Development and Verification of Calculation Tool of Operational Intervention Levels for HANARO Research Reactor

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1. Introduction

The Operational Intervention Levels (OILs) are crucial for guiding the prompt protective actions during nuclear and radiological emergencies, based on monitoring results (i.e. ambient dose rate or activity concentrations) [1]. In Korea, current radiation emergency planning documents follow OILs outlined in IAEA-TECDOC955 [2]. However, the proposed OILs based on IAEA-GSR Part 7 [3] necessitate an update.

In this paper, we present the OIL1 calculation tool for research reactors, developed based on the IAEA 'OIL calculation'. Additionally, to calculate $OIL1_\gamma$ for ground monitoring based on GSR Part 7, we construct a dataset for a Channel Flow blockage accident scenario of a research reactor. Subsequently, we analyze the $OIL1_\gamma$ for HANARO using the developed calculation tool and verify the accuracy of calculation structure.

2. Materials and Methods

2.1 Structure of the Calculation Sheets

The IAEA provides Microsoft Excel 2010 spreadsheets for OILs value calculations, contained mostly in the OILs calculation spreadsheet. These calculations are performed based on Excel VBA according to the user's options set in the 'setting' sheet.

Based on the methodology and structure of the IAEA 'OIL calculation', a Microsoft Excel sheet was developed for performing OIL calculations for research reactors. Additional functions were added to enhance user experience and convenience. These features can be seen in the program flowchart below in Fig 1.

2.2 Assumption and Equation of Calculation OILs

All members of the public take response actions based on the dose projected or received by the representative person and fetus considered in the calculations. For the 'ground' scenario, four exposure pathways are considered: (a) ground shine, (b) air shine, (c) inhalation of resuspended radioactive material, and (d) inadvertent ingestion of soil.

The calculation of default $OIL1_\gamma$ values entails the assessment of the $OIL1_\gamma$ function for individual mixtures.

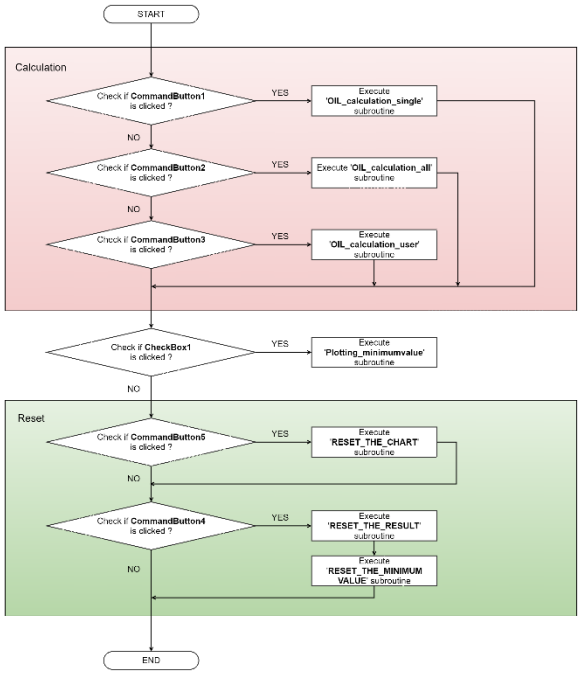

Fig 1. Program flow chart of OIL1 Calculation tool for research reactor

The calculations to determine the time- and mix-dependent $OIL1_\gamma$(t,mix) function on which to base the selection of the default $OIL1_\gamma$ value are as follows

$$OIL1_\gamma(t,mix) = \left(\sum_i \left(RA_i(t,mix) \times H^*_{grd-sh,i}\right)\right) \times WF_{OIL1_\gamma} \times UC \times DA_{OIL1_\gamma}(t,mix) \quad (1)$$

The relative activity of radionuclide i for a specific mix, $RA_i(t,mix)$ is determined by Eq. (2), while $H^*_{grd-sh,i}$ represents the ambient dose equivalent rate at 1 m above ground level per unit ground surface activity of radionuclide *i*. The $OIL1_\gamma$ values, derived from ground monitoring, account for instrument characteristics by using $H^*_{grd-sh,i}$ to consider instrument response into the calculation.

$$RA_i(t,mix) = \frac{A_i(t,mix)}{\sum_j^n A_j(t,mix)} \quad (2)$$

The expression $A_i(t,mix)$ is determined as the product of $I_{fuel-type,i}(t)$ and $RF_i(mix)$ as given by

Equation (3). $I_{fuel-type,i}(t)$ follows an exponential decay presented by Equation (4), where t_0 signifies the initial time, and $\lambda_i$is the decay constant.

$$A_i(t, mix) = I_{fuel-type,i}(t) \times RF_i(mix) \quad (3)$$
$$I_{fuel-type,i}(t) = I_{fuel-type,i}(t_0) \times e^{-\lambda_i \times (t-t_0)} \quad (4)$$

2.3 Accident Scenario and Source Term

The HANARO Safety Analysis Report (SAR) [4] identifies the channel flow blockage accident as a maximum postulated accident, focusing solely on the environmental release of radionuclides. Given the conservatism of this accident, we prioritize its source term in the dataset of the OIL1 calculation tool for research reactors.

The radionuclides considered in HANARO include halogens (Br, I), alkali metals (Rb, Cs), the Tellurium group (Te), and transition metals (Ru). Since this list of radionuclides considered is different from the list considered for Nuclear power reactor accidents, the calculation factors for radionuclides such as Br are derived using the same methodology as for IAEA-EPR-NPP-OILs [1]. The core inventories for the 36 assemblies of nuclear fuel in HANARO [3] form the dataset utilized in these calculations by the OIL1 calculation tool for research reactors.

Table 1. Release fraction of core to containment

Group \ RF_i	TID-14844	NUREG-1465	SRS No. 53 (ASTRA)
Halogens (I,Br)	5.0.E-02	4.0 E-05	1.0 E-04
Alkali metals (Cs, Rb)	1.0 E-03	3.0 E-05	1.0 E-06
Tellurium Group (Te)	1.0 E-03	5.0 E-06	1.0 E-06
Transition metal, Noble metal (Ru)	1.0 E-03	2.5 E-07	1.0 E-06

The release fraction of radionuclides from the fuel for specific mixtures, denoted as $RF_i(mix)$, is determined based on various sources, including the data from TID14844 [6] for the channel flow blockage accident, the data from NUREG-1465 taking into account the decontamination effect under water [7-8], and data from the ASTRA research reactor for release fractions assuming underwater release [9].

3. Results and Discussions

Using the OIL1 calculation tool for research reactors, the ground monitoring-based $OIL1_\gamma$ for the HANARO were analyzed, as depicted in Fig 2.

Subsequently, to verify the accuracy of the OIL1 calculation tool for research reactors developed in this study, we compared the calculation results between this tool and the IAEA's OIL calculation tool. To facilitate this comparison, we applied identical inventory and release fraction data in both tools. Given that the types of radionuclides considered in the research reactor differ from those in the nuclear power reactor, we focused on the radionuclides commonly used in both tools : Rb-86, Ru-103, Ru-105, Ru-106, Te-127, Te-127m, Te-129m, Te-131m, Te-132, I-131, I-133, I-134, I-135, Cs-134, Cs-136, and Cs-137.

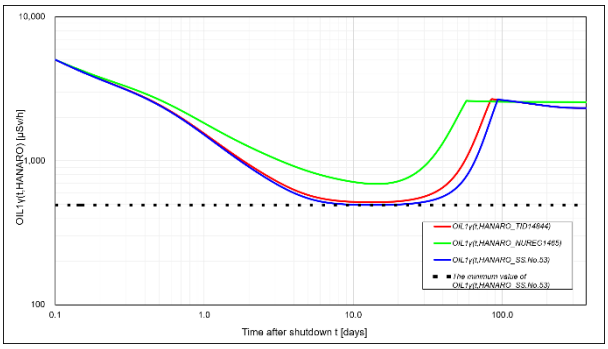

Fig 2. $OIL1_\gamma$(t,HANARO) [μSv/h] function using the 'OIL1 CALCULATOR For Research Reactor' calculation tool

Table 2. Relative error between $OIL1_\gamma$(t,mix) results for 16 radionuclides

Time [d]	$OIL1_\gamma$(t,mix1)	$OIL1_\gamma$(t,mix2)	$OIL1_\gamma$(t,mix3)
0.10	-0.81%	-0.79%	-0.78%
1.00	-0.83%	-0.81%	-1.32%
2.04	-0.84%	-0.82%	-1.48%
3.02	-0.83%	-0.82%	-1.54%
4.07	-0.83%	-0.82%	-1.56%
5.01	-0.83%	-1.31%	-1.55%
6.03	-0.82%	-0.82%	-1.53%
7.10	-0.82%	-0.82%	-1.50%
8.13	-0.81%	-0.81%	-1.45%
9.12	-0.80%	-0.81%	-1.42%
10.00	-0.80%	-0.80%	-1.36%

The relative errors between the results of the two tools over time were compared as shown in Table 2. The relative errors were calculated with reference to the results from the IAEA's 'OIL Calculation' tool.

The relative errors between the two calculation tools for the 16 radionuclides ranged from a -0.78% to -1.56% for $OIL1_\gamma$(t,mix)

4. Conclusion

This study has developed the 'OIL1 calculation tool for research reactors' based on the IAEA OIL calculation worksheet and analyzed the $OIL1_\gamma$ calculations within the context of the maximum postulated accident, specifically the channel flow blockage accident outlined in the HANARO SAR. The accuracy of the developed calculation tool was verified, with the maximum relative error confirmed to be within 1.56%.

Moving forward, similar verification procedures will be conducted for OIL2 and OIL3 to ensure their accuracy. Additionally, future work will focus on implementing other accident scenarios into the OILs calculation tool for research reactor. Furthermore, the calculation tool will

incorporate datasets for various accident scenarios applicable to research reactors to enable an analysis across potential accidents. The results of these analyses are anticipated to make a significant contribution by informing the proposal of specific OILs for research reactors upon the adoption of IAEA GSR Part 7 into national nuclear emergency response.

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