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DEFENSE PROGRAMS TRANSPORTATION RISK ASSESSMENT

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SUMMARY

This paper provides an overview of the methodology used in a probabilistic transportation risk assessment conducted to assess the probabilities and consequences of inadvertent dispersal of radioactive materials arising from severe transportation accidents. The model was developed for the Defense Program Transportation Risk Assessment (DPTRA) study. The analysis incorporates several enhancements relative to previous risk assessments of hazardous materials transportation including newly-developed statistics on the frequencies and severities of tractor semi-trailer accidents and detailed route characterization using the 1990 Census data.

I. INTRODUCTION

The DPTRA project was conducted to quantify the risks from inadvertent dispersal of radioactive material associated with transportation of Defense Program (DP) materials. The DPTRA is one element of an integrated program to develop an overall DP Transportation Safety Evaluation Report.

Radioactive materials transported to support DP requirements include but are not limited to isotopes of plutonium, uranium, thorium and hydrogen. Plutonium and uranium isotopes do not pose a significant health hazard in the form in which they are transported; they must first be converted to an aerosol with respirable size particles. Three mechanisms by which aerosol may be generated and released are considered: violent reaction of high explosive (HE), oxidation in a fire, and spalling and break-up of the surface oxide layer by mechanical forces. The vast majority of off-site, DP shipments involving radioactive materials are made in the Armored Tractor/Safe-Secure Trailer (AT/SST), including nuclear weapons, test devices, components, and bulk material in various forms. Origins and destinations for shipments of DP materials include nuclear weapons production facilities, DOE laboratories and test facilities, and Military First Destinations.

There are three basic elements of the risk assessment. Probabilities of release by the three mechanisms that can produce respirable-sized aerosols and specific consequence scenarios are developed based on an event tree analysis. Consequences are evaluated for each end event in the tree through an assessment which integrates dispersal calculations, route characterization, population data, and dose-health effects models to provide an estimate of excess latent cancer fatalities (LCFs) and contaminated area. Uncertainties are evaluated by incorporating Latin hybercube sampling into the calculations for probabilities and consequences. The uncertainty analysis will not be discussed further in this paper. The basic elements of the event tree and consequence analysis are described in more detail in the body of this report.

II. EVENT TREE

The basis for the probability analysis is an event tree, which provides a description of accident sequences that can lead to specific consequence scenarios. The event trees are composed of questions that define the types and severities of transportation accidents that occur, the resulting damage to the transporter and cargo, release mechanisms, accident locations, and the meteorological conditions. The event tree developed for transportation of radioactive materials in the SST for the DPTRA study consists of 18 questions. The questions and branches are depicted in Figures 1-4. Each question is used in all paths through the tree (scenarios), although for some scenarios, results of some questions may not be used.

A. Initiating Event

The initiating events for the tree are traffic accidents in one of four operating environments. The operating environments are based on road type and population area.[1] Road types are divided into limited access roads and non-limited access roads. Population areas are divided into urban and rural areas.

In the DPTRA study, the initiating event probabilities were calculated as the product of (1) the overall tow-away accident rate per mile for the AT/SST, (2) the fraction of tow-away accidents that have severities comparable to fatal accidents, (3) influence factors that relate the overall rate to the operating environment of interest, and (4) the average annual mileage for the cargo in the operating environment of interest.

The operating history with the AT/SST is sufficient to define an overall tow-away accident rate. The mean estimate for the rate of tow-away accidents involving an AT/SST is 0.066 per million miles.[1] However, the number of accidents experienced with the AT/SST is not sufficient to quantify the accident rate in the operating environments of interest or the types and severities of accidents. Thus, general commerce data for heavy truck transportation is used as a surrogate for AT/SST data to quantify the relative accident rates in different operating environments and the types and severities of accidents. Details on the other factors used to calculate the initiating event probabilities can be found in Reference 2.

B. Accident Environments

DP materials are shipped in packaging systems designed to mitigate accident environments and to prevent releases to the environment. In general, normal transportation environments do not produce environments that threaten the integrity of the packaging system. However, the environments produced from very severe traffic accidents could exceed the capabilities of the packaging system and cause a release of radioactive material.

The risk assessment developed for the DPTRA study considers impact, puncture, crush and thermal environments. In traffic accidents, impact, puncture and crush environments are associated with collision and rollover events; thermal environments are associated with fires involving the fuel system, cargo or other elements of the vehicles and/or objects involved in the accident. The response of the packaging system to these environments is likely to be interdependent. For example, the response of the packaging system to a fire should reflect damage to the packaging system caused by collision and rollover.

The accident data needed to define the probability of packaging system failure include probabilities of various accident types and distributions of collision, rollover, and fire severity. The response of the packaging system and the collision, rollover and fire severity depend on the type of accident.

Question 1 Most Harmful Event	Question 2 Impact Direction	Question 3 Impact Location	Question 4 Rollover	Question 5 Mechanical Environment
Collision w/ Heavy Truck	Front/Rear	AT only	Yes	Impact only
Collision w/ Lt Truck/Auto	Side	SST	No	Impact and puncture
Involvement w/ Tanker	Non-collision			Impact and crush
Collision w/ Hard Object				
Collision w/ Soft Object				
Collision w/ Non-fixed Object				
Collision w/ Train				
Rollover				
Fire				
Immersion				

Figure 1 Event Tree Questions and Branches for SST Transportation - Part A

Question 6 Collision Damage	Question 7 Rollover Damage	Question 8 Fire	Question 9 Fire Temp (F)
Collision Damage State 1	Rollover Damage State 1	Yes	$2200<T<2400$
Collision Damage State 2	Rollover Damage State 2	No	$2100<T<2200$
Collision Damage State 3	Rollover Damage State 3		$2000<T<2100$
Collision Damage State 4	Rollover Damage State 4		$1900<T<2000$
			$1800<T<1900$
//			$1700<T<1800$
			$1600<T<1700$
Collision Damage State 25			$1400<T<1600$

Figure 2 Event Tree Questions and Branches for SST Transportation - Part B

Question 10 Separation (ft)	Question 11 Fire Diameter (ft)	Question 12 HE Ignition	Question 13 HE Thermal Violent Reaction	Question 14 Oxidation
Engulfed	50<d<100	Yes	Yes	Yes
1<s<5	40<d<50	No	No	No
5<s<10	35<d<40			
10<s<20	30<d<35			
20<s<40	25<d<30			
40<s<80	(Complete with additional ranges of 5 ft)			
80<s	5<d<10			

Figure 3 Event Tree Questions and Branches for SST Transportation - Part C

Question 15 Route	Question 16 Location	Question 17 Met Stability	Question 18 Wind Direction
R(1)	X(1), Y(1)	A	0-22.5
R(2)	X(2), Y(2)	B	22.5-45
R(3)	X(3), Y(3)	C	45-67.5
(complete as appropriate)	(complete as appropriate)	D	67.5-90
		E	(complete with additional ranges of 22.5 degrees)
R(nrte)	X(nloc), Y(nloc)	F	337.5-360

Figure 4 Event Tree Questions and Branches for SST Transportation - Part D

The packaging system used by the DOE to transport Defense Program materials includes the cargo, containers and the SST. The most important features of the SST that protect the cargo in accident environments include the walls of the trailer, which provide significant thermal protection in fire environments, and the cargo tie-down system, which provides a means of holding the cargo in place. In general, damage to the packaging system in an accident depends on a number of factors:

1. If the accident involves a collision, accident characteristics that may affect the response of the packaging system include the location of the principal impact, the impact direction, the collision energy absorbed, the peak contact velocity and the collision duration.

2. If the accident involves a rollover, the response of the packaging system (primarily damage to trailer walls) is evaluated based on the skid distance.

3. If the accident involves a fire, the effective fire temperature, the size of the fire, the separation between the fire and the trailer, and the duration of the fire are the primary variables used to characterize the fire.

The types of vehicles and/or other objects involved, collision occurrence, angle of impact, location of principal impact , rollover occurrence and fire occurrence are factors that define the types of accidents. The peak contact velocity, skid distance, effective fire temperature, fire size, fire separation, and fire duration are factors that define the severity of the accident.

The branches of Questions 1-4 and 8 define the factors used to characterize the type of accident. Questions 9-11 are used to describe the fire temperature, fire size, and fire separation. The peak contact velocity, skid distance, and fire duration are used in the evaluation of the branch probabilities for Questions 6, 7, 12 and 14. Details of the statistical distributions for each of the factors used to characterize the type and severity of accidents can be found in Reference 3.

C. Response Of Packaging System To Accident Environments

The response of the packaging system to the accident environments is addressed in Questions 5-7 and 12-14. The possible responses to collisions, rollovers and fires are considered. The response states address mechanisms that lead to release of radioactive material (e.g., violent reaction of HE, by either mechanical or thermal initiation). The response states also address damage to the SST walls and cargo that may affect subsequent thermal response to a fire environment.

Question 5 is used to define the type of mechanical environments to which the cargo may be subject. An impact environment exists for all scenarios in which a collision occurs. The probability that a puncture environment also exists depends on the existence of probes and the likelihood that they will be aligned in such a way as to cause damage. The probability that a crush environment also exists depends on the loading configuration of the cargo. The details of the types of cargoes carried and how they are loaded in the SST are not discussed in this paper.

Question 6 addresses the damage to the packaging system associated with collision events. Twenty-five collision damage states, which are determined from combinations of SST wall damage and cargo damage, are represented in the event tree. The damage states are hierarchical and are listed from the most severe to no significant damage. For scenarios in which a collision occurs, the branch probabilities are obtained by the split fraction method, which entails evaluating the probability that the peak contact velocity is greater than a calculated threshold value for the damage state of interest.

Question 7 is used to define the SST wall damage from rollover. Damage due to rollover is limited to the outer skin and insulation, i.e., the probability of openings in the SST walls or damage to the cargo from rollover is considered negligible. For scenarios in which a rollover occurs, the branch probabilities are obtained by evaluating the probability that the skid distance is greater than the threshold value for the damage state of interest. Additional details on the expressions used to evaluate the branch probabilities in Questions 6 and 7 can be found in Reference 2

The response of the cargo to fire environments is addressed in Questions 12-14. For scenarios in which a fire occurs, the probability of HE ignition is obtained by evaluating the probability that the fire duration is greater than the minimum fire duration for HE ignition, t^*, which depends on the cargo of interest, cargo damage, total wall damage, effective fire temperature, fire separation and fire size. Since collision and rollover can occur in the same accident, the total wall damage is obtained from the combination of the wall damage from collision with that from rollover. The computer code MELTER was developed to calculate t^*.[4]

Question 13 is used to define the probability of a thermally initiated violent reaction of the HE given ignition. If a violent reaction of the HE does not occur, Question 14 is used to assess the probability that aerosol is generated by oxidation of the radioactive material. Detailed discussion of these questions is not included in this paper.

D. Consequence Scenario

For a given release mechanism, Questions 15-18 provide the remaining conditions needed to define a consequence scenario. Specific locations are sampled randomly from each route and operating environment considered. The sampling density is higher in urban areas than in rural areas. The location of the accident affects both the distribution of meteorological stability and the exposed population. The probabilities of the meteorological stability classes (as defined by Pasquil-Gifford stability A-F) depend on the accident location and are obtained from data recorded at upper air stations operated by the National Climactic Data Center. The meteorological stability affects dispersal. The wind direction, which is defined in Question 18, affects the exposed population.

III. CONSEQUENCE ASSESSMENT

Health and environmental effects are estimated in the consequence assessment. Health consequences are expressed in terms of the expected number of excess LCFs produced in the exposed population. The exposed population is defined as those members of the public subject to a maximum individual risk of contracting an excess latent cancer resulting in fatality greater than one in ten thousand. Collective committed effective dose is calculated based on dispersal analysis using the ERAD code[5] and exposed populations determined from route characterization and population counts obtained from the 1990 Census data.[6,7] The number of excess LCFs is determined from the collective committed effective dose based on conversion factors in the BEIR V report.[8] The dispersal analysis depends on the dispersal mechanism, meteorological stability, and the cargo of interest. The exposed population depends on the accident location and wind direction. Environmental consequences are expressed in terms of land area contaminated to levels greater than 0.1 $\mu Ci/m^2$. The contaminated area is taken directly from the dispersal analysis and depends only on the cargo, release mechanism, and meteorological stability.

IV. CONCLUSION

An overview of the methodology used in the DPTRA study for assessing the risks from inadvertent dispersal of radioactive material associated with SST transportation of DP materials has been presented. The DOE has completed a review of the DPTRA study. A final report on the DPTRA study will be completed in September 1994.

V. ACKNOWLEDGMENT

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