Proceedings of ICONE12
12th International Conference on Nuclear Engineering
April 25-29, 2004, Arlington, Virginia USA

ICONE12-49309

Development of the Methodology for Application of Revised Source Term to Operating Nuclear Power Plants in Korea

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ABSTRACT

Considering the current trend in applying the revised source term proposed by NUREG-1465 to the nuclear power plants in the U. S., it is expected that the revised source term will be applied to the Korean operating nuclear power plants in the near future, even though the exact time can not be estimated. To meet the future technical demands, it is necessary to prepare the technical system including the related regulatory requirements in advance. In this research, therefore, it is intended to develop the methodology to apply the revised source term to operating nuclear power plants in Korea.

Several principles were established to develop the application methodologies. First, it is not necessary to modify the existing regulations about source term (i.e., any back-fitting to operating nuclear plants is not necessary). Second, if the pertinent margin of safety is guaranteed, the revised source term suggested by NUREG-1465 may be useful to full application. Finally, a part of revised source term could be selected to application based on the technical feasibility.

As the results of this research, several methodologies to apply the revised source term to the Korean operating nuclear power plants have been developed, which include 1) the selective (or limited) application to use only some of all the characteristics of the revised source term, such as release timing of fission products and chemical form of radio-iodine and 2) the full application to use all the characteristics of the revised source term. The developed methodologies are actually applied to Ulchin 3&4 units and their application feasibilities are reviewed.

The results of this research are used as either a manual in establishing the plan and the procedure for applying the revised source term to the domestic nuclear plant from the utility's viewpoint; or a technical basis of revising the related regulations from the regulatory body's viewpoint.

1. INTRODUCTION

The development of the revised radiological accident source term is an outgrowth of more than 20 years of accident source term studies beginning with the Reactor Safety Study (WASH-1400) of 1975 and continuing with research work involving the nuclear power industries of several nations and their regulatory agencies. The U. S. NRC suggested revised source term, NUREG-1465 in 1995 and the characteristics of the revised source term are the changes of the release timing of fission products, nuclide types, quantities and chemical form to put it shortly[1].

TID-14844 or Reg. Guide 1.4 is the current accident source term in Korea. It is expected that, however, the revised source term will be applied to the operating nuclear power plants, gradually. Therefore, it is necessary to develop the methodology to apply the revised source term to operating plants in Korea.

In this study, several methodologies such as timing-only, chemical-only applications and full application have been developed for applying the revised source term to Korean operating nuclear power plants. The developed methodologies are applied to Ulchin 3&4 units for identifying their application feasibilities.

2. METHODOLOGY

2.1 FUNDAMENTAL PRINCIPLES

There are three principles which provide the basic framework for applying the revised source term to operating power plants[2] .

First, continued use of the existing licensing basis is acceptable (i.e., no back-fitting of the revised source term is necessary) for operating plants. This principle simply states that there is no necessity for licensees to change the source term and that such undertakings are voluntary and optional.

Second, essentially complete implementation of NUREG-1465 as a substitute for the existing licensing basis source term is acceptable based on maintaining adequate margin of safety. To demonstrate that an adequate margin of safety is maintained, the licensee may show that the doses associated with the revised design basis are less than the licensing acceptance limits for the plant.

Finally, selective implementation of some, but not all, aspects of the revised source term (i.e., limited application) is acceptable based on adequate technical justification. As a practical matter, certain applications of NUREG-1465 are expected to be "limited" applications (e.g., "timing-only" or "chemical form only") or to involve approximations to NUREG-1465 parameters in order to simplify the analyses.

In particular, the last principle is focused in our study and the detailed methodologies are discussed in the following section.

2.2 APPLICATION METHODOLOGY

Limited applications may be of interest since such applications would simplify the analysis and spend smaller amount than full applications. Two types of limited applications are considered here: release timing-only of fission products release and chemical form-only of radio-iodine. While this discussion centers on these two types of limited applications, there may be variations which could emerge as individual researches begin the revised source term application process.

First of all, a revised source term application involving only a change in the timing of fission products release was considered. Other parameters such as release fractions and chemical form would remain the same as in the current basis. Detailed process for this application was as follows:

1) **Identify plants design changes.**

2) **Identify the field of the design basis accident analysis according to the plants design change terms.**

3) **Identify the current licensing basis for above design basis accident.** TID-14844 (or Reg. Guide 1.4) is the current licensing basis for release timing aspect in Korea[3, 4].

4) **Assume the release timing of fission products.** Two types of fission products releases for LOCA accident could be considered, which are linear ramp release and puff release.

5) **Assume that the chemical form of radio-iodine is same as in the current licensing basis.** Iodine consists of 91% elemental, 5% particulate, and 4% organic from TID-14844[3].

6) **Estimate the spray removal effects for radio-iodine in containment.** It is expected that the aerosol size of radio-nuclides for application of NUREG-1465, is smaller than that for TID-14844. Thus, the spay removal efficiency for elemental iodine during gap release should be evaluated carefully.

7) **Perform an analysis of the dose for the revised design basis** (i.e., revised source term plus the plant change being considered). This analysis should make use of existing design basis methods with the exception of the timing-only shift.

The second methodology was for a revised source term application involving only a change in the chemical form of the iodine. The steps envisioned for chemical form-only application included the following:

1) **Identify plants design changes.**

2) **Identify the field of the design basis accident analysis according to the plants design change terms.**

3) **Identify the current licensing basis for above design basis accident.** In Korea, TID-14844 (i.e., 91% elemental, 5% particulate, and 4% organic form of iodine) is the current licensing basis.

4) **Assume the chemical form of iodine from the revised source term, NUREG-1465.** It is suggested that iodine is made up of 95% particulate (CSI), 4.85% elemental and 0.15% organic form. Especially, the raised release fraction of Cs should be assessed corresponding with the particulate iodine release rate.

5) **Assume that the release timing of fission products is same as in the current licensing basis.**

6) **Estimate the spray removal effects for radio-iodine in containment.** While the elemental iodine is dominant under current regulations, the particulate iodine is under view of the revised source term. Since spray removal efficiency may be underestimated for particulate iodine, the removal effects should be reevaluated with the revised source term.

7) **Confirm the containment water pool accident pH is maintained at 7 or above over the 30 days dose period or alternatively, including the impact of elemental iodine re-evolution.** This should be satisfied since NUREG-1465 premised the above condition for the proposed chemical form of iodine.

8) **Perform an analysis of the dose for the revised design basis** (i.e., revised source term plus the plant change being considered). This analysis should make use of existing design basis methods with the exception of the chemical form of the iodine leaked into the secondary containment atmosphere and the assumption that no charcoal filter exists.

The last consideration was the full application of revised source term to operating nuclear power plants. The application process was similar to that above mentioned. The release timing of fission products or chemical form of radio-iodine would be substituted with the full application of revised source term. And circumstances for spray removal effects as well as pH control should be contained in the application steps.

3. FEASIBILITY STUDY

The feasibility study for applying the revised source term to operating nuclear power plants in Korea was performed. Ulchin 3&4 units in Korea were selected as representatives of the operating nuclear power plants. For all accidents with the potential for release of radioactivity into the environment, the design basis large LOCA was considered. Three types of release pathways for radio-nuclides from containment to environment were considered; low-volume purge, containment leakage and re-circulation leakage. The evaluation of radiation dose was referred to ICRP-26[5]. The assessment tools used in this study were STARDOSE code for radiation dose evaluation and STARNAUA code for radio-nuclides behavior in containment, spray lambda[6]. Major parameters used in the calculation were presented in table 1[7].

Table 1. Major parameters of Ulchin 3&4 units

System	Parameters	Value
Containment	- free volume, ft^3	2.273×10^6
	- leakage rate, %/day	
	0~24 hours	0.2
	1~30 days	0.1
	- spray region, %	75
	- unspray region, %	25
	- spray removal rate, hr^{-1}	
	elemental iodine	20.0
	particulate iodine	0.55
	- mixing rate, hr^{-1}	
	turnover in unspray region	2
	- containment low-volume purge rate, cfm	2.335×10^4
ESF	- iodine distribution rate, %	10
	- re-circulation loop leakage, gpm	4.250×10^{-2}
	- ECCS feature room HAVC	
	flow rate, cfm	6,000
	volume covered by HAVC, ft^3	1.350×10^6
Environment	- atmospheric dispersion factor EAB(700 m), 0~4 hours, sec/m^3	1.960×10^{-4}

The feasibility study was performed in case of current source term, timing-only application, chemical-only application and full application of the revised source term. Each case was divided into two branches according to concerned matter except full application.

3.1 CURRENT SOURCE TERM

In this case, the radiological accident source term was based on TID-14844 (or Reg. Guide 1.4). The design parameters of FSAR for Ulchin 3&4 units were used in this assessment. Radiation dose for first 2 hours after accident initiated was evaluated which performed in Ulchin 3&4 units FSAR. Case 1 and Case 2 applied to dose conversion factor (DCF) of Reg. Guide 1.4 and ICRP-30, respectively[8]. The radiation dose at exclusion area boundary (EAB) was shown in table 2.

Table 2. Radiation dose at EAB for first 2 hours (rem)

Case 1 (Reg. Guide 1.4 DCF)			
Thyroid	Whole-Body	Skin	TEDE
222	2.43	1.12	6.50
Case 2 (ICRP-30 DCF)			
Thyroid	Whole-Body	Skin	TEDE
129	1.75	2.99	5.82

The evaluation process of case 2 was same as that of case 1 except for dose conversion factor. The change of dose conversion factor was reduced by about 10% in aspect of TEDE. It should be noted that following evaluation was adopted to dose conversion factor proposed by ICRP-30.

3.2 TIMING-ONLY APPLICATION

The fission products release timing-only application was used in this evaluation. In case 3 and 4, it was assumed that the fission products were released in the form of puff and linear ramp, respectively. The chemical form of radio-iodine was mostly elemental as suggested by Reg. Guide 1.4[4]. The radiation dose at EAB was depicted in table 3 and figure 1.

Table 3. Radiation dose at EAB for worst 2 hours (rem)

Case 3 (Puff Release)			
Thyroid	Whole-Body	Skin	TEDE
70.8	1.25	2.13	3.48
Case 4 (Linear Ramp Release)			
Thyroid	Whole-Body	Skin	TEDE
103.8	0.99	1.65	4.24

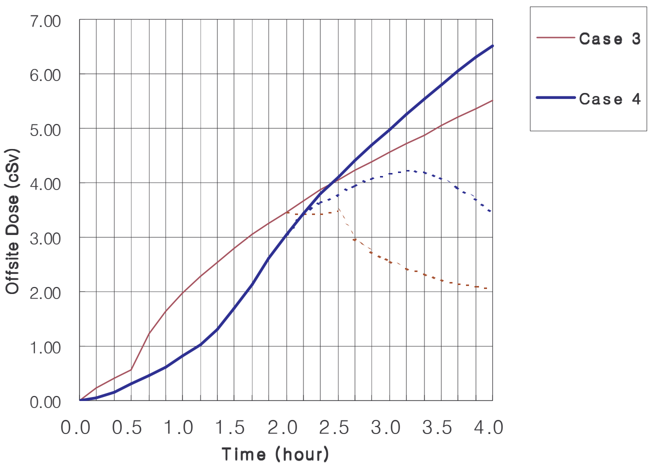

Figure 1. Radiation dose for timing-only application

The solid line was presented to accumulated dose at given time and the dashed line to dose for sliding 2-hour period. Since the release of fission products in the revised source term was continuous such as puff and linear ramp, the maximum (or worst) radiation dose for sliding 2-hour period was more useful than for first 2-hour period. The worst resultant 2-hour dose for linear ramp release was greater than that of puff release by about 20%.

3.3 CHEMICAL FORM-ONLY APPLICATION

In this evaluation, the chemical form of radio-iodine proposed in NUREC-1465 was only applied. The chemical form of radio-iodine was made up of 95% particulate (CSI), 4.85% elemental and 0.15% organic, namely. As mentioned at section 2.2, it was assumed that the containment water pool accident pH was maintained at 7 or above over the 30 days dose period or alternatively, including the impact of elemental iodine re-evolution. For reviewing the spray removal effects, its rate of elemental iodine was increased to 5 times which was represented by the spray removal rate for typical PWRs[1]. Table 4 and figure 2 presented the radiation dose at EAB.

Table 4. Radiation dose at EAB for worst 2 hours (rem)

Case 5 (Normal Spray Removal)			
Thyroid	Whole-Body	Skin	TEDE
316.0	2.44	4.02	12.39
Case 6 (5 Times Higher Spray Removal)			
Thyroid	Whole-Body	Skin	TEDE
80.8	1.67	2.87	4.22

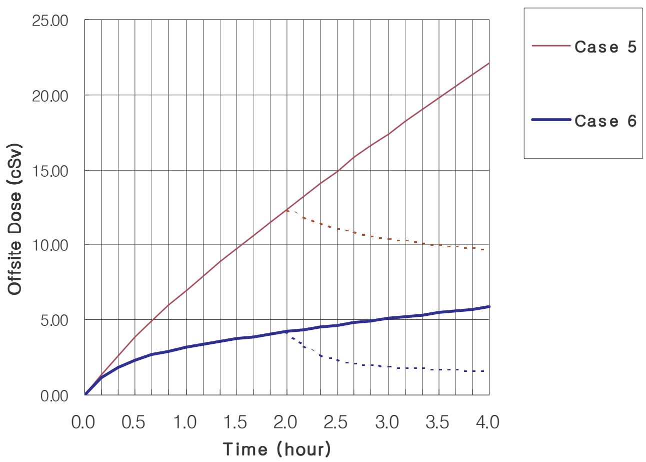

Figure 2. Radiation dose for chemical form-only application

The results of case 5 for TEDE satisfied the off-site dose limit which was 25 rem TEDE for any 2 hour period following onset of the postulated fission products release. However, it was shown more realistic that the spray removal rate was re-evaluated like a case 6.

3.4 FULL APPLICATION

Considering all characteristics of the revised source term such as the amount of release, the release timing and the chemical form of radio-iodine, this evaluation was performed. The spray removal rate as a function of time has been calculated using STARNAUA code instead of SRP 6.5.2 method[9]. Figure 3 depicted the spray removal rate according to change of time.

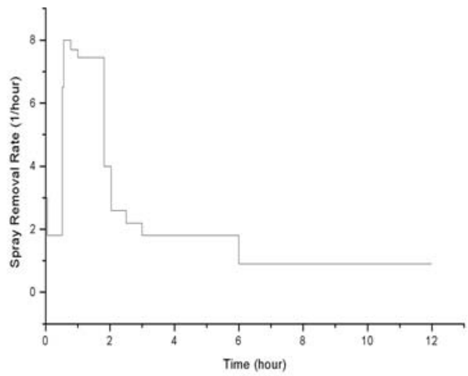

Figure 3. Spray removal rate as a function of time

Also, the results of full application were shown in table 5 and figure 4.

Table 5. Radiation dose at EAB for worst 2 hours (rem)

Case 7 (Full Application of the Revised Source Term)			
Thyroid	Whole-Body	Skin	TEDE
49.0	0.89	1.44	2.44

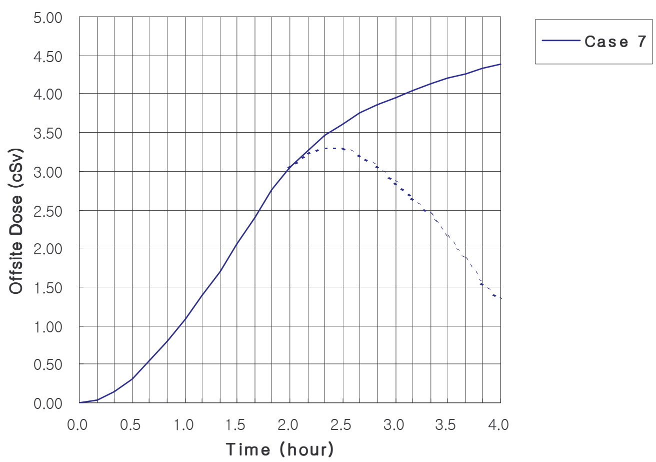

Figure 4. Radiation dose for full application of the revised source term

3.5 DISCUSSION

The application of revised source term to operating nuclear power plants might increase the safety margin. As an example, the 300 rem thyroid dose limit used in deciding EAB distance was reduced by 49.0 rem for the full application of the revised source term. Therefore, the usage of the revised source term could simplify the operation method and reduce the distance of EAB, LPZ (Low Population Zone) and so on. For chemical form-only application, one might confirm the containment water pool accident pH is maintained at 7 or above over the 30 days dose period or alternatively, including the impact of elemental iodine re-evolution. Also, spray removal rate should be re-evaluated for the full application of the revised source term.

It is noted that, however, the biased application of the revised source term should not be used for reduction of radiation dose intentionally.

4. CONCLUSION

Several methodologies such as timing-only, chemical-only applications and full application have been developed for applying the revised source term to Korean operating nuclear power plants in this study. The developed methodologies were applied to Ulchin 3&4 units for identifying their application feasibilities. The application of revised source term to operating nuclear power plants might increase the safety margin. The results of this research are used as either a manual in establishing the plan and the procedure for applying the revised source term to the domestic nuclear plant from the utility's viewpoint; or a technical basis of revising the related regulations from the regulatory body's viewpoint.

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