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Sensitivity Analysis for Input Parameters of RADTRAN Code

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1. Introduction

The high level radioactive waste such as a spent fuel has been transported substantially within a plant site in Korea, only small amount of spent fuels for the research have been transported from the nuclear power plants to KAERI(Korea Atomic Energy Research Institute). However, it is expected that the transportation of the high level radioactive waste would increase from now on.

The high level radioactive waste can be transported by rail, sea and road. In Korea, all nuclear power plants are located near the sea. Thus most high level radioactive waste would be transported by sea. However the high level radioactive waste in KAERI located inland should be transported by road. When these high level radioactive wastes are transported, transport licenses are required to guarantee public health and safety during transport. The RADTRAN(the Radioactive Material Transport) code is used to calculate the radioactive material transportation risk assessment [1].

This RADTRAN code is developed for the U.S. Nuclear Regulatory Commission (NRC) by Sandia National Laboratories specifically to support the NUREG-0170 study [2]. RADTRAN calculates the radiological consequences and risks associated with the shipment of a specific radioactive material in a specific package along a specific route. RADTRAN contains default values for input parameters, but these values are based on the US data. If the input parameter is not available, these default values are used. Thus these default values are required how to be sensitive prior to the analysis. In this paper the sensitivity analysis for input parameters of RADTRAN code (version 6.02.1) is performed.

2. Methods and Results

2.1 RADTRAN code 6.02.1

This version of the RADTRAN computer code, version 6.02.1, is the U.S. NRC approved version of the RADTRAN computer code based upon the RADTRAN 6.02 code developed by Sandia National Laboratory (SNL) in 2009 with funding from the NRC and the U.S. Department of Energy. RADTRAN calculates the radiological consequences and risks associated with the shipment of a specific radioactive material in a specific package along a specific route. Early development, this code was used as a calculation tool for performing a radiation impact assessment on the transportation of radioactive material by transport means, including aircraft. It has been used as a computer code that can carry a safety evaluation on its own, depending on the various mobile models, routes, transport scenarios through improvements. Also this RADTRAN code is used in the United States as a review program for the transportation of radioactive materials.

2.2 Input Parameters

In RADTRAN parlance, a “package” is the container and its radioactive contents that are being transported, “packaging” is the container, “vehicle” usually refers to the part of the vehicle that holds the package, like a railcar or semi-detached trailer, and “mode” refers to the transportation medium (highway, secondary road, rail, water). Since more than one mode may be used to transport a single package of radioactive material from its point of origin to its final destination, RADTRAN allows each mode to be considered separately in assessing radiological impact.

The input parameters used in the code are largely classified as Package-Specific Parameters, Vehicle-Specific Parameters, Route-Specific Parameters, Radionuclide Data, MODSTD Data. The parameters used in this sensitivity analysis are mainly MODSTD data, these parameters are presented in Table I below.

Table I: The definition of input parameters used in the sensitivity analysis

No.	Variable	Definition
1	IUOPT	a building shielding option
2	DISTOFF FREEWAY	Any limited-access divided highway
3	DISTON FREEWAY	Any limited-access, divided highway
4	ADJACENT	the minimum perpendicular distance between shipment centerline and centerline of adjacent passing vehicles
5	BDF	Building Dose Factor: fraction of outside air inside buildings
6	BRATE	Breathing Rate
7	CULVL	Clean-up Level
8	EVACUATION	Evacuation time
9	INTERDICT	Interdiction threshold

10	LCFCON	Latent cancer fatalities per rem
11	SURVEY	Survey interval
12	UBF	fraction of urban population in buildings
13	USWF	Urban Sidewalk Fraction
14	CAMPAIGN	Campaign duration
15	MITDDIST	Distance for Maximum In-Transit Dose
16	MITDVEL	Speed for Maximum In-Transit Dose
17	RPD	Ratio of Pedestrian Density to resident density
18	RR	Rural shielding factor
19	RU	Urban shielding factor
20	RS	Suburban shielding factor
21	SMALLPKG	Size of smallest package for nondispersal analysis

2.3 Sensitivity Analysis

2.3.1 Base model

The base model used for this paper is provided from the RAMP website as a sample output files. The vehicle (GE2000_1) travels 1,350 km with a cask in this model. And this vehicle stops 21 times before arriving to a final destination. RADTRAN analyzes only one accident, because only one accident would occur during a trip on any route. There are 7 conditional probabilities of an accident. The national average weather condition is applied for a weather option, and the vehicle is supposed to only move on the highway. The route is divided into rural, suburban, and urban portions, and traveling distance of 1,350 km is divided into 18 parts (LINKs). The information of source term within the cask is below as a table II.

Table II: The information of source term within the cask

No.	Name	Inventory (Ci)	No.	Name	Inventory (Ci)
1	Pu-239	28.4	15	Y-91	159.0
2	Pu-240	17.4	16	Nb-95	643.0
3	Pu-238	14.2	17	Eu-155	47.3
4	Am-241	6.43	18	Cm-242	7.57
5	Am-243	0.00454	19	Sb-125	73.8
6	Am-242	0.053	20	Y-90	511.0
7	Cm-244	0.0246	21	Cs-134	30.3
8	Pu-241	1270.0	22	Sr-89	73.8
9	Ce-144	3780.0	23	U-237	0.0303
10	Ru-106	1310.0	24	H-3	4.73
11	Sr-90	511.0	25	Nb-95	3.78
12	Cs-137	624.0	26	U-236	0.00359
13	Pm-147	1660.0	27	Te-125	18.0
14	Zr-95	303.0	28	Te-127	13.8

2.3.2 Analysis method

The sensitivity range of the input parameters for the sensitivity analysis was generally set to −50 ~ +200%. Depending on the input parameter characteristics, some parameters are applied to the maximum value or the minimum value. Here, parameters that always appear proportional to the result, such as distance and stop were omitted.

2.3.3 Analysis Results

The results of sensitivity analysis using the input parameters presented in Table I are summarized in Table III.

Table III: Sensitivity results summary

No.	Variable	Result summary
1	IUOPT	In-transit population exposure of Off Link
2	DISTOFF FREEWAY	
3	DISTON FREEWAY	In-transit population exposure of On Link
4	ADJACENT	
5	BDF	Population risk for the accident occurring in urban
6	BRATE	Dose to an individual from inhalation and resuspension
7	CULVL	Societal ingestion risk of rural Link
8	EVACUATION	Population risk of resuspension and graundshine for the accident occurring in Link
9	INTERDICT	Not affected
10	LCFCON	
11	SURVEY	
12	UBF	Population risk for the accident occurring in urban
13	USWF	
14	CAMPAIGN	Total exposed population in incident free
15	MITDDIST	Maximum individual in transit dose
16	MITDVEL	
17	RPD	Population risk for the accident occurring in urban
18	RR	In-transit population exposure of Off Link
19	RU	
20	RS	
21	SMALLPKG	Not affected

The input parameters affecting the results of in-transit population dose for off link are IUOPT, DISTOFF FREEWAY, RR, RU, and RS. An expression for the radiation dose sustained by people along the route ("Off Link dose") is given by [3] :

$$D_{off} = 4 \cdot Q_1 \cdot k_{0_v} \cdot DR_v \cdot \frac{PD_L}{V_L} \cdot DIST_L \cdot \left[\begin{array}{l} FG_v \left[\int_{min}^{sw} I_G(x)dx \cdot RPD_{s\,or\,u} + \int_{sw}^{max} I_G(x)dx \cdot SF \right] \\ + FN_v \left[\int_{min}^{sw} I_N(x)dx \cdot RPD_{s\,or\,u} + \int_{sw}^{max} I_N(x)dx \cdot SF \right] \end{array} \right]$$

Except for distance-related parameter DISTOFF FREEWAY, all of these parameters are related to the shielding and the most effective parameter is IUOPT. The parameters affecting the results of in-transit population dose for on link are DISTON FREEWAY and ADJACENT. Both parameters are related to the distance and used as an input below [3];

$$D_{opp} = \frac{2 \cdot k_0 \cdot DR_v \cdot N'}{V_v^2} \cdot I'(x) \cdot PPV \cdot DIST_L$$

The input parameters affecting the results of population risk for the accident are BDF, BRATE, EVACUATION, UBF, USWF and RPD. The input parameter of CULVL affects the results of societal ingestion risk. Finally, it is confirmed that the input parameters of MITDDIST and MITDVEL the affect Maximum individual in transit dose.

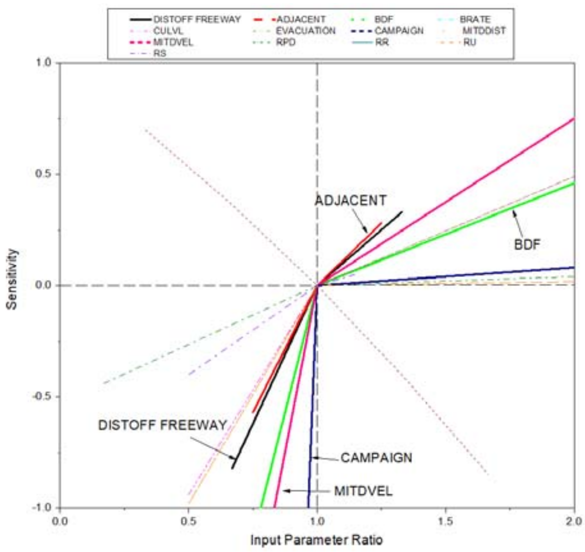

Fig. 1. Sensitivity result along the input parameter ratio

Fig. 1 represents that how much effectiveness is when the parameters in Table I is changed. The horizontal axis in Figure 1 represents input parameter ratio based on the default value. And the vertical axis shows how much affected when these input parameters are changed. The grater the slope in this figure, the grater the effect on the results. The most affected input variable is CAMPAIGN, and the effect is significant when it is less than the default value. Other sensitive variables are MITDVEL, BDF, DISTOFF FREEWAY and ADJACENT.

3. Conclusions

It is necessary to obtain a permit before transporting the high level radioactive waste, at this time the RADTRAN code is used for the licensing. Because this RADTRAN code was developed on SNL in the United States, the base default values are presented by US standards. When analyzed using the code in the country, the default value is used in the phase that there is no domestic value. In this paper, the sensitivity was analyzed on the input parameters presented in the latest version of the RADTRAN computational code. Factors that greatly affect the evaluation results were evaluated as CAMPAIGN, MITDVEL, BDF, DISTOFF FREEWAY and ADJACENT. Therefore, it is determined that the analysis must be carried out using the domestic data for these 5 input parameters.

REFERENCES

[1] R. F. Weiner, D. Hinojosa, T. J. Heames, C. O. Farnum, E. A. Kalinina, RADTRAN 6/RadCat 6 User Guide, SANDIA REPORT, 2013.

[2] US NRC, Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes, NUREG-0170, 1977.

[3] R. F. Weiner, K. S. Neuhauser, T. J. Heames, B. M. O'Donnell, M. L. Dennis, RADTRAN 6 Technical Manual, SANDIA REPORT, 2014.