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RISK ASSESSMENT OF DOE DEFENSE PROGRAM PACKAGES IN A BEYOND 10 CFR 71.73 TRANSPORTATION ACCIDENT ENVIRONMENT

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RISK ASSESSMENT OF DOE DEFENSE PROGRAM PACKAGES IN A BEYOND 10 CFR 71.73 TRANSPORTATION ACCIDENT ENVIRONMENT*#

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ABSTRACT

A comprehensive program is being conducted by the DOE to determine the risks related to the domestic transportation of radioactive and hazardous materials associated with nuclear weapons. The program is designed to identify, quantify and manage potential risks to public health and safety including potential radiological and toxicological health consequences which may exceed the 10 CFR 71.73 transportation accident environment. A major objective of this program being performed by the Lawrence Livermore National Laboratory (LLNL) and the University of Utah is to provide the DOE with the methodology and bases for evaluating highway transportation activities by DOE contractors. This paper describes the approach and the HITRA model which is based upon probabilistic risk assessment (PRA) methodology and route specific data associated with the proposed transportation activity. The model is capable of providing detailed, location and time specific data for assessing projected risks to public health and safety from DOE defense program materials shipments.

INTRODUCTION

I. DOE Policy

The policy of the Department of Energy (DOE) is that the general public be protected so that no individual bears significant additional risk to health and safety from the operation of a DOE nuclear facility above the risk to which members of the general public are normally exposed. Specifically, the risk to an individual within one mile of the site boundary from prompt fatality should not exceed 0.1 percent of the sum of all prompt fatalities resulting from other accidents to which the public is generally exposed. The risk to the population within 10 miles of the site boundary from cancer fatalities should not exceed 0.1 percent of the sum of all cancer fatalities to which the public is generally exposed. (This safety policy applies to accidents involving the transportation of DOE nuclear weapons related materials).[1]

When a DOE contractor seeks approval to make shipments of radioactive or hazardous material for the DOE, a Safety Analysis Report for the Packaging (SARP) which will contain the material during shipment must be prepared to support the application for an Offsite Transportation Authorization (OTA). For those packages which cannot satisfy the test conditions specified by 10 CFR 71.73, a Transportation System Risk Assessment (TSRA) document must also be prepared by the applicant. The TSRA must address the projected health and safety risks associated with the potential releases of radioactive or hazardous materials from the package in the event of a credible transportation accident (frequency of the order of 10^{-6} per year or greater). The applicant's TSRA is then reviewed by a Transportation Safety Review Panel (TSRP) which documents their findings and recommendations in a Safety Evaluation Report (SER). The TSRP and SER are then submitted to the Deputy Assistant Secretary for Military Applications (DASMA) for final review and approval on behalf of DOE if the application and assessed risks are judged to be acceptable.[2]

II. Development of Safety Guides

Lawrence Livermore National Laboratory (LLNL) is preparing a set of comprehensive Safety Guides which provide DOE transportation contractors with the background, requirements and recommended methodology for assessing the risks and consequences to public health and safety associated with the possible release of radioactive or hazardous materials in transportation

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accidents. This study contributes to the development of these Guides which assist applicants in preparing applications for an OTA.

III. DOE Orders and other Regulations and Standards.

The draft DOE Order for "Safety Requirements for Offsite Packaging and Transportation of Nuclear Components, Special Assemblies, and Radioactive Materials Associated with the Nuclear Weapons Program" is DOE Order 5610.12, dated 31 August 1992. This order replaces DOE Order 5610.1 and establishes DOE policy and requirements for protecting the health and safety of the public from transportation accidents involving DOE materials. Other DOE Orders and the Code of Federal Regulations (CFR) also pertain to certain aspects and activities associated with safety, security (49 CFR 173.7), and quality assurance for nuclear materials transportation. Furthermore, other agencies such as the NRC, DOT, and IAEA have pertinent studies, regulations and guides which provide comparison and guidance basis for DOE.[3,4,5]

BACKGROUND

The dramatic and unexpected events which have occurred in the former USSR have led to a critical reassessment of U.S. nuclear weapons requirements and resulted in national commitments for partial disarmament. The elimination, reduction and modification of U.S. inventories of certain nuclear weapons is anticipated to significantly increase domestic transportation of nuclear weapons and components. However, these DOE materials transportation activities must be conducted so as to insure public health and safety and to comply with national laws and DOE Orders.

A comprehensive assessment program is being conducted for the DOE to evaluate the risks associated with the domestic transportation of nuclear materials related to nuclear weapons. In particular, the study is designed to identify, quantify and manage risks to public health and safety arising from potential radiological and associated hazardous material consequences which may exceed the 10 CFR 71.73 transportation accident environment. A major objective of the program is to provide the DOE with the methodology and quantitative bases for determining credible risks and acceptance criteria for specific highway transportation scenarios. DOE seeks critical open peer review of their methodology and data bases used for performing the risk assessment within the limits permitted by security requirements. To permit public disclosure only results for generic highway routes and unit mass source terms will be reported in this study.

I. Inventory of Radioactive and Hazardous Materials

The radioactive and hazardous materials typically associated with the transportation of nuclear weapons and their components include tritium, uranium isotopes, plutonium isotopes, beryllium and other selected materials. These materials serve as the potential radiological and hazardous material source term for assessing releases and consequences from transportation accidents.

Radio nuclides (e.g., tritium and the isotopes of uranium and plutonium) and hazardous materials (e.g., beryllium) released in the form of particulates or gases, may form an airborne plume that disperses downwind and can affect the public in two principal manners:

- an external dose caused by photon exposure from the plume or ground surface
- internal dose by inhalation, ingestion or dermal absorption.

If nuclear criticality occurs as a consequence of the particular accident scenario (e.g., water submersion of the package and the fissile nuclear materials), then fission products could be added to the source term.

II. Transportation Routes

Because of concern for security and safeguards of DOE nuclear weapons related materials, surface transportation is conducted along preplanned and approved routes. Typically, highway movement of these materials is made along U.S. Interstate highways and other secure roads.

The mean accident rate for truck transport per unit distance traveled (e.g., accidents per million vehicle miles - mvm) along various types of highways has been reasonably well established and documented. However, this mean rate is affected by route and highway specific features. The specific route features which can alter this accident rate and the consequences of a given accident include major population centers, regions of increased traffic and traffic congestion, interchange on and off ramps and intersections, under- and overpasses, traffic control devices, type of median and shoulders, percentage grade, average speed of majority of traffic, temporary and unusual road features such as highway construction and adverse weather conditions impacting the roadway.

III. Transportation Accidents

Factors which affect traffic accidents include driver experience and performance, traffic conditions and equipment performance.[6] Driver competence and equipment performance are determined and assessed by records, past experience, and appropriate testing. Traffic conditions are readily amenable to PRA methods.

The significant aspect resulting from a given highway transportation accident is the consequences delivered to the package containing the radioactive or hazardous material. For the material response in the package the transportation accident can be classified into three categories: mechanical disruption resulting in physical release, chemical release associated with exothermic reactions such fire and heating, water submersion which can result in dissolution and possibly criticality of fissile materials in the package.

IV. Release and Transport Pathways

Given a transportation accident with release of material outside the package, there three principal pathways, atmospheric, surface water and others, by which this material can be transported through the environment to the public.

As the airborne materials move from the point of release through the atmosphere they may deposit on ground surfaces and vegetation as a result of dry deposition and precipitation scavenging. Photon radiation from the radioactive materials deposited on the ground contribute to the external doses. Finally some of these radioactive and hazardous materials deposited on plant surfaces and agricultural land may subsequently enter food chains, concentrating in crops and animal products. Consumption of these contaminated foodstuff may contribute to the internal doses.

The are numerous physical mechanisms by which the release of radioactive and hazardous materials within a shipment package is instigated or enhanced. These mechanisms include impact and mechanical rupture, diffusion, leaching, chemical reaction and rapid oxidation and criticality. Diffusion, leaching and heating are important processes which can transport the source material across the package boundary to the environment.

A. Atmospheric Dispersion

Atmospheric releases of radioactive and other hazardous materials may occur in transportation accident scenarios as a result of violent mechanical impact, detonation of chemical high explosive, combustion of pyrophoric substances, and/or vaporization of nuclear materials from burning diesel or aviation fuel. The released material, in the form of gases, particulates, and aerosols, form a plume which is transported and dispersed in a manner determined by the physical properties of the material, the initial release conditions, and the state of the ambient atmosphere. Two principal processes influence plume dispersal: gross transport in the direction of the mean wind by advection and diffusion by turbulent eddies which contribute to transport in the vertical and lateral directions. As the plume disperses, the materials eventually deplete through the processes of dry deposition and precipitation scavenging and ultimately contaminate ground surfaces. Additional processes including chemical reaction, isotopic exchange, buoyancy effects, and resuspension of deposited materials may affect their distribution in the environment.

Atmospheric dispersion is favored by the turbulent motion of the atmosphere which enhances mixing with entrained air thereby diluting and gradually spreading the material in the vertical and crosswind directions from the point of release. The surface layer is the lowest level of the planetary boundary layer (PBL) where large fluctuations in mechanical and thermal turbulence and wind velocity are generated by surface friction and in the vertical temperature gradient which exhibits a marked diurnal variation. Mechanical turbulence is generated by wind shear as a result of the frictional drag of air flowing over the ground and around obstacles such as vegetation, buildings, and topographical features. Thermally-induced turbulence and atmospheric stability are directly related to the degree of insolation and resultant heat flux. Unstable conditions exist and vertical motion is increased during daylight hours when there is strong insolation. Stable conditions occur at night or at any time in an elevated inversion layer and vertical motion is suppressed. Neutral condition prevail on cloudy and windy days. The stability of the atmosphere mediates turbulent intensity and therefore the diffusion processes affecting released materials.

The most common method for performing atmospheric dispersion calculations is the familiar Gaussian plume model in which the dispersion parameters are related to observed meteorological conditions obtained during field diffusion experiments. The model is valid for the following conditions: homogeneous and stationary turbulence conditions, spatially-constant and non-divergent flow conditions, non-zero wind speed, steady-state source concentration, sufficiently long diffusion times, and total reflection of the plume on the ground surface.

More recent and accurate treatment of atmospheric diffusion problems are based on Monin-Obukhov similarity theory[7] with scaling as appropriate for the different regions of the PBL. This theory provides satisfactory characterization of turbulence and the vertical profiles of important meteorological parameters. These parameters facilitate implementation of numerical simulation models such as the ERAD computer code[8].

B. Surface Water

Surface water transport of contaminants is considered even though the probability of occurrence is low the consequences of release to a major water supply could be severe. For instance, an off the road transportation accident on a bridge spanning the Mississippi river, could introduce materials into the river with the possibility of criticality could result in significant risk to water users downstream.

The concentration of contaminants deposited in surface water is dependent upon the source term, accident release conditions and prevailing weather conditions. The flow characteristics of the contaminated water body determines how the materials are dispersed thereafter. Advection, diffusion, and interaction with sediment are important transport mechanisms in dispersing the contaminant.

In a stream or river system advection is usually the dominant transport mechanism. In a lake or reservoir system where the system is geometrically constrained, diffusion and interaction with suspended and bed sediments become the dominant factors. Only far-field mixing and dispersion models are considered for this study because of risks considered A simple model based on Gaussian dispersion has been used to model surface water borne contaminants.

C. Other Mechanisms

Besides atmospheric and surface water transport pathways for moving radiological and hazardous materials through the environment to humans, there are other mechanisms which are generally less significant, but should be quantified. These include source material sequential transport via the atmosphere to soil and surface water. The source materials can produce direct radiation exposure (from radioactive materials) and also be transported to ground water, food crops, animals and eventually to humans. Generally, these pathways result in much smaller risks than direct air and surface water pathways. However, under certain accident scenarios these sequential pathways can be significant.

V. Doses and Latent Health Effects

Radiation doses and hazardous material exposures to the public may result in specific health effects. These effects are usually classified as chronic effects and include carcinogenic, mutagenic and tetratogenic health effects (HE) and arise from inhalation, ingestion , dermal contact and direct exposure to external radiation fields associated with the radioactive and hazardous materials.

Radiation doses and hazardous material exposures may be converted to health effects using appropriate dose conversion factors. These factors are available from a variety of sources. The data base generally employed for assessing health effects (including carcinogenic and non carcinogenic effects) from hazardous materials is IRIS[9] (Integrated Risk Information System) and HEAST[10] (Health Effects Assessment Summary Tables) prepared by the U.S. EPA. HEAST also provides data for the radio nuclides anticipated in DOE nuclear weapons materials shipments (viz., tritium and uranium and plutonium isotopes) as shown in Table 1 which provides lifetime excess total cancer risk (HE) per unit intake or exposure (viz., slope factors). Other dose conversion data bases are available from published data provided by NRC, DOE, ICRP and others.[11]

Table 1 - Health Effects Assessment Summary Table (6)

Nuclide	Slope Factors		
	Inhalation HE/(pCi)	Ingestion HE/(pCi)	Ground Surface HE/(yr-pCi/sq m)
H-3	7.8E-14	5.5E-14	0.0
Pu-238	4.2E-8	2.8E-10	6.1E-14
Pu-239	4.1E-8	3.1E-10	2.6E-14
Pu-239(oxide)	4.1E-8	3.1E-11	2.6E-14
Pu-240	4.1E-8	3.1E-10	5.9E-14
Pu-240(oxide)	4.1E-8	3.1E-11	5.9E-14
Pu-241	2.9E-10	4.8E-12	0.0
Pu-240	3.9E-8	3.0E-10	4.9E-14
Pu-240	3.9E-8	3.0E-11	4.9E-14
U-233	2.7E-8	1.4E-10	3.2E-14
U-234	2.7E-8	1.4E-10	5.7E-14
U-235	2.5E-8	1.3E-10	9.6E-12
U-238	2.4E-8	1.3E-10	4.6E-14
Be	2.4E-3 HE/ug/cu m		--
Be	--	1.2E-4 HE/ug/liter	

HITRA MODEL AND DATA BASES

To provide the DOE with its own independent capability for performing PRA for transportation accidents involving the shipment of nuclear weapons materials, LLNL and select contractors including the University of Utah have developed a comprehensive highway transportation risk assessment model. The model and supporting computer codes and data bases provide the framework for quantitatively estimating for a given transportation route and containment package, the accident rate, source releases, source material transport in the environment, deposition, resulting doses and dose health consequences in the form of latent health effects and the overall uncertainty associated with the PRA process.

The model for assessing risk posed by the transportation is called the Highway Transportation Risk Assessment (HITRA) Model. Ideally the model is capable of assessing the risk from highway transportation at any specific point along the transportation path and at any time. The computer code which implements the model has been designed to resolve the accident location and occurrence to within a spatial cell of 1 square kilometer and time period within 4 representative daily time periods (morning, noon, evening, night). Although seasonal data can affect road conditions and meteorological conditions, it is considered by other parameters. Often complete data are not available to provide this level of spatial and temporal detail for traffic accident frequencies, population density, meteorological conditions, etc. so estimates (e.g., interpolations) are employed as default values. The model is sufficiently adaptable to accommodate to any reasonable level of available information. Data bases can range from individual square kilometer spatial and temporal resolution data to mean, global default data values for highway features, population density, meteorology, deposition, exposure, and health effects and risks.

Figure 1 provides a logic flow diagram associated with the HITRA model and the essential computerized data bases required for assessing the potential health risks arising from a transportation accident. The data base for a specific highway route for transportation of a unit mass of a specific nuclear weapon related material is generated for each unit spatial cell along the route. The main program then accesses the accident condition factors data base which provides the associated probability density function for the occurrence of transportation accidents as function of route location and time of day. This information is then combined with the source release factor data base which provides the essential source term data associated with the transportation package and the type of accident. The source term includes the radiological and hazardous material release with time and the essential material characteristics for transport evaluation. The source term data is then processed with the local meteorological, route terrain and demographic factors data to provide the final dose commitment and related latent health effects (HE) resulting from the transportation accident occurring at that particular route location and time. HITRA employees the IRIS and HEAST data bases for assessing health effects. These risks in the form of population doses and latent health effects may then be summed for each spatial cell along the route and the total risk assessment for the proposed transportation route may then be estimated and assessed.

I. ERAD Computer Code

The atmospheric transport and deposition of radiological and hazardous material released from the transportation accident are modeled using the ERAD computer code which serves as a file input to the HITRA model. ERAD provides a three-dimensional numerical simulation for the dispersal of both gaseous and particulate airborne source materials. Initial cloud dynamics, turbulent diffusion, and buoyancy effects coupled with elevation-dependent physical and thermodynamic properties of the plume are considered. The meteorological component of ERAD implements state-of-the-art scaling derived from empirical, laboratory, and numerical studies to model dispersion parameters. Particle dispersion and deposition are modeled as stochastic processes and simulated using a discrete time Lagrangian Monte Carlo method[8]. The current ERAD implementation provides for nonbuoyant and explosive source release mechanisms. A fire-plume release model is being developed and should be available in early 1993.

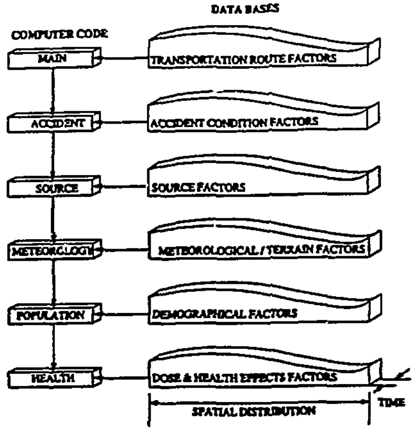

Figure 1. Diagram for HITRA Model

Figure 2 shows typical ERAD generated dosage contours for a one kg (i.e., unit source) of weapons grade Pu released as a nonbuoyant plume in a mechanical impact type of transportation accident. Input parameters include surface atmospheric pressure, relative humidity, temperature and wind speed and direction as functions of elevation, and assumed particle size distribution. A hodograph of the wind vector used as input for Figure 2 is presented in Figure 3. Note that in the case of nonbuoyant release, the dosage isopleths are affected primarily by the wind vector in the lower levels of the atmosphere.

The ERAD model has been confirmed by comparing dosage and deposition measurements obtained from the "Double Tracks" and "Clean Slate" events of Operation Roller Coaster conducted at the Nevada Test Site in the 1960's. The dosage and deposition distributions predicted by ERAD were within a factor of two of experimental measurements performed for the events. Furthermore, other standard radiological release and transportation accident codes (e.g., RADTRAN-4 and AIRDOSE-EPA) are being examined for comparative and verification purposes.

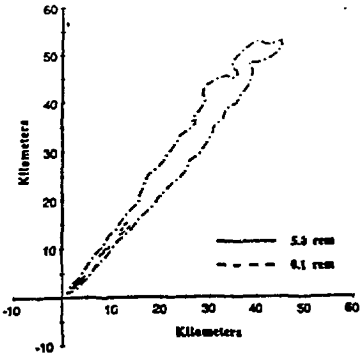

Figure 2. Dose Contours (isopleths) for a Unit Mass, Nonbuoyant Release of Pu Generated by ERAD

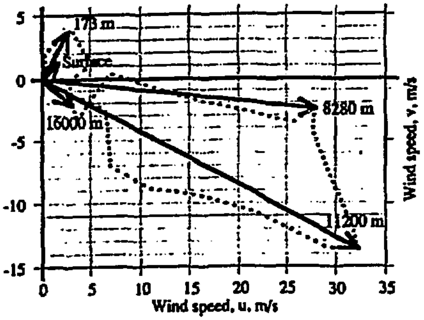

Figure 3. Hydrograph of Wind-Vector used as Input for ERAD

SUMMARY

A comprehensive Highway Transportation Risk Assessment (HITRA) model for assessing the health risks associated with radiological and hazardous material releases from transportation accidents involving nuclear weapons materials is under development. The model provides both individual and population health risks and uncertainty analysis for specific routes, shipment times, shipment inventories and configurations, specific material release fractions and scenarios and meteorological and population characteristics.

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