Verification Study on New Safety Goal for Avoiding Long-term Off-site Contamination

Kyuntae Kim [a*], Yongjin Lee [a], Dongwon Lee [a], Seungwoo Lee [a], Dohyoung Kim [a]
[a]*Korea Institute of Nuclear Safety, 62 Gwahak-ro, Yuseong-gu, Daejeon, KOREA 305-338*
[*]*Corresponding author: kkt@kins.re.kr*

1. Introduction

In 2015, Nuclear Safety and Security Commission (NSSC) made an amendment in the Nuclear Safety Act(NSA) reflecting the lessons learned from the Fukushima accident. According to the rulemakings subsequent to this amendment of the NSA, NSSC set the safety goals in its regulation [1] as follows; 'Even if an accident should occur, the release of large amount of radioactive materials that may threaten the health of people in the surrounding area of NPP or cause the long-term off-site contamination should be avoided.' NSSC notice [2] further specified this safety goal, so that for avoiding long-term off-site contamination, the sum of frequencies for the accident scenarios in which the amount of Cs-137 release exceeds 100 TBq should be less than 1.0 E-06/ry.

The purpose of this study is to assess the Cs-137 100 TBq requirement is sufficient to satisfy the safety goal for avoiding long-term off-site contamination. Therefore, in this study, exposure dose assessment for 'Cs-137 100TBq' requirement was performed and verified that the requirement was properly set based on calculation results.

2. Methods and Code

2.1 Development of Verification Framework for 'Cs-137 requirement'

In this chapter, research framework was developed to perform the verification of Cs-137 requirement as shown in Fig.1.

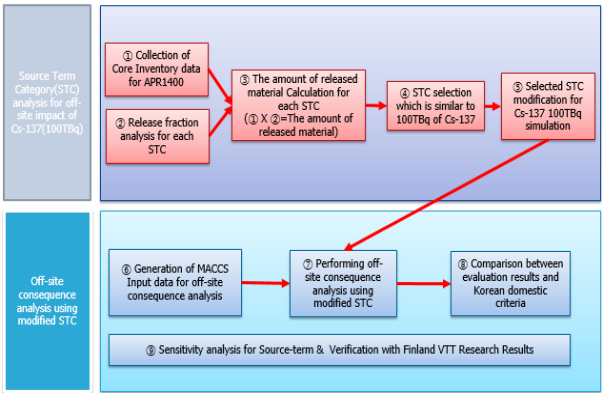

Fig. 1. Research Framework for Verification of 'Cs-137 requirement'

The research framework for verification of 'Cs-137 requirement' is divided into 2 steps. First step is selection of target Source Term Category(STC) using PSA information. In Step 1, the amount of released Cs-137 was calculated by multiplying core inventory and release fraction using level 2 PSA results. Based on calculation results for released amount of radionuclide, the final source-term was selected, where the amount of Cs-137 release was most similar to 100TBq.

In Step 2, exposure dose from released radionuclides was analyzed using the source-term which is derived in Step 1. Dose assessment was performed using WinMACCS and the results were compared with the criteria which is described in the NSA. In addition, comparison study was made with similar analytical case which was performed in Finland VTT. In this study, overall dose assessment was performed using the developed research framework.

2.2 WinMACCS code

In this study, WinMACCS was used to calculate exposure dose from developed source-term. WinMACCS is developed by U.S. NRC to evaluate off-site risk when the radioactive materials leak from containment. This code is originated from CRAC code which is used at WASH-1400 study. The calculation framework and relation diagram of WinMACCS are described in Fig.2.
WinMACCS can treat below phenomenon by utilizing some site-specific data.

- ✓ Atmospheric transport and deposition onto the ground
- ✓ Statistical effect of variability in weather
- ✓ Dose pathways for cloudshine, groundshine, inhalation, ingestion, and deposition onto skin
- ✓ Protective actions during emergency, intermediate, and long-term phases

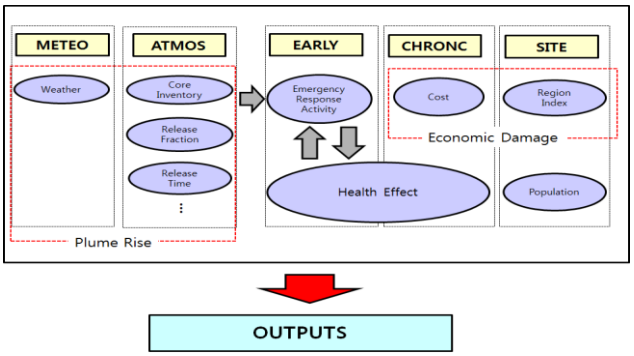

Fig. 2. WinMACCS Calculation Framework

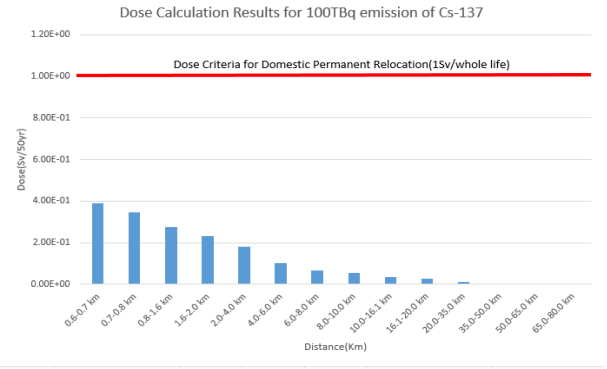

Fig.3. Dose Calculation Results for Cs-137 100TBq

3. Research Results

3.1 Deduction of Source Term using PSA information

According to the Level 2 PSA results, there are 31 STCs in the APR1400. In this study, the source-term which is equivalent to 'Cs-137 100TBq' was selected as analysis target STC. Each release amount of radionuclide was calculated by multiplying the core inventory and the release fraction. In addition, since the amount of Cs-137 release of the selected STC does not exactly matched with 100TBq, it should be adjusted using core multiplication factor(CORSCA) in WinMACCS.

The table below summarizes STC 27 information including the release amount of Cs-137 and accident scenarios.

Table 1. The information of selected STC

Target STC	STC 27
Release amount of Cs-137	28.9 TBq
Core multiplication factor	3.448
Adjusted release amount of Cs-137	100TBq
Containment Failure Mode	Late Containment Fail (Rupture)
STC Frequency	1.74E-07/yr

In this analysis, the dose assessment was performed using the source term described in Table 1.

3.2 Dose calculation for Cs-137 100TBq

In this section, the dose assessment was performed by inputting the source-term selected in Section 3.1 into WinMACCS. In addition to the source term information, default values were used for data input to WinMACCS, and site characteristics data were used for reference NPPs. The evaluation was carried out up to 50 years. Dose assessment results for each evaluation distance are shown in the figure below.

As you can see in Fig.3., it is obvious that the highest dose is calculated at the closest range. The dose at the exclusive area boundary(EAB) where can't accessible to residents near the NPP was analyzed as 0.39 Sv/50yr. The dose was found to be well below the relocation standard (1Sv/whole life) recommended by the NSA. This confirms that the basis of 'Cs-137 100TBq requirement' is a sufficiently conservative set-up.

3.3 Verification of Dose Calculation Results

This section compares the results of analysis with similar analysis cases to confirm that the dose calculated in Section 3.2 is properly evaluated. In Finland, VTT has experience in calculating doses for each exposure pathway when Cs-137 and Cs-134 are released at a distance of 1 km. The Finnish VTT analyzed the Olkiluoto site and detailed assumptions are as follows.

1) Source-term: Cs-137(100TBq), Cs-134(148TBq)
2) Exposure pathway: Cloudshine, Groundshind, Ingestion
3) Release height: 20m
4) Release duration: 86400sec
5) Emergency preparedness: Not considered

The assumptions are entered in WinMACCS code and default parameter were used except for mentioned assumptions. The comparison result between VTT and WinMACCS calculation is as follows,

Table 2. Verification Study of Dose Calculation

VTT Result (Sv)			WinMACCS Result (Sv)		
Distance (1km)	cloudshine	2.5E-06	Distance(0.8 ~1.6km)	Early phase	1.96E-02
	inhalation	1.0E-03		Chronc phase	2.15E-02
	groundshine	9.5E-03			
	cow's milk	1.0E-02		Total	4.11E-02
	cow's meat	9.0E-03			
	Total	2.95E-02			
Error			28 %		

As a result of the comparison, it can be seen that the dose from WinMACCS is about 28% larger than that of the VTT analysis. It can be concluded that the errors described in Table 2 are small because the meteorological data, which have a significant impact on dose assessment, are different in the two analyzes. Therefore, it can be said that the dose evaluated in Section 3.2 ensures reliability.

4. Conclusion & Discussion

In this study, the new safety goal which is added as the amendment of NSA were verified. A verification framework has been developed to perform dose assessments for the source-term corresponding to Cs-137 100TBq. Using the developed verification framework, the target source term was derived and modified. And dose assessment was performed using WinMACCS code based on the derived source term. As a result, the exposure dose was evaluated as 0.39 Sv in the EAB, confirming that it is less than the 1Sv, the permanent relocation criteria. And even if all the cesium inventories in the core is released to containment atmosphere, total amount of released cesium to outside of containment is about 0.1 % of total core inventory in 1 day under the design pressure. Furthermore considering the ratio of core damage and solubility of cesium, it is not so impracticable to limit the amount of Cs release by a tenth or a hundredth. In addition, the assumptions of VTT analysis were inputted into the WinMACCS code to ensure the reliability of analysis results. As a result of the calculation, the error was estimated to be 28%, and it can be concluded that the analysis result is reliable considering the different weather data which have a great influence on dose calculation.

This study verified the requirements for Cs-137 100TBq is sufficient to satisfy the safety goal for avoiding long-term off-site contamination.

REFERENCES

[1] NSSC, Regulation on Technical Standards for Nuclear Reactor Facilities, Article 85-22.
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[3] U. S. Nuclear Regulatory Commission, Code Manual for MACCS2: Volume1, User's Guide, NUREG/CR-6613, 1998.
[4] KINS, Study on the Off-site Impact Assessment for Long-term Radionuclide(Cs-137), NSTAR-18RS53-11, 2018.
[5] KHNP, Shin-kori 3,4 PSA report,