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Sensitivity Analysis for RADTRAN 4 Input Parameters

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INTRODUCTION

The transportation risk analysis code, RADTRAN 4[1], computes estimates of incident-free dose consequence and accident dose-risk. The output of the code includes a tabulation of sensitivity of the result to variation of the input parameters for the incident-free analysis. The values are calculated using closed mathematical expressions derived from the constitutive equations, which are linear. However, the equations for accident risk are not linear, in general, and a similar tabulation has not been available. Because of the importance of knowing how accident-risk estimates are affected by uncertainties in the input parameters, a direct investigation was undertaken of the variation in calculated accident dose-risk with changes in individual parameters. A limited, representative group of transportation scenarios was used, initially, to determine which of 23 accident-risk parameters affect the calculated accident dose risk significantly[2]. Many of the parameters were observed to have minimal effect on the output, and others were judged as "fixed" either by regulation, convention or standards. The remaining 5 variables were selected for further study through Latin Hypercube Sampling (LHS)[3]. LHS yields statistical information from observations (risk calculations) resulting from multiple input-parameter sets compiled from "random" sampling of parameter distributions. The LHS method requires fewer observations than classical Monte Carlo methods to yield statistically significant results. This paper presents the preliminary parameter study and LHS application results together with further LHS evaluations of RADTRAN input parameters.

ANALYSIS

A list of the RADTRAN 4 input variables employed in accident-risk calculations was compiled and is presented in Table 1. RADTRAN calculations of accident risk were carried out for transportation scenarios developed either from actual experience or special cases to emphasize a parameter of interest (e.g., non-dispersal accidents). The baseline values used in this study were adapted from archived input files supporting published Sandia analyses of shipments of spent nuclear fuel and other materials by highway over a variety of routes. These analyses include six-category or eight-category accident-severity schemes and both Type A or B packages, which provide suitable breadth of application. Relationships between various possible severity schemes and characteristics of package types are discussed elsewhere[4,5]. To provide clear, brief comparisons, the examples presented here are limited to the eight-category severity scheme and Type A packages (see SEVFRC and RFRAC in the Appendix).

A list of variables is given in Table 1; the sensitivities of total risk to them are presented in Table 2 together with an indication of whether they were to be studied further with LHS. Previously[2], two of the parameters identified in Table 2 as suitable for LHS analysis were investigated: Pasquill Category Weights (PSPROB) and Link Population Densities (LPOPD). These inputs were selected for initial study because conservative distributions of their values could be estimated easily and because LPOPD and PSPROB array sizes were not affected by the choice of accident-severity scheme. The present paper continues those accident-risk sensitivity studies and focuses on two additional variables in Table 2: LARAT and RFRAC.

Use of LHS requires definition of probability distributions for each variable of interest. In the case of the eight distinct accident rates (LARAT) employed in the twelve links defined in the sample RADTRAN input file (see the Appendix), normal distributions centered on the point estimates were used. The widths of the distributions were determined from averages, over all 48 states in the continental U.S., of accident rates for each of four highway types. The value of σ for each distribution was set to approximately the same fraction of the mean as the standard deviation of each average (approximately 50% or 100%).

For the investigation of sensitivity to package release fractions (RFRAC), Log-Uniform distributions were defined for each of the four lowest severity levels (see the Appendix). Ranges of the distributions were chosen to span values from approximately 0 to 1 in four decades: 1E-09 to 0.001, 0.001 to 0.01, 0.01 to 0.1, and 0.1 to 1.0. Use of Log-Uniform distributions (versus Uniform distributions) concentrates samples at the lower end of each of the decade ranges to conform with the overall relationship between probability and accident severity, i.e., accidents of higher severity have lower probability. Accidents having severities in the highest four categories are expected to result in 100% release from the Type A packages treated in this example and the RFRAC values were set to 1.0.

Table 3 presents the results of 50 observations (individual RADTRAN runs) incorporating samples from the RFRAC and LARAT distributions together with the results obtained in the earlier study[2] and the case of all four variable sets combined. The LHS code was used to generate fifty RADTRAN input sets which included independent samples from the appropriate distribution functions; then the 50 total accident-risk estimates calculated by RADTRAN were averaged. The risk value calculated for the same transportation scenario without LHS, 5.32E-05 person-rem, is clearly within the standard deviation of the accident-rate case (LARAT). This is to be expected since the means of the normal distributions equaled the point estimates used without LHS. However, for the release-fraction (RFRAC) case, the mean of the 50 risk estimates is shifted to a slightly lower value since the upper limits of the distribution ranges (listed above) were set equal to the point estimates of the non-LHS calculation. The last line of Table 3 also presents the result of including simultaneous, independent variations of all four input types (arrays).

CONCLUSIONS

This continuation of RADTRAN accident-risk sensitivity analysis agrees with the results of the previously reported study[2] in that the variation in the risk estimates is relatively small in spite of conservatively broad distributions of input parameters. This is true whether the four input-parameter arrays investigated to date, PSPROB, LPOPD, LARAT and RFRAC, are allowed to vary individually or in combination. The efficiency of Latin Hypercube Sampling technique makes explicit calculation of the sensitivity of risk values to input variations a reasonable approach to general accident-risk analysis. In cases involving substantial uncertainty of critical input parameters, accident-risk estimates may be calculated more realistically by application of a maximum parameter value as the upper limit of an appropriate distribution rather than as a point estimate, since the corresponding uncertainty in the result is then determined explicitly.

REFERENCES

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

2. G.S. Mills, K.S. Neuhauser and F.L. Kanipe, "RADTRAN 4 Truck Accident Risk Sensitivity Analysis," in Proceedings of the Symposium on Waste Management at Tucson, Arizona, WM'95. (To be published)

3. R.L. Iman and M.J. Shortencarier, "A FORTRAN Program and User's Guide for the Generation of Latin Hypercube and Random Samples for Use with Computer Models," NUREG/CR-3624, SAND83-2365, Sandia National Laboratories, Albuquerque, NM, March 1984.

4. J.D. Whitlow and K.S. Neuhauser, "A Methodology for the Transfer of Probabilities between Accident Severity Classification Schemes," in Transportation of Dangerous Goods: Assessing the Risks, F.F. Saccomano and K. Cassidy, Eds., Institute for Risk Research, Waterloo, Canada, 1993.

5. U.S. Code of Federal Regulations 49 Part 173, "Shippers - General Requirements for Shipments and Packagings," October, 1992.

APPENDIX

Base RADTRAN 4 input file used in LHS calculations:

```
&& _Shipped_by_Truck_from_SNL/NM_to_NTS_
&& _Package_Dimension_Approximates_a_55gal_Drum_
TITLE _LABORATORY_WASTE_FROM_AREA_V _DRUM_
FORM UNIT
DIMEN 5 8 1 10 18
PARM 1 3 2 1 1
PACKAGE
  LABGRP
       A
SHIPMENT
  LABISO
    CS137     CS134     CE144     NB95     ZR95
NORMAL
  NMODE=1
     1.000E+00 0.000E+00 0.000E+00 8.856E+01 4.032E+01 2.416E+01
     2.000E+00 6.760E+00 0.000E+00 1.100E-02 0.000E+00 0.000E+00
     0.000E+00 5.000E+01 2.000E+01 0.000E+00 1.000E+02 1.000E+02
     2.000E+00 0.000E+00 0.000E+00 1.000E+00 4.700E+02 7.800E+02
     2.800E+03
ACCIDENT
  SEVFRC
    NPOP=1
     NMODE=1
     4.62E-01 3.02E-01 1.76E-01 4.03E-02 1.18E-02 6.47E-03
     5.71E-04 1.13E-04
    NPOP=2
     NMODE=1
     4.35E-01 2.85E-01 2.21E-01 5.06E-02 6.64E-03 1.74E-03
     6.72E-05 5.93E-06
    NPOP=3
     NMODE=1
     5.83E-01 3.82E-01 2.78E-02 6.36E-03 7.42E-04 1.46E-04
     1.13E-05 9.94E-07
RELEASE
  RFRAC
    GROUP=1
     0.00E+00 1.00E-02 1.00E-01 1.00E-01 1.00E+00 1.00E+00
     1.00E+00 1.00E+00
EOF
```

```
ISOTOPES -1   1    1.00   10.000   1.00   0.00 MTAP
     CS137  1.81E-01      A  7
     CS134  9.40E-03      A  7
     CE144  6.70E-02      A  7
      NB95  3.46E-02      A  7
      ZR95  1.90E-02      A  7
LINK  1 1.40E+00 2.42E+01 9.16E+02 7.80E+02 2.07E-07 S 2
LINK  1 1.80E+00 2.42E+01 2.68E+03 2.80E+03 7.40E-06 U 2
LINK  1 2.38E+02 8.86E+01 7.20E+00 4.70E+02 2.69E-07 R 1
LINK  1 2.01E+01 8.86E+01 4.98E+02 7.80E+02 2.69E-07 S 1
LINK  1 7.20E+00 8.86E+01 2.10E+03 2.80E+03 3.24E-07 U 1
LINK  1 4.74E+02 8.86E+01 1.70E+00 4.70E+02 2.60E-07 R 1
LINK  1 2.03E+01 8.86E+01 3.40E+02 7.80E+02 2.60E-07 S 1
LINK  1 1.60E+00 8.86E+01 2.14E+03 2.80E+03 2.81E-07 U 1
LINK  1 1.16E+02 8.86E+01 1.90E+00 4.70E+02 2.69E-07 R 2
LINK  1 1.17E+02 8.86E+01 3.00E+00 4.70E+02 4.51E-07 R 2
LINK  1 2.59E+01 8.86E+01 5.69E+02 7.80E+02 4.51E-07 S 2
LINK  1 1.47E+01 4.80E+01 2.46E+03 2.80E+03 4.51E-07 U 2
PKGSIZ
      MTAP    1.00
EOF
```

Table 1 - RADTRAN 4 Accident risk analysis input variables.

RADTRAN Variable	Definition
SEVFRC	Fractions of Accidents Having a Given Severity
RFRAC	Fractions of Package Contents Released in an Accident of a Particular Severity
AERSOL	Fractions of Released Materials Which Are Aerosols
RESP	Fractions of Aerosols Which Are Respirable
PSPROB	Pasquill Atmospheric Stability Class Weights
CIPKG	Curies per Package by Isotope
FRGAMA, FRNEUT [1]	Fractions of Radiation Which Are Gamma & Neutron
Isotope Definition Constants [2]	Cloudshine Factor
	Inhalation Effective Dose Equivalent
	Ingestion Effective Dose Equivalent
	Food Transfer Factor
	Soil Transfer Factor
	Deposition Velocity
	Lung Type Designation
LDIST	Link Length
LPOPD	Link Population Density
LARAT	Link Accident Rate
RADIST [1]	Radii of Non-dispersal Accident Exposure Annuli
BRATE	Breathing Rate
BDF	Fraction of Respirable Aerosol Inside Buildings
RPD	Ratio of Pedestrian Density to Population Density
RU [1]	Urban Building Shielding Factor
CULVL [3]	Cleanup Level

1 Non-dispersal accidents only

2 Taken from published sources; not suitable for statistical variation

3 Adjustable but there are no guidelines for valid range

Table 2 - RADTRAN Accident risk input variables, sensitivity and disposition

RADTRAN Variable	Sensitivity	Suitable for LHS?
SEVFRC	Proportional	Yes
RFRAC	Proportional	Yes
AERSOL*	Proportional	No
RESP*	Prop., Inhal. & Resusp.	No
PSPROB	Significant to Dispersal	Yes
CIPKG**	Proportional	No
FRGAMA, FRNEUT**		No
Isotope Definition Constants	Generally not subject to variation	No
LDIST**	Proportional	No
LPOPD	Proportional	Yes
LARAT	Proportional	Yes
RADIST**	Negligible	No
BRATE	Negligible	No
BDF	Negligible	No
RPD**	Negligible	No
RU	Negligible	No
CULVL	Small	No

* These variables describe ranges of behavior corresponding to general physical/chemical characteristics.
** These variables are not generally subject to random uncertainties.

Table 3 - Results (person-rem) of LHS analysis

Input Variable	Total Accident Risk (Average of 50 Obs's.)	Standard Deviation
(1) LARAT (1-8)	5.80E-05	1.50E-05
(2) RFRAC (1-4)	4.57E-05	1.51E-05
(3) PSPROB (1-6)*	2.57E-05	4.14E-06
(4) LPOPD (±25%)*	5.30E-05	6.18E-06
(5) All**	2.30E-05	1.06E-05

* Values taken from ref. 2.
** LHS applied to four arrays; lower average is due to (3), see ref. 2.