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Development of Source Term Release Modeling Methodology by NAME_LSC code

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1. INTRODUCTION

In KOREA, an accident dose assessment is underway covering design basis accidents, multiple failure accidents, and severe accidents.
From 2017~2018, the NAME_LSC (Nuclear reactor Accident's Modeling and effects Evaluation_LSC) code began to be developed to enable accident impact assessment for all types of accidents. And in 2021, the NAME_LSC code with updated performance was completed [1-3].
The NAME_LSC code uniquely includes a function that simulate the source term to be divided into several stages and emitted.
In particular, it is possible to freely simulate the emission step by dividing it into about 50 steps.
Since the follow-up to TMI, the method of dividing the emission stage of the source term into four stages in NUREG-1465 and performing separate calculations accordingly has been widely used.
Generally, Gap Release, Early In-Vessel, Ex-Vessel, and Late In-Vessel are used to simulate the emission stage of source term.
However, this method is roughly applicable to simulate the general release step.
The existing method, which has been widely used, could only simulate separate source term emission one by one when implementing complex emission modeling. In contrast, the NAME_LSC code can precisely simulate the complex source term behavior by dividing it into multiple stages, resetting it, and mixing the behavior of multiple release type source terms.
NAME_LSC code was developed using PASCAL and FORTRAN. And the code includes calculation and modeling modules [3-6].
In this study, using the source term emission simulation module of NAME_LSC, we try to simulate the complex and multiple source term release by one simulation without tedious separate calculations.
For even highly complex source term release, the NAME_LSC code can integrate and include the complex and diverse simulations of multiple stage into only one simulation.
This study introduces the methodology for generating source term release (emission) modeling and simulation by NAME_LSC code.

2. METHODOLOGY

2.1. Source Term Release Modeling

In general, when applying the emission of the source term in severe accidents and multiple failure accidents, the following NUREG-1465 method can be applied as a partially applicable method.
However, it is difficult to simulate the initial physical phenomena and detailed emissions in four stages.
Table 1 shows the release steps of the NUREG-1465 method, and Table 2 shows the release steps of the NAME_LSC code.

Table 1. Source Term Release Modeling in NUREG-1465

Items	Gap Release	Early In-vessel	Ex-Vessel	Late In-Vessel
Duration (Hours)	0.5	1.3	2.0	10.0
Noble Gases	0.05	0.95	0	0
Halogens	0.05	0.35	0.25	0.1
Alkali Metals	0.05	0.25	0.35	0.1
Tellurium group	0	0.05	0.25	0.005
Barium, Strontium	0	0.02	0.1	0
Noble Metals	0	0.0025	0.0025	0
Cerium group	0	0.0005	0.005	0
Lanthanides	0	0.0002	0.005	0

Table 2. Source Term Release in NAME_LSC code

	Step1	Step2	Step3	Step4	Step5	Step6	Step7	Step8	....	....	Step N
Duration (Hours)	0.5	1.3	2.0	10.0	…	….	….	….	….	….	
Noble Gases	0.05	0.95	0	0	…	….	….	….	….	….	
Halogens	0.05	0.35	0.25	0.1	…	….	….	….	….	….	
Alkali Metals	0.05	0.25	0.35	0.1	…	….	….	….	….	….	
Tellurium group	0	0.05	0.25	0.005	…	….	….	….	….	….	
Barium Strontium	0	0.02	0.1	0	…	….	….	….	….	….	
Noble Metals	0	0.025	0.025	0	…	….	….	….	….	….	
Cerium group	0	0.005	0.005	0	…	….	….	….	….	….	
Lanthanides	0	0.002	0.005	0	…	….	….	….	….	….	

As can be seen in Table 1 and Table 2, Table 2 shows that the release step can be controlled precisely and in detail by subdividing release steps. In this study, we will compare the difference between the calculation through the method in Table 1 and the evaluation with the performance of NAME_LSC, and from the results, we will find the advantages of NAME_LSC code.

2.2. Existing Possible Methods and Improvement Directions

As a current possible method, there is no way to simulate multiple steps at once, because of that, one-step calculations are performed multiple times by RADTRAD. And the summation of these results is used as dose calculation result. This method is widely used. In the four stages of NUREG-1465 of RADTRAD, it is difficult to use when complex source term emission occurs at each time point. The reason is that it is expressed only as a cumulative sum in a single form unconditionally. This means that it is difficult to simulate the reset at each time point and the behavior of a new source term separately at each time point.

It can be used when the source term behavior patterns is the type of increases over time in several sections, but when the behavior of a new complex source term is inserted in the middle and changed, the only way is to do separate calculations and separate modeling for each timing.

For the detailed source term analysis, the source terms for each step must not be accumulated after being released, and each source term release only is required in each time step. For this reason, RADTRAD code performs only one step of calculation with one modeling.

However, this method requires too many calculations and procedures.

A way to simplify this calculation procedure and to calculate the complex source term at once is to use the source term release step module of the NAME_LSC code.

3. RESULTS AND DISCUSSIONS

3.1. Comparison between the Existing method and the NAME_LSC code method for Source Term Release Modeling

Among the existing methods, the method of calculating one step at a time is preferred as shown in Figure 1.

In the case of Figure 1, the RADTRAD code requires a total of four calculations to simulate the 4-step emission. The 4-step emission simulation requires 4 separate inputs as shown in Figure 1 and 4 corresponding simulation inputs.

This is effective in describing the appearance of complex source term emission step by step.

However, a calculation corresponding to that complex stage is required.

Figure 2 shows the process of creating the source term emission simulation module of the NAME_LSC code, and Figure 3 is the shape of the input statement used in the module that simulates the source term emission step of the NAME_LSC code.

```
 5.7000E-01  1.4300E+00  0.0000E+00  0.0000E+00
Noble Gases:
 0.0000E+00  4.7874E-05  0.0000E+00  0.0000E+00
Iodine:
 0.0000E+00  3.7549E-06  0.0000E+00  0.0000E+00
Cesium:
 0.0000E+00  1.5531E-06  0.0000E+00  0.0000E+00
Tellurium:
 0.0000E+00  1.5824E-06  0.0000E+00  0.0000E+00
Strontium:
 0.0000E+00  8.5607E-08  0.0000E+00  0.0000E+00
Barium:
 0.0000E+00  1.7203E-07  0.0000E+00  0.0000E+00
Ruthenium:
 0.0000E+00  5.1001E-10  0.0000E+00  0.0000E+00
Cerium:
 0.0000E+00  1.4955E-08  0.0000E+00  0.0000E+00
Lanthanum:
 0.0000E+00  2.1722E-09  0.0000E+00  0.0000E+00
Non-Radioactive Aerosols (kg):
 0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
```

Fig. 1 Difficulty in Multiple Modeling of source term Release in existing method in RADTRAD

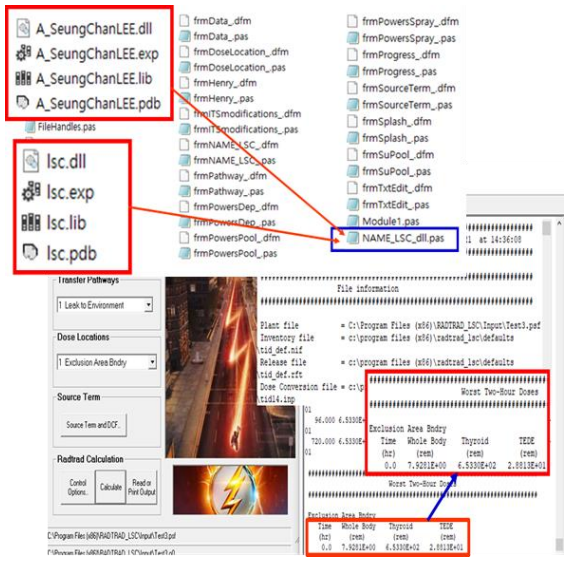

Fig. 2 Dynamic linked library Structure for Source Term Release Modeling Tool of NAME_LSC code

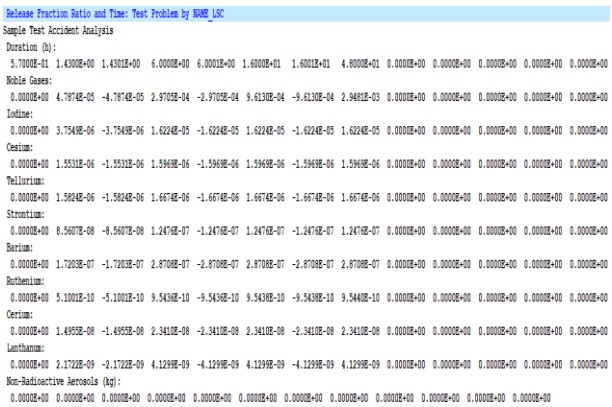

Fig. 3 Multiple Modeling Possibility of Source Term Release in NAME_LSC code

3.2. Comparison between Multi Calculation in Existing Method and Single Calculation of NAME_LSC code

The current methodology requires 4 calculations and 4 separate input files. On the other hand, the NAME_LSC code can complete the entire calculation process with only one input file and one calculation.

This difference is due to the modeling flexibility and the input characteristics of the NAME_LSC code. The biggest difference is that NAME_LSC has the ability to enable resetting of source term emission and separate emission modeling at the same time for any arbitrary modeling time point.

Figure 4 and Figure 5 show a comparison between the current method and the results of this study.

Figure 4 shows the hassle of modeling the emission of four source terms and the several step calculation.

Figure 5 shows that emission simulation in various stages of the source term is possible with only one calculation and one modeling by using the modeling function installed in NAME_LSC.

Duration:	5.7000E-01	1.4300E+00	0.0000E+00	0.0000E+00
Noble Gases:	0.0000E+00	4.7874E-05	0.0000E+00	0.0000E+00
Iodine:	0.0000E+00	3.7549E-06	0.0000E+00	0.0000E+00
Cesium:	0.0000E+00	1.5531E-06	0.0000E+00	0.0000E+00
Tellurium:	0.0000E+00	1.5824E-06	0.0000E+00	0.0000E+00
Strontium:	0.0000E+00	8.5607E-08	0.0000E+00	0.0000E+00
Barium:	0.0000E+00	1.7203E-07	0.0000E+00	0.0000E+00
Ruthenium:	0.0000E+00	5.1001E-10	0.0000E+00	0.0000E+00
Cerium:	0.0000E+00	1.4955E-08	0.0000E+00	0.0000E+00
Lanthanum:	0.0000E+00	2.1722E-09	0.0000E+00	0.0000E+00

Duration:	2.0000E+00	6.0000E+00	0.0000E+00	0.0000E+00
Noble Gases:	0.0000E+00	2.4918E-04	0.0000E+00	0.0000E+00
Iodine:	0.0000E+00	1.2469E-05	0.0000E+00	0.0000E+00
Cesium:	0.0000E+00	4.3771E-08	0.0000E+00	0.0000E+00
Tellurium:	0.0000E+00	8.4996E-08	0.0000E+00	0.0000E+00
Strontium:	0.0000E+00	3.9149E-08	0.0000E+00	0.0000E+00
Barium:	0.0000E+00	1.1505E-07	0.0000E+00	0.0000E+00
Ruthenium:	0.0000E+00	4.4435E-10	0.0000E+00	0.0000E+00
Cerium:	0.0000E+00	8.4552E-09	0.0000E+00	0.0000E+00
Lanthanum:	0.0000E+00	1.9577E-09	0.0000E+00	0.0000E+00

Duration:	8.0000E+00	1.6000E+01	0.0000E+00	0.0000E+00
Noble Gases:	0.0000E+00	6.6425E-04	0.0000E+00	0.0000E+00
Iodine:	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Cesium:	0.0000E+00	1.5926E-11	0.0000E+00	0.0000E+00
Tellurium:	0.0000E+00	1.0961E-12	0.0000E+00	0.0000E+00
Strontium:	0.0000E+00	3.4208E-15	0.0000E+00	0.0000E+00
Barium:	0.0000E+00	8.0883E-15	0.0000E+00	0.0000E+00
Ruthenium:	0.0000E+00	2.2151E-14	0.0000E+00	0.0000E+00
Cerium:	0.0000E+00	3.7223E-16	0.0000E+00	0.0000E+00
Lanthanum:	0.0000E+00	1.3694E+16	0.0000E+00	0.0000E+00

Duration:	2.4000E+01	4.8000E+01	0.0000E+00	0.0000E+00
Noble Gases:	0.0000E+00	1.9868E-03	0.0000E+00	0.0000E+00
Iodine:	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Cesium:	0.0000E+00	7.0792E-12	0.0000E+00	0.0000E+00
Tellurium:	0.0000E+00	1.4298E-12	0.0000E+00	0.0000E+00
Strontium:	0.0000E+00	1.1516E-19	0.0000E+00	0.0000E+00
Barium:	0.0000E+00	2.1927E-19	0.0000E+00	0.0000E+00
Ruthenium:	0.0000E+00	1.9973E-14	0.0000E+00	0.0000E+00
Cerium:	0.0000E+00	1.2471E-18	0.0000E+00	0.0000E+00
Lanthanum:	0.0000E+00	3.5327E-19	0.0000E+00	0.0000E+00

Fig. 4 4 files and 4 calculations for multiple modeling required in the current method

Duration:	5.7000E-01	1.4300E+00	1.0000E-05	6.0000E+00	1.0000E-05	1.6000E+01	1.0000E-05	4.8000E+01
Noble Gases:	0.0000E+00	4.7874E-05	1.0000E-05	2.4918E-04	1.0000E-05	6.6425E-04	1.0000E-05	1.9868E-03
Iodine:	0.0000E+00	3.7549E-06	1.0000E-05	1.2469E-05	1.0000E-05	0.0000E+00	1.0000E-05	0.0000E+00
Cesium:	0.0000E+00	1.5531E-06	1.0000E-05	4.3771E-08	1.0000E-05	1.5926E-11	1.0000E-05	7.0792E-12
Tellurium:	0.0000E+00	1.5824E-06	1.0000E-05	8.4996E-08	1.0000E-05	1.0961E-12	1.0000E-05	1.4298E-12
Strontium:	0.0000E+00	8.5607E-08	1.0000E-05	3.9149E-08	1.0000E-05	3.4208E-15	1.0000E-05	1.1516E-19
Barium:	0.0000E+00	1.7203E-07	1.0000E-05	1.1505E-07	1.0000E-05	8.0883E-15	1.0000E-05	2.1927E-19
Ruthenium:	0.0000E+00	5.1001E-10	1.0000E-05	4.4435E-10	1.0000E-05	2.2151E-14	1.0000E-05	1.9973E-14
Cerium:	0.0000E+00	1.4955E-08	1.0000E-05	8.4552E-09	1.0000E-05	3.7223E-16	1.0000E-05	1.2471E-18
Lanthanum:	0.0000E+00	2.1722E-09	1.0000E-05	1.9577E-09	1.0000E-05	1.3694E+16	1.0000E-05	3.5327E-19

Fig. 5 Multiple emission modeling method with one file by NAME_LSC code.

3.3. Verification of Single Calculation of NAME_LSC code

In order to see how valid the multiple source term emission modeling method performed in this study was, it was compared with the current method.

The current method requires multiple steps and multiple calculation to simulate the separate behavior of the source term for each time period.

In Table 3, the "current method" is the evaluation result by the 4-step calculation and modeling method. And the "NAME_LSC" of Table 3 is the result of performing the same calculation with one modeling and one calculation.

As a result of the comparison, the results show very good agreement without any difference. Through this, it was proved that the current code is complex and requires multiple calculations and modeling, but in this study, NAME_LSC code shows the same performance by using only one modeling and one calculation.

Table 3. Result between NRC model and Experimental Correlation model

Item	Current method: Four modelings	NAME_LSC: One Multiple modeling
stage1	2.9799E-01	5.8420E+00
stage2	1.3310E+00	
stage3	1.4551E+00	
stage4	2.7580E+00	
sum	5.8421E+00	5.8420E+00

4. CONCLUSIONS

In this study, various performances of the source term emission modeling loaded in the NAME_LSC code were verified.

In particular, it was confirmed that not only the behavior of a separate source term was simulated at various times, but also that complex emission characteristics could be freely modeled.

From this study, it was concluded that the NAME_LSC code can sufficiently simulate any source term emission model in a complex type with one calculation and one modeling.

The verification results of NAME_LSC code matched very well with the results of multi-step calculations and multi-step modeling in RADTRAD.

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