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Development of a Dose Assessment Computer Code for the NPP Severe Accident at Intermediate Level - Korean Case

Jae-Hak Cheong and Kun-Jai Lee
Dept. of Nucl. Eng., Korea Advanced Institute of Science and Technology
373-1, Kusong-dong, Yusong-gu, Taejon 305-701, Korea

Hang-Youn Cho and Jang-Hyun Lim
Korea Institute of Nuclear Safety (KINS)
150, Dukjin-dong, Yusong-gu, Taejon 305-353, Korea

ABSTRACT

A real-time dose assessment computer code named RADCON (RADiological CONsequence analysis) has been developed. An approximation method describing the distribution of radionuclides in a puff was proposed and implemented in the code. This method is expected to reduce the time required to calculate the cloud shine (external dose from radioactive plumes). RADCON can simulate an NPP emergency situation by considering complex topography and continuous washout phenomena, and provide a function of effective emergency planning. To verify the code results, RADCON has been compared with RASCAL [1], which was developed for the U.S. NRC by ORNL, for eight hypothetical accident scenarios. Sensitivity analysis was also performed for the important input parameters.

I. INTRODUCTION

Today Korea has nine nuclear power plants (8 PWRs and 1 CANDU) in operation and has very active nuclear power program - additional eighteen units are planned to be completed by 2006-. After the Chernobyl reactor accident, however public concern about the severe accident has been also increased in Korea. Considering the specific site conditions of Korean NPPs, it is ultimately requested for us to operate a large scale computer code system, such as ARAC and SPEEDI for the effective emergency planning. This research is meaningful as a preliminary step to develop our own nation-wide computer code for the NPP emergency preparedness.

RADCON was originally developed to be operated on SUN-4 SPARC workstation. The original source files were coded by using C language in order to increase its compatibility with the other computer systems. RADCON is modularized into ten program groups according to the function and characteristic of each module, which consists of several functions. The modularization was accomplished to make it easy to analyze and modify the code in the future.

II. MODEL DESCRIPTIONS

A. Atmospheric Dispersion Model

The atmospheric dispersion calculations in RADCON are mainly based on the well-known Gaussian puff model that was adopted in MESORAD code [2]. The horizontal and vertical diffusion coefficients are calculated by Brigg's formulation. Puff release rate can be specified by user, however the default value is set to 4 puffs per hour (i.e. each puff releases every 15 minutes).

Washout rate method proposed by Vrenk and Vogt [3] was adopted in order to describe the continuous washout phenomenon. This method makes it possible to simulate the washout phenomenon by considering the different behaviors between radioactive iodines and the other radionuclides. The equation implemented to RADCON has a continuous form, and is adequate to simulate the rainy season or the localized torrential downpour.

B. Cloud Shine Calculation Model

Compared with the other models, the cloud shine calculation algorithm is very time-consuming and contains lots of uncertainties. Various approximation methods to assess the cloud shine have been developed and proposed. But there exist serious discrepancies among the assessed doses calculated from different models, since they adopt different puff-geometries and integration procedures. We have developed a simple approximation method to simply the distribution of radionuclides in a puff and implemented it to the code.

The geometrical shape of a puff was assumed to be a sphere with a radius of $4\sigma_{eff}$. This assumption was turned to be quite reasonable (see Table 2), because most of the radionuclides (>99.889%) are to exist within the radius of $4\sigma_{eff}$. The effective (or average) diffusion coefficient σ_{eff} is defined as:

$$\sigma_{eff} = (\sigma_x \cdot \sigma_y \cdot \sigma_z)^{1/3} = (\sigma_y^2 \cdot \sigma_z)^{1/3} \qquad (1)$$

where,

σ_x, σ_y, σ_z = diffusion coefficients for each direction in the Gaussian model [m].

In the Gaussian puff model, the released radionuclides are diffused, and it is assumed that they have a normal (or Gaussian) distribution in each puff. We derived the three-dimensional Gaussian distribution function by expanding its one-dimensional probability density function. The fraction of radionuclides exist between r and r + dr (r is a radius of a spherical puff) is given by.

$$\frac{N_r}{N_{total}} = 4\pi \cdot r^2 \cdot \exp\left(-\frac{1}{2}r^2\right)dr \qquad (2)$$

where,

N_{total} = total number of radinuclides in a puff.

N_r = number of radionuclides exist between r and r + dr in a puff.

We calculated the fraction of three-dimensionally distributed radionuclides between each radial compartment ($0 - \sigma_{eff}$, $\sigma_{eff} - 2\sigma_{eff}$, $2\sigma_{eff} - 3\sigma_{eff}$ and $3\sigma_{eff} - 4\sigma_{eff}$) by numerical integration of the equation (2). These results are illustrated in Table 2. Dividing a puff spherically at σ_{eff}, $2\sigma_{eff}$, $3\sigma_{eff}$ and $4\sigma_{eff}$ gives a core and three shells. In addition, dividing each shell -except the core- vertically twice and horizontally once gives eight volume segments for each shell. By assuming all the radionuclides which exist in each volume segment act as a point source at the center of each segment (i.e., at 0, $1.5\sigma_{eff}$, $2.5\sigma_{eff}$ and $3.5\sigma_{eff}$). In this approximation method, the number of calculations for a shell is reduced to just two due to the simplified geometry of the puff.

C. Area Specification and Topographic Data

A 30 x 30 km square grid has been adopted to RADCON as a default, however the grid size and resolution can be adjusted by users. RADCON simulates the heights of a series of moving puffs by considering topography around the release point. The topographic data are to be input as a file for each site. In this research, we've prepared a topographic data file of Kori site. The three-dimensional representation of Kori site, based on the input data file, is illustrated in Fig. 3.

III. CODE FEATURES

A. Dose-Monitoring and Decision-Making

The dose-monitoring for total whole body and thyroid dose is performed in MONITOR module. This module compares the calculated dose at each grid point with the pre-determined limiting values in PAGs (Protective Action Guides) and decides an appropriate protective action for each area. The calculation results in MONITOR module are to be output as some files named TOT_HR:MN and THY_HR:MN (HR:MN means the time elapsed from the first release) every 15 minutes.

B. RADCON Graphic Tool

A simple graphic tool for effective decision-making was also developed. This graphic tool plots various dose-distribution patterns according to the pre-determined three limiting values recommended by PAGs. The lower exposure area (no action region) is plotted in yellow, the medium one (sheltering region) is plotted in green and the upper one (evacuation region) is plotted in red as shown in Fig. 2. RADCON also draws dose versus down-wind distance graphs immediately after finishing numerical calculation.

Drawing iso-dose lines might be very helpful for the decision makers in order to analyze the whole exposure situation around a release point. RADCON also has a function to output pre-formatted files, which can be directly used in a commercial graphic tool, such as SURFER.

III. RESULTS AND DISCUSSION

A. Comparison with RASCAL Version 1.3

The simulation results from RADCON were compared with those from RASCAL version 1.3 for eight imaginary accident scenarios. As a result, it is turned out that most of the simulation results from the above two codes are reasonably agreed within a maximum one-order relative error bound (see Fig. 3).

B. Sensitivity Analysis

Qualitative analysis has been performed for the potentially significant six input parameters. In general, the most dominant input parameters are dose factors. However, the values suggested by health physicists are to be adopted in the code without any modifications. Therefore, the sensitivity analysis was performed for the other input parameters. We analyzed the effects of source term, atmospheric stability, mixing layer lid-height, rainfall rate and the calculation method of diffusion coefficients.

Time-dependent variations of the various doses were also analyzed. As a result, it is proved that the cloud shine and internal exposure are important pathways for the short-term time frame, while the ground shine (exposure from the contaminated ground) becomes important for the long-term time frame in the accidental release at an NPP.

IV. CONCLUSION

RADCON has been developed as an intermediate level dose-assessment computer code for the NPP severe accident. Compared with RASCAL version 1.3 using the same input data, RADCON was turned to give favorable predictions. However Radcon has some features which are believed to be more adequate to consider Korean NPPs site-characteristics. The dose-monitoring and decision-making capability, and the graphic tool added in the code make it easier to prepare an emergency situation.

The approximation method calculating cloud shine proposed in this paper has not yet been fully verified, however it gave quite reasonable predictions in the comparison with RASCAL version 1.3. The accuracy of the approximation method is expected to be improved by subdividing the existing divisions in a puff.

REFERENCES

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2. R.I. Scherpelt et al., "The MESORAD Dose Assessment Model Vol. 1 : Technical Basis", NUREG/CR-4000, PNL, 1986.
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Table 1. Module Structure in RADCON

Modules	Module Descriptions
MAIN	Main and Control Module
INPUT	Reading Input Data
SOTERM	Source Term Calculation
METOPO	Reading Meteorological and Topographic Data
DISPER	Dispersion Calculation
DOSCAL	Dose Calculation

MONITOR	Dose-Monitoring and Decision-Making
ISODOSE	Plotting Iso-Dose Lines
GRAPHIC	Calling RADCON Graphic-Tool
WRITER	Writing Output Files

Table 2. Distribution of Radionuclides in a Puff

Range	Radionuclides Fractions		
	1-D	2-D	3-D
$0 - \sigma_{eff}$	0.3412	0.3935	0.1988
$\sigma_{eff} - 2\sigma_{eff}$	0.1359	0.4712	0.5398
$2\sigma_{eff} - 3\sigma_{eff}$	0.0214	0.1242	0.2322
$3\sigma_{eff} - 4\sigma_{eff}$	0.0013	0.0108	0.0282

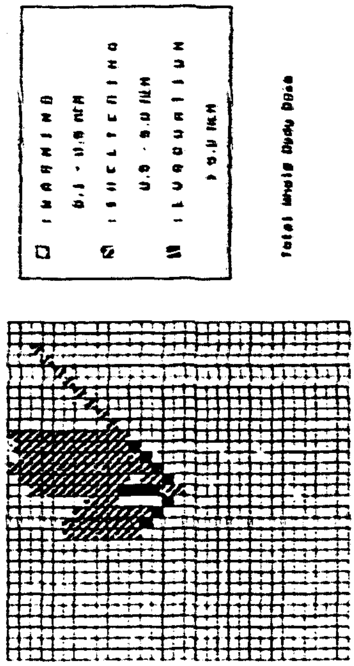

Figure 2. RADCON Graphic Tool Sample Output

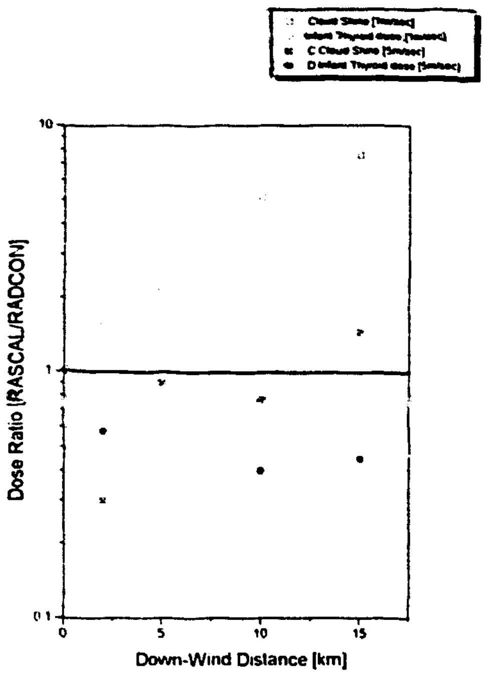

Figure 1. Sample Result of Calculation between RADCON and RASCAL Version 1.3

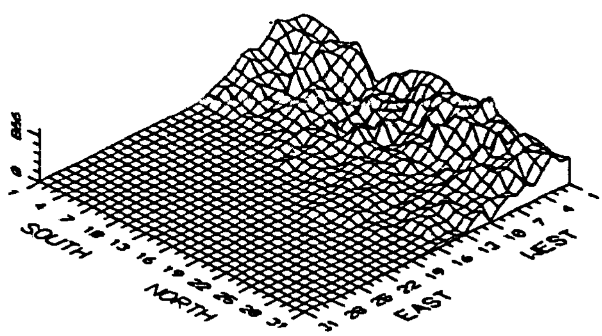

Figure 3. Three-Dimensional Representation of Kori Topography