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RADTRAN Release 1: Retrieval and Verification from Archive

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Abstract

This report describes the recovery and verification of the first version of the RADTRAN transportation risk analysis code, together with its modification to run on modern workstations. RADTRAN was used to calculate the risks documented in the Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes (NUREG-0170), which was published by the US Nuclear Regulatory Commission in December 1977.

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1.0 Introduction

This report describes the restoration and functional testing of Release 1 of the RADTRAN code for transportation risk assessment. It also describes the restoration of input files for Release 1 and their use to obtain output that can be compared with results from more recent releases of the code for the same input values.

1.1 Background

RADTRAN Release 1 was developed in the mid-1970's to support analyses performed for the Nuclear Regulatory Commission's (NRC) environmental statement entitled "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes," also known as NUREG-0170 (NRC, 1977). Although no mention of RADTRAN is made in NUREG-0170 itself, it was used to generate the values in Chapters 4 and 5 of that report, and output for a similar analysis is documented in Appendix B of the original RADTRAN manual (Taylor and Daniel, 1977).

There have been four additional releases of the RADTRAN code since 1977 (Taylor and Daniel, 1982; Madsen et al., 1986; Neuhauser and Kanipe, 1992, and Neuhauser and Kanipe, 1998). The most recent release, RADTRAN 5, is available in draft form. The code is most often used to perform transportation risk and consequence analyses for environmental impact statements (EIS) and environmental assessments (EA). One trend over this time has been an increasing emphasis on removing excess conservatism. In the case of spent fuel, detailed calculations based on the nature and amount of radioactive gases, vapors and aerosols potentially released from spent fuel rods, together with new calculations of the probabilities of such releases, have supported this process. For example, finite element calculations of the probability of spent fuel cladding failure were included in Sanders et al., 1992. Similarly, Sprung et al., 1995, applied the MELCOR hydrodynamics code (Gauntt et al., 1998) and, for the first time, accounted for pressure differences between the interior and exterior of the cask. Health-effects models have been updated during this period as well.

These developments have been incorporated in the code in the form of model changes or new models and, in some cases, as recommended input values. Not surprisingly, the most recent release of RADTRAN produces risk estimates different from those of Release 1 for spent-fuel transportation. In general, recent risk estimates tend to be lower than those published in NUREG-0170.

1.2 Report Rationale

Because of advances in risk assessment, in general, over the last two decades and changes in RADTRAN, in particular, the NRC asked Sandia National Laboratories to formally compare the risks of transporting spent nuclear fuel as calculated by the current version of

RADTRAN and the first release of the code. In order to carry out that project, Release 1 had to be restored.

There were two reasons for this. First, Release 1 ran on a CDC-6600 computer. RADTRAN 2 was run on a larger CDC machine and RADTRAN 3 and 4 ran on a DEC VAX. RADTRAN 5 runs on a UNIX work station. As successive versions of RADTRAN were developed on machines of newer architecture, in newer dialects of FORTRAN, earlier versions became obsolete along with the hardware on which they ran and were no longer supported by Sandia. Thus Release 1 of RADTRAN was no longer capable of being run on current machines. It existed only as a hard copy code listing on microfiche. Release 1, therefore, had to be rendered into electronic form and modified to run on a UNIX workstation.

1.3 Report Organization

There are four main sections in this report. The first section describes the changes necessary to update the code to run with the UNIX operating system. The next two sections compare results obtained with the new UNIX version (RADTRAN-1U) against results for the same problems as originally published in 1977. The second section addresses a sample problem from the original RADTRAN user manual (Taylor and Daniel, 1977). The third section addresses results from a restored input file derived from the user manual and NUREG-0170 itself (NRC, 1977). Appendix A, included on the attached floppy disk, contains the complete input and output files for both problems.

2.0 Modifications to RADTRAN-1 for UNIX

The CDC-6600 hardware on which RADTRAN was originally developed had a 60-bit word made up of ten bytes each six bits long. The UNIX work-station to which that original version has now been ported has a 32-bit word made up of four 8 bit bytes. These hardware differences defeat a strategy used by the original programmers of RADTRAN, which was to confine all character data to groups of 10 or fewer characters, which could then be stored in a single integer word as a Hollerith constant.

Two alternatives for handling the hardware differences are possible under UNIX, while still remaining within the current ANSI standard for FORTRAN. In the first, the integer based Hollerith constants would be changed into character arrays; this would require extensive revision of the common blocks holding the code's variables and arrays, as well as introducing other elements from later versions of FORTRAN. The second alternative, which is the one chosen because it is more faithful to the original FORTRAN dialect and requires fewer coding changes, expands the character grouping to 12 characters in three sets of 4 characters each.

Each set of characters occupy twelve bytes, or three words. Thus, integer words on the CDC-6600, when they are to hold Hollerith data, are replaced by an array of three integers on today's work stations. In the input deck the corresponding field width changes from 10

to 12. One-dimensional integer arrays of Hollerith data changed to 2 dimensional arrays. Since many of the FORMAT statements involved the reading or writing of such information, these were revised as needed, along with the read and write statements that used them.

The smaller word size on a Hewlett Packard workstation also affects the arithmetic precision of some calculations in the code, particularly in the computation of probabilities from expected values. Hence this version is run with floating point variables increased to double precision. This, in effect, replaces the CDC 60-bit with 64-bit precision on the HP machine.

3.0 RADTRAN-1 Sample Problem

Appendix D to the user manual for RADTRAN-1 (Taylor and Daniel, 1977) presents listings of the input and output files for an example transportation risk assessment. This section compares summary results from the new UNIX version with those of the original user manual. In particular, percentage deviations are given showing the degree of agreement between the new results and those published in Taylor and Daniel, 1977. Complete listings of the recalculated input and output files are given on the attached floppy disk, Appendix A.

The problem relates to shipment of two materials, called XXXX and YYYY in the original user manual. Material XXXX is shipped in three Type-B packages per shipment, for a total of 10,000 airborne shipments per year. Each package has a TI of 5, and carries 1000 curies of the material. It is considered to be a soluble liquid, for which the lungs are the only vulnerable organ. The health effects for this material are calculated based on an assumed organ dose of 10^8 rem per curie inhaled. Material YYYY is shipped in one cask per shipment, by truck, 10,000 times per year. The cask is assigned release fractions that are designed to model loss of shielding in accidents, with airborne release of gases and volatiles but no particulates. The TI of each cask is 10, and carries 10 million curies of the material. It is described as an "NS" material, where NS means non-dispersable solid. A whole body dose is calculated using a dose-conversion factor of 1.3 rem per curie of material.

3.1 Sample Problem: Incident-Free Results

Table 1 shows the incident-free summary table from the recalculated sample problem. It shows the cumulative population dose in person-rem broken down by exposed population group and material shipped. For example, since there are no passengers or attendants involved in any of the shipments modeled, there is no dose to these groups. The crew and truck drivers receive a total of 1684 person-rem, of which 1569 person-rem is from material YYYY. As another example, the dose at stops is 16.15 person-rem from material XXXX, but 1894 person-rem from material YYYY, and the total exposure for all shipments is calculated to be about 27,000 person-rem.

Table 1. Recalculated Incident-Free Population Dose Summary

SUMMATION OF GROUP POPULATION EXPOSURE TO RADIATION IN PERSON REM AS A RESULT OF TRANSPORT OF VARIOUS RADIOACTIVE MATERIALS UNDER NORMAL CONDITIONS

ISOTOPE SHIPMENT	GROUPS				SURROUNDING POPULATION				
	PASSENGERS	CREWMEN	ATTENDANTS	HANDLERS	OFFLINK	ONLINK	STOPS	STORAGE	TOTALS
XXXX	0.000E+00	1.158E+02	0.000E+00	2.250E+02	1.486E+01	6.275E+01	1.615E+01	2.383E+01	4.584E+02
YYYY	0.000E+00	1.569E+03	0.000E+00	2.000E+04	1.904E+03	9.405E+02	1.894E+03	4.964E+02	2.680E+04
TOTALS	0.000E+00	1.684E+03	0.000E+00	2.023E+04	1.919E+03	1.003E+03	1.910E+03	5.202E+02	2.726E+04

Table 2 shows the small deviations that exist between the recalculated results in Table 1 and those given in the user manual. In 16 cases the agreement is complete to the accuracy with which the published numbers were presented, a deviation of 0.0%. Seven entries show a deviation of about 0.05%, and two entries are at about 0.15 %. The differences may be due to illegibility of some characters in the microfiche copy used to generate the data set.

Table 2. Comparison of Calculated Incident-Free Doses Obtained from RADTRAN-1U and Values Given in Taylor and Daniel, 1977.

THE DEVIATION IN PERCENT FROM NUREG-0170 OF THE SUMMATION OF GROUP POPULATION EXPOSURE TO RADIATION IN PERSON REM AS A RESULT OF TRANSPORT OF VARIOUS RADIOACTIVE MATERIALS UNDER NORMAL CONDITIONS

ISOTOPE SHIPMENT	GROUPS				SURROUNDING POPULATION				
	PASSENGERS	CREWMEN	ATTENDANTS	HANDLERS	OFFLINK	ONLINK	STOPS	STORAGE	TOTALS
XXXX	0.0%	0.0%	0.0%	0.0%	0.0672%	0.0%	0.0%	0.0%	0.0%
YYYY	0.0%	0.0%	0.0%	0.0%	0.0525%	0.0525%	0.1581%	0.0%	0.0373%
TOTALS	0.0%	0.0%	0.0%	-0.0495%	0.0521%	0.0521%	0.1568%	0.0%	0.0367%

3.2 Sample Problem: Accident Case Results.

Radiological risk associated with transportation accidents is defined as the sum over all scenarios of the product of accident probability and the consequences in dose or health effects. Since probability has no units, the units of risk are the same as the consequence units. If the consequence being discussed is population dose in person-rem, then the risk will have the same unit – although the values will be reduced by the probabilities of the accidents considered (usually a very small number). The values quoted in the tables in this section are risk, not consequence, values.

Table 3 shows the summary accident dose-risk values in person-rem from Taylor and Daniel, 1977, the risk as recalculated by RADTRAN-1U, and the percentage deviation between them. A complete listing of the RADTRAN-1U output is on the attached floppy disk (Appendix A).

Table 3. Comparison of Calculated Dose-Risks in Person-Rem for the Sample Problem

Material Name	Risk from SAND76-0243 (Person-rem)	Risk from RADTRAN-1U (Person-Rem)	Percentage Difference %
XXXX	1.586×10^{5}	1.586×10^{5}	0.0
YYYY	7.778×10^{-2}	7.778×10^{-2}	0.0
Totals	1.586×10^{5}	1.586×10^{5}	0.0

RADTRAN-1 also gives estimates of the probability of occurrence of various numbers of latent cancer fatalities as a result of accidents which might occur during all shipments. Table 4 shows a comparison of those results as published in Taylor and Daniel, 1977, against the same quantities recalculated using RADTRAN-1U. The agreement is complete for all probabilities greater than 10^{-9}. The differences here are attributed to the extra four bits of precision available on the Hewlett Packard workstation operating in double precision.

Table 4. Sample Problem Latent Cancer Fatality Probability Comparison

Number of LCF's	Probability From SAND76-0243	Probability From RADTRAN-1U	Difference %
1	1.041581×10^{-1}	1.041581×10^{-1}	0.0
2	1.833316×10^{-1}	1.833316×10^{-1}	0.0
3	2.151421×10^{-1}	2.151421×10^{-1}	0.0
4	1.893542×10^{-1}	1.893542×10^{-1}	0.0
5	1.333258×10^{-1}	1.333258x10-1	0.0
6	7.822985×10^{-2}	7.822985×10^{-2}	0.0
7	3.934449×10^{-2}	3.934449x10-2	0.0
8	1.731424×10^{-2}	1.731424×10^{-2}	0.0
9	6.772833×10^{-3}	6.772833×10^{-3}	0.0
10	2.384404×10^{-3}	2.384404x10-3	0.0
15	3.578413×10^{-6}	3.578413×10^{-3}	0.0
20	1.048192×10^{-9}	1.040190×10^{-9}	0.00019
25	9.237656×10^{-14}	8.826273×10^{-14}	4.5

4.0 NUREG-0170 Comparison

NUREG-0170 contains neither the input file nor the detailed output for the RADTRAN Release 1 computer runs used to generate the values given in Chapters 4 and 5 of that report. The original copies of those files were not preserved. Furthermore, output values given in the relevant tables in NUREG-0170 have been rounded off, reducing the number of significant digits available for comparison. This was an appropriate action, but it makes it impossible to verify that the results obtained with the re-created code are *exactly* the same as the original values.

The input file was restored primarily from information in Appendix A of NUREG-0170. Two other sources were used as well: the first was the RADTRAN-1 user manual (Taylor and Daniel, 1977), which contains an incomplete listing of a calculation closely resembling the shipments detailed in NUREG-0170; the other was an unpublished, archived, computer run with the title "NUREG-0170 DATA for RTN2.1."

By checking the details of each material specification in these sources it has been possible to approximate the original input file, and thereby redo the original analysis – although the results do not completely agree with those published in the environmental statement. The differences are attributed to unresolved data discrepancies introduced during the input reconstruction process.

4.1 NUREG-0170 Incident-Free Results Comparison

Table 5 presents the incident-free summary table as recalculated for the NUREG-0170 analysis. It shows the integrated population dose in person-rem for each material, referred to as a Standard Shipment in the environmental statement. A Standard Shipment carries all the individual packages of the material, for the distance shipped by truck, rail, air or van mode, aggregated over the entire year 1975. The results of the calculation are in good agreement with Table 4-16 of NUREG-0170.

4.2 Incident-Free Deviation From NUREG-0170

The results in Table 5 can be compared with Table 4-16 of NUREG-0170, material by material. The differences, expressed as a percentage of the NUREG values, are given in Table 6. In most cases the deviation is less than 0.1 percent, but there are exceptions that arise from the numerical noise induced by the rounding and truncation present in the NUREG values. The worst case value is a good illustration of this: CO60-LQ1 for the ON-LINK exposure group shows a 32% deviation. This arises because the NUREG value is given to three decimal places, as 0.001, which has only one significant figure. The value calculated with RADTRAN-1U is 1.328×10^{-3}. The deviation is attributed to round-off in the value given in NUREG-0170.

Table 5. Incident-Free Summary for NUREG-0170 Recalculated by RADTRAN-1U

SUMMATION OF POPULATION EXPOSURE TO RADIATION IN PERSON REM AS A RESULT OF TRANSPORT OF VARIOUS RADIOACTIVE MATERIALS UNDER NORMAL CONDITIONS

ISOTOPE	GROUPS				SURROUNDING POPULATION WHILE MOVING				
SHIPMENT	PASSENGERS	CREWMEN	ATTENDANTS	HANDLERS	OFF LINK	ON LINK	STOPS	STORAGE	TOTALS
LIMITED-A	1.781E+01	2.659E+01	8.526E-01	1.160E+01	8.753E-01	1.651E+00	1.684E+00	2.173E+00	6.325E+01
AM241-A	1.891E+01	1.152E+02	9.053E-01	7.904E+01	4.368E+00	1.043E+01	1.457E+01	1.841E+01	2.618E+02
AM241-B	4.138E-01	1.097E+00	1.981E-02	2.403E-01	3.241E-02	4.658E-02	4.583E-02	5.861E-02	1.954E+00
AU198-A	1.547E+01	2.516E+01	7.402E-01	1.659E+01	9.346E-01	2.172E+00	2.434E+00	3.139E+00	6.664E+01
CO57-A	6.512E+00	4.598E+00	3.117E-01	1.957E+00	1.495E-01	2.777E-01	2.310E-01	3.051E-01	1.434E+01
CO60-A	0.000E+00	4.319E+02	0.000E+00	1.221E+02	1.291E+01	1.889E+01	2.601E+01	3.249E+01	6.443E+02
CO60-B	0.000E+00	1.086E+01	0.000E+00	3.285E+00	2.652E-01	1.310E-01	8.354E-01	1.044E+00	1.642E+01
CO60-LQ1	0.000E+00	1.101E-01	0.000E+00	0.000E+00	2.688E-03	1.328E-03	4.285E-03	1.123E-03	1.195E-01
CO60-LQ2	0.000E+00	6.237E-01	0.000E+00	8.000E-01	7.572E-02	3.739E-02	7.575E-02	1.986E-02	1.632E+00
CO60-LSA	7.486E+00	1.103E+02	3.583E-01	4.388E+01	3.711E+00	7.242E+00	1.043E+01	1.309E+01	1.965E+02
C14-A	2.789E+00	1.230E+00	1.335E-01	8.052E-01	4.562E-02	1.084E-01	7.895E-02	1.069E-01	5.297E+00
CS137-A	3.442E+00	1.375E+02	1.648E-01	1.301E+02	5.876E+00	1.625E+01	2.701E+01	3.381E+01	3.542E+02
CS137-B	0.000E+00	6.043E-01	0.000E+00	2.220E-01	2.019E-02	3.899E-02	5.372E-02	6.735E-02	1.007E+00
GA67-A	3.358E+00	7.885E+00	1.607E-01	6.014E+00	3.075E-01	7.647E-01	9.519E-01	1.217E+00	2.066E+01
H3-A	3.139E-01	1.662E-01	1.502E-02	1.136E-01	6.136E-03	1.441E-02	1.178E-02	1.570E-02	6.567E-01
H3-LSA	3.193E-01	2.116E-01	1.528E-02	2.535E-01	1.015E-02	3.180E-02	2.597E-02	3.493E-02	9.026E-01
IR192-A	2.050E+01	1.823E+01	9.810E-01	8.926E+00	6.363E-01	1.345E+00	1.125E+00	1.495E+00	5.324E+01
IR192-B	1.702E+02	2.637E+02	8.146E+00	8.201E+01	8.484E+00	1.521E+01	1.389E+01	1.814E+01	5.798E+02
I131-A	1.002E+03	5.027E+02	4.796E+01	4.260E+02	2.043E+01	5.426E+01	4.295E+01	5.790E+01	2.154E+03
I131-B	8.504E-01	1.144E+00	4.070E-02	5.535E-01	4.077E-02	8.931E-02	8.770E-02	1.143E-01	2.920E+00
MIXED-A	1.678E+00	2.499E+01	8.031E-02	1.763E+01	9.520E-01	2.283E+00	3.536E+00	4.437E+00	5.558E+01
MIXED-B	0.000E+00	1.494E+00	0.000E+00	5.757E-01	4.977E-02	9.502E-02	1.464E-01	1.829E-01	2.544E+00
MIXED-LSA	1.252E+00	1.897E+01	5.993E-02	6.974E+00	6.245E-01	1.165E+00	1.666E+00	2.091E+00	3.280E+01
MF+MC-A	0.000E+00	1.862E+01	0.000E+00	0.000E+00	8.937E+00	4.414E+00	3.219E+01	8.437E+00	7.260E+01
MF+MC-B	0.000E+00	1.077E+00	0.000E+00	0.000E+00	2.630E-02	1.299E-02	1.061E-01	2.780E-02	1.250E+00
MF+MC-LQ	0.000E+00	3.250E-01	0.000E+00	0.000E+00	7.936E-03	3.919E-03	1.091E-02	2.859E-03	3.506E-01
MF+MC-LSA	0.000E+00	2.245E+01	0.000E+00	0.000E+00	3.470E+00	1.714E+00	1.606E+01	4.208E+00	4.790E+01
MO99-A	8.734E+02	7.138E+02	4.180E+01	3.927E+02	2.502E+01	5.355E+01	4.753E+01	6.258E+01	2.210E+03
MO99-B	1.439E+02	1.271E+02	6.888E+00	3.108E+01	3.803E+00	5.770E+00	4.496E+00	5.919E+00	3.289E+02
PO210-A	1.866E-02	1.770E-02	8.932E-04	1.300E-02	7.388E-04	1.798E-03	1.527E-03	2.114E-03	5.643E-02
PO210-LQ	1.705E-01	1.500E-01	8.160E-03	5.782E-02	5.467E-03	1.004E-02	7.895E-03	1.108E-02	4.210E-01
P32-A	1.084E+01	6.587E+00	5.186E-01	4.511E+00	2.479E-01	5.951E-01	4.901E-01	6.541E-01	2.444E+01
XE133-A	1.078E+01	1.283E+01	5.160E-01	5.455E+00	4.198E-01	7.854E-01	7.421E-01	9.643E-01	3.249E+01
WASTE-A	0.000E+00	1.391E+02	0.000E+00	0.000E+00	2.535E+02	1.252E+02	7.447E+02	1.952E+02	1.458E+03
WASTE-B	0.000E+00	5.651E-01	0.000E+00	0.000E+00	3.567E-01	1.762E-01	1.576E+00	4.130E-01	3.087E+00
WASTE-LSA	0.000E+00	1.739E+01	0.000E+00	0.000E+00	3.445E+00	1.701E+00	1.255E+01	3.289E+00	3.837E+01
RA226-A	0.000E+00	5.867E+01	0.000E+00	2.730E+01	1.961E+00	3.766E+00	5.815E+00	7.263E+00	1.048E+02
RA226-B	1.038E-01	1.315E+00	4.969E-03	1.372E+00	6.355E-02	1.982E-01	3.132E-01	3.938E-01	3.765E+00
KR85-A	1.011E+01	2.497E+01	4.837E-01	6.274E+00	8.071E-01	1.132E+00	1.079E+00	1.380E+00	4.623E+01
KR85-B	9.213E-02	2.232E-01	4.410E-03	6.000E-02	6.851E-03	1.095E-02	1.125E-02	1.441E-02	4.233E-01
PU238-A	8.024E-02	1.790E-01	3.841E-03	1.579E-01	7.429E-03	1.996E-02	2.440E-02	3.130E-02	5.041E-01
PU238-B	5.887E-01	1.246E+00	2.818E-02	3.567E-01	3.860E-02	6.301E-02	6.579E-02	8.440E-02	2.472E+00
PU239-LG-B	9.157E-01	2.789E+01	4.383E-02	6.192E+00	8.244E-01	1.168E+00	1.526E+00	1.910E+00	4.047E+01
PU239-LG-LQ	0.000E+00	2.965E-03	0.000E+00	3.000E-03	1.982E-04	8.366E-04	2.154E-04	3.177E-04	7.533E-03
SF-ES-T	0.000E+00	3.130E+01	0.000E+00	5.080E+01	3.800E+00	1.876E+00	4.810E+00	1.261E+00	9.384E+01
SF-ES-R	0.000E+00	6.742E-02	0.000E+00	6.800E+00	1.744E-01	2.209E-01	8.336E-02	4.266E-01	7.773E+00
U3O8-N-LSA	0.000E+00	1.128E+02	0.000E+00	1.716E+02	4.694E+01	3.873E+01	4.690E+01	6.705E+01	4.840E+02
UF6N-LG-A	0.000E+00	1.720E+01	0.000E+00	6.500E+00	1.024E+00	1.300E+00	1.780E+00	2.540E+00	3.034E+01
UF6E-LG-B	0.000E+00	3.143E+00	0.000E+00	1.470E-01	1.180E-01	1.351E-01	2.179E-01	1.071E-01	3.868E+00
UO2E-LG-B	0.000E+00	1.955E+01	0.000E+00	2.968E+00	2.832E+00	3.249E+00	5.207E+00	2.571E+00	3.638E+01
UO2-rods-B	0.000E+00	1.239E+01	0.000E+00	3.948E-01	4.412E-01	4.641E-01	6.885E-01	3.409E-01	1.472E+01
U+PU-B	1.839E+00	1.271E+01	8.801E-02	1.960E+00	3.558E-01	4.205E-01	4.389E-01	5.535E-01	1.836E+01
TC99m-A	3.434E+00	4.209E+01	1.643E-01	5.769E+01	2.148E+00	7.005E+00	1.114E+01	1.401E+01	1.377E+02
TOTALS	2.330E+03	3.131E+03	1.115E+02	1.734E+03	4.216E+02	3.862E+02	1.088E+03	5.720E+02	9.774E+03

Table 6. Deviation in Incident-Free Dose between NUREG-0170 and RADTRAN-1U

PERCENTAGE DEVIATION FOR THE

SUMMATION OF POPULATION EXPOSURE TO RADIATION IN PERSON REM AS A

RESULT OF TRANSPORT OF VARIOUS RADIOACTIVE MATERIALS UNDER NORMAL CONDITIONS

	GROUPS				SURROUNDING POPULATION				
ISOTOPE					WHILE MOVING				
SHIPMENT	PASSENGERS	CREWMEN	ATTENDANTS	HANDLERS	OFF LINK	ON LINK	STOPS	STORAGE	TOTALS
AM241-A	-5.291E-02	-1.739E-01	-3.315E-02	-5.063E-02	2.740E-01	6.667E-01	2.055E-01	-5.435E-02	7.634E-02
AM241-B	-1.937E-01	2.727E-01	9.500E-01	-1.250E-01	-1.281E+00	8.936E-01	3.696E-01	6.610E-01	-2.051E-01
AU198-A	1.935E-01	1.587E-01	-2.702E-02	6.024E-02	3.625E-01	3.670E-01	2.459E-01	3.185E-02	8.996E-02
CO57-A	-1.846E-01	-1.743E-01	-2.251E-01	1.531E-01	3.333E-01	4.659E-01	0.000E+00	-3.279E-02	-2.797E-01
CO60-A	0.000E+00	2.540E-01	0.000E+00	-8.197E-02	6.923E-01	5.789E-01	3.448E-01	3.077E-02	1.085E-01
CO60-B	0.000E+00	3.670E-01	0.000E+00	1.520E-01	-7.547E-02	0.000E+00	3.310E+00	-3.846E-01	-1.220E-01
CO60-LQ1	0.000E+00	-9.091E-02	0.000E+00	0.000E+00	1.037E+01	-3.280E+01	-7.125E+00	-1.230E+01	4.167E-01
CO60-LQ2	0.000E+00	5.263E-01	0.000E+00	0.000E+00	-9.600E-01	1.605E+00	3.289E-01	7.000E-01	4.878E-01
CO60-LSA	5.340E-02	-2.727E-01	-8.380E-02	4.556E-02	2.419E-01	5.220E-01	-2.885E-01	7.634E-02	2.538E-01
C14-A	3.584E-02	0.000E+00	3.731E-01	-2.484E-02	8.261E-01	5.505E-01	6.329E-02	9.346E-02	5.661E-02
CS137-A	-5.814E-02	3.623E-01	1.212E-01	-7.692E-02	-1.087E+01	3.067E-01	3.321E-01	-2.959E-02	2.254E-01
CS137-B	0.000E+00	1.157E-01	0.000E+00	0.000E+00	-9.500E-01	2.564E-02	5.185E-01	-5.224E-01	2.970E-01
GA67-A	5.952E-02	6.927E-01	1.863E-01	2.653E-01	1.442E+00	2.087E+00	3.246E-01	2.459E-01	6.731E-01
H3-A	3.185E-02	1.657E+00	-2.000E-01	1.217E+00	-2.267E+00	3.933E+00	1.833E+00	1.875E+00	9.502E-01
H3-LSA	5.296E-01	6.573E-01	-1.867E+00	-1.976E-01	-1.500E+00	6.250E-01	1.154E-01	2.000E-01	3.753E-01
IR192-A	0.000E+00	9.239E-01	-0.000E+00	4.739E+00	2.665E-01	3.704E-01	1.316E+00	3.333E-01	1.041E+00
IR192-B	-1.176E-01	4.906E-01	-7.370E-02	3.518E+00	1.882E-01	5.882E-01	7.857E-01	-2.210E-01	7.192E-01
I131-A	-2.000E-01	2.579E-01	8.333E-02	0.000E+00	3.415E-01	6.227E-01	1.163E-01	0.000E+00	2.778E-01
I131-B	-2.830E-01	-3.509E-01	7.317E-01	9.025E-02	5.610E-01	7.667E-01	3.409E-01	-2.632E-01	-2.066E+01
MIXED-A	1.190E-01	4.000E-02	-3.875E-01	-1.136E-01	4.184E-01	7.391E-01	1.130E-01	6.757E-02	-2.154E-01
MIXED-B	0.000E+00	4.000E-01	0.000E+00	5.208E-02	4.600E-01	1.021E+00	4.082E-01	2.868E+00	-1.760E+00
MIXED-LSA	-1.600E-01	1.579E-01	1.167E-01	-5.739E-02	2.396E-01	4.274E-01	2.395E-01	-4.785E-02	0.000E+00
MF+MC-A	0.000E+00	-1.075E-01	0.000E+00	0.000E+00	3.356E-02	-9.070E-02	3.106E-02	3.555E-02	1.376E-01
MF+MC-B	0.000E+00	2.778E-01	0.000E+00	0.000E+00	-1.154E+00	7.692E-02	-9.434E-02	7.143E-01	0.000E+00
MF+MC-LQ	0.000E+00	3.067E-01	0.000E+00	0.000E+00	8.000E-01	2.025E+00	8.182E-01	4.700E+00	1.140E-01
MF+MC-LSA	0.000E+00	2.222E-01	0.000E+00	0.000E+00	0.000E+00	-2.339E-01	2.484E-01	4.751E-02	0.000E+00
MO99-A	-4.582E-02	1.678E-01	0.000E+00	7.633E-02	3.187E-01	4.647E-01	1.471E-01	3.194E-02	0.000E+00
MO99-B	6.944E-02	-7.874E-02	2.903E-02	6.431E-02	1.837E-01	5.172E-01	8.889E-02	1.689E-02	3.040E-02
PO210-A	1.789E+00	1.667E+00	7.556E-01	0.000E+00	-5.543E+00	1.010E+01	2.365E+01	-5.700E+00	-7.679E-01
PO210-LQ	2.924E-01	0.000E+00	-2.000E+00	3.103E-01	-9.340E+00	-4.000E-01	1.313E+00	-7.273E-01	0.000E+00
P32-A	5.505E-01	6.486E-01	6.513E-01	-2.217E-02	8.400E-01	6.511E-01	1.833E-01	-1.529E-02	6.504E-01
XE133-A	1.852E-01	-2.344E-01	0.000E+00	9.158E-02	2.650E-01	4.563E-01	1.211E-01	-3.112E-02	3.077E-02
WASTE-A	0.000E+00	-7.194E-02	0.000E+00	0.000E+00	1.969E-01	-1.600E-01	1.743E-01	-1.026E-01	1.370E-01
WASTE-B	0.000E+00	-1.770E-02	0.000E+00	0.000E+00	8.403E-02	-1.136E-01	2.532E-01	0.000E+00	9.709E-02
WASTE-LSA	0.000E+00	5.747E-02	0.000E+00	0.000E+00	1.449E-01	-5.882E-02	3.968E-01	3.040E-02	7.813E-02
RA226-A	0.000E+00	5.111E-02	0.000E+00	0.000E+00	4.569E-01	6.332E-01	8.591E-02	-4.132E-02	1.905E-01
RA226-B	1.923E-01	1.128E+00	6.200E-01	5.797E-01	2.231E+00	2.843E+00	2.548E-01	5.556E-01	9.211E-01
KR85-A	-9.901E-02	5.179E-01	-1.449E-01	2.578E+00	1.091E+00	3.248E+00	1.009E+00	1.429E+00	7.940E-01
KR85-B	-1.413E-01	3.571E-01	-1.025E+01	0.000E+00	2.129E+00	4.545E-01	-2.273E+00	-2.929E+00	9.163E+00
PU238-A	-3.000E-01	0.000E+00	3.975E+00	6.329E-02	-6.129E+00	2.000E-01	-1.667E+00	-9.677E-01	1.782E-01
PU238-B	5.093E-02	3.200E-01	-6.429E-01	8.403E-02	-1.579E+00	-1.587E-02	3.182E-01	-4.762E-01	3.226E-01
PU239-LG-B	-7.650E-02	3.584E-02	3.864E-01	-3.231E-02	7.273E-02	1.709E-01	2.614E-01	0.000E+00	7.407E-02
PU239-LG-LQ	0.000E+00	1.167E+00	0.000E+00	0.000E+00	9.000E-01	-4.575E+00	-7.700E+00	-5.900E+00	5.838E+00
SF-ES-T	0.000E+00	-0.000E+00	0.000E+00	0.000E+00	-0.000E+00	2.128E-01	2.075E-01	-7.937E-02	-4.264E-02
SF-ES-R	0.000E+00	8.529E-01	0.000E+00	0.000E+00	3.429E-01	4.955E-01	6.337E+00	9.368E-02	8.997E-02
U3O8-N-LSA	0.000E+00	1.770E-01	0.000E+00	2.326E-01	1.277E-01	4.370E-01	1.883E+00	7.452E-02	2.062E-01
UF6N-LG-A	0.000E+00	0.000E+00	0.000E+00	0.000E+00	5.825E-01	0.000E+00	1.657E+00	0.000E+00	1.974E-01
UF6E-LG-B	0.000E+00	-9.554E-02	0.000E+00	0.000E+00	0.000E+00	-7.407E-02	4.587E-02	-9.346E-02	5.168E-02
UO2E-LG-B	0.000E+00	-2.564E-01	0.000E+00	6.734E-02	-7.067E-02	3.077E-02	5.758E-02	-3.891E-02	-2.204E-01
UO2-rods-B	0.000E+00	8.800E-01	0.000E+00	5.063E-02	4.063E-01	1.935E-01	7.257E-02	2.933E-02	1.867E+00
U+PU-B	5.435E-02	-7.874E-02	-1.136E-02	0.000E+00	5.618E-02	3.555E-01	2.278E-02	-9.042E-02	2.174E-01
TC99m-A	1.744E-01	2.607E-01	4.242E-01	1.733E-02	5.556E-01	6.383E-01	5.357E-01	-7.143E-02	2.174E-01
TOTALS	0.000E+00	-2.866E-01	4.464E-01	3.448E-01	-9.478E-02	-4.639E-01	-1.835E-01	-0.000E-01	-1.534E-01

4.3 Accident Comparison Between NUREG-0170 and RADTRAN-1U

Three types of material data, used with RADTRAN-1 for calculations of accident risk, were not tabulated in NUREG-0170. The first is the INMODE value, which details the selection between the three curves A, B and C of Figure 3-3 in NUREG-0170 for the several materials shipped. The curves describe the probability of a fatality within one year from exposure to short half life isotopes (Curve A) and low or high Linear Energy Transfer (LET) radiation from long half life isotopes (Curves B and C). The three curves correspond to INMODE values of 1, 2 and 3 respectively. The values were taken instead from Appendix B of SAND76-0243, where possible. In a few cases the SAND report omits materials which were included in NUREG-0170; INMODE values for similar materials were used for those cases.

Two other types of data not included in the EIS tables are the arrays REQCTM, and REQDOS, which are optional in RADTRAN-1 and do not appear in later versions. Whether they were used in the original NUREG-0170 calculations is not known. For these calculations they were set to zero in every case.

4.3.1 Latent Cancer Risk Compared Between RADTRAN-1U and NUREG-0170

The accident risk in NUREG-0170 (for year 1975 and 1985 shipments) is reported in Table 5-9 as expected latent cancer fatalities for the twenty highest contributing materials, with an additional line giving the sum over all other standard shipments. Table 7 shows the original NUREG values for year 1975, with a column added for the RADTRAN-1U results and another showing the percentage difference. The results are in good agreement except for material UF6-N and UF6-E, and the "all others category." These deviations are attributed to unresolved errors in the RADTRAN-1U input file.

Table 7. Accident Case Latent Cancer Fatality Comparison

Standard Shipment	NUREG-0170 LCFS	RADTRAN-1U LCFS	Deviation %
PO210-LQ	0.00131	0.00131	0.00
MF+MC-LSA	0.000709	0.000709	0.00
U-PU-B	0.000514	0.000511	0.58
MF+MC-A	0.000478	0.000478	0.00
Waste-A	0.000388	0.000391	0.77
UF6-N	0.000328	0.000307	6.40
Waste-B	0.000182	0.000182	0.00
CO60-LQ1	0.00013	0.000130	0.00
PU239-B	0.000129	0.000130	0.77
Mixed-A	0.00011	0.0000110	0.00
U3O8	0.0000817	0.0000817	0.00
MF+MC-LQ	0.0000800	0.0000800	0.00
MO99-A	0.0000708	0.0000708	0.00
UF6-E	0.0000594	0.0000557	6.23
Limited	0.0000579	0.0000578	0.17
MO99-B	0.0000573	0.0000572	0.17
CO60-LSA	0.0000478	0.0000477	0.21
I131-A	0.0000384	0.0000383	0.26
Mixed-B	0.0000383	0.0000382	0.26
Spent Fuel	0.0000356	0.0000357	0.28
All Others	0.000482	0.000342	29.0

4.3.2 Early Fatality Probability Comparison

A second measure of accident risk is given in Figure 5-10 of NUREG-0170, namely the probability of an early fatality summed over all annual shipments. Curves are given for years 1975 and 1985. The 1975 values calculated with RADTRAN-1U agree with the NUREG values, except at 11 fatalities. Apparently Figure 5-10 was incorrectly drawn in NUREG-0170, since other RADTRAN data sets do not calculate an 11 fatality value, but go in 5 fatality increments after 10 years. This causes the tail of the curve to descend too steeply, making the graph inaccurate for probability values smaller than 10^{-6}.

Table 8. Accident Case Early Fatality Probability Comparison

Number of Early Fatalities	Estimate from Figure 5-10 NUREG-0170	Value as Recalculated with RADTRAN-1U
1	3.0×10^{-4}	3.419×10^{-4}
2	2.0×10^{-4}	2.276×10^{-4}
3	1.5×10^{-4}	1.652×10^{-4}
4	1.0×10^{-4}	1.255×10^{-4}
5	9.5×10^{-5}	9.110×10^{-5}
6	8.0×10^{-5}	6.020×10^{-5}
7	5.0×10^{-5}	3.559×10^{-5}
8	1.5×10^{-5}	1.858×10^{-5}
9	9.0×10^{-6}	8.274×10^{-6}
10	2.0×10^{-6}	2.716×10^{-6}
11	2.0×10^{-8}	-----
15	Not shown	2.014×10^{-8}
20	Not shown	2.907×10^{-11}
25	Not shown	1.221×10^{-14}

5.0 Summary and Conclusions

After restoring the RADTRAN-1 code and modifying it to run on modern UNIX workstations, it was tested by running two problems. The first was the Sample Problem in Appendix D of the original RADTRAN user manual (Taylor and Daniel, 1977); the second was a reconstruction of the calculations published in "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes," (NRC, 1977)

There is good agreement between the recalculated Sample Problem and the published results in Taylor and Daniel, 1977. There is also agreement, generally within 0.1% though with exceptions, between the *incident-free* results for the recalculated NUREG-0170 problem and the published results in Chapter 4 of NUREG-0170.

The results for the *accident case* are less favorable, although all but two of the twenty materials show results in agreement to better than one percent. The exceptions, for UF6-E and UF6-N, are attributed to unresolved discrepancies in the input file created for the RADTRAN-1U calculations. It was also noted that probability values smaller than 10^{-6} in Figure 5-10 of the NUREG are distorted because a data point corresponding to 15 fatalities was inadvertently drawn at the 11 fatality position.

In all cases the agreement for spent fuel was close between the published and recalculated values. In the incident-free case, the deviations for total exposures due to truck shipments (SF-ES-T) was 0.04%, and for rail shipments (SF-ES-R) was 0.09%. The deviations for latent cancer fatalities from spent fuel shipments of all types was 0.28%.

6.0 Reference List

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7.0 Appendix A

The attached floppy disk contains input and output files for the problems discussed in this report. There are four files on the disk, specifically:

1.	nr0170.in	The input file for the recalculation of NUREG-0170.
2.	nr0170.out	The output file for the recalculation of NUREG-0170.
3.	sample.in	The input file for the recalculation of Appendix D to SAND76-0243.
4.	sample.out	The output file for the recalculation of Appendix D to SAND76-0243.

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