RADTRAN 4.0—Advanced Computer Code for Transportation Risk Assessment*

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INTRODUCTION

RADTRAN 4.0 is a computer code for transportation risk assessment developed by Sandia National Laboratories for the U.S. Department of Energy. While retaining the most useful and time-proven features of its predecessors, RADTRAN 4.0 incorporates significant advances over the earlier versions (Taylor and Daniel, 1977, 1982; Madsen et al. 1986). The most useful new features are:

* improved route-specific analysis capability,
* internal radionuclide data library,
* improved logic for analysis of multiple-radionuclide packages such as spent fuel,
* separate treatment of gamma and neutron components of Transport Index (TI), and
* increased number of accident-severity categories.

In this paper, each of these features will be described, and, where appropriate, potential applications will be discussed.

REVIEW OF BASIC STRUCTURE OF RADTRAN

In common with previous versions of the code, RADTRAN 4.0 consists mainly of two modules which estimate exposure during "normal" (i.e. incident-free) transport and accident risks, respectively, for all modes of commercial transport. For incident-free transport, the TI and packaging-specific characteristics are used to model the radioactive-material package or shipment as a modified point source (or as a line source for certain situations). Salient features of the

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**A United States Department of Energy Facility transportation system are then incorporated into a set of mode-specific models. These models require user-defined input parameters to describe the population around the package and other critical parameters (e.g., vehicle velocities, stop durations), which are used to calculate population doses. Because of operational and demographic considerations, population densities must be defined and doses to distinct subgroups of persons within each user-defined population-density zone must be modeled separately. The subgroups include persons adjacent to the transport link (offlink dose), persons in vehicles sharing the transport link (onlink dose), passengers in the transport vehicle (passenger dose), transport-vehiclc crew members (crew dose), persons at stops (stop dose), package handlers (handling dose), and warehouse personnel (storage dose). The presence or absence of each potentially exposed subgroup and the values of the numerical parameters used to describe the subgroup may vary by mode and by population-density zone. RADTRAN 4.0 allows the user to adjust the analysis to the specific problem being analyzed, but the resolution of an analysis may be limited by the quality of available data.

The RADTRAN approach to accident risk uses problem-specific, user-supplied data on packaging integrity and accident severity to estimate package release fractions for various classes of accidents. A series of separate consequence calculations are performed for each accident-severity category in each population-density zone. Each consequence value is multiplied by an appropriate probability of occurrence (usually derived from historical accident data) to give a risk value; the sum of these individual risk calculations is the total radiological accident risk. In order to perform the consequence calculations, dispersion of released material must be considered. In RADTRAN 4.0 dispersion from a presumed ground-level release point may be calculated by use of tables of time-integrated concentration (TIC) and deposition areas within isopleths that either correspond to Pasquill stability classes A through F at characteristic windspeeds or are entirely user-defined. The remainder of the radiological consequence calculation in RADTRAN 4.0 includes models describing exposure pathways (inhalation, resuspension, groundshine, cloudshine, ingestion, and direct exposure) and the accompanying health effects models.

NEW FEATURES OF RADTRAN 4.0

The following sections describe the major new features of RADTRAN 4.0.

1. Route-Specific Analysis Capability

   In any approach to route-specific analysis, the route or routes being analyzed are subdivided in some way on the basis of some route-related variable or set of variables such as offlink population density, traffic density, or accident rate. In previous versions of RADTRAN, only three route divisions per run could be treated, and these usually were defined in terms of offlink population density (i.e. rural, suburban, and urban). With RADTRAN 4.0, however, the user may analyze up to 40 separate route divisions in a single run. The following route-related parameters may be independently specified for each segment:

   - mode

- distance (kilometers),
- vehicle velocity (meters/second),
- offlink population density (persons/square kilometer),
- one-way traffic count (vehicles/hour)
- accident rate (accidents/kilometer),
- link type (highway or railroad type or classification).

The routes segments themselves are user-definable and may represent:

- summations of like segments,
- actual sequential route segments,
- the same segment(s) in two or more conditions (e.g., at various times of day).

Summation is the accumulation of all segments of a route that satisfy some predetermined criterion. Each resulting segment summation is treated in the analysis as a single route segment of length equal to the sum of the lengths of the individual qualifying segments. This technique has been widely used in transportation risk analysis (e.g., Wilmot et al. 1983, Neuhauser et al. 1984, and Cashwell et al. 1986) and offlink population density has been the criterion most commonly used to classify route segments. Regardless of what criterion is selected, all route segments must fall into some category established by the criterion, so that the grand total of the summations of all like-segment sets is equal to the total length of the route(s) studied. If this is not done properly, route segments may be either omitted or double-counted.

The analysis of route segments in sequential order from origin to destination corresponds most closely to one's intuitive definition of "route-specific" risk analysis; RADTRAN 4.0 allows the user to perform this type of analysis with relative ease. Actual data, such as measured population densities (rather than mean values of population-density zones) and actual accident rates, may be used for each route segment. One should note, however, that the usefulness of this approach is strongly dependent on the availability and quality of the segment-specific input data. When one considers potential differences in reporting bases and statistical reliability from one jurisdiction to another along cross-country routes, this approach may not yield better risk estimates than the segment-summation method described above. Nevertheless, this option is suitable for designation of alternative routes and similar problems, particularly when applied to routes within a jurisdiction with uniform reporting practices, etc.

An analysis that addresses differences in segment conditions would treat each route segment as if it were two or more separate segments. For example, to address time-of-day variations on an urban route segment, one could represent normal (i.e., offpeak) traffic flow conditions as one segment, and also represent peak traffic flow (i.e. rush hour) conditions as another segment. If the fraction of travel on the segment in each condition is known, then the user may determine the magnitude of the difference in transportation risks for the two conditions. Alternatively, the user may generate unit-risk factors (risk per kilometer of travel in each condition that each segment type may assume) for application in route-selection techniques.

2. Internal Radionuclide Data Library

RADTRAN 4.0 contains a data library of radionuclide-specific parameters for about 50 of the isotopes most commonly encountered in radioactive material shipments. The user needs only to input the radionuclide name; the following variables are then automatically entered into the data deck from the file:

- half-life (days)
- photon energy (Mev)
- cloudshine dose factor (rem-cubic meter/curie-second)
- 1-year effective ingestion dose equivalent (rem per curie ingested)
- 50-year effective inhalation dose equivalent (rem per curie inhaled)
- food transfer factor (curies transferred/curies deposited)
- soil transfer factor (curies transferred/curies deposited)
- deposition velocity (meters/second)
- 1-year dose equivalent, lung (rem per curie inhaled)
- 1-year dose equivalent, bone marrow (rem per curie inhaled)
- isotope classification (1 = short half-life; 2 = long half-life, low LET; and 3 = long half-life, high LET).

The user always has the option of overwriting these variables with his or her own values.

3. Multiple-Radionuclide Packages

In actual practice, many radioactive materials shipments contain more than one radionuclide. Some of these shipments (e.g., spent fuel, TRU waste, and defense high-level waste) are the subject of considerable controversy. Previous versions of RADTRAN had no provisions for making a distinction between the material being shipped and the individual isotopes that comprised it. The user had to create a "virtual material" to represent the intact package, assign to it the entire TI value, and include it in the isotope list. This was required because the incident-free consequence calculations concern the intact package or, more specifically, the radiation field produced by the intact package, which is a function of the TI value. However, in the calculation of accident risks the amounts (in curies) and properties of the individual isotopes that comprise the material become important. Thus, since the virtual material was used to represent the package and was assigned all the TI, all incident-free impacts were properly assigned to this material in the printed output. Conversely, since the virtual material was assigned zero curies, the contribution to accident risk of the individual isotopes was properly calculated without interference from the virtual material.

Particularly for complex materials made up of many isotopes, the manipulations described above can be confusing. Therefore, RADTRAN 4.0 has been modified to contain logic that performs these manipulations in a manner that is transparent to the user. The user is merely asked to enter a name for the multiple-isotope material and to give the package TI and the names and amounts (in curies) of the individual isotopes that comprise the material. The code then automatically creates a virtual material bearing the user-specified name, allocates the TI value to the material and the curie values to the individual isotopes.

4. Neutrons in the Incident-Free Dose Calculation.

RADTRAN 4.0 allows the user to treat the gamma and neutron components of the TI separately if the dose rate allocation is known to the user. The effect of air transmission has been built into the dose equations for each population group. Thus,

$$\text{Dose Rate} = K \frac{e^{-\mu r}\left(1 + a_1 r^1 + a_2 r^2 + a_3 r^3 + a_4 r^4\right)}{r^2}$$

For moving sources this involves an integrated form that includes the changing exposure distance and results in a series of terms that use a type of Bessel function. The coefficients in the transmission factor (a_1, a_2, a_3, a_4) have been evaluated for a fission product neutron spectrum and are available in the code as default data. If the default values are used, the user must still specify the fractional gamma-neutron dose rate split. The coefficient evaluation was performed using standard non-linear regression techniques applied to the results of a neutron transport calculation that was performed with 1DANT, a one-dimensional transport code, applied to air with humidity that ranged from 0 to 100%.

5. Accident-Severity Categories,

Earlier codes allowed the user to divide a mode-specific universe of transportation accidents into a maximum of eight accident-severity categories per population-density zone. Each accident-severity category employed by the user is assigned a conditional probability of occurrence (i.e., the conditional probability, given that an accident occurs, that it will be of that particular severity). Both eight-category and six-category schemes have been used in previous analyses (USNRC, 1977, Wilmot 1981) More recently, the NRC Modal Study (Fischer et al. 1987) introduced a 20-category scheme in their analysis of a present-generation spent fuel cask. In the study only average probabilities of occurrence were given, and no attempt was made to account for differences in severity distribution between population-density zones. No other radioactive material packaging has as yet been subjected to the same type of analysis, but one may expect that this will be attempted in the future. Therefore, RADTRAN 4.0 was modified to permit the use of up to 20 accident-severity categories. For this large number of categories, obtaining defensible probabilities and related package behavior values is not presently possible for most packagings. For many of the radioactive material packages found in general commerce, use of this number of accident-severity categories would clearly be neither sensible or cost-effective. Thus, it should be emphasized that the user is not required to use 20 severity categories.

Any accident-severity matrix involving any number of categories less than or equal to 20 may be used.

RADTRAN 4.0 ON TRANSNET

Within the United States and Canada, RADTRAN 4.0 will be available free of charge on the TRANSNET system in late 1989 (Cashwell, 1989). Qualified users may access the system with an IBM-compatible personal computer, a Hayes-compatible modem, and communication software. Like RADTRAN (Version 3.1), which is currently on TRANSNET and which will be replaced by RADTRAN 4.0, data entry is menu-driven and the 80-column output is directly compatible with ordinary personal computer printers. Two types of output may be requested - summary risk tables only or a full printout of results including intermediate consequence tables.

CONCLUSION

Five major modifications have been incorporated in RADTRAN 4.0. Summarizing, these modifications are:

- Route-Specific Analysis Capability
- Radionuclide Data Library
- Logic for Multiple-Radionuclide Packages
- Gamma-Neutron Split in the Transport Index
- 20 Accident Severity Categories

The intent of these changes has been (a) to permit various types of route-specific analysis to be accomplished with relative ease, and (b) to increase the flexibility and broaden the scope of application of RADTRAN 4.0.

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