SAND 77-2140

A MODEL TO PREDICT THE RADIOLOGICAL CONSEQUENCES OF TRANSPORTATION OF RADIOACTIVE MATERIAL THROUGH AN URBAN ENVIRONMENT*

J. M. Taylor, S. L. Daniel and A. R. DuCharme
Sandia Laboratories
Albuquerque, New Mexico 87115

Nancy N. Finley
University of New Mexico
Albuquerque, New Mexico 87106

CONF-771173--6

MASTER

ABSTRACT

A model has been developed to predict the radiological consequences of transportation of radioactive material in an urban environment. The model uses estimated values for several urban parameters such as street widths, building heights, and vehicle speeds to compute the radiological impacts of "normal" (non-accident) transport and uses the urban parameters plus local meteorological data to compute the radiological impacts of accidents in which radioactive material is released to the environment. These impacts are quantified in terms of expected numbers of health effects, including early fatalities, early morbidities, latent cancer fatalities, and genetic effects. The model explicitly addresses unique aspects of urban areas such as high population densities, large structures and diurnal population variations. A grid consisting of cells which are homogeneous with respect to any of the assigned parameters is used to represent the urban area for the analysis. Integrated population radiation exposures and individual radiation exposures are computed across the grid and are converted to expected numbers of health effects.

A MODEL HAS BEEN DEVELOPED WHICH PREDICTS the radiological consequences of the transportation of radioactive material in and around urban environments. This discussion of the model includes discussion of the following general topics: health effects from radiation exposure, urban area characterization, computation of dose resulting from normal transportation, computation of dose resulting from vehicular accidents or sabotage, and preliminary results and conclusions.

HEALTH EFFECTS

Health effects from radiation exposure are subdivided into early and late effects. Early effects are those which manifest themselves within 1 year of the radiation exposure. The early effects considered in this model are early morbidities and early fatalities. Specific dose response data taken from other studies (1,4,5) are used to estimate early fatalities resulting from acute total marrow radiation exposure and acute pulmonary radiation exposure. Because the effects of sublethal doses are not as well understood, any person who receives a radiation dose in excess of a specified early morbidity dose threshold is considered an early morbidity candidate.

The late effects considered are those which manifest themselves throughout the rest of the life of the person who has received a radiation dose. These effects, resulting primarily from low doses delivered over long periods of time, are quantified using data derived from population segments known to have been exposed to specific doses (1,2). The results are quantified in terms of expected latent cancer fatalities and expected numbers of induced genetic effects.

The model computes expected values for each of the early and late effects. These expected values are then used for overall evaluation of the environmental impact of transportation of radioactive material under current regulations and for comparison of alternative restrictions or regulations.

URBAN AREA CHARACTERIZATION

The characterization of the urban area, in terms of a specific number of parameters used in the model, is a key element of the environmental impact assessment. The urban area is described by a grid consisting of 100 cells. Each cell is described by a set of parameters which constitute the properties of the cell, such as building heights, street widths, etc. The properties of a cell are assumed to be homogeneous. In this study, the urban area is a portion of the New York City Metropolitan area.

One of the significant characteristics of an urban area is the large diurnal variability in parameters which depend on localized variations in population densities. These time-dependent parameters include traffic density, population density, and number of pedestrians. Less obvious time-dependent parameters include traffic speed, response time to accidents, and vehicle separation distance. These characteristics of urban areas are considered by assigning each shipment a departure time in one of six time periods (morning and evening commuter rush periods, morning and afternoon work periods, noon hour, or nighttime). Each of these time periods has a unique set of assigned time-dependent characteristics. The shipment is permitted to change time periods as it traverses the grid.

Numerous data sources have been used in assembling the data required for this study. Shipment data (mode, size, route, radioisotopes, etc.) were compiled from detailed surveys conducted in 1975 (3) of shippers of radioactive material. Other data sources include personal contact with shippers, users, regulators of the transportation of radioactive material, and published urban-area descriptive statistics.

NORMAL TRANSPORT MODEL

"Normal" transport has been previously defined (4) as transport which does not involve vehicular accidents. Our model also excludes packaging and handling abnormalities from the "normal" transport model. Transportation of radioactive material is unique among transportation hazards in that, even if everything is done properly and no accidents occur, there is still some inevitable

*Prepared by Sandia Laboratories Albuquerque, New Mexico 87115 and Livermore, California 94500 for the United States Nuclear Regulatory Commission under DOE Contract AT(29-1)-789.

EB

radiation exposure to the general public. Although the consequences to individuals may be so small as to be undetectable, the number of shipments is large enough that a significant integrated exposure from low dose-low dose rate radiation does occur and should be evaluated. A previous study (4) found that this hazard may be as much as three orders of magnitude more significant than the hazards of potential transportation accidents on an annual risk basis (Risk = Probability of Event x Consequences of Event).

The following discussion concerns primarily the estimation of radiation dose received by the population due to normal transport of radioactive material. The hazards from other modes of transportation are evaluated in a similar manner. The radiation dose is apportioned among several population subgroups including crewmen, pedestrians, people in vehicles, people in buildings, handlers, and warehousemen. Subdivision of the population at risk in this manner allows the inclusion of unique radiation exposure geometries and shielding considerations for each subgroup.

The computational scheme to estimate the dose is based on the following formula for dose rate from a point source of ionizing radiation.

$$DR = \frac{Ke^{-\mu r}B(r)}{r^2} \qquad (1)$$

where, DR = dose rate (mrem/hr)
K = dose rate factor for package ($mrem\text{-}m^2/hr$)
μ = linear attenuation coefficient for medium (m^{-1})
r = distance from source (m)
B(r) = dose buildup factor for medium (dimensionless).

Integrating over distance and time, expressions for integrated population exposures (in person-rem) were derived. Values of integrated radiation exposure calculated using these expressions can be converted into expected numbers of adverse health effects.

ACCIDENTS

Although the environmental impact of accidents may not be severe from an annual risk perspective, individual accidents during the transport of radioactive material have the potential to cause large health and economic consequences. In order to evaluate these consequences, several submodels must be combined as shown on Figure 1. Transported radioactive material is characterized as being either dispersible or nondispersible under accident conditions. Nondispersible material is treated in a similar manner to that used to analyze normal transportation, i.e., a point source of external penetrating radiation is assumed and this point source is integrated over the surrounding population.

Dispersible materials are primarily inhalation hazards. However, the dose from the passing cloud of released radioactive material and the dose from non-aerosolized material which remains at the scene of the accident are also explicitly included.

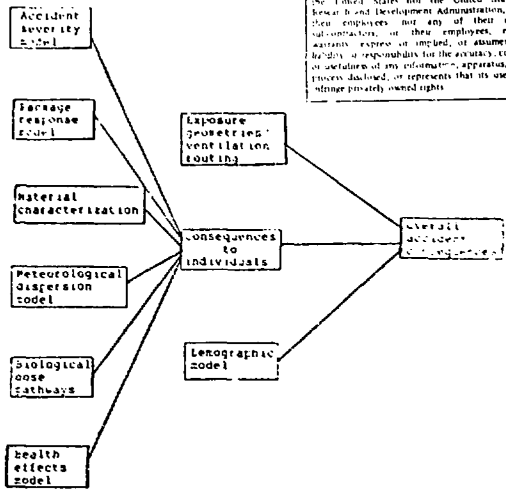

Fig. 1. Schematic of accident consequence calculation

The accident severity and package response models are based on models used in a previous transportation study (4). In this model, accidents are subdivided into severity categories for each transport mode. Probabilities of occurrence of accidents of various severities have been obtained from previous Sandia Laboratory studies (6). Values for the fraction of material which escapes from the package are based on correlations of the severity categorization with available package test data.

The atmospheric dispersion of the released radioactive material is discussed in another paper at this conference (7) and so will not be discussed here.

Allowance is made within the model for the effects of building ventilation systems on the amount of radioactive material inhaled by persons inside the buildings. The effects of both filtration and building air change rate are explicitly included.

Once the individual doses have been computed, the time and cell dependent demographic data is factored in to give an overall accident consequence. This is presented in two ways - initially as consequence data alone and secondly in terms of risk. In the latter case, the probability of occurrence of a spectrum of accidents of varying severities is included. All of these consequences are expressed in terms of health effects.

RESULTS/CONCLUSIONS

Currently the computer model is being exercised on a 100-cell New York City grid. Preliminary results suggest that:

(1) The significant contributors to the dose from "normal" transport are the dose to people in vehicles and the dose to crewmen.

(2) The time of day when the shipment occurs is an extremely sensitive parameter and can make several orders of magnitude difference in overall impacts resulting from "normal" transport of radioactive materials.

(3) Buildings significantly limit both "normal" and accidental radiation exposures.

(4) Routing restrictions can significantly alter the total dose ("normal" and/or accident).

(5) On a risk basis, the impact of accidents involving radioactive material is lower than the impact of transportation under "normal" conditions.

REFERENCES

(1) "Appendix VI to Reactor Safety Study," U.S. Nuclear Regulatory Commission, WASH-1400, October 1975.

(2) "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," Advisory Committee on the Biological Effects of Radiation (BEIR), National Academy of Sciences, National Research Council, November 1972.

(3) "Survey of Radioactive Material Shipments in the United States," Battelle-Pacific Northwest Laboratories, BNWL-1972, April 1976.

(4) "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes (Draft)," U.S. Nuclear Regulatory Commission, NUREG-0170, February 1977.

(5) M. Goldman, "An Estimate of Early Mortality and Morbidity Following Acute Inhalation of Plutonium," University of California-Davis, October 1976.

(6) R. K. Clarke, J. T. Foley, W. F. Hartman, D. W. Larson, "Severities of Transportation Accidents," Sandia Laboratories Albuquerque, N.M., 87115, SAND74-0001, July 1975.

(7) R. E. Akins, H. W. Church, M. S. Tierney, "Simulated Atmospheric Dispersion of Radioactive Material in an Urban Area, Sandia Laboratories, Albuquerque, N.M., 87115, presented to Fourth Joint Conference on Sensing of Environmental Pollutants, New Orleans, Nov. 6-11, 1977.