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The Study of Methodology for SGTR Dose Estimation based on New Idea

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1. INTRODUCTION

SGTR(Steam Generator Tube Rupture) dose calculation has been analyzed based on DBA(Design Basic Accident) safety review. Here, new access instead of general method is introduced. Other assumptions and some library files are introduced in this paper.

In the case of DBA, the key factor of SGTR dose calculation is iodine spiking. In general method, the iodine spiking should be calculated using plant's power, spiking factor, a spiked concentration and the renormalization of the input data. Renormalization means that the source term and the spiked concentration in RCS are averaged by the weighting factor for the gamma energy and beta energy per decay counts of each fission product. In addition, the spiked iodine concentration is averaged by considering each iodine dose effect for I-131. In this study, without the renormalization, RCS inventory, RCS concentration and secondary side concentration itself are directly used for the SGTR dose calculation. The iodine spike is very complicated in calculation process.

In this study, easier calculation method is introduced using RADTRAD 3.03. The basic idea is based on the concept of NUREG 0409. Specially, the source term and scenario are used the standard problem given in NUREG 0409 [1-3].

2. METHODOLOGY

2.1. Models of Analysis for released materials

RADTRAD code can be used for the accident scenario modeling for SGTR dose calculation. The transport model of noble gases is different comparing with the transport model of non-noble gas nuclides. In this case, a separated RADTRAD model has studied. Here, new modeling is required for determining the noble gas dose. The concentration and release rate of noble gases is the same for both PIS (Pre Iodine Spike) case and GIS (Generated Iodine Spike) case.

Spiking effect is the phenomena that Iodine isotopes in the gap between "the fuel cladding" and "the fuel itself" are suddenly extracted into RCS inventory by the big change of the temperature and pressure in the primary side. Here, PIS means "before the accident" and GIS means "after the accident".

SGTR analysis has two cases as named PIS and GIS. These cases have other names such as "Pre-accident Spike" and "Concurrent Iodine Spike". It is required to calculate the dose from each source. Listed below is the key factor for both cases in the model of release materials.

a. Pre-accident Iodine Spike case
   - Dose from noble gas release
   - Dose from iodine spike and RCS initial activity
   - Dose from initial activity on the secondary side of the steam generators
b. Concurrent Iodine Spike Case
   - Dose from noble gas release
   - Dose from iodine spike
   - Dose from RCS non-iodine initial activity
   - Dose from initial activity on the secondary side of the steam generators

2.2. Release Fraction Time of fission products

Each isotope of source term should have the specific release fraction time. RADTRAD 3.03 can control the isotope release fraction value and the release fraction timing using RFT(Release Fraction Time) file. In RADTRAD 3.03, the release fraction time file for all non-noble gas nuclides are set to zero. 100% of all noble gas are specified to be released over a short period of time during the gap activity release phase. The release fraction time file of RADTRAD can be adjusted by accident scenario.

2.3. Steam Release from a faulted Steam Generator Pathway

According to Regulatory Guide 1.195 and Regulatory Guide 1.183, the radioactivity in the bulk water is assumed to become vapor at a rate that is the function of the steaming rate and the partition coefficient. A partition coefficient for iodine of 100 may be assumed. The retention of particulate radionuclides in the steam generators is limited by the moisture carry over from the steam generators [1-3].

The carryover fraction of iodine is about 1%. So, a partition coefficient of 100 is used for release through the MSSV and ADV.

Secondary side steam release consists of an initial release through the MSSVs followed by a controlled release from the ADVs for plant cooldown. And 700 second delay time used before closure of the turbine valves.

The MSSV release for the faulted SG is generated from 700 seconds to 1800 seconds. Operators start ADV release at 1800 seconds.

2.4. Assumptions and Iodine Spiking

Some assumptions are used in analyzing the SGTR referred from NUREG 0409.
Operator action and makeup flow from AFW (Auxiliary Feed Water) system are assumed to maintain a constant in the secondary side of the steam generators.
The initial relative concentrations of the iodine isotopes in the RCS are assumed to remain constant during accident [1-3].
The relative concentrations of the iodine isotopes are 1.0 uCi/gram and 60uCi/gram as D.E. I-131(Dose Equivalent I-131). This is specified by PIS spiking effect. Here, the iodine concentrations of 60uCi/gram mean that it is 60 times the concentrations for 1.0uCi/gram of D.E. I-131. In other word, the initial RCS iodine concentration is 60 times of 1.0uCi/gram.
And the secondary side concentrations are 1/10 times of 1uCi/gram D.E. I-131 concentrations in the primary side.

With the exception of the flashed flow from the ruptured tube and the noble gasses that are assumed to be the minimum decontamination factor. And no steam is assumed to be released until the first MSSV/ADV opens.

2.5. New idea of Calculation Input

In order to calculate the SGTR dose, RADTRAD use some files such as source term library, release fraction time file, dose conversion factor file, scenario input file and atmospheric dispersion factor.
In general method, the currently library files are made by using plant power specific nuclide concentrations.
Otherwise, in this study, the RCS inventory specific concentration method is used to apply the RCS concentration itself into source term and to make the easy library file.
In the method of this study, the source term can be used without input preparation by using the nuclide concentrations per RCS mass and per secondary coolant mass inventory.

```
Duration (h):  Design Basis Accident
 0.1000E-02  0.0000E+00  0.0000E+00  0.0000E+00
Noble Gases:
 0.1000E+01  0.0000E+00  0.0000E+00  0.0000E+00
Iodine:
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
Cesium:
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
Tellurium:
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
Strontium:
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
Barium:
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
Ruthenium:
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
Cerium:
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
Lanthanum:
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
Non-Radioactive Aerosols (kg):
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
```

Fig.1 Noble gas and PIS iodine release fraction time input

```
Duration (h):  Design Basis Accident
 0.0100E+00  0.7990E+01  0.0000E+00  0.0000E+00
Noble Gases:
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
Iodine:
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
I-131:
 0.0000E+00  0.2789E+05  0.0000E+00  0.0000E+00
I-132:
 0.0000E+00  0.3832E+05  0.0000E+00  0.0000E+00
I-133:
 0.0000E+00  0.4326E+05  0.0000E+00  0.0000E+00
I-134:
 0.0000E+00  0.3554E+05  0.0000E+00  0.0000E+00
I-135:
 0.0000E+00  0.3311E+05  0.0000E+00  0.0000E+00
Cerium:
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
Lanthanum:
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
Non-Radioactive Aerosols (kg):
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
```

Fig.2 GIS iodine release fraction time input

And also, spiking effect and release fraction time are efficiently controlled by library files itself.
Then, E-bar and D.E. I-131 are directly controlled by release fraction time. The source terms and the fraction time are controlled by above release fraction time library files as like Fig.1 and Fig.2.

3. INPUT PARAMETERS AND CALCULATIONS

3.1. Source Term

KR-83M	2.349E-01	I-131	0.8305
KR-85M	8.808E-01	I-132	0.1917
KR-85	3.890E-01	I-133	0.8624
KR-87	5.505E-01	I-134	0.0751
KR-88	1.615E+00	I-135	0.3673
XE-131M	3.303E-01		
XE-133M	1.248E+00		
XE-133	5.138E+01		
XE-135	5.432E+00		

Fig.3 Source Term Information as E-bar and D.E. I-131

Fig. 3 shows E-bar and D.E. I-131 concentrations.
Here, the E-bar means “the average energy” distributed by decay count summation of radioactive material (fission products). From E-bar, we can consider the effect of radiation dose for the averaged energy of fission products. In addition, D.E. I-131 means that Iodine isotopes are specified by only one isotope of I-131, when calculating the total radiation effect from Iodine isotopes such as I-131, I-132, I-133, I-134, and I-135.
So, each dose effect of Iodine isotopes is divided by I-131 dose effect and the results are sum up. Finally the results are named as D.E. I-131.
In this study, this source term is used directly without preparing the input format. This input method is new idea.
In this method, instead of the isotopes inventory per plant power, the isotopes inventory per RCS mass is used as source term library.

GIS iodine spike activity is in equilibrium directly. GIS source term generations are calculated as below:

$$R = A\lambda \qquad (1)$$

Where R= generation rate(Ci/min)
λ= removal rate (min^{-1})
A= activity (Ci)

The removal rate is consists of decay, purification, and RCS leakage as below:

$$\lambda = \lambda_{decay} + \lambda_{purification} + \lambda_{leakage} \quad (2)$$

The iodine removal rate due to leakage and purification can be determined by a simple ratio as below:

[(Purification mass flow + leakage mass flow)]/RCS mass (3)

Where, the purification mass flow means RCS purification system's flow and the leak mass flow means the leak flow between the primary side and the secondary side.

3.2. Advantage of New Idea Method

In the new idea, the source term is very simple. In case of Iodine, each isotopes concentration of RCS is expressed as only 1.0 uCi/gram.
And the Iodine source term is directly controlled by the GIS Iodine release fraction time input of Fig.2.
Otherwise, in general method, Iodine source term should be calculated by making library file as text format.
The text format is consists of plant's power, specific concentration of RCS, RCS inventory, and spiking factors.
Because of that, new-idea method is very efficient and very easier than the general method.
The source term generation, the source term calculation, and the source term control are directly controlled by using the only "release fraction time input" of Fig.2.
The compared results will be shown in Table 7 and Table 8.

3.3. Release Term Calculations

Steam release from intact SG pathway, steam release from faulted SG pathway, and flashed steam generator tube break flow pathway are calculated and summarized in Table. 1.

Table 1. Summary of input for steam release from SG

Input items	Values (time : flow rate)
Faulted Steam Generator (lbm / min)	0.0 : 0 0.2 : 29.1334 0.5 : 3.6302 1.5 : 4.1536 2.0 : 7.6765 3.5 : 7.3152 8.0 : 0.0
Intact Steam Generator (lbm / min)	0.0 : 0 0.2 : 29.4120 0.5 : 20.5556 1.5 : 14.8458 2.0 : 14.8458 3.5 : 14.8458 8.0 : 0.0
Steam Generator Tube Break flow(gpm)	0.0 : 0.27 0.2 : 3.06 0.5 : 4.28 1.5 : 0.0 2.0 : 0.07 3.5 : 0.07 8.0 : 0.0
Plant Power and Release Information (fraction)	First release time : 0.0 Aerosol Iodine : 0.0 Elemental Iodine : 0.97 Organic Iodine : 0.03

4. RESULTS AND DISCUSSIONS

4.1. Comparison between the New Idea Methodology and the General Methodology

From the previous chapter 3.2, the advantage of this study is shown in Table 2 and Table 3.

Table2. Source term control in the general method.

Process	Action Item
step1	Plant's Power is used as specific concentration level (Mw)
step2	Source Term (Ci/Mw)
step3	RCS Concentration Calculation (Ci/kg)
step4	RCS Concentration Calculation (uCi/gram)
step5	Removal rate calculation (m^{-1})
step6	I-131 concentration, each calculation (uCi/gram)
step7	I-132 concentration, each calculation (uCi/gram)
step8	I-133 concentration, each calculation (uCi/gram)
step9	I-134 concentration, each calculation (uCi/gram)
step10	I-135 concentration, each calculation (uCi/gram)
step11	Release Fraction time file adjust : Release fraction control only.

Table3. Source term control in the new idea method (in this work).

Process	Action Item
step1	RCS mass is used as specific concentration level (kg or gram)
step2	Source Term (uCi/gram)
Step3	Removal rate calculation (m^{-1})
Step4	Iodine has fixed values as 1.0 uCi/gram I-131 concentration (1.0 uCi/gram) I-132 concentration (1.0 uCi/gram) I-133 concentration (1.0 uCi/gram) I-134 concentration (1.0 uCi/gram) I-135 concentration (1.0 uCi/gram)
Step5	Release Fraction time file adjust: Source term, scenario and release fraction are directly controlled.

From Table 2, the general method has 11steps to calculate and to control the source term of SGTR.
Otherwise, from Table3, the new idea method of this work has 5 steps to calculate and to control the source term of SGTR at most.
Because of that, the new idea-based methodology is very simple and much easier than the general method.

4.2. Calculation Results

Iodine spiking effect is considered by factor of 60 and 500 in the case of PIS and GIS.

Table 4. Removal rate results from Iodine spiking

Iodine	Purification (1/minute)	Decay/leakage (1/minute)	removal rates (1/second)
λ_{131}	0.000942	5.986968E-05	0.0000167
λ_{132}	0.000942	0.005023	9.941667E-05
λ_{133}	0.000942	0.000555	2.495000E-05
λ_{134}	0.000942	0.013178	0.000235333
λ_{135}	0.000942	0.001748	4.483333E-05

Table 5. Generation rate calculations

Iodine	Concentration	RCS Inventory	Iodine Inventory	removal rate	generation rate
	uCi/gram	gram	Ci	1/minute	Ci/minute
I-131	8.3050E-01	2.0840E+08	1.7310E+02	0.0010	0.1734
I-132	1.9170E-01	2.0840E+08	3.9950E+01	0.0060	0.2383
I-133	8.6240E-01	2.0840E+08	1.7970E+02	0.0015	0.2690
I-134	7.5100E-01	2.0840E+08	1.5650E+01	0.0141	0.2210
I-135	3.6730E-01	2.0840E+08	7.6550E+01	0.0027	0.2059

Table 6. GIS source term calculations

Iodine	GIS generation rate	GIS source of 8hours
	1/minute	Ci
I-131	58.0966961	2.789e+04
I-132	79.8319317	3.832e+04
I-133	90.1310904	4.326e+04
I-134	74.0318685	3.554e+04
I-135	68.9790622	3.311e+04

From equation(1), equation(2) and equation(3), the removal rates are ranged from 0.0000167 to 0.0002353. For 1.0 uCi/gram specific activity, RCS Iodine generation rate is ranged from 0.1734 to 0.2690. In the case of GIS, the generated source terms of D.E. I-131 are ranged from 2.789e+04 to 4.326e+04.

4.3. Dose Estimations

In this study, the calculated information of Table.1 ~ Table 6 and the release fraction time files of Fig.1 and Fig.2 are used to estimate the dose calculation.
SGTR dose calculation results are shown in Table 7 and Table 8. The difference value between Table 7 and Table 8 is very small and the both of them are in good agreement with each other.

Tabel 7. Dose results from this study based on new idea

Dose contribution (in this study)		EAB (rem)	LPZ (rem)
PIS	Noble gas	5.86E-02	8.47E-03
	RCS	8.84E-01	1.99E-01
	SG	1.46E-03	2.83E-04
	sum	9.44E-01	2.07E-01
GIS	Noble gas	5.86E-02	8.47E-03
	RCS	4.89E-01	6.80E-02
	SG	1.46E-03	2.83E-04
	sum	5.49E-01	7.67E-02

Tabel 8. Dose results from general method

Dose contribution (in general method)		EAB (rem)	LPZ (rem)
PIS	Noble gas	5.82E-02	8.46E-03
	RCS	8.80E-01	1.96E-01
	SG	1.41E-03	2.83E-04
	sum	9.40E-01	2.05E-01
GIS	Noble gas	5.82E-02	8.46E-03
	RCS	4.85E-01	6.83E-02
	SG	1.41E-03	2.83E-04
	sum	5.45E-01	7.70E-02

5. CONCLUSIONS

In order to calculate the SGTR dose, easer method is carried out by RCS inventory specific nuclides activity methodology. From this study, some findings are as below:

a. RCS inventory specific activity is directly applied to RADTRAD input.
b. Release fraction time file can control Iodine spiking effect source term in the new idea.
c. The ratio between RCS inventory and nuclide inventory is directly used in the release fraction time input in the new idea.
d. Source term control and spiking effect control is much easier in the new idea method than in the general method from Table2 and Table3.
e. The comparisons between the currently method and the new method are in good agreement.

From "b" to "d" of these results, we can find that the new-idea SGTR dose analysis methodology is very simple and much easier than the general method.

REFERENCES

[1] NUREG 0409, Iodine Behavior in a PWR Cooling System Following a Postulated Steam Generator Tube Rupture Accident (1987)
[2] NRC Regulatory Guide 1.195.
[3] NRC Regulatory Guide 1.183