, for population dose, the ratio of the variable meteorology result to the constant meteorology result has an average value and standard deviation of 1.31±0.31 for population dose and 1.34±0.41 for cancer fatalities. The MOTSU dock calculation yielded the largest values for these ratios, 2.04 for mean population dose and 2.27 for cancer fatalities. Thus, the use of meteorological data recorded at a nearby National Weather Service station yields expected (mean) values for population dose and cancer fatalities that are on average



…l Dose (Sv) (Dock) and Total
…able and Constant Meteorology,
…eases

D.5.4.3.2 High-Temperature Sensitivity Calculations

As previously discussed, releases of radioactive material from spent nuclear fuel transportation casks are categorized by severity. Severity category 6, which results in the largest release, is assumed for the marine transportation portion of this EIS to be caused by a severe ship collision that results in damage to the transportation cask and a severe fire that engulfs the cask. Only around one in five severe ship fires reach temperatures above approximately 700°K or 800°F (see Attachment D5, Section 4). As discussed below, extremely high temperatures, above 900°K (1,160°F), result in phenomena that could significantly alter the release fraction for aluminum-based and TRIGA fuel (previous studies have not specifically addressed the impact of these phenomena). Therefore, the release fractions assumed for severity category 6 (Table D-21) are for temperatures of the spent nuclear fuel above 700°K (800°F) but below 900°K (1,160°F).

Section D.5.3.1 of this appendix developed probabilities of the more severe marine accidents. Table D-24 stated that the probability of a severity category 6 accident is 6 x10^{-10}, or less than one chance in a billion per cask shipment. This very low probability is made even lower if the probability of the severe fire causing the spent nuclear fuel temperature to exceed 900°K (1,160°F) is considered. Appendix D [illegible]

[illegible] temperatures of 900°K (1,160°F) is 0.1. Multiplying the probability of a severity category 6 accident (6 x 10^{-10}) by the probability of a severe fire on the ship (0.1) results in the probability of a severity category 6

Table D-39 High-Temperature Sensitivity Calculation Results

	BR-2				*TRIGA*	
Accident Severity Category	5	5B	6	6B	6	6B
Accident Probability	5×10^{-9}	5×10^{-10}	6×10^{-10}	6×10^{-11}	6×10^{-10}	6×10^{-11}
Peak Probability [0-1.6 km [0-1 mi)]	8.41×10^{-5}	7.65×10^{-5}	8.41×10^{-5}	7.03×10^{-5}	8.41×10^{-5}	2.17×10^{-4}
Peak Probability [0.80.5 km (0-50 mi)]	8.41×10^{-5}	1.16×10^{-5}	8.41×10^{-5}	1.45×10^{-5}	8.41×10^{-5}	1.45×10^{-5}
EDE Whole Body Population Dose (person-rem)						
0-1.6 km (0-1 mi)						
Mean	236	1,490	192	3,810	26.8	3,980
Peak	42,100	203,000	45,900	271,000	6,390	297,000
0-80.5 km (0-50 mi)						
Mean	6,930	68,400	6,770	639,000	937	298,000
Peak	133,000	1,450,000	145,000	14,400,000	20,200	6,390,000
Total Cancer Fatalities						
0-1.6 km (0-1 mi)						
Mean	0.098	0.622	0.0802	1.59	0.0112	1.66
Peak	17.5	84.5	19.1	113	2.66	123
0-80.5 km (0-50 mi)						
Mean	2.90	28.7	2.84	268	0.392	125
Peak	55.3	603	60.4	6,000	8.39	2,660
Impact Distances (km)						
Decontamination						
Mean	0.0	0.0156	0.0	0.302	0.0	0.0993
Peak	0.0	1.61	0.0	8.05	0.0	6.44
Cond. Peak Prob.	---	0.00969	---	0.00116	---	7.53×10^{-5}
Interdiction						
Mean	0.0	0.0156	0.0	0.302	0.0	0.0993
Peak	0.0	1.61	0.0	8.05	0.0	6.44
Cond. Peak Prob.	---	0.00969	---	0.00116	---	7.53×10^{-5}
Condemnation						
Mean	0.0	0.0	0.0	0.0292	0.0	0.00263
Peak	0.0	0.0	0.0	3.22	0.0	1.61
Cond. Peak Prob.	---	---	---	0.000648	---	0.00163
Population Dose Risk						
0-1.6 km (0-1 mi)						
Mean	1.2×10^{-6}	7.5×10^{-7}	1.2×10^{-7}	2.3×10^{-7}	1.6×10^{-8}	2.4×10^{-7}
Peak	1.8×10^{-8}	7.8×10^{-9}	2.3×10^{-9}	1.1×10^{-9}	3.2×10^{-10}	3.9×10^{-9}
0-80.5 km (0-50 mi)						
Mean	3.5×10^{-5}	3.4×10^{-6}	4.1×10^{-6}	3.8×10^{-5}	5.6×10^{-7}	1.8×10^{-5}
Peak	5.6×10^{-8}	8.4×10^{-9}	7.3×10^{-9}	1.3×10^{-8}	1.0×10^{-9}	5.5×10^{-9}
Cancer Fatality Risk						
0-1.6 km						
Mean	4.9×10^{-10}	4.4×10^{-10}	4.8×10^{-11}	9.5×10^{-11}	6.7×10^{-12}	1.0×10^{-10}
Peak	7.4×10^{-12}	3.2×10^{-12}	9.6×10^{-13}	4.8×10^{-13}	1.3×10^{-13}	1.6×10^{-12}
0-80.5 km						
Mean	1.5×10^{-7}	1.6×10^{-7}	1.7×10^{-9}	1.6×10^{-8}	2.4×10^{-10}	7.5×10^{-9}
Peak	2.3×10^{-11}	3.5×10^{-12}	3.0×10^{-12}	5.2×10^{-12}	4.2×10^{-13}	2.3×10^{-12}

However, because the probabilities of occurrence of these high-temperature release fractions (see Attachment D-5) for BR-2 aluminum uranium alloy fuel inventories are generally ten times smaller than those associated with the severity category 5 and severity category 6 accident categories, the risks associated with these larger releases are comparable to or smaller than those predicted for base case BR-2 calculations. For TRIGA fuel, severity category 6B release fractions are much larger than the severity category 6 release fractions. The probability of the severity category 6B release fractions is only ten times smaller than that of the severity category 6 release fractions. Therefore, the risks associated with a TRIGA fuel category 6B release are significantly larger than those obtained for the base case accident severity category 6 calculation. But, because the TRIGA inventory is substantially smaller than the BR-2 inventory, the TRIGA severity category 6B risks are still smaller than the risks obtained for base case calculations using the BR-2 inventory and the severity category 5 set of release fractions.

Other environmental impacts in addition to the public health consequences are presented in Table D-39. These impacts were determined as part of the MACCS calculations. MACCS calculated land impacts based on a habitability dose criterion and cost effectiveness of mitigative actions such as evacuation, temporary relocation, and land decontamination and interdiction. The habitability criterion is based on the need to take action to ensure that the dose to a person remains below 4 rem[1] over a 5-year period. MACCS code determines the mitigative actions in a predetermined sequence in order to select the least stringent action which will allow the habitability dose criterion to be satisfied. The order of actions is: 1) decontamination alone (minimum decontamination process, three levels of decontamination process can be specified), 2) maximum level of decontamination followed by an interdiction period, and 3) permanent interdiction (condemnation) of the land. The decontamination distance is that distance from the accident location that requires post-accident clean-up to ensure this dose level is not achieved. The land is usable, that is, people may live and work in the area, within a relatively short period after the accident. The interdiction distance is that distance from the accident that even after decontamination would require some time, typically seven years, before the land area would be useable. The condemnation distance characterizes the land area that even after decontamination would remain unusable for at least 30 years.

MACCS code calculates both the affected population in the urban areas and the affected farmlands in the rural areas. The affected distances, (i.e., decontamination, interdiction, and condemnation distances), in the rural areas are generally larger than those of the urban area. Since one of the principal uses of rural land is agricultural, the consumption of contaminated food produced in these areas would result in larger doses to some members of the public.

Table D-39 provides the land impact distances for an accident that occurs in the Port of Elizabeth for the most severe accident severity categories of both the base case calculations (category 5 and 6 for the BR-2 fuel and category 6 for the TRIGA fuel) and for the most severe of the high temperature accident scenarios (categories 5B and 6B for BR-2 fuel and category 6B for the TRIGA fuel). Since the ports are located primarily in urban areas, the impact distances presented are those based on the urban (population) impact calculations. For the base case accident scenarios, MACCS predicted no impact on the usability of the land. However, when temperatures reaching the melting point of the aluminum based fuel and the combustion temperature of the TRIGA fuel are realized, some land-use impacts are calculated. All mean impact distances are well under 1 km (0.6 mi), with the largest distance being approximately 300 m

1 *This arises from 2 rem in first year and 0.5 rem per year for the years 2 to 5. This criterion is consistent with the Environmental Protection Agency's long-term objectives of the Protective Action Guide, (Section 4.2.1 of "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," EPA 1991).*

(1000 ft). The peak values quoted in Table D-39 represent the worst possible consequences, driven by meteorological conditions that create the maximum potential damage. The occurrences of these meteorological conditions are of low probabilities which are ranging from approximately one-in-one hundred to less than one-in-ten thousand.

In addition to the Port of Elizabeth, the land impact analysis was performed for several of the candidate ports, including Concord NWS, CA; Galveston, TX; MOTSU, NC; and Tacoma, WA. For these four ports, the mean values for the land impacts resulting from the category 6B accidents, the most severe of all accident categories, were of the same order of magnitude as, and slightly smaller than, the results presented in Table D-39 for the Port of Elizabeth.

D.5.4.3.3 Other Sensitivity Calculations

In addition to the two sensitivity calculations discussed above, sensitivity calculations were also performed that examined the effect on consequences of (1) plume buoyancy, (2) the size of the set of nuclides used to specify inventories, (3) Modal Study release fractions, (4) corrosion deposits release, and (5) work force population. Table D-40 summarizes the calculations performed. For all of these calculations, the reference calculation was the base case Elizabeth dock or channel calculation that used the BR-2 inventory, severity category 5 release fractions, and variable meteorology recorded at the New York City National Weather Service station. Work force sensitivity calculations used the Elizabeth dock population distribution. All of the other sensitivity calculations used the Elizabeth channel population distribution. Table D-41 presents mean and peak population doses and cancer fatalities for two distance ranges, 0-1.6 km and 0-80.5 km, (0-1 and 0-50 mi) for all of the "other" sensitivity calculations, and also for the reference Elizabeth base case calculations to which sensitivity calculation results should be compared.

D.5.4.3.3.1 Plume Buoyancy

As Table D-21 showed, a severity category 5 release scenario results from a collision and a severe fire. Thus, the first sensitivity calculation performed examined the effect of plume buoyancy (i.e, of plume rise) on accident consequences. This was done by repeating the Elizabeth channel reference calculation setting the sensible heat content of the release to zero. This change produces a cold plume that is not subject to plume rise and thus is not lofted over the population located close to the release point (the accident location). The results of this sensitivity calculation are presented in Table D-41.

Table D-41 shows that changing the reference Elizabeth channel calculation to a cold release not subject to plume rise causes mean and peak population doses and cancer fatalities to increase somewhat for the 0-80.5 km (0-50 mi) distance range and substantially for the 0-1.6 km (0-1 mi) distance range. For the 0-80.5 km (0-50 mi) distance range, mean population dose and cancer fatalities both increase by a factor of 2.4, and peak population dose and cancer fatalities increase by a factor of 1.1. For the 0-1.6 km (0-1 mi) distance range, mean population dose and cancer fatalities both increase by a factor of 17, and peak population dose and cancer fatalities both increase by a factor of 2.7. Thus, if engulfing fires increase release magnitudes, consequence magnitudes will not increase proportionately because the fire will produce a hot plume that will be lofted over nearby populations decreasing radiation exposures and thus health effects among those populations. It should be mentioned that the releases assumed here (category 5) are not considered possible *without* the fire. This calculation was done to show the sensitivity of the results to the presence of a fire.

Table D-40 Other Sensitivity Calculations

Run No.	Meteorology[a]		Nuclides[b]		Release Fractions[c]			Heat[d]		Shielding[e]	
	Variable	Constant	MACCS	EIS	5	MS/nM5	MS/M5	H	C	N	C
BC	x			x	x			x		x	
Buoyancy Calculations											
1a.	x			x	x				x	x	
Nuclide Sensitivity Calculations											
2a.	x		x		x			x			x
2b.	x		x		x				x		x
Modal Study Release Fraction Calculations											
3a.	x			x		x		x		x	
3b.	x			x			x	x		x	
Corrosion Products Calculations											
4a.[f]	x			x	EA3				x	x	
4b.[g]	x			x	x			x		x	
Work Force Calculations											
5a.	x			x	x			x		x	
5b.	x			x	x				x	x	
5c.	x			x	x				x		x
5d.[h]	x			x	x				x	x	
5e.[h]	x			x	x				x		x
5f.[i]	x			x	x				x	x	

[a]*Meteorology: Variable = hourly National Weather Service data, Constant = Joint Frequency Data.*

[b]*Nuclides: MACCS = 22 MACCS nuclides, EIS = 34 EIS nuclides.*

[c]*Release Fractions: 5 = severity category 5 release fractions; MS/nM5 = release fractions for nonmetallic (TRIGA) spent nuclear fuel for Modal study cask response region roughly corresponding to severity category 5; MS/M5 = release fraction for metallic (aluminum-based) spent nuclear fuel for Modal study cask response regions roughly corresponding to severity category 5.*

[d]*Heat: H = hot plume, C = cold plume.*

[e]*Shielding: N = normal shielding factors; C = sheltering shielding factors from 0-8 km (0-5 mi) for one day and normal shielding factors at all other times and distances.*

[f]*Only Corrosion Products released*

[g]*With Corrosion Products release added to the reference release.*

[h]*With puff and tail*

[i]*With puff and tail, and evacuation from 0-1.6 km (0-1 mi.)*

D.5.4.3.3.2 Size of Nuclide Set

Table D-25 presented the three inventories used in the base case analyses. Each inventory contains 34 radionuclides. The default set of radionuclides used by MACCS does not contain dose conversion factors for 13 of these 34 radionuclides. These 13 radionuclides are hydrogen-3, tin-123, antimony-125, tellurium-125m, promethium-147, promethium-148m, europium-154, europium-155m, uranium-234, uranium-235, uranium-238, americium-242m, and americium-243. *Chronic* health effect dose conversion factors for all 13 of these radionuclides were available (DOE, 1988a; DOE, 1988b) and were added to the MACCS dose conversion factor library for this study. However, because generally accepted *acute* health effect dose conversion factors were not available, all calculations performed for this study were run not including acute health effects for these 13 radionuclides.

[illegible] Study Results, Elizabeth Dock and Channel, Inventory significant impact on the estimation of acute health effects, especially since none of these nuclides contributes significantly to chronic dose or health effects and since no acute effects were observed at any level including peak results for any calculation performed during this study.

D.5.4.3.3.3 Modal Study Cask Response Regions Release Fractions

The Modal Study (Fischer et al., 1987) developed release fractions for truck and rail accidents involving transportation cask containing commercial spent nuclear fuel. DOE as part of the preparation of the Programmatic SNF&INEL EIS, developed representative release fractions for metallic (aluminum-based) and nonmetallic (TRIGA) fuel for each of the Modal Study's cask response regions (DOE, 1995). Although there is not a direct relationship between the accident classification used in this EIS for ship accidents and that developed in the Modal Study, attempts were made to establish a meaningful comparison based on the definition of accidents and their consequences. Based on the accident definitions, one can approximate the severity category 5 ship accidents to the Modal Study's cask response region resulting from a medium impact mechanical force with a medium intensity thermal load. Table D-42 provides the values of release fractions used in this EIS for severity category 5 accident and that used for metallic and nonmetallic fuel in the Programmatic SNF&INEL EIS for a similar accident category. For ease of comparison, the EIS release fractions that were used in all of the base case calculations performed for this study are repeated in this table.

Table D-42 Programmatic SNF&INEL EIS Release Fractions

	Release Fraction		
		Programmatic SNF&INEL EIS	
Element Group	*EIS (Base Case Category 5)*	*Metallic*	*Nonmetallic*
Krypton	0.1	0.39	0.39
Cesium	9.0×10^{-4}	1.0×10^{-6}	0.00020
Ruthenium	1.0×10^{-6}	2.4×10^{-7}	0.000048
Particulate	5.0×10^{-8}	1.0×10^{-8}	0.0000020

Source: DOE, 1995

Inspection of the table shows that, except for the krypton element group, the base case EIS release fraction values for severity category 5 are somewhat larger than the values for nonmetallic fuel and are quite a bit larger than the values for metallic fuel. Thus, as would be expected, Table D-41 shows that mean and peak population doses and cancer fatalities for the distance ranges 0-1.6 and 0-80.5 km (0-1 and 0-50 mi) obtained using EIS release fractions are about five times larger than those obtained using nonmetallic fuel release fractions, which in turn are about 200 times larger than those obtained using metallic fuel release fractions. Therefore, since severity category 5 largely determines risk, use of EIS release fractions is conservative even if metallic and nonmetallic release fractions better represent releases during ship collisions.

D.5.4.3.3.4 Corrosion Products Release

During the operation of power reactors, radioactive cobalt is formed by neutron activation of chemical deposits on the outer surfaces of fuel rods. Thus, during transportation accidents, release of these radioactive deposits, usually referred to as corrosion products, can be a significant contributor to the size of the accident source term.

Because corrosion products formation is usually not a problem for research reactors, radioactive cobalt is not present in the inventories used in this study, and the sets of source terms input to MACCS do not contain fractions for corrosion products release. The potential impact of corrosion products release on foreign research reactor spent nuclear fuel accident source terms was examined by performing two sensitivity calculations. For these calculations, after scaling to match the size of the BR-2 inventory used [illegible] category 4 release fractions from the severity category 5 release fractions. The puff was released when the collision occurred and lasted for 10 minutes; the tail was released one hour later and had a one hour release duration. Finally, the puff and tail calculation that did not use increased shielding factor values was repeated assuming that an evacuation would be called for should a severe accident lead to a fire that engulfed a radioactive material transportation cask, that the evacuation would begin about one hour after the accident took place (i.e., at about the time the tail release begins), and that the average evacuation speed would be slow because of city congestion.

Inspection of Table D-41 shows that, when a hot release is assumed (run 5a), adding a work force population increases mean population dose and cancer fatalities by less than a factor of 2 in the 0-1.6 km (0-1 mi) distance range, but has little effect on peak values in this distance range or on either mean or peak values in the 0-80.5 km (0-50 mi) distance range. When the release is cold (run 5b), 0-1.6 km (0-1 mi) mean population doses and cancer fatalities are increased by factors of about 26 and 2 respectively, and peak doses and cancer fatalities are increased by factors of about 3. For the 0-80.5 km (0-50 mi) distance range mean results are increased by factors of about 2 and peak results actually decrease by a factor of about 0.7. Moreover, these results are little changed by using increased shielding factors for commercial buildings, by assuming a puff and tail release, or by assuming a slow delayed evacuation.

The insensitivity to short-term shielding factor values, to release timing, and to evacuation is easy to understand when one remembers that population dose and cancer fatalities in these calculations are determined almost entirely by long-term groundshine exposures, which are of course little influenced by variation of any of these three short-term effects. Thus, as was shown above, elimination of lofting by assuming a cold release increases consequences, especially those that occur at short distances, but little else has much effect because only recovery actions (decontamination, temporary interdiction, condemnation) not examined by these sensitivity calculations can significantly affect long-term groundshine dose.

D.5.5 Port Accident Risk

The port accident risk analysis combines the results of the analysis of the frequency of ship accidents in the port area with the results of the consequence analysis of each of these accidents. Each of the accident

where R_{IP} is the risk from an accident in one of the intermediate ports of call. All other parameters have the same definitions as in the equation defining R_{PE}. The risks associated with accidents in the channel of the port is considered twice for the intermediate ports because the vessel must enter the harbor and approach the dock and, with the foreign research reactor spent nuclear fuel still on board, must depart the harbor. The accident frequency data is derived as a per transit frequency. For this risk analysis the approach to the dock has been considered to be part of one transit, the departure as part of a second transit.

From Section D.5.3.1.7, the probabilities per transit for the three accident severity categories evaluated are provided in Table D-43. These accident frequencies were used to develop the per transit probabilities for the accidents at the dock and in the channel for each of the intermediate ports and the ports of entry for the [illegible]. The port accident data collected was not detailed enough to

Table D-44 Port Accident Analysis—Total Effective Dose Equivalent Population Dose (Person-Rem)

Location	BR-2 Spent Nuclear Fuel			RHF Spent Nuclear Fuel			TRIGA Spent Nuclear Fuel		
	Severity Category			Severity Category			Severity Category		
	4	5	6	4	5	6	4	5	6
Elizabeth (D)[1]	0.23	6600	6500	0.093	2600	2600	0.028	910	900
Elizabeth (C)[2]	0.38	6900	6800	0.15	2700	2700	0.045	960	940
Long Beach (D)[1]	0.21	4700	4800	0.085	1900	1900	0.025	650	660
Long Beach (C)[2]	0.081	4300	4400	0.032	1700	1700	0.0097	590	610
Philadelphia (D)[1]	0.18	2800	2800	0.071	1100	1100	0.021	380	380
Philadelphia (C)[2]	0.085	2700	2800	0.034	1100	1100	0.010	370	380
Portland (D)[1]	0.077	1200	1200	0.031	450	450	0.0093	160	160
Portland (C)[2]	0.053	1100	1200	0.021	430	440	0.0065	150	150
Norfolk (D)[1]	0.055	850	830	0.022	330	320	0.0067	110	110
Norfolk (C)[2]	0.030	670	660	0.012	250	250	0.0037	87	87
[illegible] (D)[1]	0.024	420	410	0.0096	150	150	0.003	53	53

Table D-45 Port Accident Analysis—Accident Consequences (LCF)

Location	BR-2 Spent Nuclear Fuel			RHF Spent Nuclear Fuel			TRIGA Spent Nuclear Fuel		
	Severity Category			Severity Category			Severity Category		
	4	5	6	4	5	6	4	5	6
Elizabeth (D)[1]	0.00010	2.8	2.7	0.000041	1.1	1.1	0.000011	0.38	0.38
Elizabeth (C)[2]	0.00016	2.9	2.8	0.000066	1.1	1.1	0.000018	0.40	0.39
Long Beach (D)[1]	0.000093	2.0	2.0	0.000038	0.78	0.80	0.000010	0.27	0.28
Long Beach (C)[2]	0.000035	1.8	1.9	0.000014	0.71	0.73	0.0000040	0.25	0.26
Philadelphia (D)[1]	0.000078	1.2	1.2	0.000031	0.47	0.46	0.0000087	0.16	0.16
Philadelphia (C)[2]	0.000037	1.2	1.2	0.000015	0.45	0.47	0.0000042	0.16	0.16
Portland (D)[1]	0.000034	0.52	0.53	0.000014	0.20	0.20	0.0000039	0.068	0.069
Portland (C)[2]	0.000023	0.50	0.51	0.0000093	0.19	0.19	0.0000027	0.065	0.067
Norfolk (D)[1]	0.000024	0.38	0.37	0.0000097	0.14	0.14	0.0000028	0.049	0.048
Norfolk (C)[2]	0.000013	0.30	0.30	0.0000053	0.11	0.11	0.0000015	0.039	0.039
Charleston Wando Terminal (D)[1]	0.000011	0.19	0.19	0.0000042	0.070	0.070	0.0000012	0.024	0.024
Charleston NWS (D)[1]	0.0000068	0.22	0.22	0.0000027	0.080	0.080	0.00000084	0.028	0.028
Charleston(C)[2]	0.000017	0.19	0.19	0.0000067	0.070	0.071	0.0000019	0.024	0.024
Tacoma (D)[1]	0.000024	0.75	0.80	0.0000097	0.29	0.30	0.0000028	0.10	0.11
Tacoma (C)[2]	0.000017	0.63	0.66	0.0000068	0.24	0.25	0.0000020	0.083	0.087
Concord NWS (D)[1]	0.000019	0.90	0.96	0.0000076	0.34	0.37	0.0000022	0.12	0.13
Concord NWS (C)[2]	0.000041	1.4	1.5	0.000017	0.55	0.56	0.0000046	0.19	0.20
Jacksonville (D)[1]	0.000012	0.31	0.31	0.0000049	0.11	0.11	0.0000015	0.039	0.039
Jacksonville (C)[2]	0.000011	0.24	0.25	0.0000045	0.090	0.092	0.0000013	0.031	0.032
Savannah (D)[1]	0.000025	0.23	0.23	0.0000099	0.083	0.085	0.0000028	0.028	0.029
Savannah (C)[2]	0.0000059	0.18	0.19	0.0000023	0.065	0.067	0.00000074	0.022	0.023
Wilmington (D)[1]	0.000017	0.22	0.23	0.0000067	0.081	0.084	0.0000019	0.028	0.029
Wilmington (C)[2]	0.0000042	0.098	0.10	0.0000017	0.035	0.037	0.0000005	0.012	0.013
Galveston (D)[1]	0.000032	0.64	0.70	0.000013	0.24	0.27	0.0000037	0.084	0.092
Galveston (C)[2]	0.000014	0.63	0.69	0.0000056	0.24	0.26	0.0000017	0.082	0.090
MOTSU (D)[1]	0.0000032	0.099	0.11	0.0000013	0.035	0.038	0.00000041	0.012	0.013
MOTSU (C)[2]	0.0000042	0.098	0.10	0.0000017	0.035	0.037	0.00000052	0.012	0.013

[1] *Accident is at the Dock*

[2] *Accident is in the Channel, the approach to the dock*

Table D-46 Summary of Latent Cancer Fatalities and Population Exposure Risk—Per Shipment and for the Entire Program (Basic Implementation)

	Risks per Shipment		Program Risks	
	Population Exposure per Shipment (person-rem)	Risk per Shipment (LCF)	Expos. (person-	[illegible]

Port	Risks per Shipment						Program Risks	
	Population Exposure per Shipment (person-rem)			Risk per Shipment (LCF)			Expos. (person-rem)	Risk (LCF)
	BR-2	RHF	TRIGA	BR-2	RHF	TRIGA		
Two Intermediate Population Ports	0.000056	0.000022	0.0000076	0.000000024	0.0000000093	0.0000000032	0.030	0.000013
One Intermediate and One Low Population Port	0.000051	0.000020	0.0000070	0.000000022	0.0000000085	0.0000000029	0.027	0.000011
Two Low Population Ports	0.000046	0.000018	0.0000063	0.000000020	0.0000000077	0.0000000026	0.024	0.000010
Direct	0.000042	0.000017	0.0000058	0.000000018	0.0000000070	0.0000000024	0.022	0.0000094
Long Beach via:								
Two High Population Ports	0.000011	0.000044	0.000015	0.000000047	0.000000018	0.0000000064	0.058	0.000025
One High and One Intermediate Population Port	0.000080	0.000032	0.0000011	0.000000034	0.000000013	0.0000000043	0.042	0.000018
One High and One Low Population Port	0.000071	0.000028	0.0000097	0.000000030	0.0000000012	0.0000000041	0.038	0.000016
Two Intermediate Population Ports	0.000050	0.000019	0.0000067	0.000000021	0.0000000083	0.0000000022	0.026	0.000011
One Intermediate and One Low Population Port	0.000041	0.000016	0.0000055	0.000000018	0.0000000068	0.0000000020	0.022	0.0000092
Two Low Population Ports	0.000032	0.0000013	0.0000043	0.000000014	0.0000000053	0.0000000018	0.017	0.0000072
Direct	0.000028	0.0000011	0.0000038	0.000000012	0.0000000046	0.0000000016	0.015	0.0000062
Philadelphia via:								
Two High Population Ports	0.00011	0.000042	0.000015	0.000000045	0.000000018	0.0000000061	0.057	0.000024
One High and One Intermediate Population Port	0.000088	0.000035	0.000012	0.000000037	0.000000015	0.0000000050	0.047	0.000020
One High and One Low Population Port	0.000083	0.000033	0.000011	0.000000035	0.000000014	0.0000000048	0.044	0.000019
Two Intermediate Population Ports	0.000031	0.000012	0.0000041	0.000000014	0.0000000052	0.0000000018	0.016	0.0000072

Port	Risks per Shipment						Program Risks	
	Population Exposure per Shipment (person-rem)			Risk per Shipment (LCF)			Expos. (person-rem)	Risk (LCF)
	BR-2	RHF	TRIGA	BR-2	RHF	TRIGA		
One Intermediate and One Low Population Port	0.000026	0.000010	0.0000035	0.000000011	0.0000000044	0.0000000015	0.014	0.0000061
Two Low Population Ports	0.000021	0.0000083	0.0000028	0.0000000093	0.0000000036	0.0000000012	0.011	0.0000049
Direct	0.000017	0.0000069	0.0000023	0.0000000075	0.0000000029	0.0000000099	0.0092	0.0000040
Portland via:								
Two High Population Ports	0.000090	0.000035	0.000012	0.000000038	0.000000015	0.0000000050	0.047	0.000020
One High and One Intermediate Population Port	0.000059	0.000023	0.0000080	0.000000025	0.0000000099	0.0000000029	0.031	0.000013
One High and One Low Population Port	0.000050	0.000020	0.0000068	0.000000022	0.0000000084	0.0000000027	0.027	0.000011
Two Intermediate Population Ports	0.000029	0.000011	0.0000039	0.000000013	0.0000000049	0.00000000088	0.015	0.0000066
One Intermediate and One Low Population Port	0.000020	0.0000077	0.0000027	0.0000000090	0.0000000034	0.00000000068	0.011	0.0000048
Two Low Population Ports	0.000011	0.0000042	0.0000015	0.0000000051	0.0000000019	0.00000000049	0.0059	0.0000026
Direct	0.0000073	0.0000028	0.00000098	0.0000000032	0.0000000012	0.00000000026	0.0039	0.0000017
Norfolk via:								
Two High Population Ports	0.000095	0.000037	0.000013	0.000000040	0.000000016	0.0000000054	0.050	0.000021
One High and One Intermediate Population Port	0.000076	0.000030	0.000010	0.000000032	0.000000013	0.0000000043	0.040	0.000017
One High and One Low Population Port	0.000071	0.000028	0.0000097	0.000000030	0.000000012	0.0000000040	0.037	0.000016
Two Intermediate Population Ports	0.000019	0.0000071	0.0000024	0.0000000083	0.0000000031	0.0000000011	0.0098	0.0000044
One Intermediate and One Low Population Port	0.000014	0.0000052	0.0000018	0.0000000061	0.0000000023	0.00000000078	0.0072	0.0000032
Two Low Population Ports	0.0000088	0.0000033	0.0000011	0.0000000040	0.0000000015	0.00000000050	0.0046	0.0000021

Port	Risks per Shipment						Program Risks	
	Population Exposure per Shipment (person-rem)			Risk per Shipment (LCF)			Expos. (person-rem)	Risk (LCF)
	BR-2	RHF	TRIGA	BR-2	RHF	TRIGA		
Direct	0.0000048	0.0000018	0.00000062	0.0000000021	0.0000000081	0.00000000028	0.0025	0.0000011
Charleston (Wando Terminal) via:								
Two High Population Ports	0.000092	0.000036	0.000013	0.000000039	0.000000015	0.0000000053	0.049	0.000021
One High and One Intermediate Population Port	0.000074	0.000029	0.000010	0.000000031	0.000000012	0.0000000042	0.039	0.000016
One High and One Low Population Port	0.000069	0.000027	0.0000094	0.000000029	0.000000011	0.0000000039	0.036	0.000015
Two Intermediate Population Ports	0.000016	0.0000063	0.0000021	0.0000000074	0.0000000028	0.00000000095	0.0087	0.0000039
One Intermediate and One Low Population Port	0.000012	0.0000043	0.0000015	0.0000000052	0.0000000019	0.00000000066	0.0061	0.0000027
Two Low Population Ports	0.0000066	0.0000024	0.00000082	0.0000000031	0.0000000011	0.00000000038	0.0035	0.0000016
Direct	0.0000027	0.000001	0.00000034	0.0000000012	0.00000000045	0.00000000015	0.0014	0.00000064
Charleston NWS via:								
Two High Population Ports	0.000093	0.000033	0.000013	0.000000039	0.000000015	0.0000000053	0.049	0.000021
One High and One Intermediate Population Port	0.000074	0.000029	0.000010	0.000000031	0.000000012	0.0000000042	0.039	0.000016
One High and One Low Population Port	0.000069	0.000027	0.0000094	0.000000029	0.000000011	0.0000000039	0.036	0.000015
Two Intermediate Population Ports	0.000017	0.0000063	0.0000022	0.0000000075	0.0000000028	0.00000000096	0.0084	0.0000039
One Intermediate and One Low Population Port	0.000012	0.0000044	0.0000015	0.0000000053	0.0000000020	0.00000000067	0.0058	0.0000028
Two Low Population Ports	0.0000068	0.0000025	0.00000084	0.0000000032	0.0000000011	0.00000000039	0.0032	0.0000017
Direct	0.0000028	0.0000011	0.00000036	0.0000000013	0.00000000048	0.00000000016	0.0011	0.00000068
MOTSU via:								
Two High Population Ports	0.000091	0.000036	0.000012	0.000000039	0.000000015	0.0000000052	0.048	0.000020

Port	Risks per Shipment						Program Risks	
	Population Exposure per Shipment (person-rem)			Risk per Shipment (LCF)			Expos. (person-rem)	Risk (LCF)
	BR-2	RHF	TRIGA	BR-2	RHF	TRIGA		
One High and One Intermediate Population Port	0.000072	0.000028	0.0000099	0.000000031	0.000000012	0.0000000041	0.038	0.000016
One High and One Low Population Port	0.000067	0.000026	0.0000092	0.0000000028	0.0000000011	0.0000000038	0.036	0.000015
Two Intermediate Population Ports	0.000015	0.0000057	0.0000019	0.0000000068	0.0000000025	0.00000000087	0.0080	0.0000036
One Intermediate and One Low Population Port	0.000010	0.0000038	0.0000013	0.0000000046	0.0000000017	0.00000000058	0.0054	0.0000024
Two Low Population Ports	0.0000053	0.0000019	0.00000064	0.0000000025	0.00000000088	0.0000000003	0.0028	0.0000013
Direct	0.0000013	0.00000047	0.00000016	0.00000000062	0.00000000022	0.000000000075	0.00069	0.00000032
Galveston via:								
Two High Population Ports	0.000099	0.000039	0.000013	0.000000042	0.000000016	0.0000000056	0.052	0.000022
One High and One Intermediate Population Port	0.000080	0.000031	0.000011	0.000000034	0.000000013	0.0000000046	0.042	0.000018
One High and One Low Population Port	0.000075	0.000029	0.0000010	0.000000032	0.0000000012	0.0000000043	0.040	0.000017
Two Intermediate Population Ports	0.000023	0.0000087	0.0000030	0.000000010	0.0000000038	0.0000000013	0.012	0.0000053
One Intermediate and One Low Population Port	0.000018	0.0000067	0.0000023	0.0000000080	0.000000003	0.000000001	0.0094	0.0000042
Two Low Population Ports	0.000013	0.0000048	0.0000017	0.0000000058	0.0000000022	0.00000000074	0.0068	0.0000031
Direct	0.0000090	0.0000034	0.0000012	0.0000000040	0.0000000015	0.00000000052	0.0047	0.0000021
Jacksonville via:								
Two High Population Ports	0.000094	0.000037	0.000013	0.000000040	0.000000016	0.0000000053	0.050	0.000021
One High and One Intermediate Population Port	0.000075	0.000029	0.00001	0.000000032	0.000000012	0.0000000043	0.040	0.000017

Port	Risks per Shipment						Program Risks	
	Population Exposure per Shipment (person-rem)			Risk per Shipment (LCF)			Expos. (person-rem)	Risk (LCF)
	BR-2	[illegible]	TRIGA	BR-2	[illegible]	TRIGA		

Port	Risks per Shipment: Population Exposure per Shipment (person-rem)			Risk per Shipment (LCF)			Program Risks	
	BR-2	RHF	TRIGA	BR-2	RHF	TRIGA	Expos. (person-rem)	Risk (LCF)
One Intermediate and One Low Population Port	0.000011	0.0000042	0.0000014	0.0000000050	0.0000000019	0.00000000064	0.0058	0.0000026
Two Low Population Ports	0.0000062	0.0000022	0.00000076	0.0000000029	0.0000000010	0.00000000035	0.0032	0.0000015
Direct	0.0000022	0.00000082	0.00000028	0.0000000010	0.00000000037	0.00000000013	0.0012	0.00000053
Tacoma via:								
Two High Population Ports	0.000092	0.000036	0.0000013	0.000000039	0.000000015	0.0000000053	0.049	0.000021
One High and One Intermediate Population Port	0.000062	0.000024	0.0000084	0.000000026	0.000000010	0.0000000032	0.033	0.000014
One High and One Low Population Port	0.000053	0.000021	0.0000072	0.000000023	0.0000000088	0.0000000031	0.028	0.000012
Two Intermediate Population Ports	0.000031	0.000012	0.0000042	0.000000014	0.0000000053	0.0000000012	0.017	0.0000072
One Intermediate and One Low Population Port	0.000023	0.0000086	0.0000030	0.000000010	0.0000000038	0.00000000099	0.012	0.0000053
Two Low Population Ports	0.000014	0.0000052	0.0000018	0.0000000061	0.0000000023	0.00000000079	0.0072	0.0000032
Direct	0.0000097	0.0000038	0.0000013	0.0000000043	0.0000000016	0.00000000057	0.0051	0.0000023
Concord NWS via:								
Two High Population Ports	0.000099	0.000039	0.000013	0.000000042	0.000000016	0.0000000057	0.052	0.000022
One High and One Intermediate Population Port	0.000069	0.000027	0.0000093	0.000000029	0.000000011	0.0000000036	0.036	0.000015
One High and One Low Population Port	0.000060	0.000024	0.0000081	0.000000025	0.0000000099	0.0000000034	0.032	0.000013
Two Intermediate Population Ports	0.000038	0.000015	0.0000051	0.000000017	0.0000000064	0.0000000016	0.020	0.0000087
One Intermediate								

	Risks per Shipment		Program Risks	
	Population Exposure per Shipment		Expos.	

Acceptance of Foreign Research Reactor Spent Nuclear Fuel from Developing Countries Only: Developing countries are defined as countries other than high-income economies. Under this alternative 168 transportation casks of foreign research reactor spent nuclear fuel would be shipped to the United States (see Appendix C.4.2 for details). All of these shipments would be shipped by ocean vessel and, therefore, would enter the United States through ports.

In addition to a reduced number of shipments associated with this alternative, the mix of fuel types changes. In the basic implementation of Management Alternative 1, most of the foreign research reactor spent nuclear fuel shipments would be BR-2 type fuel. Only about 20 percent of the shipments would be [illegible] fuel type. From the information provided in Appendix B, most of the shipments from [illegible]

Port	Exposure (person-rem)	Risk (LCF)
Two Low Population Ports	0.0016	0.00000068
Direct	0.0013	0.00000055
Portland via:		
Two High Population Ports	0.0066	0.0000028
One High and One Intermediate Population Port	0.0044	0.0000018
One High and One Low Population Port	0.0037	0.0000016
Two Intermediate Population Ports	0.0021	0.00000085
One Intermediate and One Low Population Port	0.0015	0.00000060
Two Low Population Ports	0.00082	0.00000035
Direct	0.00054	0.00000022
Norfolk via:		
Two High Population Ports	0.0070	0.0000030
One High and One Intermediate Population Port	0.0056	0.0000024
One High and One Low Population Port	0.0052	0.0000022
Two Intermediate Population Ports	0.0014	0.00000061
One Intermediate and One Low Population Port	0.0010	0.00000045
Two Low Population Ports	0.00064	0.00000029
Direct	0.00035	0.00000016
Charleston (Wando Terminal) via:		
Two High Population Ports	0.0069	0.0000029
One High and One Intermediate Population Port	0.0054	0.0000023
One High and One Low Population Port	0.0051	0.0000021
Two Intermediate Population Ports	0.0012	0.00000054
One Intermediate and One Low Population Port	0.00084	0.00000038
Two Low Population Ports	0.00048	0.00000022
Direct	0.00020	0.000000089
Charleston NWS via:		
Two High Population Ports	0.0068	0.0000029
One High and One Intermediate Population Port	0.0054	0.0000023
One High and One Low Population Port	0.0051	0.0000021
Two Intermediate Population Ports	0.0012	0.00000054
One Intermediate and One Low Population Port	0.00084	0.00000038
Two Low Population Ports	0.00048	0.00000022
Direct	0.00020	0.000000089
MOTSU via:		
Two High Population Ports	0.0067	0.0000028
One High and One Intermediate Population Port	0.0053	0.0000022
One High and One Low Population Port	0.0050	0.0000021
Two Intermediate Population Ports	0.0011	0.00000049
One Intermediate and One Low Population Port	0.00074	0.00000034
Two Low Population Ports	0.00038	0.00000018
Direct	0.000095	0.000000045
Galveston via:		
Two High Population Ports	0.0073	0.0000031
One High and One Intermediate Population Port	0.0059	0.0000025
One High and One Low Population Port	0.0055	0.0000023
Two Intermediate Population Ports	0.0017	0.00000074
One Intermediate and One Low Population Port	0.0013	0.00000058
Two Low Population Ports	0.00094	0.00000043
Direct	0.00066	0.00000029
Jacksonville via:		
Two High Population Ports	0.0069	0.0000029

Port	Exposure (person-rem)	Risk (LCF)
One High and One Intermediate Population Port	0.0055	0.0000023
One High and One Low Population Port	0.0052	0.00000022
Two Intermediate Population Ports	0.0013	0.00000057
One Intermediate and One Low Population Port	0.00093	0.00000042
Two Low Population Ports	0.00056	0.00000026
Direct	0.00028	0.00000013
Savannah via:		
Two High Population Ports	0.0068	0.0000029
One High and One Intermediate Population Port	0.0055	0.0000023
One High and One Low Population Port	0.0051	0.0000021
Two Intermediate Population Ports	0.0012	0.00000054
One Intermediate and One Low Population Port	0.00085	0.00000039
Two Low Population Ports	0.00049	0.00000023
Direct	0.00021	0.000000095
Wilmington via:		
Two High Population Ports	0.0068	0.0000029
One High and One Intermediate Population Port	0.0054	0.0000023
One High and One Low Population Port	0.0050	0.0000021
Two Intermediate Population Ports	0.0012	0.00000052
One Intermediate and One Low Population Port	0.00081	0.00000037
Two Low Population Ports	0.00045	0.00000021
Direct	0.00016	0.000000074
Tacoma via:		
Two High Population Ports	0.0068	0.0000029
One High and One Intermediate Population Port	0.0045	0.0000019
One High and One Low Population Port	0.0039	0.0000017
Two Intermediate Population Ports	0.0023	0.00000095
One Intermediate and One Low Population Port	0.0017	0.00000070
Two Low Population Ports	0.00010	0.00000045
Direct	0.00072	0.00000032
Concord NWS via:		
Two High Population Ports	0.0073	0.0000031
One High and One Intermediate Population Port	0.0051	0.0000021
One High and One Low Population Port	0.0044	0.0000019
Two Intermediate Population Ports	0.0028	0.0000012
One Intermediate and One Low Population Port	0.0022	0.00000091
Two Low Population Ports	0.0015	0.00000066
Direct	0.0012	0.00000053

Acceptance of Foreign Research Reactor Spent Nuclear Fuel for 5 Years Only: Under this implementation alternative, 586 transportation casks of foreign research reactor spent nuclear fuel would be shipped to the United States. All of these shipments would be shipped by ocean vessel and would enter the United States through ports.

In addition to a reduced number of shipments associated with this implementation alternative, the mix of fuel types changes slightly. From the information provided in Appendix B, 376 of the 586 shipments in this alternative are BR-2 spent fuel shipments, 56 are RHF, and 154 are TRIGA.

The risks of the basic implementation of Management Alternative 1, provided in Table D-46, have been recalculated to incorporate the change in the number and makeup of the shipments associated with this implementation alternative. These results are presented in Table D-48. The highest calculated port accident risks are associated with the shipment of all of the foreign research reactor spent nuclear fuel through the port of Elizabeth via two high population intermediate ports. The port accident risks for the implementation alternative for this route are 0.055 person-rem and 0.000023 LCF. The lowest calculated impacts are for the shipment of all of the material directly into MOTSU (no intermediate port calls) which [illegible]

Table D-48 Summary of Risk and Population Exposure—For the Implementation Alternative of a 5-Year Acceptance Duration

Port	*Exposure (person-rem)*	*Risk (LCF)*
Elizabeth via:		
Two High Population Ports	0.055	0.000023
One High and One Intermediate Population Port	0.047	0.000020
One High and One Low Population Port	0.045	0.000019
Two Intermediate Population Ports	0.023	0.000010
One Intermediate and One Low Population Port	0.021	0.0000091
Two Low Population Ports	0.019	0.0000082
Direct	0.018	0.0000074
Long Beach via:		
Two High Population Ports	0.046	0.000019
One High and One Intermediate Population Port	0.033	0.000014
One High and One Low Population Port	0.030	0.000013
Two Intermediate Population Ports	0.021	0.0000089
One Intermediate and One Low Population Port	0.017	0.0000073
Two Low Population Ports	0.013	0.0000057
Direct	0.012	0.0000049
Philadelphia via:		
Two High Population Ports	0.045	0.000019
One High and One Intermediate Population Port	0.037	0.000016
One High and One Low Population Port	0.035	0.000015
Two Intermediate Population Ports	0.013	0.0000057
One Intermediate and One Low Population Port	0.011	0.0000048
Two Low Population Ports	0.0089	0.0000039
Direct	0.0073	0.0000031
Portland via:		
Two High Population Ports	0.038	0.000016
One High and One Intermediate Population Port	0.025	0.000011
One High and One Low Population Port	0.021	0.0000090

Port	Exposure (person-rem)	Risk (LCF)
One Intermediate and One Low Population Port	0.0048	0.0000022
Two Low Population Ports	0.0028	0.0000013
Direct	0.0011	0.00000051
Charleston NWS via:		
Two High Population Ports	0.039	0.000016
One High and One Intermediate Population Port	0.031	0.000013
One High and One Low Population Port	0.029	0.000012
Two Intermediate Population Ports	0.0066	0.0000031
One Intermediate and One Low Population Port	0.0048	0.0000022
Two Low Population Ports	0.0025	0.0000013
Direct	0.00087	0.00000054
MOTSU via:		
Two High Population Ports	0.038	0.000016
One High and One Intermediate Population Port	0.030	0.000013
One High and One Low Population Port	0.028	0.000012
Two Intermediate Population Ports	0.0063	0.0000028
One Intermediate and One Low Population Port	0.0042	0.0000019
Two Low Population Ports	0.0022	0.0000010
Direct	0.00055	0.00000028
Galveston via:		
Two High Population Ports	0.041	0.000018
One High and One Intermediate Population Port	0.033	0.000014
One High and One Low Population Port	0.031	0.000013
Two Intermediate Population Ports	0.0095	0.0000042
One Intermediate and One Low Population Port	0.0074	0.0000033
Two Low Population Ports	0.0054	0.0000024
Direct	0.0037	0.0000017
Jacksonville via:		
Two High Population Ports	0.039	0.000017
One High and One Intermediate Population Port	0.031	0.000013
One High and One Low Population Port	0.029	0.000012
Two Intermediate Population Ports	0.0073	0.0000033
One Intermediate and One Low Population Port	0.0053	0.0000024
Two Low Population Ports	0.0032	0.0000015
Direct	0.0016	0.00000072
Savannah via:		
Two High Population Ports	0.039	0.000016
One High and One Intermediate Population Port	0.031	0.000013
One High and One Low Population Port	0.029	0.000012
Two Intermediate Population Ports	0.0069	0.0000031
One Intermediate and One Low Population Port	0.0049	0.0000022
Two Low Population Ports	0.0028	0.0000013
Direct	0.0012	0.00000055
Wilmington via:		
Two High Population Ports	0.039	0.000016
One High and One Intermediate Population Port	0.031	0.000013
One High and One Low Population Port	0.029	0.000012

Port	Exposure (person-rem)	Risk (LCF)
Tacoma via:		
Two High Population Ports	0.039	0.000016
One High and One Intermediate Population Port	0.026	0.0000011
One High and One Low Population Port	0.022	0.0000094
Two Intermediate Population Ports	0.013	0.0000057
One Intermediate and One Low Population Port	0.0094	0.0000041
Two Low Population Ports	0.0057	0.0000026
Direct	0.0041	0.0000018
Concord NWS via:		
Two High Population Ports	0.041	0.000017
One High and One Intermediate Population Port	0.029	0.000012
One High and One Low Population Port	0.025	0.000011
Two Intermediate Population Ports	0.016	0.0000070
One Intermediate and One Low Population Port	0.012	0.0000054
Two Low Population Ports	0.0086	0.0000037
Direct	0.0070	0.0000030

D.5.7 Port Accident Impacts Associated with Management Alternative 2

Of the two subalternatives under Management Alternative 2, only subalternative 1b requires assessment of the impacts of accidents in port. This subalternative involves overseas reprocessing of foreign research reactor spent nuclear fuel. Under this subalternative, which is explained in detail in Chapter 2, up to eight transportation casks of vitrified high-level waste might pass through U.S. ports on their way to storage sites in the United States. The port accident impacts associated with this subalternative are evaluated below.

Foreign Reprocessing with Shipment of Vitrified Waste to a U.S. Storage Facility: In this subalternative to Management Alternative 2, all of the foreign research reactor spent nuclear fuel (including that generated in Canada) would be sent to either Great Britain or France for reprocessing and part or all of the vitrified high-level waste generated in the process could be shipped to the United States. Based on the reprocessing of approximately 23 metric tons of spent nuclear fuel (all of the fuel considered by the basic implementation of Management Alternative 1), enough vitrified high-level waste would be generated to require the transportation of up to eight transportation casks carrying logs of vitrified high-level waste to the United States.

The consequences of an accident in port involving a cask of vitrified high-level waste could not be derived from the analysis of the port accidents for the foreign research reactor spent nuclear fuel. Two significant differences in the contents of the cask carrying vitrified high-level waste and the casks carrying foreign research reactor spent nuclear fuel dictate that revised source terms be calculated for the vitrified high-level waste case. The release fractions associated with the accident severity categories are different for the vitrified high-level waste than they are for the foreign research reactor spent nuclear fuel. Based on previous DOE efforts (DOE, 1994b) the release fractions for vitrified high-level waste are the same for all three release categories (categories 4, 5, and 6). Vitrified waste release fractions are relatively insensitive to the affects of the fires that differentiate the category 5 and 6 accidents from the category 4 accidents. The release fractions used in this analysis are a factor of 0.05 higher than those used in the referenced analysis because the use of the MACCS code eliminates the need to describe a respirable fraction of the

These release fractions apply to all material in the vitrified high-level waste. Each isotope contained in the glassified waste has been assigned the same release fraction.

All of the wastes generated in reprocessing the foreign research reactor spent nuclear fuel would be transported in no more than eight casks, compared to the 837 marine and overland shipments of spent [illegible] fuel required under the basic implementation of Management Alternative 1. This means that the [illegible]

[illegible] risk of foreign research reactor spent nuclear fuel [illegible]

Table D-49 Radionuclide Inventory for Each of Eight Vitrified High-Level Waste Shipments

Radionuclide	Vitrified High-Level Waste Inventory (Ci)	Radionuclide	Vitrified High-Level Waste Inventory (Ci)
Hydrogen-3	7,302	Cerium-141	559,300
Krypton-85	207,000	Cerium-144 Promethium-144	24,890,000
Strontium-89	3,072,000	Promethium-147	3,703,000
Strontium-90 Yttrium-90	1,743,000	Promethium-148m	7,133
Yttrium-91	5,477,000	Europium-154	62,390
Zirconium-95	8,079,000	Europium-155	12,900
Niobium-95	16,540,000	Plutonium-238	8,484
Ruthenium-103 Rh-103m	716,000	Plutonium-239	405
Ruthenium-106 Rh-106m	1,882,000	Plutonium-240	326
Tin-123	33,340	Plutonium-241	78,440
Antimony-125	75,700	Americium-241	98
Tellurium-125m	18,060	Americium-242m	0.67
Tellurium-127M	69,720	Americium-243	1.4
Tellurium-129M	15,870	Curium-244	122
Cesium-134	1,413,000	Curium-242	990
Cesium-137	1,743,000		

Table D-50 Port Accident Consequences for Vitrified High-Level Waste

Location	Mean Accident Consequences		99th Percentile Consequences	
	Population Exposure (person-rem)	LCF	Population Exposure (person-rem)	LCF
MOTSU at the Dock	93.1	0.04	572	0.25
MOTSU in the Channel	66.1	0.029	332	0.13
Charleston at the Dock	202	0.088	747	0.32
Charleston in the Channel	293	0.13	2450	1.02
Philadelphia at the Dock	1250	0.54	5110	2.12
Philadelphia in the Channel	733	0.32	2990	1.21

The port accident risks associated with the implementation of this subalternative to Management Alternative 2 results in a negligible risk to the public. The highest mean port accident risk results in a less than one-in-ten thousand chance of a single LCF.

D.5.9 Port Accident Impacts Associated with a Combination of Returning Foreign Research Reactor Spent Nuclear Fuel and Overseas Management

In addition to evaluating the port accident impacts for the various alternatives associated with bringing all of the foreign research reactor spent nuclear fuel to the United States (Management Alternative 1) and managing all of the spent nuclear fuel overseas (Management Alternative 2), a hybrid scenario was analyzed. In this scenario, those countries that have the capability to store high-level waste would be

Table D-51 Port Accident Risks for the Acceptance of Vitrified High-Level Waste

Port	Risk per Shipment of One Cask of Waste		Risk of the Entire Waste Acceptance Option	
	Population Dose (person-rem)	LCF	Population Dose (person-rem)	LCF
Philadelphia	0.006	0.000003	0.05	0.00002
Charleston	0.001	0.0000007	0.01	0.000005
MOTSU	0.0005	0.0000002	0.004	0.000002

research reactor spent nuclear fuel from those countries deemed not to have the high-level waste storage capability. In this option, this includes all of the countries identified in Table C-1, except for those listed above. Under the hybrid scenario, 452 shipments of spent nuclear fuel are assumed to be sent to the United States through U.S. ports, excluding shipments of Canadian origin, which are assumed to be transported overland. Of these, 290 are of the BR-2 fuel type and 162 are of the TRIGA type.

In analyzing the exposure and risk associated with this scenario, much of the information that was developed for Management Alternative 1 can be used. Both the per-transit probability of an accident and the conditional probabilities of severity category 4, 5, and 6 accidents are valid for this hybrid scenario. The consequences associated with each of the three accident severity categories also do not change, because the only thing that is changing is the number of shipments. Since neither the probability nor the consequences of the accidents change, the per-shipment risks are identical to those of the basic implementation of Management Alternative 1.

The risks associated with the basic implementation of Management Alternative 1 (Table D-46) have been recalculated to incorporate the change in the number and makeup of the shipments associated with the hybrid scenario. These results are presented in Table D-52. The highest calculated port accident risks are associated with the shipment of all of the foreign research reactor spent nuclear fuel through the port of Elizabeth via two high population intermediate ports. The port accident risks for the Management Alternative for this route are 0.041 person-rem and 0.000017 LCF. The lowest calculated impacts are for the shipment of all the material directly into MOTSU (no intermediate port calls), which results in port accident risk of 0.0004 person-rem and 1.9×10^{-7} LCF.

Table D-52 Summary of Risk and Population Exposure—For the Hybrid Scenario

Port	Exposure (person-rem)	Risk (LCF)
Elizabeth via:		
Two High Population Ports	0.041	1.7×10^{-5}
One High and One Intermediate Population Port	0.035	1.5×10^{-5}
One High and One Low Population Port	0.034	1.4×10^{-5}
Two Intermediate Population Ports	0.017	7.5×10^{-6}
One Intermediate and One Low Population Port	0.016	6.8×10^{-6}
Two Low Population Ports	0.014	6.1×10^{-6}
Direct	0.013	5.5×10^{-6}
Long Beach via:		
Two High Population Ports	0.034	1.5×10^{-5}
One High and One Intermediate Population Port	0.025	1.1×10^{-5}
One High and One Low Population Port	0.022	9.4 x 10-6
Two Intermediate Population Ports	0.015	6.6 x 10-6
One Intermediate and One Low Population Port	0.013	5.4 x 10-6
Two Low Population Ports	0.0099	4.3×10^{-6}
Direct	0.0087	3.7×10^{-6}
Philadelphia via:		
Two High Population Ports	0.033	1.4×10^{-5}

Port	Exposure (person-rem)	Risk (LCF)
Two High Population Ports	0.033	1.4×10^{-5}
[illegible]	0.028	1.2×10^{-5}

Port	Exposure (person-rem)	Risk (LCF)
One Intermediate and One Low Population Port	0.0056	2.5×10^{-6}
Two Low Population Ports	0.0040	1.8×10^{-6}
Direct	0.0028	1.2×10^{-6}
Jacksonville via:		
Two High Population Ports	0.029	1.2×10^{-5}
One High and One Intermediate Population Port	0.023	9.9×10^{-6}
One High and One Low Population Port	0.022	9.2×10^{-6}
Two Intermediate Population Ports	0.0055	2.4×10^{-6}
One Intermediate and One Low Population Port	0.0039	1.8×10^{-6}
Two Low Population Ports	0.0024	1.1×10^{-6}
Direct	0.0012	5.3×10^{-7}
Savannah via:		
Two High Population Ports	0.029	1.2×10^{-5}
One High and One Intermediate Population Port	0.023	9.7×10^{-6}

Since it is impossible to determine with certainty the probability of a deliberate act of sabotage or terrorist attack, this section presents an analysis of potential consequences of sabotage or terrorist attack on a spent nuclear fuel shipping cask, and does not attempt to estimate the risk of such an activity. Although judged very unlikely to actually occur, a malicious attack on a foreign research reactor spent nuclear fuel shipping cask has been postulated to occur at a U.S. port or during transportation from the port to the management site, for purposes of illustrating the effects that might result from such an event.

The spectrum of attacks that can be postulated is broad, falling into three categories or scenarios: (1) exploding a bomb near a shipping cask, (2) attacking a cask with a shaped charge, or an armor-piercing weapon (i.e., an anti-tank weapon), and (3) hijacking (stealing) a shipping cask. None of the scenarios considered would lead to a criticality accident.

D.5.9.1 Exploding a Bomb Near a Shipping Cask

This sabotage/terrorist attack scenario assumes that a large bomb, similar to that detonated in Oklahoma City in April of 1995, is detonated in the immediate vicinity of a spent nuclear fuel shipping cask. The primary threats to the cask integrity would arise from: (1) direct blast forces (shock wave) from the bomb, (2) impact forces from fragments (e.g., motor vehicle parts) generated by the bomb, and (3) other dynamic forces such as a roll-over of the cask transport vehicle in response to the blast forces. The casks are rugged structures that would be expected to survive the effects of a nearby bomb explosion with no significant loss of integrity. At worst, the blast might produce a crack in the wall of the cask. In any case, all spent nuclear fuel elements would remain inside the cask. Blast-related damage might, however, reduce the effectiveness of cask shielding and/or cause locally higher dose rates outside the cask (e.g., from damaged shielding areas and radiation streaming through a crack in the cask wall).

Although no mechanism has been postulated that could cause such an event, an analysis of a total loss of cask shielding has been performed for the purposes of demonstrating limiting case effects of an attack on a spent nuclear fuel shipping cask, such as that discussed above. The analysis scenario assumes that the cask was full of a highly irradiated foreign research reactor spent nuclear fuel, and that the spent nuclear fuel elements were spread on the ground producing the highest possible direct dose rate. For the calculation of direct dose, no credit was taken for self-shielding of the spent fuel, and it was assumed that no other obstacle would exist between the spent nuclear fuel and individual members of the public. Since the spent nuclear fuel would be a solid metal structure, this analysis assumes that no spent nuclear fuel damage occurs, therefore, no radioactive materials would be dispersed. The results of this unrealistically conservative analysis are shown in Figure D-60. This figure provides a conservative estimate of the direct dose rate (rem per hour) to an individual member of the public versus distance from a spent nuclear fuel pile consisting of 30 highly irradiated fuel elements. Based on the results of this hypothetical, conservative analysis, an evacuation distance of about 900 meters (3000 ft) would be sufficient to maintain a dose rate of less than 10 mrem per hour, (or 0.01 rem per hour). This is a very conservative evacuation distance, but it would provide a good measure for consideration by an emergency response team. This scenario would result in minimal or no contamination of the area where it occurred and once the spent nuclear fuel was shielded, the evacuation zone would be greatly reduced. Once the spent nuclear fuel was removed from the site, the area would be decontaminated, if necessary, before it returned to normal.

D.5.9.2 Attacking a Cask with a Shaped Charge or Armor-Piercing Weapon

If a cask were attacked by an armor-piercing weapon or a shaped charge, the cask would be penetrated and spent nuclear fuel elements inside the cask could be damaged. An analysis of a hypothetical attack on a spent nuclear fuel shipping cask using a shaped charge was performed using the MACCS code. The

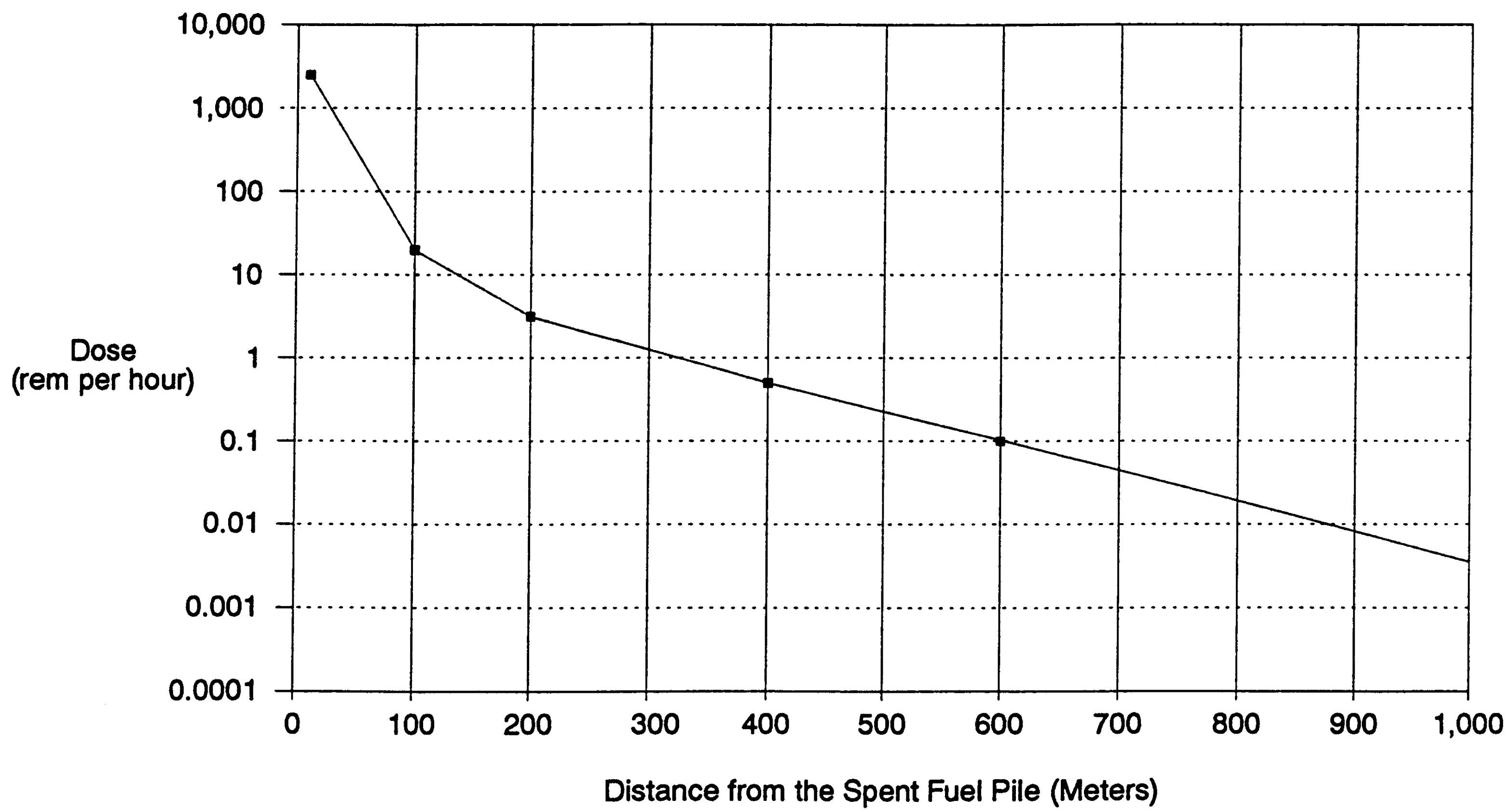


Figure D-60 Direct Dose vs Distance to an Individual Member of the Public

accident was assumed to occur on a city street in a highly populated area near the harbor where the spent nuclear fuel cask was transferred to a truck after trans oceanic shipment from overseas. The analysis assumed that the cask contained the highest radionuclide inventory, and the blast released all of the noble gases and one percent of the bulk of the spent nuclear fuel as airborne aerosols. The one percent of bulk spent nuclear fuel release assumption was based on measurements of aerosols released during tests where spent nuclear fuel was explosively disrupted. These tests yielded spent nuclear fuel release mass fractions that ranged from 0.05 to 2.5 percent (Sanders, et al., 1992). The blast energy would be quickly dissipated and the released fission products and gases and aerosols were assumed to be relatively cool; thus no plume rise was assumed to occur. These assumptions are very conservative and the results provide an enveloping estimate of consequences on the environmental and health effects. The MACCS calculations estimated a population dose of 208,000 person-rem with no acute fatalities or short-term adverse health effects among the exposed population. The MACCS results estimated that 91 latent cancer fatalities could occur among the 16 million persons living within 80 kilometers (50 miles) of the attack. The average individual lifetime radiation dose among the one to two million people who would be exposed is estimated to be about 200 mrem. This is less than one percent of a person's lifetime natural background radiation dose. This evaluation did not consider any evacuation and/or sheltering activities after the attack. MACCS also estimated a contamination distance of about 1 kilometer (0.6 miles) down wind from the attack. This distance, though conservative, could be used by an emergency response team for evacuation purposes. Of course, any actual evacuation distance would be determined on a case-by-case basis, if such an event were ever to occur. Mitigation activities in the aftermath of such an explosion, as required by law (EPA), would reduce the size of the contaminated area drastically and the area could become rehabitable in a short period of time. It is important to bear in mind that the explosion itself would be likely to produce fatalities, injuries and property damage that far exceed that caused by any release of radioactive material from the spent nuclear fuel.

In a terrorist attack using an anti-tank weapon, any cask damage and resulting consequences would be less severe than the accidents analyzed elsewhere in the EIS. This is because (1) there would be no explosive material inside the cask so the cask would not explode. Therefore, no additional radioactivity, other than that released directly by the projectile, would be forced out of the cask, and (2) there would be no fire to disperse the radioactivity that would be released when the cask was breached. At worst, the consequences of a terrorist attack on a spent nuclear fuel shipping cask with an anti-tank weapon would be similar to that analyzed above for a hypothetical terrorist attack on a cask with a high explosive shaped charge.

D.5.9.3 Hijacking a Shipping Cask

The discret theft of a spent nuclear fuel transportation cask is considered to be very unlikely, due to security measures that would be in place during transportation activities, especially the guarding of the cask, and communication and tracking systems (see Section 2.8 and Appendix H). In addition, the large size and weight of these casks (20 to 30 metric tons) and the inherent radioactivity of the spent nuclear fuel (which could kill a person upon contact) would deter most would-be hijackers. In the event of a hijack attempt, required communications systems would ensure timely notification of authorities who would mobilize response forces. The installed tracking system would allow the location of the cask to be determined in real time, thereby aiding timely interception of hijackers by response forces.

No release of radioactive material or increase in radiation level would be expected during a hijack scenario unless the hijacker could blow up the cask using explosive material (e.g., a shaped charge), or open the cask. In case of a cask explosion using a shaped charge, the consequences would be the same as, or smaller than (depending on the location of the accident), the case described in Section D.5.9.2. If the cask level in the immediate vicinity of the cask would increase. The cask opening could only be accomplished at great personal risk to hijackers due to large (possibly immediately lethal) radiation exposures that they would receive while handling the unshielded fuel elements.

Should such an attempt be made, the hijackers would not be able to alter the fuel configuration inside the cask to make it critical. Criticality analyses that have been performed in support of the cask certification process consider various fuel and moderation configurations. These analyses are performed to ensure that none of potential configurations that could occur during loading and transport of the cask would lead to a criticality condition. Changing moderating material to achieve criticality, would require special materials that are not readily available (safeguard materials). Based on the time available to the hijackers, and tooling and materials that are needed, DOE considers that the potential for achieving criticality in a hijacked spent nuclear fuel cask is beyond credibility. If the hijackers were to dump the unshielded spent nuclear fuel, the resulting consequences to the public from the bare spent nuclear fuel radiation exposure would be less severe than those already analyzed for other hypothetical scenarios in this appendix.

References

AAPA (American Association of Port Authorities), 1994, *The 1994 AAPA Directory, Seaports of the Americas,* Compass North America, Inc., Coral Gables, FL.

AAPA (American Association of Port Authorities), 1993, *The 1993 AAPA Directory, Seaports of the Western Hemisphere,* Compass North America, Inc., Coral Gables, FL.

Abkowitz, M. and J. Galarraga, 1985, "Tanker Accident Rates and Expected Consequences in U.S. Ports and High Seas Regions", *Conference on Recent Advances in Hazardous Materials Transportation Research: An International Exchange,* Transportation Research Council, November 10-13.

Adams, D., 1994, Chief Wharfinger, Port of Oakland, CA, Hazardous Cargo DADAMS Data Radioactive - 1994, June 7.

Adams, D. and H. Renteria, 1994, Chief Wharfinger and Emergency Services Manager, Port of Oakland, CA, personal communication with R. L. Gotchy, Science Applications International Corporation, June 7.

Adams, D., 1993, Chief Wharfinger, Port of Oakland, CA, personal communication with C. Miller, Science Applications International Corporation, October 19.

American Shipper, 1994, *American Shipper, Southern Ports, 1994,* An American Shipper Publication, Volume 35, No. 13, Jacksonville, FL, January.

Babrauskas, V., 1986a, "Room Fire Temperature Computations," *Fire Protection Handbook,* 16th Edition, A.E. Cote and J. L. Linville, Editors, National Fire Protection Association, Quincy, MA.

Babrauskas, V., 1986b, "Pool Fires: Burning Rates and Heat Fluxes," *Fire Protection Handbook,* 16th Edition, A.E. Cote and J. L. Linville, Editors, National Fire Protection Association, Quincy, MA.

Banks, R., 1994, Field Supervisor, U.S. Fish and Wildlife Service, Letter to D. Scott, Science Applications International Corporation, October 26.

BEIR (Biological Effects of Ionizing Radiation), 1990, *Health Effects of Exposure to Low Levels of Ionizing Radiation,* BEIR V, National Academy Press, Washington, DC.

Benedict, M., T. Pigford and H. Levi, 1981, *Nuclear Chemical Engineering,* McGraw-Hill, New York.

Benham, K., W. Friedman and J. Kelly, 1994, Manager of Health and Safety, Manager of Marine Communications, and Manager of Marine Operations, Port of Seattle, WA, personal communication with R. L. Gotchy and D. Amick, Science Applications International Corporation, June 20.

Benham, K. and G. Schuler, 1993, Marine Operations and Safety Officer, Port of Seattle, WA, personal communication with C. Miller, Science Applications International Corporation, October 18.

Bennett, R. F., 1995, *Twenty-Five Questions (and Answers) About Marine Pilotage in South Carolina,* Charleston Branch Pilots' Association, Charleston, SC, April.

Boyer, M., 1994, Pennsylvania Department of Environmental Resources (PDER), Water Quality Section, personal communication to D. Scott, Science Applications International Corporation, August.

Breslin, S., 1993, Texas Natural Heritage Program, Texas Parks and Wildlife Department, Austin, TX, personal communication to M. Shafer, Science Applications International Corporation, September 15.

[illegible] personal communication with D. Amick, Science [illegible]

Applications International Corporation, November 30.

Brown, M., 1995, U.S. Coast Guard, Mobile, AL, personal communication with L. Danese, Science Applications International Corporation, January 18.

[illegible] Port of Wilmington, DE, personal communication with C. Miller, Science [illegible]

DOC (U.S. Department of Commerce), 1993d, *United States Coast Pilot; Atlantic Coast: Cape Henry to Key West,* Volume 4, 29th ed., National Oceanic and Atmospheric Administration, Washington, DC.

DOC (U.S. Department of Commerce), 1992a, *United States Coast Pilot; Atlantic Coast: Gulf of Mexico, Puerto Rico, and Virgin Islands,* Volume 5, 23rd ed., National Oceanic and Atmospheric Administration, Washington, DC.

DOC (U.S. Department of Commerce), 1992b, *United States Coast Pilot; Pacific Coast: California, Oregon, Washington, and Hawaii,* Volume 7, 27th ed., National Oceanic and Atmospheric Administration, Washington, DC.

1995, *Department of Energy Programmatic Spent Nuclear Fuel Management*

FHI (Frederick R. Harris, Inc.), 1994a, *Yorktown Naval Weapons Station, Yorktown, Virginia; Assessment for Receipt of Foreign Research Reactor Spent Nuclear Fuel,* Final Report, Iselin, NJ, January 17.

FHI (Frederick R. Harris, Inc.), 1994b, *Ports of Virginia Ports Authority; Norfolk Terminal, Portsmouth Terminal, Newport News Terminal, Assessment for Receipt of Foreign Research Reactor Spent Nuclear Fuel,* Iselin, NJ, January 17.

FHI (Frederick R. Harris, Inc.), 1993a, *Port of Charleston, Assessment for Receipt of Foreign Research Reactor Spent Nuclear Fuel,* Iselin, NJ, August 31.

FHI (Frederick R. Harris, Inc.), 1993b, *Kings Bay Naval Submarine Base; Assessment for Receipt of Foreign Research Reactor Spent Nuclear Fuel,* Final Report, Iselin, NJ, November 1.

FHI (Frederick R. Harris, Inc.), 1993c, *Ports of North Carolina Ports Authority; Wilmington and Morehead City Terminals, Assessment for Receipt of Foreign Research Reactor Spent Nuclear Fuel,* Iselin, NJ, November 23.

Fischer, L. E., C. K. Chou, M. A. Gerhard, C. Y. Kimura, R. W. Martin, R. W. Mensing, M. E. Mount and M. C. Witte, 1987, *Shipping Container Response to Severe Highway and Railway Accident Conditions,* NUREG/CR-4829, UCID-20733, Lawrence Livermore National Laboratory, Livermore, CA.

Flint, R. J., H. Mangues, R. Jenner and M. Garelli, 1993, Director of Operations, Director of Public Safety, Assistant Director of Public Safety, and Chief Hazardous Materials Officer, Port Everglades Authority, Port Everglades, FL, personal communications with C. Miller, Science Applications International Corporation, November 22 and November 23.

FL DEP (Florida Department of Environmental Protection), 1994, Chapter 62-302 Surface Water Quality Standards [illegible] Sections 62-302.400, 62-302.600, and 62-302.700, August 8.

[illegible]

FWS (U.S. Fish and Wildlife Service), 1981c, *Long Beach, Pacific Coast Ecological Inventory Map* (Long Beach and Los Angeles, CA).

FWS (U.S. Fish and Wildlife Service), 1981d, *Vancouver, Pacific Coast Ecological Inventory,* 45122-A1-EI-250 (Portland, OR).

FWS (U.S. Fish and Wildlife Service), 1981e, *Sacramento, Pacific Coast Ecological Inventory Map,* 38120-A1-EI-250 (NWS Concord, CA).

FWS (U.S. Fish and Wildlife Service), 1981f, *Santa Rosa, Pacific Coast Ecological Inventory Map,* 38122-A1-EI-250 (NWS Concord, CA).

FWS (U.S. Fish and Wildlife Service), 1981g, *Los Angeles, Pacific Coast Ecological Inventory Map,* 34118-A1-EI-250.

FWS (U.S. Fish and Wildlife Service), 1981h, *Victoria, Pacific Coast Ecological Inventory Map,* 48122-A1-EI-250.

FWS (U.S. Fish and Wildlife Service), 1980a, *Beaufort, Atlantic Coast Ecological Inventory Map,* 34076-A1-EI-250 (Wilmington, NC).

FWS (U.S. Fish and Wildlife Service), 1980b, *James Island, Atlantic Coast Ecological Inventory Map,* 32078-A1-EI-250 (Charleston, SC).

FWS (U.S. Fish and Wildlife Service), 1980c, *Savannah, Atlantic Coast Ecological Inventory Map,* 32080-A1-EI-250 (Savannah, GA).

FWS (U.S. Fish and Wildlife Service), 1980d, *Norfolk, Atlantic Coast Ecological Inventory Map,* 36076-A1-EI-250 (Hampton Roads, VA).

FWS (U.S. Fish and Wildlife Service), 1980e, *Jacksonville, Atlantic Coast Ecological Inventory Map,* 30080-A1-EI-250 (Jacksonville, FL and Fernandina Beach, FL).

FWS (U.S. Fish and Wildlife Service), 1980f, *Wilmington, Atlantic Coast Ecological Inventory Map,* 39074-A1-EI-250 (Wilmington, DE and Philadelphia, PA).

FWS (U.S. Fish and Wildlife Service), 1980g, *Baltimore, Atlantic Coast Ecological Inventory Map,* 39076-A1-EI-250 (Baltimore, MD).

FWS (U.S. Fish and Wildlife Service), n.d.a, *National Wetlands Inventory Map,* Galveston, TX.

Gaines, E., 1994, Oregon National Heritage Program, Letter to D. Scott, Science Applications International Corporation, April 12.

GNS (General Nuclear Systems, Inc.) 1993, *Safety Analysis Report, Vitrified High-Level Waste Type B Shipping Cask,* Columbia, SC, August.

Goldman, L., 1994, Field Supervisor, U.S. Fish and Wildlife Service, Daphne, AL, Letter to D. Scott, Science Applications International Corporation, November 23.

Gordon, K. L., 1994, Mississippi Natural Heritage Program, Mississippi Department of Wildlife, Fisheries and Parks, Letter to D. Scott, Science Applications International Corporation, September 23.

GPA (Georgia Ports Authority), 1994, Port of Savannah Brochure, Savannah, GA.

Gregory, J. J., N. R. Keltner and R. Mata, 1989, "Thermal Measurements in Large Pool Fires," *Heat Transfer,* Volume 111, May.

Gregory, J. J., R. Mata, Jr. and N. R. Keltner, 1987, *Thermal Measurement in a Series of Large Pool Fires,* SAND85-0196, Sandia National Laboratories, Albuquerque, NM, August.

Hachey, J. and R. Korvola, 1994, General Manager of Marine Operations and Manager of Environmental Sciences Division (Engineering Services), Port of Portland, OR, personal communication with R. L. Gotchy, Science Applications International Corporation, June 22.

Hamilton, W., 1976, *Plate Tectonics and Man*, U.S. Geological Survey Annual Report, Fiscal Year 1976.

Hennessy, R., 1993, Environmental Affairs, New Jersey Terminals, Port Authority of New York and New Jersey, personal communication with C. Miller, Science Applications International Corporation, October 15.

Hilliard, H., 1993, Marketing Manager, Port of Long Beach, CA, personal communication with C. Miller, Science Applications International Corporation, October 19.

Horan, J. P., 1993, Director of Operations, Port of Houston, TX Authority (HPA), personal communication with C. Miller, Science Applications International Corporation, November 19.

Horning, D., 1994, Endangered Species Coordinator, U.S. Fish and Wildlife Service, Raleigh, NC, Letter to D. Scott, Science Applications International Corporation, November 4.

Humphreys, S. L., et al., 1994, *Sector Population, Land Fraction, and Economic Estimation Program (SECPOP90)*, SAND93-4032, Sandia National Laboratories, Albuquerque, NM, July, draft.

IAEA (International Atomic Energy Agency), 1990, *Explanatory Material for the IAEA Regulations for the Safe Transport of Radioactive Materials,* Safety Series No. 7, Vienna, Austria.

IAEA (International Atomic Energy Agency), 1961, *Regulation for the Safe Transport of Radioactive Materials,* Notes on Certain Aspects of the Regulations, Safety Series No. 7, Vienna, Austria.

ICRP (International Commission on Radiological Protection), 1991, *1990 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60,* Volume 21, Pergamon Press, New York, NY, November.

IMO (International Maritime Organization), 1992, Analysis of Fire Casualty Records, FP 37/5, Sub-Committee of Fire Protection, 37th Session, Agenda Item 5, February 20.

IPA (Information Please Almanac), 1993, The 1993 Information Please Almanac, Atlas, and Yearbook, 46th edition, Houghton Mifflin Co., Boston, MA.

Jane's (Jane's Information Group, Inc.), 1992, *Jane's Containerization Directory, 1992-93*, P. Hicks, Editor, Alexandria, VA.

Johnson, C., 1995, Supervisor - South Florida Ecosystem Office, U.S. Fish and Wildlife Service, Vero Beach, FL, Letter to D. Scott, Science Applications International Corporation, April 12.

Jow, H. N., J. L. Sprung, J. A. Rollstin, L. T. Ritchie and D. I. Chanin, 1990, *MELCOR Accident Consequences Code System (MACCS), Model Description,* NUREG/CR-4691, SAND86-1562, Sandia National Laboratories, Albuquerque, NM, February.

Keltner, N. R., et al., 1994, "Simulating Fuel Spill Fires Under the Wing of an Aircraft", *4th International Symposium on Fire Safety Science,* Ottawa, Canada, June.

Kobetich, G., 1994, Field Supervisor, U.S. Fish and Wildlife Service, Carlsbad, CA, Letter to D. Scott, Science Applications International Corporation, November 16.

Kurkoski, D., 1994, U.S. Army Corps of Engineers, Portland District, OR, personal communication to D. Scott, Science Applications International Corporation, with Excerpts from Draft Environmental Assessment, Oregon Slough, Oregon, Channel Dredging, Portland, OR.

Laumeyer, P., 1994, Field Supervisor, U.S. Fish and Wildlife Service, Brunswick, GA, Letter to D. Scott, Science Applications International Corporation, November 16.

Leong, J., 1993, Port Publications, Port of Los Angeles, CA, personal communications with C. Miller, Science Applications International Corporation, October 18 and 19.

Lewis, B., 1995, Naval Weapons Station Charleston, Charleston, SC, personal communication with G. DeMoss, Science Applications International Corporation, October 26.

Lloyd's (Lloyd's Maritime Information Services), 1991, *Casualty File Manual,* London, England, November 18.

[illegible] D. Ammerman, 1995, *Extra-Regulatory Impact Tests and Analyses of the Structural Evaluation* [illegible]

Magness, M., 1993, Manager of Marine Market Development, Port of Portland, OR, personal communication with C. Miller, Science Applications International Corporation, October 18.

Mayne, K., 1994, Supervisor - Virginia Field Office, U.S. Fish and Wildlife Service, White Marsh, VA, Letter to D. Scott, Science Applications International Corporation, November 2.

MTMC (Military Traffic Management Command), 1994a, personal communication to R. L. Gotchy, Science Applications International Corporation, August 9.

MTMC (Military Traffic Management Command), 1994b, *Military Traffic Management Command Western Area Commander's Pocket Digest,* FY 1994, 2nd Quarter.

MTMCTEA (Military Traffic Management Command, Transportation Engineering Agency), 1992, *Ports for National Defense; An Analysis of Unit Deployments through U.S. East Coast Ports,* SE 90-3d-21, Newport News, VA, June.

MTMCTEA (Military Traffic Management Command, Transportation Engineering Agency), 1990, *Ports for National Defense; An Analysis of Unit Deployments through U.S. Ports,* SE 89-3d-31, Newport News, VA, October.

Mudan, K. S. and P. A. Croce, 1988, "Fire Hazard Calculations for Large Open Hydrocarbon Fires", *SPFE Handbook of Fire Protection Engineering,* P. J. DiNenno, Editor, National Fire Protection Association, Quincy, MA.

Murray, S., 1994, Florida Natural Areas Inventory, Letter to D. Scott, Science Applications International Corporation, April 27.

NCDEHNR (North Carolina Department of Environment, Health, and Natural Resources), 1992, *Water Quality Progress in North Carolina 1990-1991 305(b) Report,* Report No. 92-06, Division of Environmental Management-Water Quality Section, September.

[illegible] 1994, [illegible] North Carolina Port Brochures including: *1994* [illegible]

NOAA (National Oceanic and Atmospheric Administration), 1992c, *Local Climatological Data: Annual Summary with Comparative Data - Charleston, SC,* National Climatic Data Center, Asheville, NC.

NOAA (National Oceanic and Atmospheric Administration), 1992d, *Local Climatological Data: Annual Summary with Comparative Data - Savannah, GA,* National Climatic Data Center, Asheville, NC.

NOAA (National Oceanic and Atmospheric Administration), 1992e, *Local Climatological Data: Annual Summary with Comparative Data - Jacksonville, FL,* National Climatic Data Center, Asheville, NC.

NOAA (National Oceanic and Atmospheric Administration), 1992f, *Local Climatological Data: Annual Summary with Comparative Data - Portland, OR,* National Climatic Data Center, Asheville, NC.

NOAA (National Oceanic and Atmospheric Administration), 1992g, *Local Climatological Data: Annual Summary with Comparative Data - Seattle, WA,* National Climatic Data Center, Asheville, NC.

NOAA (National Oceanic and Atmospheric Administration), 1992h, *Local Climatological Data: Annual Summary with Comparative Data - Philadelphia, PA,* National Climatic Data Center, Asheville, NC.

NOAA (National Oceanic and Atmospheric Administration), 1992i, *Local Climatological Data: Annual Summary with Comparative Data - Mobile, AL,* National Climatic Data Center, Asheville, NC.

NOAA (National Oceanic and Atmospheric Administration), 1992j, *Local Climatological Data: Annual Summary with Comparative Data - Stockton, CA,* National Climatic Data Center, Asheville, NC.

NOAA (National Oceanic and Atmospheric Administration), 1992k, *Local Climatological Data: Annual Summary with Comparative Data - Wilmington, DE,* National Climatic Data Center, Asheville, NC.

NOAA (National Oceanic and Atmospheric Administration), 1992l, *Local Climatological Data: Annual Summary*

Paulsen, L., 1994, Director of Risk Management, Port of Tacoma, WA, personal communication with R. L. Gotchy, Science Applications International Corporation, June 21.

Paulsen, L., 1993, Director of Risk Management, Port of Tacoma, WA, personal communication with C. Miller, Science Applications International Corporation, October 19.

PEA (Port Everglades Authority), 1993, Guide to Port Everglades, Hollywood/Ft. Lauderdale/Dania, 1992-1993, Alson Marketing, Inc., Fort Lauderdale, FL; and Port Report, Spring/Summer 1993, PEA, Fort Lauderdale, FL.

Perry, E. W., 1994, U.S. Fish and Wildlife Service, State College, PA, Letter to D. Scott, Science Applications International Corporation, November 2.

Petersen, M., 1982, "Dynamics of Ship Collisions," *Ocean Engineering,* Volume 9, No. 4.

PNDI (Pennsylvania Natural Diversity Inventory Information System), 1994, Pennsylvania Department of Environmental Resources, Bureau of Forestry, Harrisburg, PA, personal communication to D. Scott, Science

POT (Port of Tacoma), 1994, Various Port Brochures including: *1993 Annual Report*; *Facilities and Services (15M/11-92)*; *Facilities & Services Summary (15M/9-91)*; *Truck on In*; *Pacific Gateway* (winter 1994); Port of Tacoma, WA.

POW (Port of Wilmington), 1994, The Port of Personal Services brochure, Port of Wilmington Profile, and *Port Illustrated* (various issues), Port of Wilmington, DE.

Powell, W. D., G. Knatz, W. Wilson and T. Johnson, 1994, Chief Wharfinger, Director of Planning, Director of Security, and Environmental Specialist, Port of Long Beach, CA, personal communication with R. L. Gotchy, Science Applications International Corporation, June 23.

Powers, D. A., L. N. Kmetyk and R. C. Schmidt, 1994, *A Review of the Technical Issues of Air Ingression During Severe Reactor Accidents,* NUREG/CR-6218, SAND94-0731, Sandia National Laboratories, September.

PT (Penn Terminals), 1994, Penn Terminals Inc. Brochure, Eddystone, PA, undated.

Reaves, R., 1994, Mississippi Department of Environmental Protection, personal communication with D. Scott, Science Applications International Corporation, August 29.

Richards, T., 1994, U.S. Fish and Wildlife Service, personal communication with D. Scott, Science Applications International Corporation, November 17.

Rohas, V., 1994, Director, Port Administration, Port of Fernandina, FL, Letter to D. Amick, Science Applications

Sanders, T. L., K. D. Seager, Y. R. Rashid, P. R. Barnett, A. P. Malinauskas, R. E. Einziger, H. Jordan, T. A. Duffey, S. H. Sutherland and P. C. Reardon, 1992, *A Method for Determining the Spent-Fuel Contribution to Transport Cask Containment Requirements,* SAND90-2406, Sandia National Laboratories, Albuquerque, NM, November.

Schmitt, D. N., 1993, *Savannah and Ogeechee River Creek Surveys,* Georgia Department of Natural Resources, Game and Fish Division, Richmond Hill, GA.

Schneider, M. E., N. R. Keltner and L. A. Kent, 1989, *Thermal Measurements in the Nuclear Winter Fire Test,* SAND88-2839, UC-722, Sandia National Laboratories, Albuquerque, NM, November.

Schultz, R. C., 1993, Director of Operations, Port of Galveston, TX, personal communication with C. Miller, Science Applications International Corporation, November 19.

Scott, J., 1994, Executive Director, Port of Wilmington, NC, personal communication with D. Amick, Science Applications International Corporation, August 9.

Shaffer, C. S., 1994, Shipping Cask Transportation Accident MELCOR Calculations, Seminar Presentation, Science

Sprung, J. L., J. A. Rollstin, J. C. Helton and H. N. Jow, 1990, *Evaluation of Severe Accident Risks: Quantification of Major Input Parameters, MACCS Input,* Volume 2, Rev. 1, Part 7, NUREG/CR-4551, SAND86-1309, Sandia National Laboratories, Albuquerque, NM, December.

SRI (SRI International), 1978, *Cost-Effectiveness of Marine Fire Protection Programs,* Prepared for the U.S. Department of Commerce, Maritime Administration, and the National Bureau of Standards, November.

Stark, T. B., 1995, Captain U.S.N., Commander of Naval Weapons Station at Charleston, SC, personal communication with K. Chacey, Department of Energy, Office of Spent Nuclear Fuel Management, Washington, DC, September 18.

State of California, 1986, *Basin Plan,* California Regional Water Quality Control Board, Oakland, CA.

Stubbs, W., 1994, President, Nassau County Ocean Highway and Port Authority, Port of Fernandina, FL, personal communication with C. Miller, Science Applications International Corporation, August 30.

TPWD (Texas Parks and Wildlife Department), 1989a, *Trends in Texas Commercial Fishery Landings, 1977-1988,* Fisheries Division, Management Data Series No. 7, Austin, TX.

TPWD (Texas Parks and Wildlife Department), 1989b, *Trends in Finfish Landings by Sport-boat Fishermen in Texas Marine Waters, May 1974-1988,* Fisheries Division, Management Data Series No. 8, Austin, TX.

UBC (Uniform Building Code), 1991, *International Conference of Building Officials,* Whittier, CA.

U.S. Army (U.S. Army Corps of Engineers), 1994, San Francisco District, *Final Supplemental Environmental Impact Report/Environmental Impact Statement Oakland Harbor Deep-Draft Navigation Improvements,* June.

U.S. Army (U.S. Army Corps of Engineers), 1993, *Environmental Assessment and Finding of No Significant Impact, Wilmington Harbor Ocean Bar Channel Deepening, Wilmington, North Carolina,* Wilmington District, June.

U.S. Army (U.S. Army Corps of Engineers), 1991, *Environmental Impact Study, Savannah Harbor, Georgia Comprehensive Study,* Savannah District, July.

U.S. Army (U.S. Army Corps of Engineers), 1990, *Draft Environmental Impact Statement/Environmental Impact Report Phase I 2020 Plan and Feasibility Study (Channel Improvements and Landfill Development),* Los Angeles District, and Long Beach and Los Angeles Harbor Departments, September.

USCG (U.S. Coast Guard), 1994a, Office of Marine Safety, Security and Environmental Protection, Washington, DC, personal communication to D. Amick, Science Applications International Corporation, November 3.

USCG (U.S. Coast Guard), 1994b, Shipping Accident Survey Data, U.S. Coast Guard Offices (Marine Safety Division, Washington, DC; Marine Safety Office, Portland, OR; Marine Safety Office, San Francisco, CA; Marine Safety Office, Long Beach/Los Angeles, CA), personal communication to D. Amick, Science Applications International Corporation, August.

U.S. District Court, 1991, Sierra Club v. Energy Department, 808 F.Supp. 852, 34 ERC 2057, District of Columbia, December 9.

USMMA (U.S. Merchant Marine Academy), 1994, *Report on the Workshop on Port Selection Criteria for Shipments of Foreign Research Reactor Spent Nuclear Fuel, Kings Point, NY* (November 15-16, 1993), Sandia National Laboratories, Albuquerque, NM.

Verhoef, R. W., E. Paz, T. L. Garrett and J. Leong, 1994, Chief Wharfinger, Hazardous Materials Investigator, Environmental Scientist, and Public Relations Specialist, Interviews with R. L. Gotchy, and D. Amick, Science Applications International Corporation, June 23.

VPA (Virginia Port Authority), 1994, Various Port Brochures including: *Promises, Results, The Ports of Virginia; The Ports of Virginia - One Stop, America and the World; Virginia Maritimer* (July/August 1994); and other related information; VPA, Norfolk, VA.

Warwick, J. E. and A. L. Anderson, 1976, *The Nature of Ship Collisions Within Ports,* Todd Shipyard Corp., Galveston, TX (prepared for the U.S. Maritime Administration), April.

Wayland, R. J. and S. Raman, 1989, "Mean and Turbulent Structure of a Baroclinic Marine Boundary Layer During the 28 January 1986 Cold Air Outbreak (GALE 86)", *Boundary-Layer Meteorology,* Volume 48, No. 3, August.

WDW [Washington (State) Department of Wildlife], 1994a, *Priority Habitats and Species Map, Seattle South,* No. 4712253, April 13.

WDW [Washington (State) Department of Wildlife], 1994b, *Priority Habitats and Species Map, Tacoma North,* No. 4712234, April 13.

Werner, F. T., 1994, U.S. Fish and Wildlife Service, Division of Ecological Services, Houston, TX, Letter to D. Scott, Science Applications International Corporation, November 2.

West, T., 1994, Virginia Department of Environmental Quality, Virginia Beach, VA, Letter (with water quality data) to D. Scott, Science Applications International Corporation, April 15.

Wilmot, E. L., 1981, *Transportation Accident Scenarios for Commercial Spent Fuel,* SAND80-2124, Sandia National Laboratories, Albuquerque, NM, February.

Wilmot, E. L., J. D. McClure and R. E. Luna, 1981, *Report on a Workshop on Transportation Accident Scenarios involving Spent Fuel,* SAND80-2012, TTC-0151, Transportation Analysis and Information Division, Sandia National Laboratories, Albuquerque, NM, February.

Wilson, J. L., 1995, Assistant to the Executive Director, North Carolina State Ports Authority, Port of Wilmington, NC, personal communications with R. L. Gotchy, Science Applications International Corporation, September 6 and 7.

Wilson, J. L., 1993, Assistant to the Executive Director, North Carolina State Ports Authority, Port of Wilmington, NC, personal communication with C. Miller, Science Applications International Corporation, October 14.

Wolflin, J., 1994, Supervisor, Chesapeake Bay Field Office, U.S. Fish and Wildlife Service, Annapolis, MD, Letter to D. Scott, Science Applications International Corporation, November 7.

World Almanac, 1992, *World Almanac and Book of Facts,* Pharos Books, New York, NY, p. 940.

Yocum, K., 1994a, Development Manager, Concord NWS, CA, personal communication with R. L. Gotchy, Science Applications International Corporation, August 15 and 16.

Yocum, K., 1994b, Strategic Planning Officer, Concord NWS, CA, personal communication to R. L. Gotchy, Science Applications International Corporation, September 1.

Attachment D1
Capital Improvement Plans and Other Significant Port Developments

[illegible]

Port	*Improvements and Other Significant Developments*
Baltimore, MD	The Board of Public Works approved the purchase of a new $7.4 million container crane to be installed at the Dundalk Marine Terminal, a 231 ha (570 acre) terminal complex with 13 deepwater berths and 9 container cranes. The new crane is expected to be operational by early 1995 (Governors Press Office, State of Maryland, May 18, 1994). Governor William Schaefer announced Board of Public Works approval of a contract to modernize and improve (up-grade to post-Panamax capacity) three container cranes located at the Dundalk Marine Terminal (Ibid, June 22, 1994).
Boston, MA	Officials of the Massachusetts Port Authority (Massport) have submitted a draft environmental impact report to Federal and State officials that calls for dredging the harbor and access channels to 12.2 m (40 ft) from 9.75-10.97 m (32-36 ft) (*American Shipper*, "Boston Seeks Direct Calls From Asia," October 1994, Pg. 94). Ralph Cox, Marine Director, and other port officials claim that the deeper water is critical to the Port's viability. Massport is also seeking support of the State Legislature for road and rail clearances to permit double-stack train service to the City of Boston and its marine terminals. A $50 million expansion and modernization of Boston's Conley Terminal is approximately 80 percent complete. When completed, Conley Terminal will have 40.5 ha (100 acres) of container storage and handling area, 4 post-Panamax container cranes, 304.8 m (1,000 ft) of berth, and a new gate complex. Reportedly, container tonnage is up for 1994 over 1993 tonnage when Boston handled 152,240 twenty-foot equivalent units for the year.

Concord NWS, CA Currently authorized improvements expected to be completed by 1997 include

The Port Authority anticipated breaking ground in 1994 for a new 203 ha (500 acre) container and general cargo terminal complex at Dames Point, immediately adjacent and upstream of its existing Blount Island terminal. The new facility is expected to cost $160 million when completed in the future. Other improvements scheduled include a $2.5 million investment in increased intermodal rail capacity at Blount Island and Talleyrand Terminals, and widening of Hecksher Drive to four lanes from the entrance to Blount Island to State Road 9A, which connects with I-95. I-295 is also being widened to four lanes (American Shipper - Southern Ports, January 1994).

Long Beach, CA

The Long Beach Port Commission and City Council have approved a 1994-95 budget of $417 million, which includes $236.5 million for port construction, land acquisition, and environmental mitigation. Last year's budget included $405 million to purchase land owned by Union Pacific Resources Company in the north harbor, which the Port plans to convert to a marine cargo terminal. The property is comprised of 117 ha (289 acres) north of the Cerritos Channel, 143 ha (354 acres) south of the Channel, and 33 ha (82 acres) within the Channel. The new budget provides allocations of $60 million for street

overpasses to cross rail lines in the port area, $22 million for other street and road improvements, $78 million for continuing container terminal improvements at Pier J, $25 million for other construction projects, and $40 million for land acquisitions and environmental mitigation. These land acquisitions will increase the Port's operating area by 35 percent (American Shipper, September 1994, p. 94; "Long Beach to Spend $417 million").

Los Angeles, CA

Los Angeles' "2020 Program" represents the Port's comprehensive long-term development plan, which is designed to accommodate a doubling of cargo throughput through the next decade and a forecast California population of 20 million people. The major components of the 2020 Program include:

a. Construction of Pier 300 on landfill completed in 1983. When completed, Pier 300 will include the American President Lines container terminal, an intermodal container/rail/truck transfer facility and a coal export terminal;

b. Landfill and construction of Pier 400, with three container terminals, an intermodal container transfer facility, and liquid bulk terminals;

c. The Alameda Corridor, a road and rail improvement program linking the Port to rail facilities in downtown Los Angeles with a full

(47 acre) intermodal rail yard that will also serve the coal export yard being constructed next to the facility. The American President Lines complex will be equipped with six to eight new-generation container cranes. The Port has also embarked on a mammoth $148.6 million dredging project that will create 4.8 km (3 mi) of new channels 13.6 m to 19.1 m (45-63 ft) deep, providing access to Pier 300, a turning basin, and 1,520 m (5,000 ft) of berthing space south of Pier 300. Dredge spoil will be used to create about 91 ha (225 acres) of new land to be called Pier 400, which will be located south (seaward) of the new American President Lines Terminal. Plans for Pier 400, call for the construction of three container terminals on the north side of the terminal, each with two berths and five container gantry cranes, and a large bulk

improvements. The Tchoupitoulas Corridor Project will provide a new, high-speed dedicated roadway from the port through the city (Annual Directory, Port of New Orleans, 1993-1994; Board of Commissioners of the Port of New Orleans, "Mississippi River Terminal Complex," 1993).

Newport News, VA	No immediate improvements identified.
Norfolk, VA	In 1991, the Virginia Ports Authority began a $40 million expansion of the Norfolk International Terminal that will double the size and cargo handling capacity of the terminal. When completed in 2004, improvements include adding 1,300 m (4,300 ft) of new berthing space and 120 ha (300 acres) of backup cargo handling area, creating a massive (819 acre) intermodal terminal with 27,000 m (89,000 ft) of onsite rail, connecting the terminal with Norfolk Southern's bullet train and providing double stack service to major U.S. markets (Virginia Port Authority, "Promises, Results," 1993; Financial World, "The Ports of Virginia: Destiny Controlled," p. 63, New York, NY, July 20, 1993).
Oakland, CA	The $50 million reconstruction of Oakland's 22.7 ha (56 acre) Seventh Street Terminal is nearing completion. Severely damaged in the 1989 Loma Prieta earthquake, three new post-Panamax cranes have been added and the entire wharf structure and upland areas have been rebuilt. The final phase of the redevelopment program is a $5 million gate relocation and construction project providing six entry and four exit lanes. Truck queues outside the terminal will be avoided by the addition of 46 inbound and 44 outbound queue spaces plus six "trouble" lanes for trucker paperwork problems within the gate area. The gate complex will use computer and video technology to speed container movements through the Port (American Shipper, August 1994, "Rebirth for Oakland Terminal," p. 77).
Philadelphia, PA	A new bi-state agency, *The Port of Philadelphia and Camden, Inc.*, has been created to assume responsibility for regional port operations previously directed by the Philadelphia Regional Port Authority (ports of Philadelphia), the South Jersey Port Corporation (terminals in Camden), and the World Trade Division of the Delaware River Port Authority—a regional economic development agency. The new agency will begin operation in 1995 (WWS/World Wide Shipping, June 1994, p. 35).
Port Everglades, FL	Completion of the Port Everglades Authority's new $100 million, 62.7 ha (155-acre) container complex at Southport, and the development of 6.7 ha (15 acres) of expanded container storage area at Midport, both scheduled for 1994, culminates years of planning and construction by Port Everglades. Southport is equipped with three 39.2 metric ton (43 ton) low-profile, post-Panamax container cranes designed to avoid interference with nearby airport operations. Design planning studies are underway for lift-on/lift-off support facilities at the new 26 ha (63 acre) lift-on/lift-off container yard located immediately adjacent to Southport's cranes. These include a container freight station, electrical outlets for reefer containers, gatehouse with scales, inspection shed, automated facilities, and a feasibility study for developing an intermodal container transfer facility nearer to the Southport complex. The

Fiscal 1993-94 budget provides $9.6 million for a tenth cruise line terminal and enhancements to the two facilities described above (FS, 1992; Southern Ports, January 1994, Pg. 33).

Port of New York, NY

The Port Authority of New York/New Jersey's 1993 capital spending budget totaled $57 million, largely for terminal improvements such as wharf rehabilitation, berth deepening, paving, etc.

Port of Elizabeth, NJ

Funds were also included for deepening Federal channels in the Kill Van Kull and into Newark Bay to the Elizabeth Marine Terminal. The total project, scheduled for completion in 1995, will provide a 12.2 m (40 ft) channel from Upper New York Bay through the Kill Van Kull into Newark Bay. The lack of adequate channel depths has resulted in the diversion of ships to other ports. Three and a half years of wrangling over permits for maintenance dredging connects with Conrail. CSX owns the Staten Island line, but was granted approval in 1991 to abandon the route, so a new owner is needed to reactivate the rail line. City officials and the prospective operator of the Howland Hook facility predicted that the future of this terminal as a viable facility may hinge on the acquisition of the trackage and the installation of on-dock rail service (American Shipper, August 1994, p. 84).

Portland, OR

The Port Commission has approved a $60 million container terminal upgrade program for Terminal 6 to increase throughput capacity to 510,000 twenty-foot equivalent units over the next 10 years, nearly double its present capacity. The Terminal currently handles 314,500 twenty-foot equivalent units a year. Improvement plans include a new $16 million post-Panamax size container crane scheduled to come on stream by late 1995. The Port Commission has also hired an engineering consulting firm to recommend a development strategy and 20-year development program for a new marine terminal complex on West Hayden Island (*American Shipper*, October 1994, "Port of Portland Builds for the Future")

In July, the Port Of Portland Commission contracted with IBM and Stevedoring Services of America to provide the hardware and software for a new $1.0 million computerized terminal management system for its Terminal 6 container facility. The Port presently handles 600 trucks a day with a cargo inventory system developed in 1980. Portland is the fastest growing port on the West Coast (Containerization International, September 1994, "Portland Buys SSA System").

Portsmouth, VA

No immediate improvements identified.

San Francisco, CA

San Francisco's future as a leading West Coast container port is in jeopardy following the decision of Evergreen line to leave the port when its lease third year of Savannah's $319 million development program called *Focus 222*, which is designed to provide the facilities and infrastructure needed to maintain growth into the year 2000. Remaining elements of the Program include steps to help restore the freshwater habitat in the Savannah National Wildlife Refuge, completion of upgrading the 1,680 m (5,500 ft) of contiguous berth at Garden City's Container Berth 6, the addition of 12 ha (30 acres) of container storage and delivery of four new post-Panamax container cranes, two of which were scheduled to arrive late in 1994, and upgrading of existing container cranes, making a total of 13 container cranes at the Garden City port complex (WWS/World Wide Shipping, May 1994, p. 27).

Seattle, WA

The ports of Seattle and Tacoma use the findings of a 1990 econometric study sponsored by the Washington Public Ports Association as an integral part of their planning strategies. In the case of Seattle, this means being capable of handling 2.1-2.5 million twenty-foot equivalent units annually, 15 years hence. The port's Container Terminal Development Plan, adopted by the Seattle Port Commission in May 1991, called for another 97 ha (240 acres) of land to be

Tacoma, WA

Tacoma's 20-year, $450 million 2010 Blair Waterway terminal expansion program is equally ambitious, but its implementation will be geared to customer demand. Major elements of the 2010 Blair Waterway program, which is designed to enable the waterway to handle the largest containerships afloat include:

a. The addition of approximately 125 ha (309 acres) of new container terminal area, 11 berths, and 30 ha (75 acres) of new intermodal rail facilities at the Port;

b. Dredging of the main access channel to a depth of 13.7 m (45 ft), and construction of a new city bypass road with subsequent dismantling of the Blair Road Bridge. The bridge is slated to be removed by the end of 1995 and the entire West Blair terminal project is to be completed by the end of 1996;

Additional planned port improvements include the construction of two new container terminals on the north side of the Blair waterway and the new terminals have two berths and 20.2 ha (50 acres) of land. The second new terminal will be built at the existing Terminal 7 and will consist of a one-berth 20.2 ha (50 acre) facility. Spoil from dredging work is being used to fill in the Milwaukee Channel and increase the Sea Land terminal by 9.7 ha (24 acres). According to the econometric study cited above, Tacoma will need to be able to handle between 2.5 and 2.8 million twenty-foot equivalent units in the year 2010 (Containerization International, July 1994, pages 87-90).

Wilmington, DE

No immediate improvements identified.

Wilmington, NC

Long term development plans by the North Carolina State Ports Authority include studies for the deepening of the outer bar channel to 14 m (46 ft), the river and harbor channel to 13.4 m (44 ft), and development of a new marine terminal upstream of the existing port complex. Dredging was expected to begin in early summer 1994 and site development work for the new terminal is slated for fiscal year 1996 provided funding is available. Similar planning for

Attachment D2
Port Population Growth Factors (1990 - 2010)

U.S. Ports	Counties	1990	2010	Growth Factor
East Coast				
Boston, Massachusetts	Suffolk Norfolk	663,906 616,087 1,279,993	792,200 631,300 1,423,500	1.11
Elizabeth, New Jersey	Essex Kings, NY Hudson Richmond, NY Union	778,206 2,369,966 553,099 385,224 493,819 4,580,314	757,200 2,364,992 566,600 463,529 502,300 4,654,621	1.02
Philadelphia, Pennsylvania	Philadelphia Camden Gloucester	1,585,577 502,824 230,082 2,318,483	1,513,674 550,500 269,300 2,333,474	1.01
Eddystone, Pennsylvania	Delaware Philadelphia	547,651 1,585,577 2,133,228	508,557 1,434,694 1,943,251	0.91
Wilmington, Delaware	New Castle	441,946 441,946	513,750 513,750	1.16
Baltimore, Maryland	Baltimore Anne Arundel Howard	692,134 427,239 187,328 1,306,701	728,898 499,204 288,701 1,516,803	1.16
Newport News, Virginia	Isle of Wight Norfolk City Hampton City York	25,053 261,229 133,793 42,422 462,497	34,283 253,809 146,648 56,000 490,740	1.06
Norfolk, Virginia	Isle of Wight Norfolk City Portsmouth City Hampton City York	25,053 261,229 103,907 133,793 42,422 566,404	34,283 253,809 101,965 146,648 56,000 592,705	1.05
Portsmouth, Virginia	Isle of Wight Portsmouth City Norfolk City	25,053 103,907 261,229 390,189	34,283 101,965 253,809 390,057	1.00
Wilmington, North Carolina	New Hanover Brunswick	120,284 50,985 171,269	150,936 79,644 230,580	1.35
Charleston, South Carolina	Charleston Berkeley	295,039 128,776 423,815	339,400 252,800 592,200	1.40
Savannah, Georgia	Chatham Byran	216,935 15,438 232,373	273,391 23,610 297,001	1.28

U.S. Ports	Counties	1990	2010	Growth Factor
Fernandina Beach, Florida	Nassau	43,941 43,941	79,800 79,800	1.82
Jacksonville, Florida	Nassau Duval	43,941 672,971 716,912	79,800 1,014,100 1,093,900	1.53
Port Everglades, Florida	Broward	1,255,488 1,255,488	1,980,900 1,980,900	1.58
Miami, Florida	Dade	1,937,094 1,937,094	2,809,700 2,809,700	1.45
		Gulf Coast		
Mobile, Alabama	Mobile Baldwin	378,643 98,280 476,923	408,600 110,300 518,900	1.09
[illegible]	Harrison	165,365	175,291	1.06

Alabama	Alabama Population Projections 1990-2015, Alabama State Data Center Center for Business and Economic Research, University of Alabama, Tuscaloosa, AL, January 1994.
California	Population Projections by Race/Ethnicity for California and its Counties, Report 93 P-1, Demographic Research Unit, Sacramento, CA, (916) 322-4651, April 1993.
Delaware	Census info and projection numbers through Evelyn Pearson, Delaware Development Office, Business Research Section, Dover, DE, Consortium Series, (302) 739-4271, June 30, 1994.
Florida	Projected from Florida Population Studies (by county) by Stanley K. Smith, Director, Bureau of Economic and Business Research, University of Florida, [illegible] Number 2/Bulletin No. 108, February, 1994.

Virginia	Projection given by Jeanne Brown, Center for Public Service University of Virginia, Charlottesville, VA, (804) 982-5580, September 28, 1994.
Washington	Census info and projections from Washington State County Population Projections, Office of Financial Management, Forecasting Division, Olympia, WA, January 31, 1992.

Attachment D3

Background Discussion of Alternative Analytical Models for Evaluation of Potentially Impacted Port Populations

In the Fall of 1993, the Department of Energy (DOE) began to collect and analyze information required for [illegible] Notice of Intent (DOE, 1993) for this environmental impact

DOE determined that a semi-quantitative analysis of all ports for all of the noticed criteria was unacceptably subjective, especially concerning the assignment and weighting of the numerical scores. Furthermore, it did not differentiate well between ports, and when weighting factors were applied to better discriminate between criteria that were very important to safety versus those that were "desirable attributes," the methodology became very difficult to justify.

Attachment D4
Derivation of Ship Collision Damage Probabilities

Derivation of the accident severity category probabilities requires that a probability of damage to the transportation cask, given a collision between two vessels, be calculated. In Appendix D, this probability has been characterized by two values, P_{Impact} and P_{Crush}. The first is a probability that the cask is

Parameters and Assumptions

The target ship in the following calculations is assumed to have a beam of 24.99 m (82 ft) and a displacement, 'm', of 25,310 metric tons (27,841 tons). The virtual mass, 'dm', due to hydrodynamic forces is 0.4 m = 10,120 metric tons (11,132 tons). Eight cases are considered for the displacement, 'm', of the striking ship: 5,600; 16,800; 28,000; 39,200; 50,400; 61,600; 72,800; and 84,000 metric tons (6,160; 18,480; 30,800; 43,120; 55,440; 67,760; 80,080; and 92,400 tons. The normal component of the striking speed at impact ranges from 1 to 10 meters per second (1.9 to 19 knots or 2.2 to 22 statute miles per hour).

A full distribution of sailing speeds (0-22 knots) was used in the penetration calculations even though speeds in port channels are likely to be no greater than 10-15 knots and speeds at dockside only a few knots (minimum required to maintain steerage). In addition, large ships (e.g., tankers) are likely to be pushed/towed by tugs near docks.

The models for energy absorption by the ship and its cargo follow the methods of ORI. The work, 'W', due to cargo compression is the product of the crush strength of the cargo, the cross sectional area of the blunted bow of the striking ship, and the difference between the penetration distance and the cargo closeup distance. ORI gave examples of this calculation, which are reproduced in the formula

$$W_{cargo} = 19.44 f \sigma (x - f(beam))$$

where f is the fraction of open space on the hold floor, σ is the crush strength of the cargo in MPa (mega pascals), 'x' is the penetration depth and beam is the width of the struck ship, both in meters. This formula follows ORI in assuming the vertical size of the damage zone is 7.62 m (25 ft), and one third of the blunted bow is the effective area.

Prior to the initiation of cargo compression, energy is absorbed solely by deformation of the ship structure; this effect is modeled using the Minorsky value of 32 'mj' (mega joules) for the energy to penetrate the hull, together with the semi-empirical curves in Figure 6.2 of the ORI report. Table D4-1 gives coefficients for a quadratic fit used to represent the ORI curves below 15 m (49.2 ft) penetration, while a second fit for greater penetration distances is given in Table D4-2.

Table D4-1 Quadratic Coefficients for Energy Absorbed Due to Ship Structures <15m

$$W_{ship} = a + bx + cx^2 \quad (x < 15m)$$

Metric ton	*a (mj)*	*b (mj/m)*	*c (mj/m²)*
5,600	9.551	0.6836	0.0405
16,800	8.709	0.8118	0.2984
28,000	8.056	1.2030	0.4558
39,200	8.121	1.0850	0.5296
50,400	9.234	0.6555	0.6217
61,600	8.956	0.8639	0.6698
72,800	8.574	1.1790	0.6906
84,000	8.204	1.5290	0.7154

Table D4-2 Quadratic Coefficients for Energy Absorbed due to Ship Structures >15m

$$W_{ship} = a + bx + cx^2 \quad (x > 15m)$$

Metric ton	*a (mj)*	*b (mj/m)*	*c (mj/m²)*
5,600	58.13	-4.837	0.1919
16,800	14.72	-0.057	0.3337
28,000	15.76	-0.304	0.5179
39,200	64.87	-5.622	0.7306
50,400	189.5	-19.21	1.162
61,600	264.4	-29.02	1.531
72,800	303.8	-36.36	1.878
84,000	412.2	-50.50	2.393

Distribution of Ship Displacements, Speeds and Angles

Analysis of two years of shipping accident data allowed ORI to develop probability distributions for 'M' (mass of the striking ship), 'V' (transverse speed of the striking ship), and θ (angle of incidence), which are presented here in Table D4-3 through D4-5. The ORI tables originally contained eleven intervals for displacement of the striking ship. Four cargo loadings were examined in the analysis: no cargo, light cargo, medium cargo, and heavy cargo (light, medium, and heavy refer to the amount of cargo on board). For the present work, the two lowest intervals were combined as were the three highest, yielding eight [illegible] ORI ranges for 'W'. There were also 11 values of 'V' in the ORI tables, with

Table D4-5 Probabilities of Striking Ship Angles of Incidence

Angle From the Normal (degrees)	Probability of Occurrence
0 - 10	0.2754
10 - 20	0.1305
20 - 30	0.0725
30 - 40	0.1305
40 - 50	0.1015
50 - 60	0.0724
60 - 70	0.1303
70 - 80	0.0435
80 - 90	0.0434

Speed During a Collision

In the following, 'M' and 'V' are the mass and transverse speed of the striking ship, while 'm' and 'v' denote the mass and transverse speed of the struck ship. Theta (θ) is the angle of impact, measured from the normal to the direction of the struck ship (this is the angle used by ORI, Minorsky and Petersen use its complement). The amount of virtual mass attributed to the struck ship to account for transverse hydrodynamic forces is 'dm'. W(x) denotes the work done in deforming the ships and compressing the cargo during a penetration to a depth 'x', and E_0 is the initial kinetic energy in the motion of the striking ship transverse to the struck ship.

The total energy in the transverse motion of the striking ship is:

$$E = MV^2 \cos^2(\theta)/2$$

Because energy is conserved during the collision, and neglecting turning effects,

$$E = \frac{MV^2}{2} + \frac{(m+dm)\,v^2}{2} + W(x)$$

Because momentum is conserved,

$$MV\cos(\theta) = MV + (m+dm)\,v$$

Together these equations yield a quadratic expression of the velocity of the struck ship:

$$\frac{Av^2}{2} - V\cos(\theta)\,v + \frac{W(x)}{m+dm} = 0$$

where A = (1+(m+dm)/M).

The value of the struck ship's transverse speed during the collision is, therefore,

$$v = \frac{V\cos(\theta)}{A} - \frac{1}{A}\sqrt{V^2\cos^2(\theta) - \frac{2AW(x)}{m+dm}}$$

The second term in this equation decreases to zero during the collision, yielding a terminal speed of $V\cos(\theta)/A$. This is also the terminal speed component of the striking ship in the same direction. The [illegible] is (1-1/A)E = (m+dm)/(M+m+dm)E, in agreement with Minorsky where $\mu = M(m+dm)/(M+m+dm)$, and $V_{\cos(\theta)}$ is the initial normal speed of the striking ship. For the no cargo case, it was found that for each of the striking ship displacements considered, initial normal speeds of 8 meters per second (15.2 knots or 17.6 statute miles per hour) and 10 meters per second (19.0 knots or 22.0 statute miles per hour) were sufficient to cut completely through the struck ship, resulting in a probable sinking; refer to Figure D4-1. On the other hand, at 2 meters per second (3.8 knots or 4.4 statute miles per hour) only the four heavier ships would even penetrate the hull of the struck ship, and at or below 1 meters per second (1.9 knots or 2.2 statute miles per hour) the hull was not punctured for striking ships of any displacement.

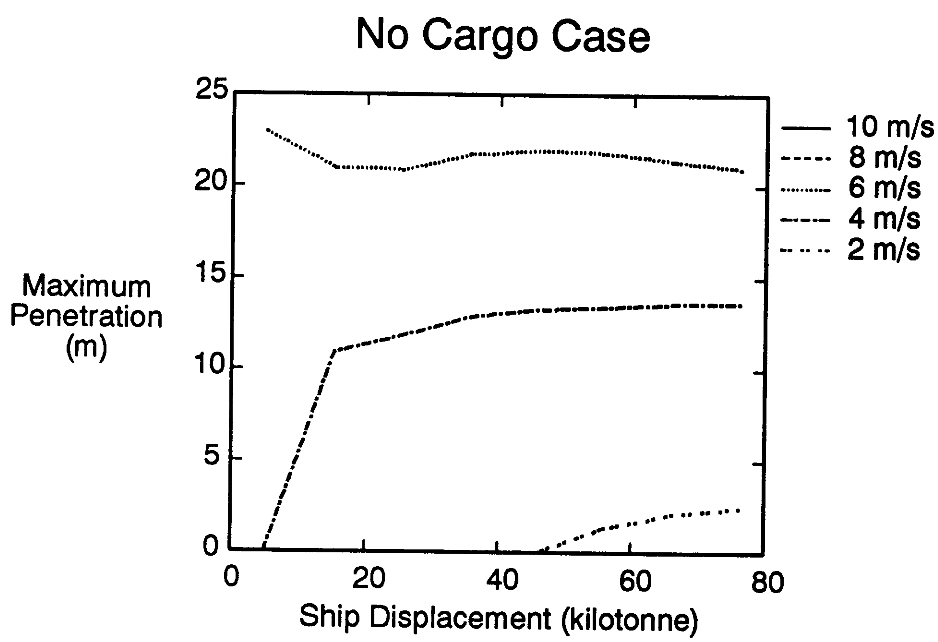


Figure D4-1 Maximum Penetration Distance in the No Cargo Case

Figure D4-2 shows the corresponding information for the light cargo case. Because of the packing fraction for this case, 0.6, the cargo effect does not begin until penetration has reached 15 m (49.2 ft). The figure shows the results as a function of the displacement of the striking ship, for normal impact speeds from 2 meters per second (3.8 knots or 4.4 statute miles per hour) to 10 meters per second (19.0 knots or 22.0 statute miles per hour). There were no cases where the struck ship would be completely cut through. At the two lower speeds, the cargo did not close up, hence was not a factor in absorbing the

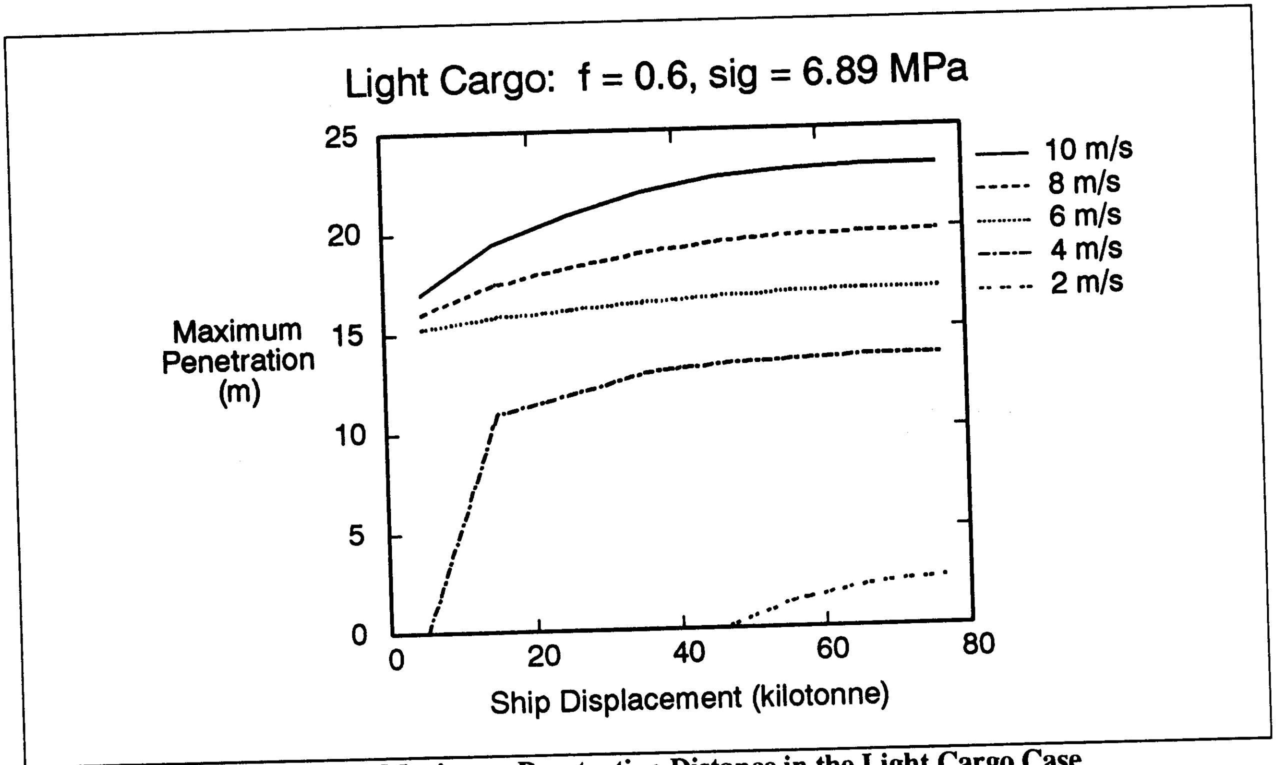


Figure D4-2 Maximum Penetration Distance in the Light Cargo Case

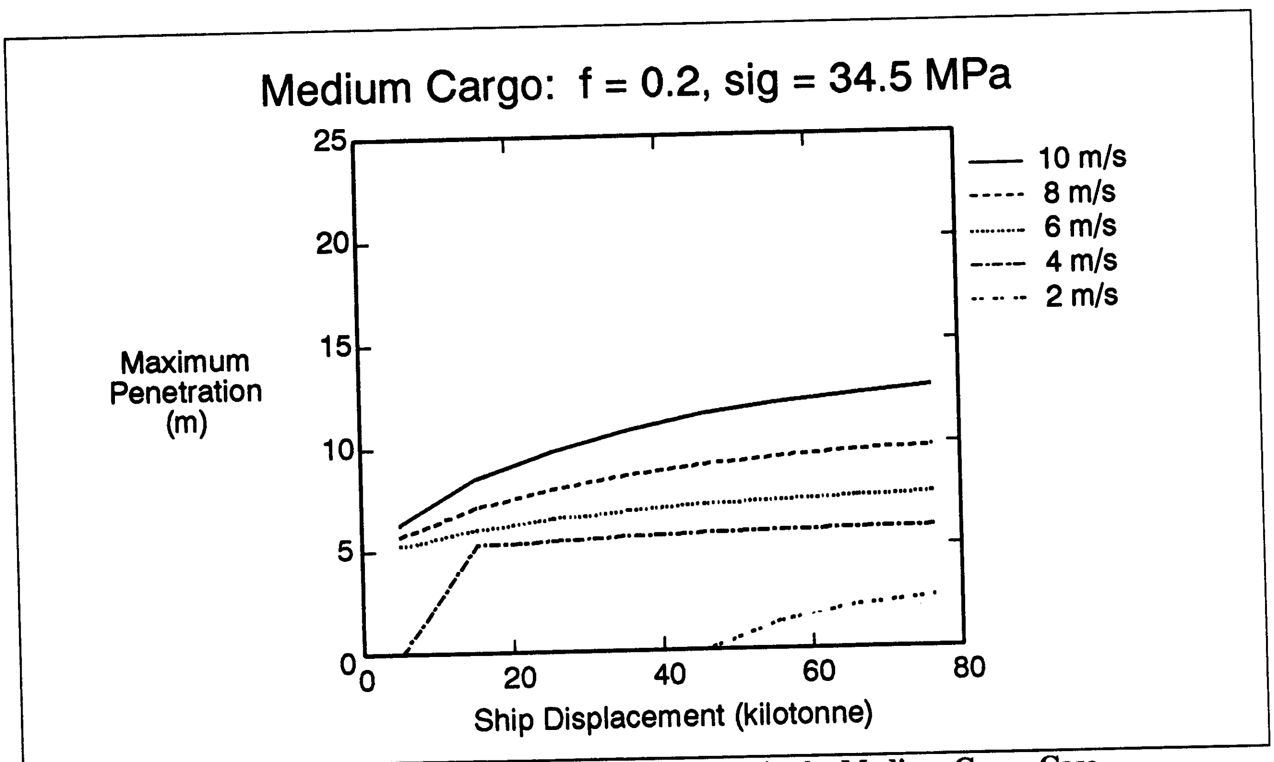


Figure D4-3 Maximum Penetration Distance in the Medium Cargo Case

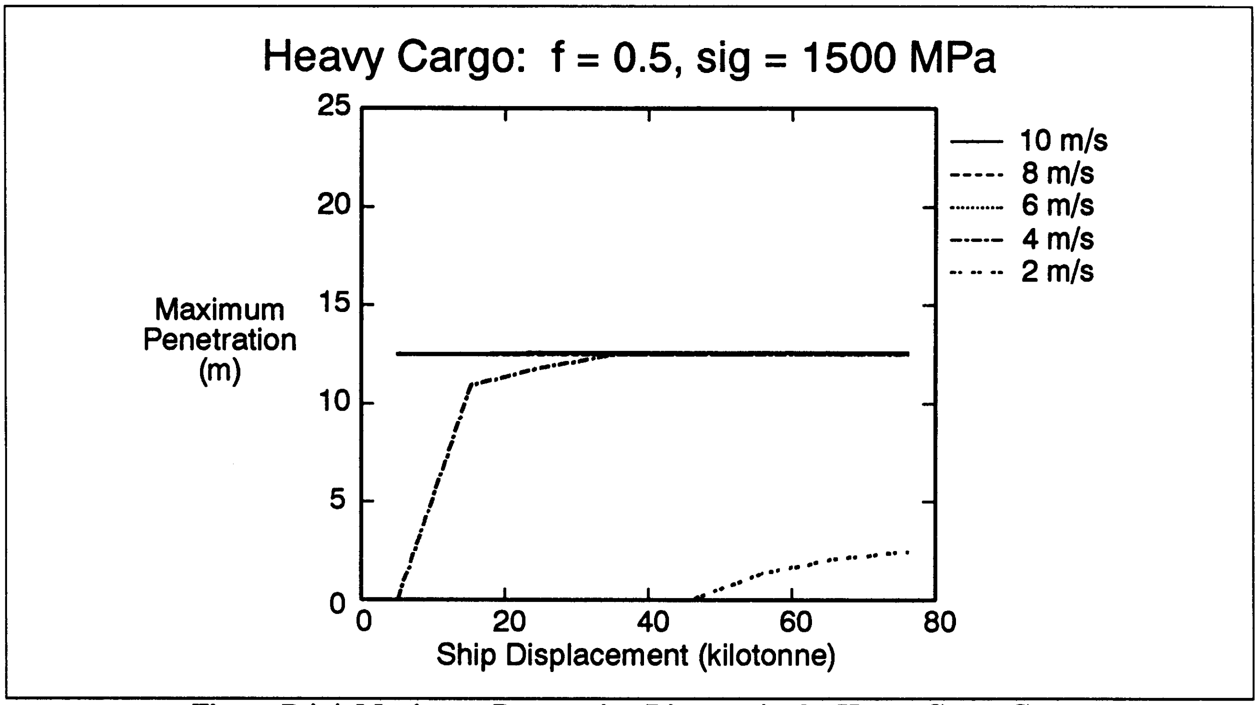


Figure D4-4 Maximum Penetration Distance in the Heavy Cargo Case

D4.2 Impact Forces During the Collision

Fuel elements experience impact forces if during a strong acceleration event they are driven against the inside of the cask or basket, or come into hard element to element contact. It is shown in Sanders et al., (Sanders, 1992) that accelerations of 100 g can be produced in the hypothetical accident conditions defined by NRC, which involve 9-m (29.5-ft) drops onto unyielding targets (NRC, 1990). They also showed there is a resulting cladding breach probability that for some power fuel types can be up to 0.0002 per rod in such events. We show here that the average acceleration experienced in ship collisions is very much smaller, usually below 1g, and conclude that inertial effects on the fuel are not significant for ship collisions.

The acceleration as a result of a ship collision is the time derivative of the transverse speed of the struck ship:

$$a = \frac{dv}{dt} = \frac{dv}{dx}\frac{dx}{dt} = v\frac{dv}{dx}$$

Performing the derivatives yields:

$$a = \frac{v(x)\,F(x)\,/(m+dm)}{\sqrt{v^2\cos^2(\theta) - \frac{2A\,W(x)}{m+dm}}}$$

where F(x) = dW(x)/dx. Notice that the acceleration peaks at the end of the collision, because the argument of the square root goes to zero there. The acceleration has a vertical asymptote at the maximum distance of penetration; the average acceleration, however, remains small.

The average acceleration during the collision is:

$$\langle a \rangle = \frac{\int_o^d a\,(x)dx}{d} = \frac{V^2 \cos^2(\theta)}{2\,d\,A^2}$$

where d is the maximum penetration depth. This is an improper integral since a (x) has a singularity at 'd'. However, the integrand increases sufficiently slowly in the neighborhood of 'd', like $(x\text{-}d)^{-1/2}$, for the integral to converge.

When there is no other cargo in the hold with the spent fuel cask, the average acceleration is only a fraction of 1g (9.8 meters per second^2) in all cases, with the average acceleration always less than 5 meters per second^2. Similar results hold for the light and medium cargo cases. Even in the extreme case of heavy cargo, the average accelerations found were less than 2.5g. The highest acceleration, corresponding to a 75,000 metric tons (82,500 ton) ship striking with a normal speed of 10 meters per second (19.0 knots or 22.0 statute miles per hour), was about 0.2g (2 meters per second^2).

Because of these low average accelerations, generally on the order 1 percent relative to the accelerations expected in the NRC regulatory accident conditions, impact of fuel elements inside the cask is not expected to do any damage to the fuel as a result of collisions either in port or on the high seas. We conclude $P_{impact} = 0.0$.

D4.3 Crush Loads on the Fuel Package During the Collision

The spent fuel package of interest is the Pegase transportation cask, a cask of french design. It is a lead shielded cask, with a mass of 18.9 metric tons (20.8 ton), a diameter of 1.875 m (6.2 ft), and a height of 2.239 m (7.3 ft). It has a body composed of two stainless steel shells built around a lead shield. It is [illegible] baskets of differing design which fit into the

But if the cargo does not close up because the penetration is shallow or there is no other cargo in the hold, the cask does not see this force. Then, unless it is within the penetration region, it will not be significantly affected.

Inside the penetration region the cask can be crushed without the cargo going solid, or even if there is no other cargo in the struck hold. Cask tiedowns are designed, under U.S. regulatory practice, to withstand about 5 million newtons of transverse force (NRC, 1990). The difference between this value and the 8.9 million newtons required to produce a 0.025 m (1.0 in) deflection in the cask wall of the generic cask is not considered significant; moreover in ORI's opinion "the RAM [Radioactive Material] package could conceivably be restrained from sliding, even in an empty hold, after the fittings failed. A buckled deck for example could do this and in effect act as an infinitely strong fitting" (ORI, 1981a).

Thus there are two cases to consider for failure due to crush forces. In the first the penetration depth exceeds the cargo close-up distance, while in the second it exceeds the cask stowage location. We assume fuel damage and closure failure in both types of events.

Cask Failure Probability

This section evaluates the probability that a cask will fail when the ship carrying it is struck in a collision with another ship. Since there are two different scenarios, the total probability of cask failure is the sum of two terms, one of cargo going solid, the other for the ship over-running the cask location, or

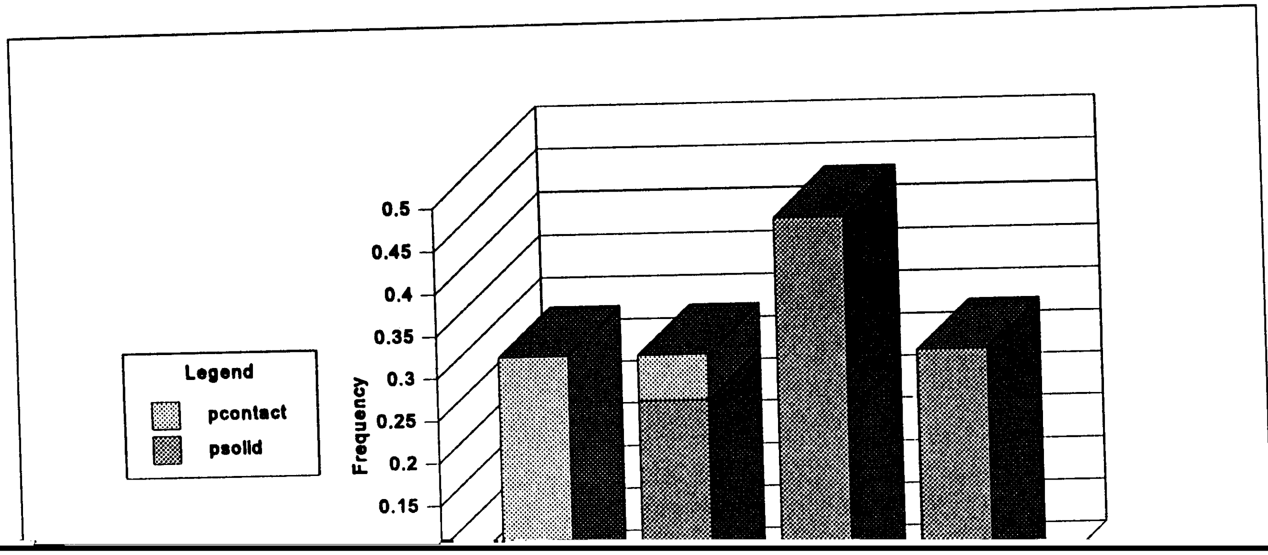
$$P_{crush} = P_{solid} + P_{contact}.$$

P_{solid} and $P_{contact}$ were evaluated by comparing the maximum penetration distance against the closeup distance and the stowage position, assumed to be on the centerline of the hull, for all combinations of striking ship displacement, speed, and angle given in Tables D4-3 to D4-5. Each individual case was counted as either resulting in cask failure (meaning the fuel is damaged and the cask seal is broken) or not, and the probability of the case was assigned according to the probability values in the referenced tables. The sum $P_{solid} + P_{contact}$ of the probabilities of all failure cases is P_{crush}.

The results are shown in Figure D4-5. The successive columns refer to the four models considered, for no cargo, and light, medium and heavy cargo. For other than the medium cargo model, the total crush probability is about 0.29, although the fraction due to the cargo going solid varies from 0 for the no cargo case to 1 for the heavy cargo case. The medium case, which as the smallest fraction of open hold space at 0.2, also has the highest failure rate, about 0.45. Of the four cases considered, this is the only case where the cargo goes solid well before the midline of the ship is reached, thus permitting a greater proportion of all the collisions to be significant from a cask damage point of view. Since this case shows the greatest probability, it is conservative to take P_{crush}= 0.45.

Alternate Case

Because the top speed in a harbor is controlled, the ORI distribution was adjusted to a top speed of 8.23 meters per second (15.6 knots or 18.1 statute miles per hour). This reduced the number of speed intervals to eight, and eliminated the three highest speed categories in Table D4-4. The total number of combinations of striking ship displacement, speed, and angle was therefore reduced from 968 to 704. Figure D4-6 shows the revised cask failure probabilities for the four cases. The highest failure probability is still from the medium cargo case, probably because this case has the earliest cargo closeup distance and fails most often from collisions which do not penetrate far into the target ship. The failure probability goes down more in the other cases because they involve penetrations going past the midline of the ship. Such events are sensitive to the high end of the speed distribution. The cask crush probability for this alternative is set equal to the largest result, P_{crush} = 0.40.



Legend
pcontact
psolid
Frequency
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15

Attachment D5
High Temperature Effects on Research Reactor Fuel Release Fractions

D5.1 Introduction

Previous assessments of the accident risks associated with the transport of research reactor fuel did not specifically address certain high temperature (somewhat above 900°K or 1160°F) effects on the fuel. In this temperature range, aluminum based fuels (the aluminum-uranium alloys used in research reactor fuels) are susceptible to melting. Additionally, TRIGA fuel is spontaneously combustible in this same temperature range, if sufficient oxygen is available. The melting point for the uranium dioxide fuels that had been used as the basis for the development of estimates of the release fractions for earlier assessments is considerably higher than for the aluminum based fuels. These earlier assessments were the basis for the release fractions used in the base case analysis of this study. This attachment provides an assessment of [illegible]

The BR-2, and RHF fuels considered by this study are fabricated as stacks of aluminum-uranium alloy plates or cylinders, that are contained in aluminum-cladding. Release of fission products from [illegible] Fission product release is minor below [illegible]

Accident Severity Category 5

When fuel temperatures remain below 900°K (1,160°F), that is, below the ignition point of TRIGA fuel in air and the melting point of aluminum-uranium alloy fuels, the release fractions from TRIGA fuel should be similar to that from uranium dioxide fuels. Also, the releases from aluminum-uranium alloy fuels should be very small, perhaps negligible, since diffusion in the metal plates from which the fuel is fabricated will be too slow to cause significant release to the cask, much less to the environment.

When research reactor fuels are heated significantly above 900°K (1,160°F) the release to the cask from TRIGA fuel pellets and from melted aluminum-uranium alloy fuels of krypton, volatile cesium, and ruthenium should be substantial (Cubicoitti, 1984; Cordfunke, 1990). Once released to the cask interior, transport of these fission products from the cask to the environment (past the failed cask seal) will only be efficient when the gases in the cask expand significantly due to heating of the cask to temperatures well above 900°K (1,160°F). For example, if melting of an aluminum-uranium alloy fuel at 923°K (1,202°F) causes essentially all of the krypton trapped in the fuel to be released to the cask interior, then further [illegible] approximately 10 percent of the gases in

D5.3 Release Fractions for High-Temperature Events

The discussion presented in Section D5.2 indicates that, at elevated temperatures, release fractions for aluminum-uranium alloy and TRIGA fuels will differ substantially from those assumed in earlier studies of research reactor fuel transportation accidents for category 6 events and also for category 5 events that reach unusually high temperatures. To allow the consequences of such high-temperature events to be examined, the severity category strategy used in the base case analysis was modified by dividing both categories 5 and 6 into a low temperature and a high temperature category. Release fractions were then estimated for all of the categories in the modified strategy (categories 4, 5A and 5B, and 6A and 6B) and sensitivity calculations were performed to estimate the effects of the new release fractions on accident consequences.

Fire events that do not heat cask contents above 900°K (1,160°F) are placed in categories 5A and 6A. Fire events that heat cask contents above 900°K (1,160°F) are placed in categories 5B and 6B. Events that lead to seal failure are placed in category 4 and 5. Events that lead to cask failures (one medium hole, two or

In order to develop release fraction values for the sensitivity study accident categories, several parameters need to be defined. These parameters are defined in Table D5-3.

Table D5-3 Definitions of Parameters used in the Sensitivity Study Accident Categories

F_{B1}	Fraction of fuel elements failed by the ships collision
F_{C1}	Release fraction for fission products from the fuel to the cask cavity due to the mechanical effects of the ship collision
F_{CE1}	Fraction of the fission products released to the cask cavity that escape from the cask in the absence of a fire
F_{FC2}	Fraction of fission products released from the fuel to cask cavity due to heating of the fuel from ambient temperature (T_a)to some elevated temperatures (T_f) less than 900°K
F_{B2}	Fraction of the fuel elements failed by burst rupture due to heating from T_a to T_f
F_{CE2}	1 - (T_a/T_f) where $T_a/T_f = V_a/V_f$ = the fraction of the gases in the cask at ambient temperature that remain in the cask after heating to Tf
F_{FC3}	Fraction of fission products released from the fuel to the cask cavity after the fuel has been heated to T_{FC3}(=temperature where aluminum-uranium fuel melts and TRIGA fuel burns if exposed to air
F_{B3}	The fraction of fuel elements failed by burst rupture due to heating from T_{FC3} to T_f
F_{CE3}	1 - (T_{FC3}/T_f) where $T_{FC3}/T_f = V_{TC3}/V_f$ = the fraction of the gases in the cask after heating to T_{FC3} that remain in the cask after further heating to T_f

Then, the release fraction (F_{R4}) for Category 4 events is given by

$$F_{R4} = F_{B1}F_{FC1}F_{CE1} \qquad (1)$$

If the collision leads to a fire that heats the cask to elevated temperatures that do not exceed 900°K (1160°F) heating of the fuel may cause more fission products to be released from the fuel to the 900° cask cavity, and expansion of cask gases due to heating by the fire will cause a substantial fraction of the gas borne fission products to be transported from the cask interior through the failed cask seal to the environment. Thus, the release fraction (F_{R5A}) for Category 5A events is given by

$$F_{R5A} = F_{R4} + F_{B1}F_{FC1}(1 - F_{CE1})F_{CE2} + F_{B2}F_{FC2}F_{CE2} \qquad (2)$$

The release fractions used in the base case assessment are the same as those (Wilmot 1981) developed for air-cooled casks for release of fission products from spent commercial UO_2 fuel for three processes: impact, burst, and oxidation. Base case Category 4 release fractions are the same as those developed by Wilmot for impact events involving air-cooled casks. Except for cesium, Category 5 release fractions are equal to the sum of Wilmot's release fractions for impact and burst, and Category 6 release fractions are equal to the sum of Wilmot's release fractions for impact, burst, and oxidation. For cesium, the base case uses release fractions that have been adjusted somewhat to reflect the effect of metallic fuel properties on cesium release. This information is used as the basis to derive several of the values for the parameters identified in Table D5-3.

For impact events, Wilmot uses $F_{B1} = 0.1$, $F_{FC1} = 0.2$ and $F_{CE1} = 0.5$ for krypton; and $F_{FC1} = 2 \times 10^{-6}$ and $F_{CE1} = 0.05$ for cesium, ruthenium and particulates for release of fuel fines and thus the fission products trapped in the fines. For burst events, Wilmot assumes that $F_{B2} = 0.9$. Table D5-2 shows that the base case used values of 0.1, 9×10^{-4}, 1×10^{-6}, and 5×10^{-8}, respectively, for the release fractions for krypton, cesuim, ruthenium, and particulates for Category 5 events. If Equation 2 is solved for F_{FC2} using the base case values for Category 5 events for F_{R5A} and Wilmot's values for F_{B1}, F_{B2}, F_{FC1}, and F_{CE1}, then the following values are obtained for F_{CE2}: 0.15 for krypton, 1.6×10^{-3} for cesium, 1.6×10^{-6} for ruthenium, and 0 for particulates.

The analysis presented in Attachment D4 of cask damage caused by impact and crush concludes that damage will not result from the impacts forces experienced by cask during ship collisions, and that if the cask is subjected to crush forces, they will always be large enough to fail all of the fuel elements contained in the cask. Therefore, $F_{B1} = F_{B2} = F_{B3} = 1.0$.

To facilitate comparison of the new release fractions developed here to the release fractions used in the base case, the release fractions for the cesium, ruthenium, and particulate chemical element groups for Category 4 events were forced to be the same as the value used in the base case. Although below 900°K, (1160°F). Even if burning does occur, efficient transport of fission products released by the burning from the cask to the environment can occur only by gas expansion caused by the heat released by fuel burning. Thus, the cask atmosphere must breath (pass through several cooling/burning cycles), if significant quantities of fission products are to be released by fuel burning, when there is no convective flow of air through the cask.

Table D5-4 lists the parameters used in Equations 1 through 5, and presents the values used for each parameter to calculate values for the release fractions F_{R4}, F_{R5A}, F_{R6A}, F_{R5B}, and F_{R6B}. For the four EA5 results for UO_2 fuel, the result calculated is the F_{FC2} value, not the F_{R5} value, which is an input and is set equal to the value used in the EA for the indicated element group.

Table D5-4 Parameters Used to Generate High Temperatures Fire Sensitivity

Inspection of Table D5-2 allows the size of the new release fractions developed for aluminum-uranium alloy and TRIGa fuels to be conpared to the release fractions used in the base case calculations. Table D5-5 summarizes these comparisons.

Table D5-5 Relative Size of the Sensitivity Study Release Fractions Compared to the Base Case Release Fractions Used to Perform the Base Case Calculations

Fuel	*Severity Category*		*Size of New Sensitivity Study Release Fractions Compared to Base Case Release Fractions*
	Sensitivity Study	*Base Case*	
Aluminum-Uranium Alloy	4	4	About the same (krypton much smaller)
	5A	5	Smaller (cesium 10,000 times smaller)
	5B	5	Cesium 10 times larger
	6A	6	Cesium 5000 times smaller
	6B	6	Cesium 100 times larger
TRIGA	4	4	10 times larger
	5A	5	About the same
	5B	5	Cesium 10 times larger
	6A	6	About the same
	6B	6	Cesium 300 times larger

D5.4 Probability of High-Temperature Events

Data on the temperatures of real ship fires is nearly non-existent. Only one of the five severe fires [illegible]

900°K (1,160°F), provided the fire burns long enough and isn't suppressed by lack of oxygen or the operation of fire suppression systems. Thus, $P_{good\ fuel}$, the chance that a long burning hold fire is supported by the burning of a good fuel, is not likely to be small and is here assumed to be 0.9.

The review of ship fires prepared by the French Bureau Veritas for the International Maritime Organization (IMO, 1992) contains data on ship fire durations. Most ship fires (70 to 80 percent) do not burn for an hour. However, most severe ship fires (95 percent) burn for more than an hour. Therefore, the chance that a severe fire involves enough fuel to burn for an hour or more, $P_{enough\ fuel}$, is assumed to be 0.95.

Figure D5-1 presents an event tree for oxygen availability during fires in cargo holds, and is used to estimate $P_{enough\ oxygen}$. The tree shows that most cargo hold fires will be partially starved for oxygen for

... or will be deliberately closed after it

When a break-bulk freighter like the seven-hold ship used in these analyses is being loaded or unloaded, usually three or four holds are being worked at any given time. Thus, when the ship is being loaded or unloaded, P_{worked}, the probability that a given hold is being worked is ½ or 0.5.

The break-bulk freighter used in these analyses has seven holds. Five of these holds contain three cargo decks, one contains four cargo decks, and one contains only two cargo decks. Thus, there are 21 possible deck locations for a spent fuel cask in this typical ship. Accordingly, $P_{location}$, the chance that a spent nuclear fuel cask has been loaded onto a given deck in one of the seven holds is 0.048.

All hold openings have covers, not just the opening in the main deck through which the hold is loaded and unloaded, but also the openings in the cargo decks within each hold. When a deck in a cargo hold is being loaded or unloaded, all openings above that deck must be open and the opening in the deck and all openings in lower decks are normally closed. Thus, while a hold is being worked, upper decks in that hold will be open to outside air more often than lower decks. For example, for a three-deck hold, while the hold is being worked, the upper deck will always be open to the outside air, the second deck will be open about two-thirds of the time, and the lowest deck will be open about one-third of the time. Thus, if N is the number of holds with two, three, or four decks, and P_{deck} is the probability that deck i in a hold is open to outside air while that hold is being worked, then P_{closed}, the chance that an engulfing fire is partially starved for oxygen because there is a cargo deck or main deck hold cover in place between the fire and the outside air will be:

$$P_{closed} = 1 - \{(0.5)(0.5)(0.048)([5(1 + \tfrac{2}{3} + \tfrac{1}{3})] + [1(1 + \tfrac{3}{4} + \tfrac{1}{2} + \tfrac{1}{4})] + [1(1 + \tfrac{1}{2})])\}$$

$$= 0.833$$

The ORI study (ORI, 1981a) found that over half (60 percent) of all cargo ships are equipped with fire detectors and CO_2 fire suppression systems. Because CO_2 fire suppression systems are not complicated, they should operate reliably on demand most of the time. To be conservative, failed operation during one of five fire events is assumed.

Using this data, the event tree in Figure D5-1 can be quantified to determine the probability of the event $P_{enough\ oxygen}$. Two branches of the oxygen availability tree lead to the outcome "enough air." The probabilities of these two branches sum to 0.087. Thus, 0.09 is a reasonable estimate for $P_{enough\ oxygen}$, the chance that a fire has adequate oxygen available to burn freely and generate maximum heat loads.

Combining the probability estimates for $P_{good\ fuel}$, $P_{enough\ fuel}$, and $P_{enough\ oxygen}$ allows $P_{T900\ K}$ to be estimated as follows:

$$P_{T900\ K} = P_{good\ fuel} \times P_{enough\ fuel} \times P_{enough\ oxygen}$$

D5.5 Probability of Convective Flow through the Failed Cask

Non-uniform heating of the cask during engulfing fires is expected to produce substantial flow of gases through the cask if two or more small holes or one medium hole have been produced in the cask by the ship collision. Because transportation casks bottoms and lid seats are welded to the cylindrical shell of the cask using full-penetration welds that are as strong or stronger than the parent material, when the cask shell is subjected to a severe stress (e.g, high impact or crush forces), the cask shell should yield before the welds fail. In fact, extra-regulatory 60 mph drop tests produced large plastic strains in the cylindrical shell of the test cask without failing its welds (Ludwigsen and Ammerman, 1995). Thus, during a ship collision, crush forces should collapse the cask walls inward without producing catastrophic failure of the lid, its seat, or the welds that attach the seat or the bottom of the cask to the cask walls. Therefore, an unusual configuration of cargo and/or deformed ship structures must be produced during the ship collision in order to subject the cask to forces that will produce failures substantially worse than failure of the lid seal. Either the lid seat must be bent significantly, or at least two penetrations must break, or the cask walls must be sheared or punctured. Although data for such failures is lacking, because casks normally do not fail by these mechanisms, the probability that a failure substantially worse than seal failure occurs is assumed to be no larger than 0.1.

D5.6 Severity Category Event Trees

Figures D5-2 and D5-3 present event trees that represent the sequence of events that lead to category 4, 5A, 5B, 6A, and 6B releases from transportation casks due to ship collisions. After rounding to the nearest

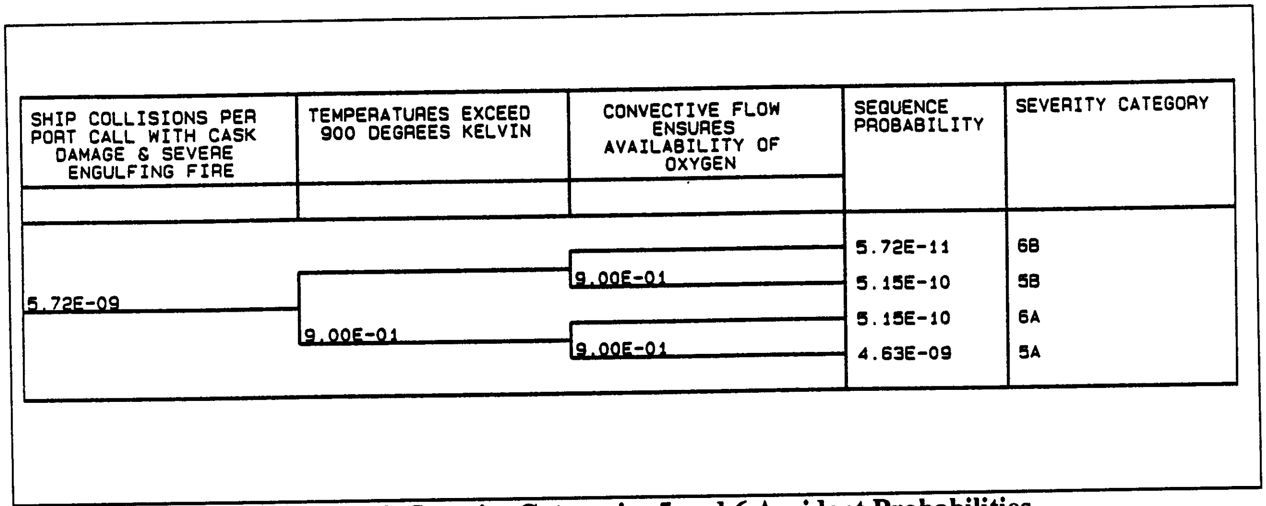


Figure D5-3 Severity Categories 5 and 6 Accident Probabilities

Table D5-4 Sensitivity Study Accident Severity Category Probabilities

Severity Category	*Probability Per Port Call*
4	$6x10^{-6}$
5A	$5x10^{-9}$
5B	$5x10^{-10}$
6A	$5x10^{-10}$
6B	$6x10^{-11}$