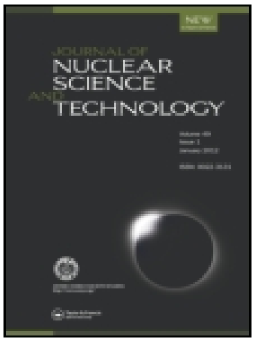

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# Development of Health Effect Assessment Software Using MACCS2 Code

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The extended regulatory interests in severe accidents management and enhanced safety regulatory requirements raise a need of more accurate analysis of the effect to the public health by users with diverse disciplines. This facilitates this work to develop web-based radiation health effect assessment software, RASUM, by using the MACCS2 code and HTML language to provide diverse users (regulators, operators, and public) with easy understanding, modeling, calculating, analyzing, documenting and reporting of the radiation health effect under hypothetical severe accidents. The engine of the web-based RASUM uses the MACCS2 as a base code developed by NRC and is composed of five modules such as development module, PSA training module, output module, input data module (source term, population distribution, meteorological data, etc.), and MACCS2 run module. For verification and demonstration of the RASUM, the offsite consequence analysis using the RASUM frame is performed for such as early fatality risk, organ does, and whole body does for two selected scenarios. Moreover, CCDF results from the RASUM for KSNP and CANDU type reactors are presented and compared.

***KEYWORDS: Accident Management, Severe Accident Phenomena, MACCS2, Level 3 PSA***

## I. Introduction

In case a hypothetical severe accident condition occurs at a nuclear power plant, radioactive materials could be released and transported through atmosphere and this may contaminate the environment and affect public health. The extended regulatory interest in severe accidents and enhanced safety requirements in regulations raise a need of more accurate analysis of the effect to the public health. The analysis generally called health effect analysis (HEA).

This effect can be evaluated deterministically or probabilistically. In comparison to the deterministic method which estimates the dose to the public conservatively for a limiting scenario, a probabilistic method can realistically treat diverse scenarios by integrating fatalities for many scenarios weighed by each frequency. This method is called Level 3 probabilistic safety assessment (PSA). This probabilistic health effect assessment (HEA) considers such factors as source terms, weather conditions, emergency plan, plant specific conditions (topography or community), definition plant damage states and frequency data.

The calculation of the factors mainly needs calculations of airborne and ground concentrations of each radionuclide and dispersion of the radioactive materials through atmosphere for various scenarios. Therefore, current HEA uses a computer program MACCS2 (MELCOR accident consequence code system) for this purpose. However this kind of computer code is very complicated to understand and thus for an analysis it needs an expertise in the severe accident phenomena, probabilities, radioactive materials transport, effect to the public organ, and so on. This prevents extended users (plant operators, regulators, engineers, doctors, general public) from easy access and analysis and moreover, this hinders HEA from evolution.

For easy access and analysis for the diverse users, health effect assessment software, RASUM, is developed in this work based on MACCS2 code by incorporating HTML[1] (hypertext markup language). The RASUM is a software where user-friendly functions are implemented such as images, tables, tags, and style-texts. Figure 1 shows the overall outline of the RASUM.

This paper is to address the overview of the base code MACCS2, development method of the software RASUM, verification of the RASUM. Finally as a demonstration, early fatalities, organ dose, whole-body dose, and CCDF (Complementary Cumulative Distribution Function) are analyzed by using the RASUM.

## II. Overview of the MACCS2 Code

The environment would be contaminated by radioactive nuclide deposited from the plume and the population would be exposed to radiation. Estimation of the range and probability of the health effects induced by the radiation exposures not avoided by protective measure actions and the economic costs and losses that would result from the contamination of the environment is the object of the MACCS2 calculation[2].

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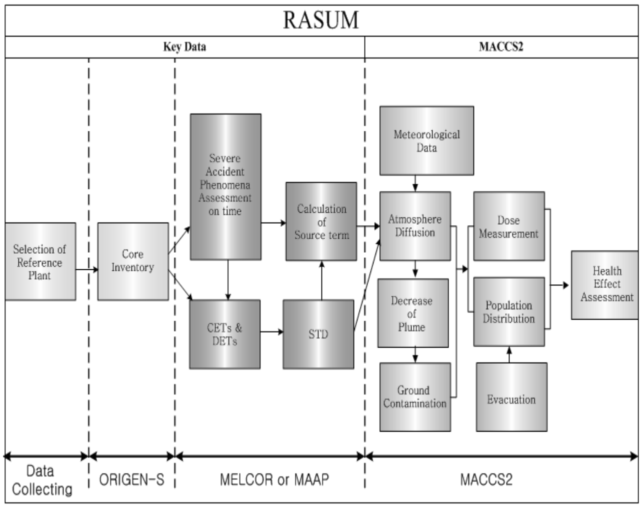


**Fig. 1** Overall outline of the RASUM software

There are two aspects of the organization of MACCS2 which are basic to its understanding: The time scale after the accident is divided into various "phases", and the region surrounding the reactor is divided into polar-coordinate grid. The time scale after the accident is divided into three phases: emergency phase, intermediate phase, and long-term phase. Of the three time phases, the only one that must be defined by the user, is the emergency phase, the other two are optional.

The spatial grid used to represent the region is centered on the reactor itself. That is, the reactor is located at the point (r=0, θ=0). The user specifies the number of radial divisions as well as their endpoint distances. Up to 35 of these divisions may be defined extending out to a maximum distance of 9999 km. The angular divisions, θ, used to define the spatial grid correspond to the sixteen directions of the compass.

All of the calculations of MACCS2 are stored on the basis of this polar-coordinate spatial grid. Since the emergency phase calculations utilize dose-response models for early fatality and early injury that are highly non-linear, it is necessary for those calculations to be performed on a finer grid than the calculations of the intermediate and long-term phases. For this reason, the sixteen compass sectors are subdivided into 3, 5, or 7 user-specified subdivisions in the calculations of the emergency phase.

In MACCS2, the dispersion and deposition of radionuclide released from the reactor containment to the atmosphere were modeled with a Gaussian plume model. Radiation doses to the population were calculated based on the radionuclide concentration that is predicted by the dispersion models. The exposure pathways considered in the evaluation of health effects are: (1) exposure to the passing plume, (2) exposure to radioactive materials deposited on the ground, (3) exposures to deposits on skin, (4) inhalation of radioactive materials directly from the passing plume, (5) inhalation of radioactive materials resuspended from the ground by natural and mechanical processes, (6) ingestion of contaminated foodstuffs, and (7) ingestion of contaminated water.

MACCS2 code used in this study is composed of 3 modules, which are processing the input data with verifying the efficiency, modeling the condition and treating the output data. It is composed of 3 main input data and the others needed to run the code. Especially, in this study, the emergency phase is only considered. During this time, other different methods as sheltering and shield by dose and evacuation can be suggested considering all the radioactive plume and exposure from ground contamination.

Intermediate and long term phase are calculated by CHRONIC module of MACCS2 code. During this period, radioactive plume disappears and only the exposure by ground contamination is considered. Then the defensive means such as temporary sheltering, decontamination and setting the restricted area are dealt. In this study, CHRONIC module is not used since it is not focused on evaluating the radiation effect. DOSDATA input data including conversion factor, meteorological data including wind direction, wind velocity, atmosphere stability and cumulative precipitation, etc. by each hour in a year, population distribution and data of the site near nuclear plant providing information about land fraction are used.

## III. Method of RASUM Development

The RASUM, written in HTML, can provide awareness training to the operators whose work has a significant impact upon safe operation of nuclear power plants during an accident. It may be basically used for fundamental training in the severe accident assessment and response strategies, instrument degradation under severe accident conditions, and alternative instrumentation to verify instrument reading necessary for the implementation of severe accident strategies.

The initiation point of the RASUM and the scopes of EOPs (Emergency Operating Procedures) and severe accident management strategy are shown in Fig. 2. It is basically developed to help the control room operators and staffs to answer questions such as the following:

- What are the possible accidents sequences under given conditions?
- What is the expected physical accident status after some evident symptoms?
- What are the minimum consequences if some of actions are initiated prematurely?

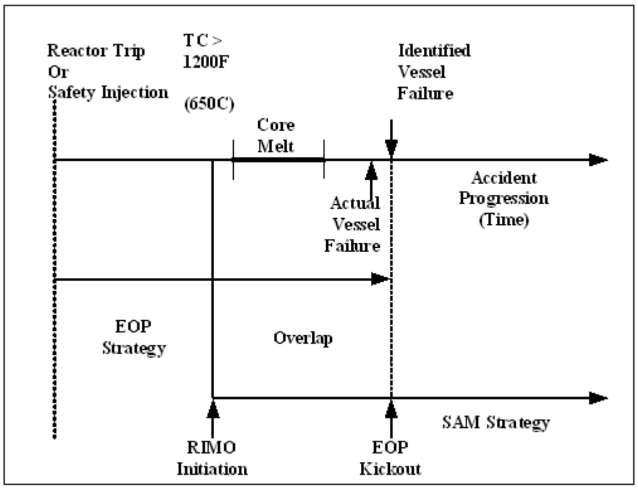


**Fig. 2** The Initiation Timing for RASUM

User can see the result graphically, which is the output by running actual MACCS2 code and creating database for off-site health effect assessment. And most users can understand and access the general concepts and methodology of PSA. Created RASUM can be used for risk informed regulation and application, accident management plan, public acceptance, etc.

Web-based RASUM consist of 5 modules as below;

① Development Module
② PSA Training Module
③ Health Effect Assessments Output Module
④ Input Data Module
⑤ MACCS2 Run Module

Background of developing web-based RASUM is written in the first module. The second module consists of PSA contents addresses the overall methodology of PSA[3]. The third module t uses KSNP as a Reference plant for users to graphically confirm the results of an off-site health effect assessment such as an average individual risk, early and latent cancer fatalities, etc, which is divided into 10 different sections in the radius of 80 km in map for KSNP. In the fourth module, source term data on 19 release groups (Table 1) of KSNP, meteorological data throughout the year, population distribution data[4] and ground data around reference part are established as key data to perform the MACCS2 calculation. In the last module, users can link the web to perform the MACCS2 code written in ANSI Standard FORTRAN 77, modify and save the input data.

## IV. Verification and Demonstration of the RASUM

### 1. Verification

In order to verify the function of the RASUM by evaluating offsite health effect, source term input, meteorological data, ground data and population distribution data, etc of KSNP for STC15 (LLOCA, large loss of coolant accident) & STC4 (LOFW, loss of feedwater flow) are used as shown in table 1.

**Table 1** Characteristics and Frequency of STC15 & STC4 n Key Data (Sample)

| Source Term | Containment Failure Mode | Initial Event | Frequency |
|---|---|---|---|
| STC 15 | • Early Containment Failure:<br>- SIT Injection Success<br>- HPSIS Injection Success<br>- Recirculation Cooling using CSS Success without CTMNT Heat Removal Sys. | Large LOCA | 4.91E-07 |
| STC 4 | • Early Containment Failure(Rupture):<br>- Reactor Trip Success<br>- AFW Fail<br>- Bleed RCS Fail<br>- LPSI Injection Fail<br>- LPSI Recirculation Success<br>- CTMNT Spray Injection Success<br>- Recirculation Cooling using CSS Success | Loss of Feed-water | 1.80E-08 |

To illustrate the verification, the following calculations are made:

1. Complementary Cumulative Distribution Frequency(CCDF) for early fatalities and latent cancer fatalities
2. Early cancer fatalities within the radius of 80 km
3. Early fatalities risk, organ dose and whole-body dose

### 2. Demonstration

The main results of health effects are stochastically calculated by RASUM for KSNP as shown in Figure 3. Early fatalities, latent cancer fatalities, organ dose, whole-body dose and CCDF are calculated within the radius of 80km. Also, If the straight-line plume model was chosen (IPLUME=1) in MACCS2 code input data, the code can keep track of the centerline dose (whole-body, acute and life time dose) for possible contamination pathway.

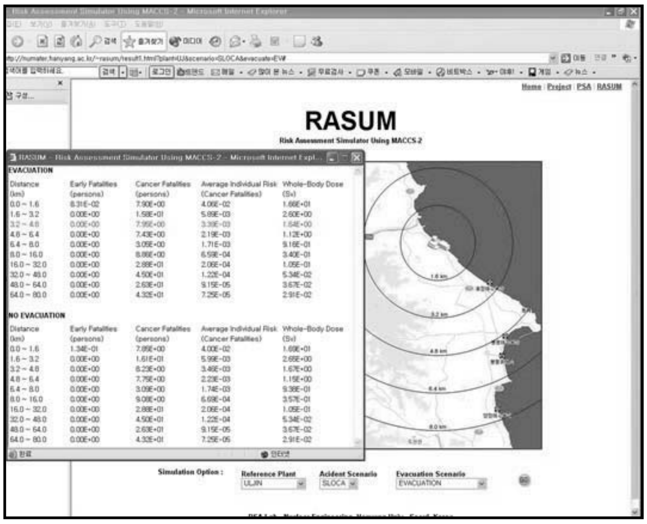


**Fig. 3** Sample Results of STC15 and STC4 in KSNP using RASUM

**Table 2** and **3** present the mean and 95 percentile value of the early fatalities risk of STC15 & STC4.

**Table 2** Mean and 95 Percentile of Early Fatalities (0~32km)

| STC | Early Fatalities | | **E/F×Frequency(Risk)** | |
|---|---|---|---|---|
| | Mean | 95 Percentile | Mean | 95 Percentile |
| STC 15 | 6.21E-01 | 2.06E+00 | 3.06E-07 | 1.01E-06 |
| STC 4 | 3.33E+01 | 7.02E+01 | 5.99E-07 | 1.26E-06 |

**Table 3** Mean and 95 Percentile of Early Fatalities (0~80km)

| STC | Early Fatalities | | **E/F×Frequency(Risk)** | |
|---|---|---|---|---|
| | Mean | 95 Percentile | Mean | 95 Percentile |
| STC 15 | 6.21E-01 | 2.06E+00 | 3.06E-07 | 1.01E-06 |
| STC 4 | 3.33E+01 | 7.02E+01 | 5.99E-07 | 1.26E-06 |

The actual MACCS2 calculations present consequences of early and latent cancer fatalities for 19 STC scenarios and frequencies. Current RASUM is developed for a test version, and thus it does not take into account all the parameters that related to atmospheric dispersion model in original MACCS2.

In addition, RASUM present results of respective organ dose depending on distance as shown in figure 4 and 5. The result of STC 15 shows that thyroid has the largest dose and stomach has the lowest value since the release fraction of iodine is the largest compared with another radionuclide out of the noble gases. The result of STC 4 shows that lung, bone and thyroid have similar values. For the case of stomach, the amount of dose shows the smallest value since stomach has a long contamination path way.

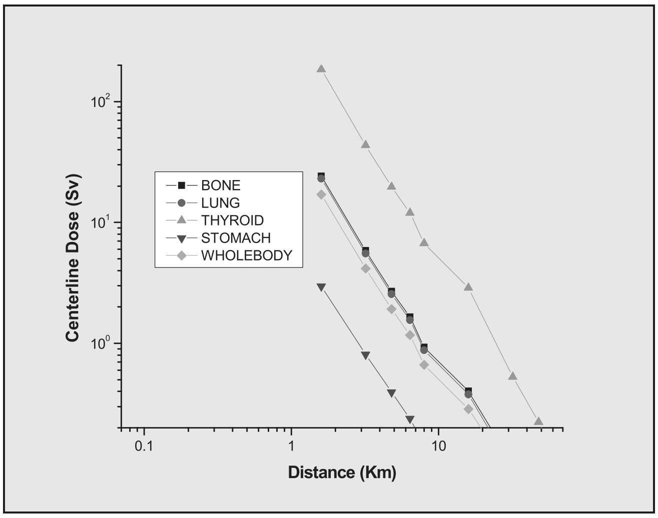


**Fig. 4** Organ Doses on the distance (STC15: LLOCA)

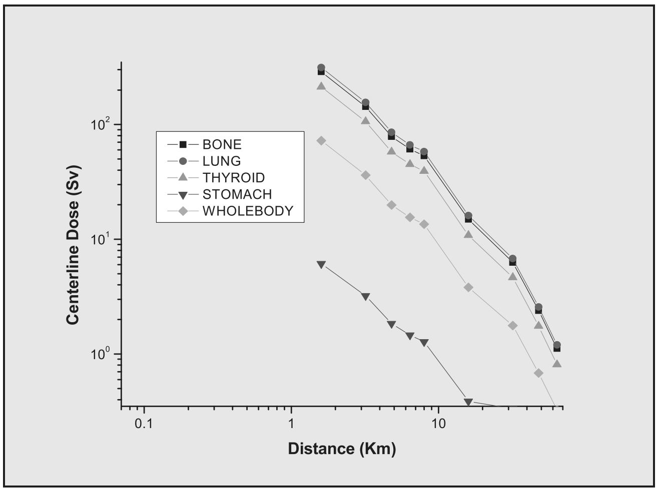


**Fig. 5** Organ Doses on the distance (STC4: LOFW)

Figure 6 shows CCDF results for KSNP and CANDU type reactor using developed RASUM. The CCDF presents an estimation of the consequence magnitude distribution and the result of CCDF for early fatalities and latent cancer fatalities is strongly influenced by local meteorological state and population distribution. UCN34 has lower population density than WS1 and YGN34. In addition, the main wind direction of UCN34 east towered.

It is thus found that the RASUM developed in this paper is effective in understanding, modeling, calculating, analyzing, documenting and reporting of the radiation health effect under hypothetical severe accidents.

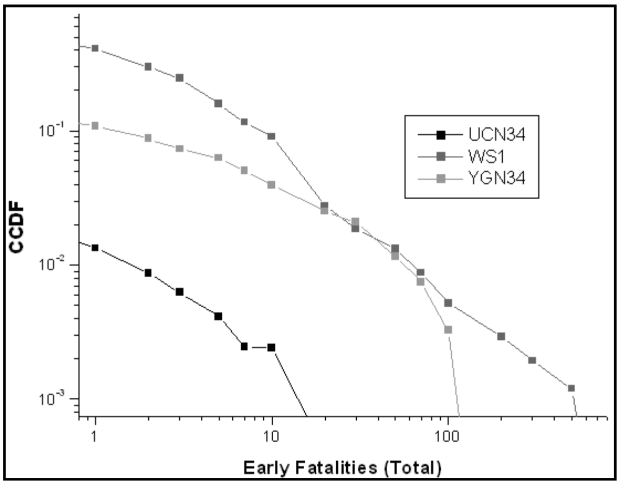


**Fig. 6** CCDF for two **PWRs** and a CANDU type plant

## IV. Conclusions

The extended regulatory interest in severe accidents and enhanced safety requirements in regulations raise a need of more accurate analysis of the effect to the public health. However, the traditional code for the HEA (MACCS2) requires an expertise in establishing input formation and running the code. Thus the RASUM software is developed to provide not only user-friendly input environment but also visualizations of HEA results such as dispersion of radioactive materials.

For verification and demonstration of the RASUM, the offsite consequence analysis using the RASUM frame is performed for such as early fatality risk, organ does, and whole body does for two selected scenarios. Moreover, CCDF results from the RASUM for KSNP and CANDU type reactors are presented and compared.

It can be concluded that the RASUM will contribute to implementation Accident Management Plan (AMP), Integration Leak Rate Test (ILRT) extension, and Risk Informed Regulation & Application (RIR&A) in Korea.

## Acknowledgement

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