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Development of Automatic Waste Estimation Program for Decommissioning of NPPs

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1. Introduction

Recently, decommissioning of nuclear facilities is one of the major technological fields in the nuclear industry. The radiological characterization is a key technology in the decontamination and decommissioning project. By accurately estimating the radioactive nuclide inventory, information on the radioactive contamination of the decommissioning area can be obtained, which is helpful for decommissioning planning. In addition, the estimation of radioactive waste amount is helpful to support informed decision-making during planning and dismantling.

However, the estimation of decommissioning waste amount needs way too much time and effort. For this reason, the development of automatic program for estimation of decommissioning waste amount has been carried out. This paper is about the automatic estimation program of decommissioning wastes developed by us; this program is named RANA (Reactor Activation aNd waste Assessment).

2. Development of RANA S/W

The RANA has been developed to automatically estimate the amount of waste generated by neutron activation during operation of NPPs (Nuclear Power Plants) in Korea.

To automate the estimation of the radioactive activation waste amount arising during decommissioning of a nuclear power plant, the operation history of the nuclear power plant is investigated, and then the neutron flux distribution of the nuclear reactor and its surrounding structures is simulated. And neutron activation analysis is performed based on this simulation. Using this activation analysis, the amount of activation waste is calculated by each radioactivity levels for each structure. The overall work-flow of the RANA is shown in the Fig 1.

The RANA provides basic information including operation history data to be required for analysis of neutron flux distribution by MCNP code, automatic linking of MCNP outputs with activation analysis code (SCALE/ORIGEN), and then automatic estimation of the amount of radioactive waste. A menu structure of the RANA is shown in Fig. 2.

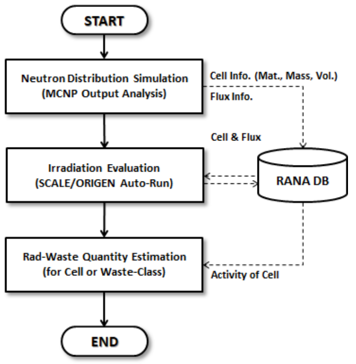


Fig. 1. Main Work-flow of RANA.

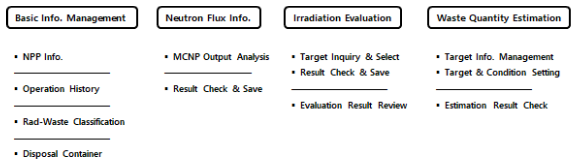


Fig. 2. Menu Structure of RANA.

2.1 Database Design & Construction

Database for the RANA was designed and constructed to evaluate the amount of radioactive (activation) waste arising during decommissioning of Kori unit 1 and Wolsong unit 1. In order to estimate radioactive waste amount, the RANA manages MCNP simulation results for neutron flux distribution of the reactor and its associated structures, creates input list to activation analysis code (ORIGEN) based on the neutron flux distribution, and manages the results of ORIGEN code.

This DB contains data such as operation history of NPPs to be decommissioned, MCNP simulation results of neutron flux distribution, and input & output of ORIGEN code as follows:

- Nuclear Power Plant (NPPs) Info.
  - ✓ NPP basic info.: ref. Rx. thermal power, operation start & shutdown date
  - ✓ Annual average utilization rate for each NPPs
- MCNP result data on simulation of neutron flux distribution for decommissioning objects
  - ✓ Tally: tally no., cell ID
  - ✓ Cell: material no., density, volume, mass
  - ✓ Material: material identification (ZAID), fraction
- Irradiation evaluation code (ORIGEN) output data: for actinides, fission products, light elements in unit mass
  - ✓ Inventory concentrations [g/basis]
  - ✓ Radioactivity [Ci/basis]

Data normalization and entity-relation modeling are performed for basic information based on the operation history of NPPs to be decommissioned, the simulation result for neutron flux distribution of the reactor and its associated structures, and the input/output analysis of activation evaluation code. Fig. 3 presents the ERD (Entity Relation Diagram) of RANA DB.

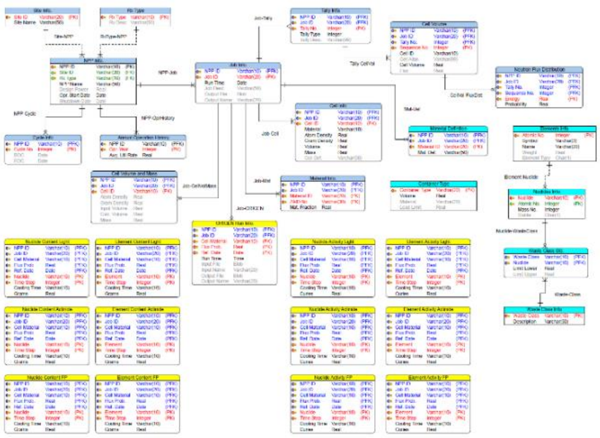


Fig. 3. ERD of RANA DB.

2.2 Neutron Distribution Simulation

Since the RANA performs activation evaluation and radioactive waste amount estimation based on geometry and material property data in the MCNP code output, detailed modeling for target NPP should be preceded [1].

When the user runs the RANA with the MCNP output files for designated NPP into the RANA, the RANA extracts the required data through text processing of the output files, and stores these in the DB.

MCNP outputs are classified by each Job ID and managed in the RANA DB. In the output text file, tally info., cell volume, neutron flux distribution probability, and cell info., are extracted and stored into corresponding tables in the RANA DB. In addition, material property data of each cell, such as material composition, are extracted from output and inserted into corresponding tables in the DB.

2.3 Irradiation Evaluation

The activation evaluation of the reactor and its associated structures for estimating the amount of radioactive waste arising during decommissioning is performed based on activation evaluation target information defined as cell among the simulation results of the MCNP code and the operation history data of NPP. The activation evaluation code input is automatically created by the RANA using material property data of the evaluation object, neutron flux distribution probability on cell, the annual average utilization rate of the NPP, and the number of annual operation days of the NPP [2], [3], [4].

Thermal neutron flux on specific cell is as follows:

$$TNF = Rxp. \times \frac{1\ MeV}{1.6023E-13\ J} \times \frac{1\ Fission}{200\ MeV} \times \frac{2.43\ n}{1\ Fission} \times Prb. \quad (1)$$

where, TNF is thermal neutron flux on cell (#/sec)
Rxp. is nominal Rx. thermal power (MW_{th})
Prb. is n-flux distribution probability of specific cell

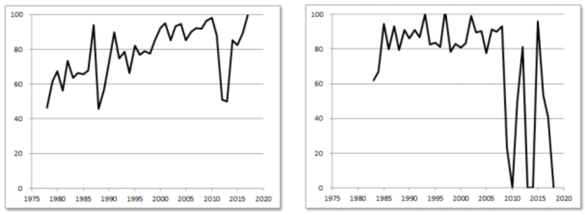
And total cumulative neutron irradiation on a specific cell is below:

$$TNI = TNF \times EFPD \quad (2)$$
$$TNI = TNF \times AUR \times Opr.Yr. \quad (3)$$

where, TNI is total neutron irradiation
EFPD is Effective Full Power Day
AUR is Average Utilization Rate

In MCNP modeling, by analyzing the material constituting the geometry and the cumulative neutron fluence, the same material and fluence are grouped to optimize ORIGEN code operation by performing the evaluation on the unit mass of object material.

Annual utilization rate of the NPP to be evaluated is shown in Fig. 4 below, and Fig. 5 presents an example of calculating decay period after shutdown at evaluation time designated by user.



(a) Kori-1 (b) Wolsong-1

Fig. 4. Annual Utilization Rate of Target NPP.

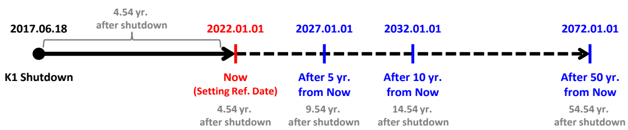


Fig. 5. Example of Decay Time after Shutdown of Kori unit 1.

The activation evaluation code installed in user's computer is automatically executed by the RANA with the input created in this way, and inventory and radioactivity data are extracted and stored in the RANA DB by text processing. The data stored in the DB are inventory and radioactive data for each element and nuclide per unit mass of evaluation object. ORIGEN code outputs are classified and managed by each the Job ID and the code execution time in the RANA DB. Among the code output text file, the inventory and radioactivity data for each element and nuclide for 50 years from the designated time after the shutdown of the NPP are extracted and inserted into corresponding tables in the RANA DB.

Fig. 6 is an example showing the result of activation evaluation result for an object in table and chart format according to decay time for inventory and radioactivity. As in the example, it is able to check the result by changing the y-axis of the chart to linear and long scale.

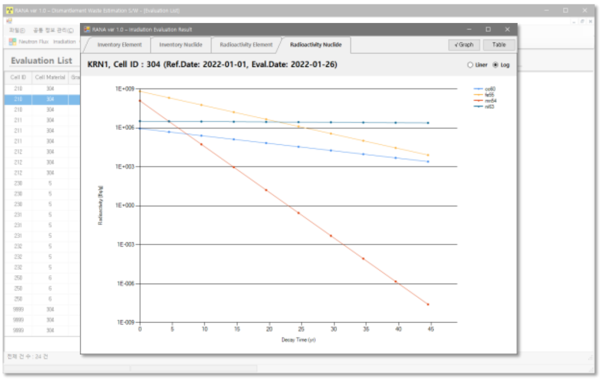


Fig. 6. Example of Irradiation Evaluation Result.

2.4 Estimation of Decommissioning Waste Quantity

In this study, radioactive waste is classified according to nuclear safety committee notice [5], and it is classified into "self-disposal waste" (SDW), "very low level waste" (VLLW), "low level waste" (LLW), and "intermediate level waste" (ILW) with excluding high level waste.

As a result of irradiation evaluation of the object, if specific activity is less than the nuclide concentration in table 1 below, it is classified as SDW, and if the specific activity is higher than concentration for SDW and less than 100 times the concentration, it is classified as VLLW. If the specific activity of the object is higher than the concentration of VLLW and less than the nuclide concentration in table 2, it is classified LLW, and if the specific activity is higher than the concentration in table 2, it is classified ILW.

Table 1. Self-Disposal Acceptable Concentration for Radioactive Nuclide

Radioactive Nuclide	Acceptable Concentration (Bq/g)
I-129	0.01
Na-22 and 33 others	0.1
C-14 and 44 others	1
Be-7 and 74 others	10
H-3 and 65 others	100
Si-31 and 32 others	1,000
Co-58m and 3 others	10,000

(For more detail information, refer the NSC's notice)

When multiple radioactive nuclides are mixed, waste is classified as follows:

$$Acc.Con. = \sum_i \frac{C_i}{C_{L.i}} < 1 \qquad (4)$$

where, Acc. Con. is Acceptable Concentration
C_i is radio-activity of rad-active nuclide i (Bq/g)
$C_{L,i}$ is self-disposal acceptable concentration (Bq/g) of rad-active nuclide i

The estimation of radioactive waste amount for the object is performed classification based on specific radioactivity per unit mass according to the NSC's notice, and volume of disposal waste is calculated by reflecting the volume of the target and the filling rate set by the user.

Table 2. Limits on Radioactivity Concentration of Low-Level Radioactive Waste

Radioactive Nuclide	Acceptable Concentration (Bq/g)
H-3	1.11E+6
C-14	2.22E+5
Co-60	3.70E+7
Ni-59	7.40E+4
Ni-63	1.11E+7
Sr-90	7.40E+4
Nb-94	1.11E+2
Tc-99	1.11E+3
I-129	3.70E+1
Cs-137	1.11E+6

(Except for All-Alpha Nuclides)

Fig. 7 shows an example of quantity estimation of radioactive waste of user selected cell according to the method mentioned above.

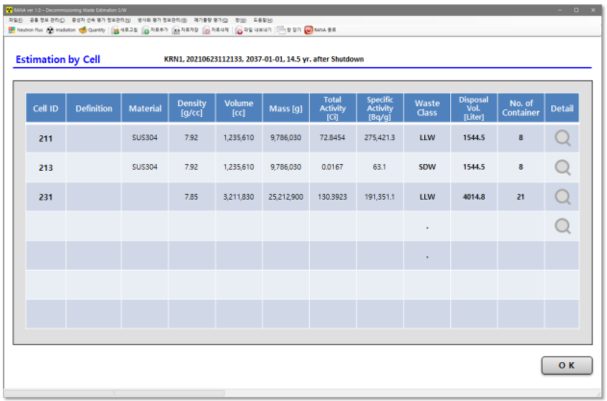


Fig. 7. Example of Estimation Result of Waste Quantity.

3. Conclusions

In order to automatically estimate the amount of radioactive waste arising during decommissioning of NPP, the DB for related data was constructed and the software called RANA was developed.

It is expected that this product and the methodology applied thereto can be used to estimate the amount of radioactive wastes to be generated during decommissioning of all NPPs in Korea as well as Kori unit 1 and Wolsong unit 1.

REFERENCES

[1] MCNP 6.2 User's Manual (LA-UR-17-29981).
[2] SCALE 6.1 User's Manual (ORNL/TN-2005/39 Version 6.1, Sect. F7).
[3] Nuclear Power Generation White book, MOTIE (Ministry of Trade, Industry and Energy), KHNP Co., Ltd., 2016.

[4] Nuclear Energy Yearbook, KAIF (Korea Atomic Industrial Forum), 2019.
[5] Regulations on radioactive waste classification and self-disposal standards, Nuclear Safety Committee Notice 2020-6.

Acknowledgments

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