EVALUATION OF FLUCTUATION FOR RADIOACTIVE MATERIALS TRANSPORT RISK

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ABSTRACT

The authors have kept on evaluating the adaptability of INTERTRAN2 to various transports such as planned LLW transport. This report discusses the way to evaluate fluctuation properties of transport risk caused by temporal and spatial fluctuations of some variables in INTERTRAN2.

INTRODUCTION

A method to evaluate the fluctuation of transport risk with INTERTRAN2 was proposed. It is necessary to reveal the fluctuation of transport risk, because some input variables of INTERTRAN2 have temporal or spatial distributions. The proposed method to evaluate fluctuations is composed of 3 steps. First, some of time or space dependent variables which have relatively large effects on calculated risk were selected according to a preceding sensitivity study, and their probability distributions were determined by their statistical characteristics or by engineering judgments. Next the combinations of input values for each variable were prepared by Latin Hypercube Sampling method, and finally the risk accompanying with radioactive material transports was calculated with these combinations by INTERTRAN2 program and fluctuations of the risk were evaluated.

A case study was made for one of actual radioactive material transports in Japan and a point in Tokyo metropolitan highway on the transportation route was focused on in an additional study. Dose risk was calculated in 500 sampled cases for six variables, and fluctuations of calculated results were analyzed with more comprehensible indicators to show their deviation such as ratio between maximum and minimum values and so on.

In the additional study, directional risk distributions were evaluated at 16 compass directions of a selected point on the urban highway with the directional distributions of population density, wind speed and rainfall. The ratio between maximum and minimum values of cumulative doses among 16 directions was evaluated to be relatively big because of non-uniform distribution of the population and directional dependency of the weather conditions. It might be suggested that safety measures should be prepared for possible accident conditions that cause higher risk as well as average conditions, and the proposed method in this study will help the consideration.

THE EVALUATION METHOD CONSIDERING VARIABLES FLUCTUATION

The proposed evaluation method is constructed by following procedures. The outlines of procedures are shown in Figure-1.

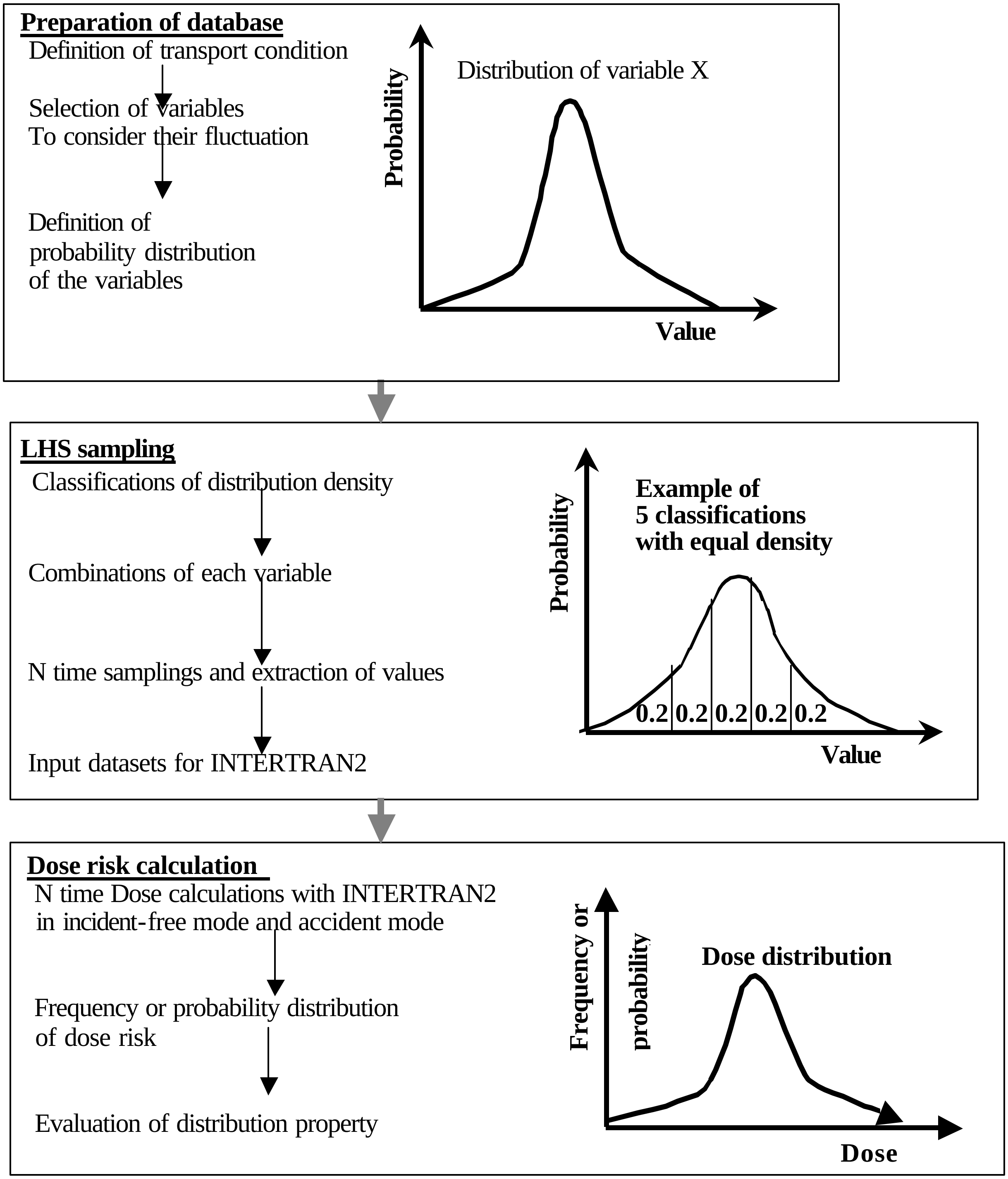


Figure –1, Outlines of procedures

The evaluation method

When executing a calculation of INTERTRAN2, the user select and input fixed values in each variable of the code. Considering each variable, most of them originally have temporal or spatial distribution. Thus, the evaluation method considering fluctuation of input variables will be helpful for discussing transport risk as output of INTERTRAN2.

(1) Preparation of database

As the first step, variables are to temporal distribution variables and spatial distribution variables except proper nouns and flag selection inputs. From the realistic aspect, some variables that should be discussed in this study are selected to produce probability distribution of them. The variables supported from a lot of stochastic data are desirable in this selection, because a realistic probability distribution based on statistics yields more exact result than imaginary uniform or normal distribution.

At the beginning of procedures, a transport route and a packaging are decided for a case study. Deciding these items, some variables, e.g. population, traffic and meteorological condition, are provided from the governmental stochastic. After concerning various data or information, which might be useful for INTERTRAN2 calculation, some variables are selected as targets by users' engineering judgment or their experiences. Then, probability distributions of these selected variables are produced and defined by stochastic treatment. The first chart in Figure-1 shows an example of probability distribution and the integral value of distribution function should be 1.0 in natural. If a user selects m variables, m probability distributions are consequently required to construct the m dimensional space matrix.

(2) LHS sampling

The second chart shows an example that the probability distribution is divided to 5 segments of 0.2 considering to equal density. After defining m probability distributions, the combination composed of m variable set is made by giving attention to avoid the same set in m dimensional space matrix. In LHS sampling, sampling number N is product of classification number and frequency in each segment. Thus, N datasets with m dimensional space matrix are prepared for INTERTRAN2 calculation.

(3) Dose risk calculation

Since the probability of transport in incident-free mode is regarded as 1.0, N time dose risk calculations with INTERTRAN2 are both executed in incident-free mode and accident mode. By processing the results stochastically, the frequency distribution according to dose risk is acquired and the probability distribution is also acquired by normalization. The method and measure to evaluate the distribution figure is described in the following chapter.

Extraction of variables to be discussed

Variables to be discussed are extracted by preliminary evaluation of sensitivity and spatial or temporal properties for main valuables. After this evaluation, six valuables, i.e. population density, traffic density, traffic speed, accident rate, rainfall and wind speed are extracted by considering to sensitivity and stochastic arrangements. Although the stochastic arrangements are discontinuous data, they are classified and processed to uniform probability density in each classification for the following random sampling.

A case study of fresh fuel transport

(1) The premises of case study

Considering to universality of INTERTRAN2 for Japanese RAM transport, a representative route and package of fresh fuel was carefully selected for the case study. The transport rout is mainly constructed by 370km expressway and Metropolitan highway, and is also constructed by 10km highway both ends of transport route. The target section was limited to 9.5km Metropolitan highway, because the development of evaluation method has priority over the whole route evaluation in this study. Fresh fuel was assumed to the objective package and surface radiation rate was assumed to be 100 micro Sv per hour. Conventional open-deck truck operated by two drivers was assumed to the transport truck, and it can load six BWR fresh fuel packages. The distance between a cockpit and the center of package was assumed to be 5.0m by referring to the vehicle drawings.

(2) Dose risk evaluation terms

In incident-free mode, “CREW”, “OFF LINK”, “ON LINK” and “STOPS” were calculated because of land transport. In accident mode, “GROUND”, “INHALED”, “RESUSPED” were calculated. “INGESTION” is not available because of program setting.

(3) Dose risks in incident-free mode

The results of incident-free mode are shown in Table–1. According to the table it is revealed that dose of “CREW” and “ON LINK” are dominant in this case. The structure of Metropolitan highway is mainly constructed continuous elevated bridges so that a lot of office workers and few inhabitants are separated and shielded from traffic lanes of highway.

Dose of “CREW” has smaller variance than “ON LINK” and “OFF LINK”, because it is considered to be the function of vehicle speed and its distribution concentrates in 70 to 90 km/hour segments. Dose of “ON LINK” has larger variance than other three doses, because it is considered to be the function of population density and vehicle speed, and the former has large variance.

Table-1, Dose risks in incident-free mode

	SAMPLE	CREW	OFF LINK	ON LINK	STOPS	TOTALS	TOT. /MEA.
MEAN	10	5.75E-03	1.33E-03	1.49E-04	8.66E-04	8.10E-03	***
	50	5.81E-03	1.66E-03	2.83E-04	8.66E-04	8.62E-03	***
	100	5.80E-03	1.75E-03	3.85E-04	8.66E-04	8.81E-03	***
	500	5.80E-03	1.86E-03	2.97E-04	8.66E-04	8.82E-03	***
	AVERAGE CONDITION	5.69E-03	5.63E-04	8.56E-05	8.66E-04	7.20E-03	***
STANDARD DEVIATION	10	2.49E-04	1.04E-03	2.14E-04	***	9.66E-04	0.12
	50	4.32E-04	1.88E-03	7.21E-04	***	2.51E-03	0.29
	100	4.22E-04	1.86E-03	1.52E-03	***	3.44E-03	0.39
	500	4.18E-04	2.67E-03	9.94E-04	***	3.65E-03	0.41
MINIMUM	10	5.62E-03	8.85E-05	2.87E-05	8.66E-04	6.88E-03	0.86
	50	5.62E-03	2.46E-05	2.25E-05	8.66E-04	6.55E-03	0.76
	100	5.61E-03	3.99E-05	2.27E-05	8.66E-04	6.64E-03	0.75
	500	5.61E-03	4.06E-07	1.91E-05	8.66E-04	6.55E-03	0.74
MAXIMUM	10	6.47E-03	3.17E-03	7.77E-04	8.66E-04	9.69E-03	1.20
	50	7.60E-03	1.16E-02	4.40E-03	8.66E-04	2.02E-02	2.34
	100	7.75E-03	1.07E-02	1.33E-02	8.66E-04	3.27E-02	3.71
	500	7.86E-03	2.84E-02	1.55E-02	8.66E-04	4.09E-02	4.64

1) N times sampling yields N times MEAN, STANDARD DEVIATION, MINIMUM and MAXIMUM on rank N. N means 10, 50, 100 and 500 time samplings respectively.
2) AVERAGE CONDITION is calculated by the average values for each variable.
3) Unit in person-mSv.

(4) Dose risks in accident mode

The results of accident mode are shown in Table-2. According to the table, it is revealed that dose risk of “RESUSPED” is dominant. A half-life period of re-suspension for deposited nuclides was assumed one year conservatively. Thus, “RESUSPED” tends to yield larger dose risk.

Table-2, Dose risks in accident mode

	SAMPLE	GROUND	INHALED	RESUSPED	CLOUDSH	TOTAL	TOT. /MEA.
MEAN	10	4.86E-18	8.07E-16	3.67E-15	4.04E-24	4.49E-15	***
	50	4.44E-18	7.39E-16	3.36E-15	3.70E-24	4.11E-15	***
	100	4.26E-08	7.09E-16	3.23E-15	3.54E-24	3.94E-15	***
	500	4.15E-18	6.91E-16	3.14E-15	3.45E-24	3.84E-15	***
	AVERAGE CONDITION	1.73E-18	2.88E-16	1.31E-15	1.44E-24	1.60E-15	***
STANDARD DEVIATION	10	5.55E-18	9.21E-16	4.19E-15	4.62E-24	5.13E-15	1.14
	50	5.89E-18	9.79E-16	4.45E-15	4.90E-24	5.45E-15	1.33
	100	5.57E-18	9.27E-16	4.22E-15	4.63E-24	5.15E-15	1.31
	500	5.77E-18	9.63E-16	4.38E-15	4.81E-24	5.35E-15	1.39
MINIMUM	10	4.18E-20	6.99E-18	3.18E-17	3.49E-26	3.88E-17	0.01
	50	7.94E-20	1.32E-17	6.01E-17	6.60E-26	7.34E-17	0.02
	100	5.38E-20	8.98E-18	4.09E-17	4.49E-26	4.99E-17	0.01
	500	3.32E-20	5.52E-19	2.51E-18	2.76E-27	3.07E-18	0
MAXIMUM	10	1.84E-17	3.05E-15	1.39E-14	1.53E-23	1.70E-14	3.79
	50	2.65E-17	4.40E-15	2.00E-14	2.20E-23	2.45E-14	5.97
	100	3.79E-17	6.30E-15	2.87E-14	3.15E-23	3.50E-14	8.89
	500	6.11E-17	1.02E-14	4.63E-14	5.08E-23	5.65E-14	14.72

NOTE is same as Table-1.

Evaluation of probability distribution

Figures-2 and 3 show dose risk distributions as the results of 500 times LHS sampling. The ratio between maximum value and average value, which represents fluctuation of output dose risk, is important from the radioprotection point of view. From the quantitative point of view for the Tables-1 and 2, the maximum-based dose risk values on bottom column in both tables are ranged 4.6 to 15 times to average-based dose risk values on second column in the tables. According to the conventional average-based INTERTRAN2 calculation, it is impossible to consider the above ratios. Besides, the results of various kind sampling, i.e. 10, 50, 100 and 500, are listed in “mean”, “standard deviation”, “minimum” and “maximum” terms.

Coefficient of variation derived from standard deviation and average is also useful to know the figure or property of probability distribution. From the results shown in Tables-1 and 2, standard deviations in incident-free mode relatively indicate wide range.

According to statistics, skewness that indicates skew shape of distribution to the left or right is considered to be useful while kurtosis or coefficient of excess that indicates sharpness of distribution is also considered to be useful.

$$SKEWNESS : a_3 = E(X - m)^3 / s^3$$

$$KURTOSIS: a_4 = E(X - m)^4 / s^4$$

where, μ: sample mean, σ: standard deviation, and E(X): expected value of X.

Here, $\alpha_3 = 0$ means a symmetry distribution, $\alpha_3 > 0$ means that the right side slope is longer than the left side slope. $\alpha_4 = 3$ means a normal distribution, $\alpha_4 > 3$ means that sharpness of distribution excesses the normal distribution. Besides, 95% values processed by EXCEL mostly correspond to each other. Results of those indexes are shown in Tables-3 and 4, respectively.

Table-3, Indexes for probability distribution

Mode	Skewness	Kurtosis	Note
Incident-free	26.4	4.6	Right slope is long and peak is sharper and higher than normal distribution.
Accident	35.8	4.9	Right slope is long and peak is sharper and higher than normal distribution.

Table-4, Comparison with 95% values

Sampling time	50	100	500
95% Incident free	1.40E-02	1.43E-02	1.46E-02
95% Accident	1.55E-14	1.07E-14	1.19E-14

(unit in person-mSv)

The above mentioned is summarized that ratio of mean and maximum or coefficient of variation are suitable to describe the spread of distribution. The above is also summarized that skewness and kurtosis are suitable to describe the figure of distribution. Besides, 95% value is available for supposing maximum value, because maximum value is changeable by sampling number.

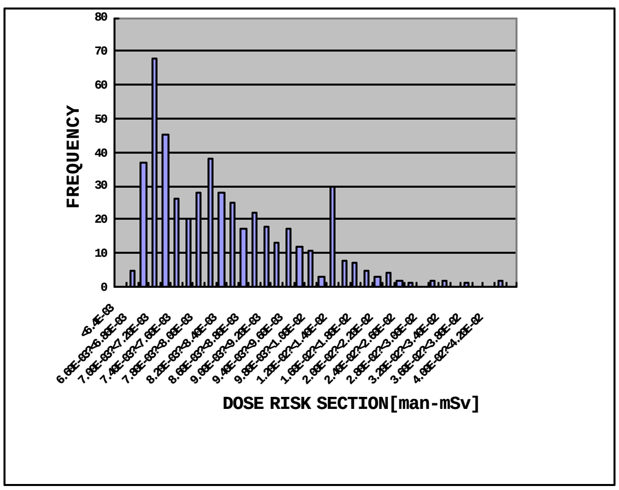


Figure-2, Dose risk distribution in incident-free.

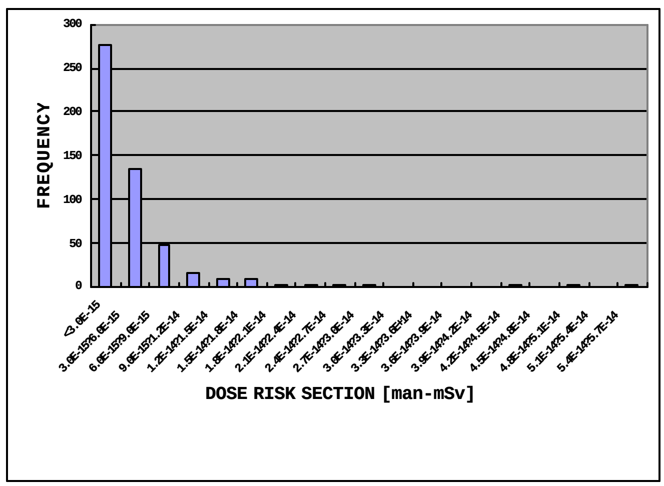
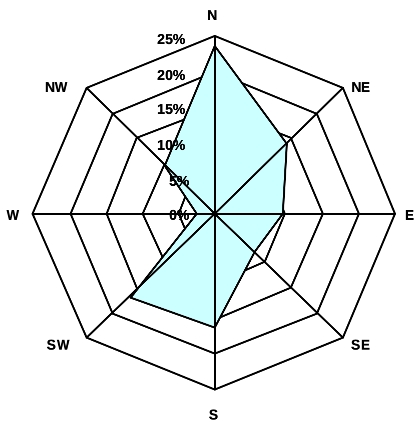


Figure-3, Dose risk distribution in accident.

Directional risk evaluation on the specific site

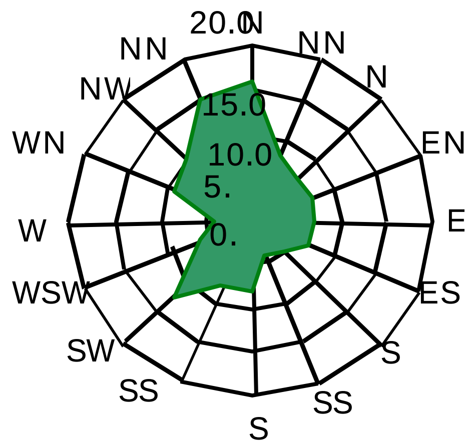
While RADTRAN4 calculates the entire dose risk of supposed transport route, risks are supposed to be different in each point on transport route and in each direction on the same point. Considering the spatial distribution of some variables, a spatial risk distribution chart was proposed as the new index for prevention of radiological disasters.

In this section, most of input variables were the same as the above case study, however 16 directional distributions based on statistics data were given to rainfall and wind speed. 8 directional distribution was given to population density. 16 directional data of three variables that mainly contribute to dose



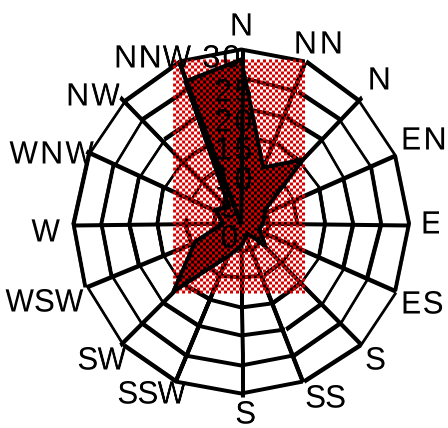
Unit: %

Figure-4, Wind appearance frequency.



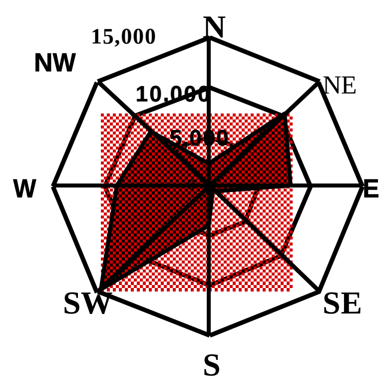
Unit: m/s

Figure-5, Wind velocity distribution



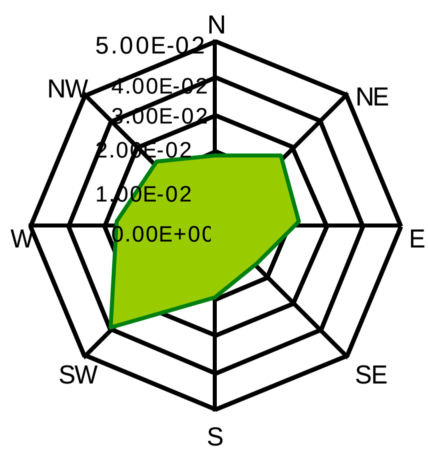
Unit: mm/h

Figure-6, Rain fall distribution.



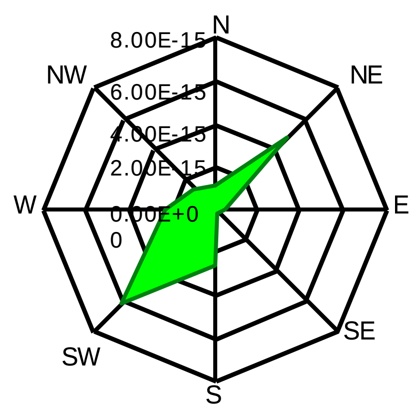
Unit: people/m^2

Figure-7, Population density distribution.



Unit: man-mSv

Figure-8, Dose risk distribution (Incident-free).



Unit: man-mSv

Figure-9, Dose risk distribution (Accident).

risks were derived from the AMEDAS meteorology statistics and the latest census. It should be noted that 8 or 16 directional distribution data were prepared as database and 8 directional distribution of dose risk was derived from the calculation. The distributions used in this study and dose risk distributions are shown in Figures-4 to 9.

The results derived from maximum condition are shown in Figures-8 and 9. For Incident free mode, dose risks of CREW and ONLINK are dominant. It is revealed that total dose risk distribution of Incident-free mode is similar to dose risk distribution combined from CREW and ONLINK. The dose risks of CREW and STOPS have no directional difference, because those risks do not depend on population density, wind directions and rainfall. The dose risk of ONLINK is practically similar to the distribution of population density, because it is a function of population density. As a result of dose risk integration, the ratio between the maximum direction and the minimum direction was acquired to be 2.5.

For Accident mode, directional dose risks show the remarkable differences. When an accident occurs at the assumed point on the Metropolitan highway, dose risks of southwest and northeast directions are relatively high because of biased population density and weather conditions shown in Figures-4 to 7. Dose of east direction shows low risk because of low wind appearance, while there are relatively a lot of inhabitants. As a result of dose risk integration, the ratio between the maximum direction and the minimum direction was acquired to be 33.

Considering these results, the directional dose risk evaluation on the remarkable transport section is supposed to be useful and effective for prevention of disasters and the conventional average based discussion may result in an insecure estimation.

SUMMARY

The method considering the fluctuation of INTERTRAN2 variables was proposed. After probability distributions of variables were prepared with the governmental statistics, LHS sampling technique was used for random sampling of discussed variables. 500 time samplings were executed in this study, and dose risks were converted to frequency or probability distributions. Then, some statistical indexes were proposed to evaluate the distribution figure. Besides, directional dose risk was estimated and discussed from the aspect of disaster prevention.

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