Radiological Consequence Analysis of Severe Accidents in a Small Modular Reactor

S.D. Suk [a*] , Y. Jin [b] and S.K. Sim [a]
[a] *Environment & Energy Technology(EN ^{2} T), 100 Sinsung-dong, Yuseong, Daejeon 305-804*
[b] *Korea Atomic Energy Research Institute,150 Dukjin dong.,Yuseong,Daejeon,Korea 305-353*
**Corresponding author : sdsuk@en2t.com*

1. Introduction

An effort has been made in this study to estimate the radiological consequences of potential severe accidents in the SMART(System-Integrated Modular Advanced Reactor) design, using MACCS2 code system [1,2]. Major parameters estimated in this study include the early fatality, late cancer, population dose, early fatality risk and late cancer risk. The results showed that the risk for early fatality and late cancer were way below the safety goals established by the regulatory organizations.

2. MACCS2 Code

The MACCS2, the MELCORE Accident Consequence Code System, was developed by the Sandia National Laboratories (SNL) under the USNRC's sponsorship to evaluate the impacts of severe accidents at nuclear power plants on the surrounding public. 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.

MACCS2 is divided into three primary modules of ATMOS, EARLY, and CHRONIC. ATMOS deals with atmospheric transport, dispersion, and deposition. It also calculates the radioactive decay that occurs both in the reactor and the atmosphere after the release.

EARLY performs all of the calculations during the emergency phase, ranging between 1 and 7 days depending on the user input. The exposure pathways considered are cloudshine, groundshine, and resuspension inhalation. Mitigative actions that can be specified for the emergency phase include evacuation, sheltering, and dose-dependent relocation.

CHRONC covers all the calculations regarding both intermediate and long-term phases. The duration of the intermediate phase is specified by the user, ranging between 0 and 1 year. The only mitigative action is dose-dependent relocation. The exposure pathways considered are groundshine, resuspension inhalation. The long-term phase begins upon the conclusion of the intermediate phase. The exposure pathways considered are groundshine, resuspension inhalation , and food and water ingestion.

3. Major Input and Assumptions

The SMART design is a small integral PWR of thermal capacity 330 MW , with the site boundary set up 300 m from the reactor core. Required to perform its consequence analysis are its site data such as weather and demography, The reactor site was not determined yet, however. Under the circumstances, such domestic site data available as Youngwang, Uljin and Kori, were tested to select the site data resulting in the most conservative radiological consequences. It turned out that the Youngwang site data rendered the most conservative results, so that its data were then made use of for the detail consequence analysis of the SMART in this study.

Source terms for 9 group of radionuclides were calculated for 11 representative accident sequence categories(STC: Source term category), using MIDAS/SMR code. Table 1 lists the frequency and major features of accident sequence for each STC.

Plume release characteristics input for MACCS2 were defined in accordance with the results of source term calculations. For instance, release height was set to be the height of the containment(28.5 m) for STC 1 to 9. For STC 10(reactor cavity-melt-through), release hight was assumed to be the elevation of cavity(9m). For the sequences of containment bypass like STC 10 and 11, release height was assumed to be 0 for the sake of conservatism. It was assumed that radionuclides are continuously released over 24 hours for the leakage-type accidents(such as STC 1,2,3,4,9,10,11), while that relatively short duration of release(2 hours) were assumed for the overpressure accidents(STC 5,6,7,8).

Table 1. Frequency of Source Term Categories(STC)

STC	Frequency (/year)	Fraction (%)	Description
1	4.052E-09	0.8	RB [(1)] Failed, Spray [(2)] on
2	2.380E-09	0.5	RB Failed, Spray Failed
3	4.521E-07	87.9	RV [(3)] & RB Integrity maintained
4	6.527E-09	0.8	RV Failed, but RB Integrity maintained
5	2.587E-09	0.8	RB Early Failure, Spray on
6	1.466E-09	0.6	RB Early Failure, Spray Failed
7	3.343E-15	<0.1	RB Late Failure, Spray on
8	1.673E-10	<0.1	RB Late Failure, Spray Failed
9	5.669E-09	1.0	Reactor Cavity Melt-through
10	3.498E-09	6.7	RB Bypass(SGTR) [(4)]
11	5.080E-09	1.0	RB Bypass(ISLOCA) [(5)]
Sum	**5.150E-07**	**100.0**	-

Note : Abbreviations used in Table 1
(1)RB for Reactor Building meaning reactor containment
(2) Spray for Containment Spray
(3) RV for Reactor Vessel
(4) SGTR for Steam Generator Tube Rupture
(5) ISLOCA for Interfacing System Loss Of Coolant Accident

4. Results

Table 2 lists the results estimated for the early fatalitiy and late cancer risk at 1.6 km and 8 km each from the reactor site, for each STC and sum of it as well. It may be noted that 99 percent of the early fatality risk comes from the STC 11(containment bypass, 94 percent) and STC 10(SGTR, 5 percent)., so that it would be essential to reduce the frequencies of these two category of accidents. Meanwhile, a number of STCs contribute to the late cancer fatality risk; STC 10(38 %), STC 11(25 %),STC 9(16 %), STC 3(12 %) in that order.

Total risks of early fatalities and late cancers amount to be 9.5 x 10^{-11} and 2.34 x 10^{-10} , respectively, which are only 0.016 % and 0.018 % of the safey goal values [3] set by the KINS(Korea Institute of Nuclear Safety(KINS). These are the results calculated without the emergency planning taken into account. Considering emergency planning such as evacuation and temporary relocation resulted in reducing risk by as much as 50 %.

Table 2. Early Fatality and Late Cancer Risk

STC	Early Fatality Risk (/Reactor-year)	Late Cancer Risk (/Reactor-year)
1	-	2.86E-12
2	7.45E-13	9.63E-12
3	-	2.70E-11
4	-	5.96E-15
5	-	1.86E-13
6	7.51E-14	5.95E-12
7	5.62E-19	5.62E-19
8	-	3.55E-12
9	1.16E-13	3.77E-11
10	4.69E-12	8.96E-11
11	8.94E-11	5.74E-11
Total	**9.50E-11**	**2.34E-10**

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References

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