Application of RADTRAN to Estimation of Doses to Persons in Enclosed Spaces*

K. S. Neuhauser

Sandia National Laboratories**, Albuquerque, New Mexico, United States of America

Introduction

The RADTRAN computer code for transportation risk analysis (Neuhauser and Kanipe, 1992) can be used to estimate doses to persons in enclosed volumes. This application was developed in response to a need to examine consequences of a hypothetical container leak during accident-free transportation by cargo air. The original problem addressed tritium containers, but the method can be applied to any gaseous or suspended particulate material potentially released in an airplane or other enclosed area (e.g., warehouse) under accident-free conditions. Such leakage can occur during shipment of any radioactive gas or material with a gaseous phase. Atmospheric dispersion is normally modeled in RADTRAN as a series of downwind isopleths each of which is assigned a dilution factor (also known as time-integrated concentration or X/Q value). These values are located in look-up tables in RADTRAN and are normally taken from externally performed Gaussian dispersion calculations. The dilution factors are used to estimate inhalation dose to persons in the specified downwind areas. The basic equation for inhalation dose in RADTRAN is:

$$Dinh = Ci \bullet PPS \bullet RF \bullet AER \bullet RESP \bullet RPC \bullet DF \bullet BR \bullet PD \bullet A \quad (1)$$

Where

Dinh	=	inhalation dose (person-rem)
Ci	=	curies in package (Ci)
PPS	=	number of packages in shipment
RF	=	fraction of material released from a package
AER	=	fraction of released material in aerosol form
RESP	=	fraction of aerosol material that is respirable
RPC	=	dose conversion factor (rem/Ci)
DF	=	dilution factor (Ci-sec/m^3/Ci released)
BR	=	breathing rate (m^3/sec)
PD	=	population density (persons/m^2)
A	=	isopleth area (m^2).

*This work performed at Sandia National Laboratories, Albuquerque, New Mexico, supported by the United States Department of Energy under Contract DE-AC04-76DP00789

**A United States Department of Energy facility

Equation 1 is located in the accident module of RADTRAN; it is usually applied iteratively. That is, a separate calculation is performed for each potentially released isotope in each downwind area for each accident severity specified by the user, and the results of these intermediate calculations are then summed. The following sections outline the procedure by which terms in Equation 1 can be replaced to yield a single calculation for an enclosed-volume dose for a fixed time of exposure.

Define Population within Enclosed Volume

The user models the enclosed volume as a single isopleth. This single isopleth must be assigned a nonzero area (m^2); the areas of all other isopleths should be set to zero. Note in Equation 1 that the product of the terms (PD • A) gives the number of persons in the isopleth. The user selects values of these two terms such that their product gives the number of persons in the crew, which is the potentially exposed population.

Substitute Concentration for Dilution Factor and Total Volume Inhaled for Breathing Rate

An isopleth would normally be assigned a dilution factor as described above, but dilution factors include a time term that accounts for wind speed. Exposure of persons within an enclosed volume does not depend on wind speed. Thus, in the application described here, the user substitutes a concentration for the dilution factor in the single isopleth being used to simulate the enclosed volume. Note that in Equation 1 the product of dilution factor (Ci-sec/m^3/Ci) and breathing rate (m^3/sec) gives curies inhaled per curie released. Note also that the product of concentration (Ci/m^3) and total volume inhaled (m^3) gives the same result. Thus, in order to preserve the equality in Equation 1, the user must also substitute total volume inhaled for the breathing rate term.

Calculation of Maximum Concentration and Total Volume Inhaled

The concentration value parameter depends on the interior volume of the aircraft and the amount of material released. Calculation may not be straightforward, however. In the tritium example, the material was shipped as tritium gas (T_2), which has a lower dose conversion factor than tritiated water (H3WTR). Tritium oxidizes rapidly in air, however, and it is conservative to model all released tritium as oxidizing instantaneously. Therefore, in this application the material was modelled as THO in vapor form. Additional complexity is introduced when what is being modeled is a potentially leaking container rather than one that releases a fraction of its contents all at once, because the enclosed-volume concentration will vary with time. A simple and conservative treatment of this problem consists of calculating the total amount of material that would be released if the container began leaking (at a constant rate) at the beginning of the flight and using this amount to calculate concentration. Using a concentration calculated in this manner to characterize the entire flight is conservative because that concentration in fact would only be achieved at the end of a flight (in-flight air exchange is neglected). Knowledge of container behavior is required, specifically expected leak rate. If there is more than one leak mechanism, then each must be analyzed separately.

Calculation of total volume inhaled (V_t) is more straightforward. One must know the number of persons in the crew, and the flight time. Using the standard ICRP breathing rate parameter for an adult male at work, one calculates V_t as follows:

$$V_t = BR \bullet T \bullet N$$

Where

BR	=	breathing rate (3.30E-04 m^3/sec)
T	=	flight time (sec)
N	=	number of crew members = PD • A

Other Parameters

In order for the calculation to proceed correctly, one must consider the other terms in Equation 1 and make certain that they are properly evaluated. The product Ci • RF normally gives the total number of curies released, but since that is already accounted for with the concentration value substituted for DF, these parameters should be set equal to 1.0. The number of packages per shipment (PPS) should represent the number of potentially leaking packages in the shipment; this may be varied in a series of runs if a probabilistic treatment is desired. The aerosol and respirable fractions (AER and RESP) should be set to 1.0. The dose conversion factor (RPC) and deposition velocity for H3WTR in vapor form are called from the internal radioisotope library in RADTRAN. The deposition velocity is not used in Equation 1, but it must be set to zero; otherwise all isopleths are automatically depleted to account for deposition, which skews the results. The default value for deposition velocity for H3WTR in the internal radioisotope library is zero. Had this not been the case, the user would have had to use the RADTRAN DEFINE function to redefine H3WTR.

Summary of Substitutions

When fully substituted as described above, the Equation 1 can be rewritten as follows

$$Dinh = Ci \bullet PPS \bullet RF \bullet AER \bullet RESP \bullet RPC \bullet C \bullet V_t \qquad (2)$$

Where

Dinh	=	inhalation dose (person-rem)
Ci	=	1.0
PPS	=	number of leaking packages in shipment
RF	=	1.0
AER	=	1.0
RESP	=	1.0
RPC	=	dose conversion factor (rem/Ci)
C	=	concentration (Ci/m^3)
V_t	=	total volume inhaled (m^3)
	=	BR (m^3/sec) • T (sec) • PD (persons/m^2) • A area (m^2).

The parameter values that must be entered in RADTRAN to realize the relationship in Equation 2 are summarized below.

- Substitute the value of C for the usual dilution factor (DF) in a single isopleth and enter zeros for all other isopleths.
- Substitute volume inhaled per person (BR • T) for the usual breathing rate value.
- Enter values of PD and A such that the product equals the number of persons in the enclosed volume.

The user must also set the accident rate equal to the probability (per flight) that a leak is expected to occur. If the failure rate is known or can be estimated (failure events/hr), then the probability is equal to the product of the failure rate and the total time per trip.

Output Formats

The risk results are listed under the output table entitled Expected Values of Population Risk in Person-Rem. In RADTRAN, consequences are calculated prior to multiplication by the probability term, and this consequence result is also given in the output in the Accident Summary in the table entitled Radiological Consequences—Mode [Cargo Air], 50-Year Population Dose in Person-Rem.

The user is encouraged to use the Comment capability of RADTRAN to enter as many comment lines (i.e., text lines) as necessary to describe the parameter substitutions being used.

Since these comments are automatically printed in the output, the user retains a record of what was done along with the results. A sample of a fully commented RADTRAN output for a tritium example is attached.

References

Neuhauser, K. S., and F. L. Kanipe, *RADTRAN 4: Volume 3, User Guide*, SAND89-2370, Sandia National Laboratories, Albuquerque, NM, 1992.