Preliminary Assessment of Population Dose during Nuclear Power Plant Normal Operation

Sang Hun Lee, Hyun Gook Kang

Author 1 Affiliation Information: Korea Advanced Institue of Science and Technology, 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea, titanic91@kaist.ac.kr
Author 2 Affiliation Information: Korea Advanced Institue of Science and Technology, 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea, hyungook@kaist.ac.kr

I. Introduction

Since the Fukushima accident happened, nuclear power plant (NPP) safety has been an important issue. To ensure the safety of NPP, probabilistic risk assessment (PRA) of operating NPP is widely conducted. Level 3 PRA estimates the consequences in terms of injury to the public and damage to the environment in case of radioactivity release accidents of NPP [1]. Most of the studies related to level 3 PRA analysis are focused on severe accident case of NPP. Along with the severe accident analysis, the offsite consequence analysis of normal operation of NPP must be conducted as well since radioactive materials are consistently released to the atmosphere and aquatic environment during normal operation of NPP. The estimation of the exposure dose and health effects resulting from the radioactive materials released to the environment during the normal operation of NPP can be useful data for the enhancement of the public acceptance of nuclear power systems. Therefore, the main objective of this study is to estimate the population dose resulting from the routine releases of gaseous radioactive wastes using MACCS2 (MELCOR Accident Consequence Code System 2).

II. Method

A. Model description

The MACCS2 code was used to estimate radiological doses, health effects, and economic consequences that could be resulted from accidental releases of radioactive materials to the atmosphere [2]. MACCS2 represents a major enhancement of its predecessor MACCS, the MELCOR Accident Consequence Code System. MACCS, distributed since 1990, was developed to evaluate the impacts of severe accidents at nuclear power plants on the surrounding public. MACCS2 was developed as a general-purpose tool applicable to diverse reactor and nonreactor facilities. MACCS2 also includes three primary enhancements: (1) a more flexible emergency-response model, (2) an expanded library of radionuclides, and (3) a semi-dynamic food-chain model. Other improvements are in the areas of phenomenological modeling and new output options. The above improvements of software allow the evaluation of the offsite risk measures during not only the severe accident of NPP but also the normal operation of NPP.

The brief MACCS2 flow diagram is shown in Fig.1 [3]. In MACCS2, The principal phenomena considered are atmospheric transport and deposition under time-variant meteorology, short and long-term mitigative actions and exposure pathways, deterministic and stochastic health effects, and economic costs. It includes three primary modules: ATMOS, EARLY, and CHRONC.

The ATMOS module employs a Gaussian plume model with Pasquill–Gifford dispersion parameters to calculate the dispersion and deposition of materials released to the atmosphere as a function of downwind distance. The treated phenomena consist of building wake effects, buoyant plume rise, plume dispersion during transport, wet and dry deposition, and radioactive decay and ingrowth.

The EARLY module performs all of the calculations pertaining to the emergency phase. The exposure pathways considered during this phase include cloudshine, groundshine, and resuspension inhalation. In case of dose calculation, acute dose used for the estimates of early fatalities and injuries, and lifetime dose commitment used for the estimates of associated excess cancer risks resulting from early exposure. The dose calculation is the product of the following quantities: radionuclide concentration, dose conversion factors, duration of exposure, and shielding factors and is spatially variant according to the polar-coordinate grid divided into 16 compass directions with 22.5 degree angle.

The CHRONC module performs the calculations during the intermediate and long-term phases. The associated exposure pathways during the intermediate phase are groundshine and resuspension inhalation, and the pathways during the long-term phase are groundshine as well as food and water ingestion.

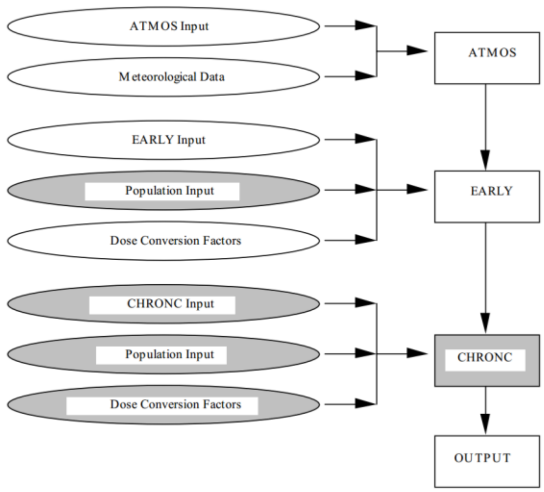

Figure 1. The diagram of the MACCS2 code.

B. *Overview of simulation*

To assess the population dose resulting from the routine releases of gaseous radioactive wastes during normal operation of NPP, reasonable hypothetical NPP site information including population distribution, target weather information, the amount of gaseous radioactive material release during normal operation of NPP is assumed. Contrast to the severe accident case of NPP, atmospheric modeling and dose evaluation method is defined according to the specific case of normal operation of NPP.

1) *Atmospheric modeling*

Since radioactive materials are assumed to be consistently released to the atmosphere environment during normal operation of NPP, the release description of the plume segment must be modeled different from short-term release of radioactive material in case of severe accident of NPP. Various important parameters including time between radioactive material release and reference time point (RT), duration of release (RD), sensible heat rate (HR), release height (RH) is defined according to the specific information of released gaseous radioactive material. All of the parameters are defined in reasonably conservative values for evaluating population dose and comparing with the environmental radiation safety criteria around NPP.

2) *Exposure dose estimation*

MACCS2 requires dose conversion factors (DCFs) for the inhalation, ingestion, cloudshine, and groundshine exposure pathways for each organ for which doses are to be calculated and for each radionuclide that is to be included in the scenario. To estimate the population exposure dose, reasonable dose conversion factor is used to express the relationship between environmental concentrations or intakes and resultant human doses or dose rates. Also, the definition of the duration of emergency phase, intermediate phase, long-term phase is important. The exposure dose of each phase is calculated in EARLY, CHRONC module. The dose during each phase differs according to the duration of each phase. So the timeline of each phase is reasonably defined according to the definition of the plume rise time and duration.

C. *Safety criteria*

The safety criteria for the gaseous radioactive material release is based on the nuclear safety regulation law enacted by Nuclear Safety and Security Commission (NSSC) and the standard for environmental radioactivity is proposed by radiological protection guide as described in table 1 [4]. Based on the environmental radiation safety criteria, the complementary cumulative distribution function (CCDF) of population dose around NPP was used to analyze the probability that could exceed the safety criteria.

TABLE I. ENVIRONMENTAL RADIOACTIVITY THRESHOLD DESIGN BASIS FOR KOREAN NPP.

Category	Design basis of NPP unit	Design basis of NPP site
Absorbed dose of air by gamma-ray	0.1 [mGy/yr]	Effective dose : 0.25 [mSv/yr]
Absorbed dose of air by beta-ray	0.2 [mGy/yr]	
Effective dose by external exposure	0.05 [mSv/yr]	Thyroid equivalent dose : 0.75 [mSv/yr]
Skin equivalent dose by external exposure	0.15 [mSv/yr]	
Organ equivalent dose by granular radioactive material, H, C and iodine	0.15 [mSv/yr]	

III. RESULT AND DISCUSSION

Using the MACCS2 code, the population dose resulting from the continuous releases of gaseous radioactive wastes during normal operation of NPP was evaluated with the conservative assumptions in atmospheric modeling. Specific organ equivalent doses were summed up to calculate the population dose for various exposure pathways. Since the amount of the released gaseous radioactive material in normal operation is substantially less than the case of severe accident of NPP, the CCDF value of exceeding threshold dose based on safety regulation was less than 10^{-5} at every distance from release site and the peak individual dose was around few percent of design basis dose threshold value. Following these results, we can conclude that the expected environmental radioactivity by the released gaseous radioactive material during normal operation of NPP has negligible health effect on public around NPP site. Future study will include more realistic atmospheric modeling and site information and assess organ specific dose in case of liquid radioactive substance released to aquatic environment during normal operation of NPP.

IV. ACKNOWLEDGMENTS

This work was supported by the ‘Valuation and Socio-economic Validity Analysis of Nuclear Power Plant In Low Carbon Energy Development Era’ of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea. 20131520000040.

REFERENCES

[1] US Nuclear Regulatory Commission. "PRA procedures guide." NUREG-2300, Washington, DC (1983).

[2] Chanin, D. I., Mary L. Young, and J. Randall. "Code manual for MACCS2: volume 1, user’s guide." SAND97-0594, Sandia National Laboratories, Albuquerque, USA (1997).

[3] DOE. MACCS2 Computer Code Application Guidance for Documented Safety Analysis, DOE-EH-4.2.1.4-Final MACCS2 Code Guidance, Final Report, U.S. Department of Energy, Washington, DC, (2004).

[4] Korea Hydro & Nuclear Power Co., Ltd. Annual Report on Environmental Radioactivity around Nuclear Power Plants, KHNP (2011).