Analysis of the Off-site Consequence According to the Occurrence Time of HANARO DBA

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1. Introduction

One significant aspect of the emergency planning for nuclear facilities is to ensure that an adequate capability for an effective response to a nuclear and radiological emergency. Arrangements for preparedness and response should be based on the hazard assessment [1]. Therefore, in order to maintain an emergency response system, it is necessary to perform the periodic safety review using the latest realistic input variables. The objective of this study is to evaluate off-site radiological environmental impacts by the occurrence time of the Design Basis Accident (DBA) for HANARO nuclear research reactor by using the estimated radiation source term with the current three years of site-specific meteorological data.

2. Materials and Methods

2.1 Description of HANARO DBA

For the HANARO research reactor, DBA that requires emergency preparedness and response is the fuel damage accident by a flow channel blockage, which results in releasing radioactive materials into environments [2, 3]. Thus, the above accident scenario was considered in this simulation, and some assumptions are adopted as follows:

- Operation Conditions for HANARO
  - Nuclear Fuel Cycle: 5th Operation
  - Neutron Flux: 7.0E+14 n/cm^2 sec
- Fuel Damage Ratio
  - 67% of 36 Fuel Elements × 3 Bundles
  - * Assumed value to simulate the large early release accident
- Release Fractions of Fission Products (FPs) [4, 5]
  - Noble Gas: 100%, Halogens: 50%, Alkali Metals: 30%
- Other Events: Earthquake, Fire, Sealing Measures for the Leakage Points inside the building

However, it should be noted that the actual probability of occurrence for the accident is extremely rare [2].

2.2 Selection of Computer Codes for Simulation

Several computer codes were used for radiation source term estimation and environmental impact assessment. The roles of each code are as follows:

- <u>ORIGEN2</u>: to calculate the fuel assembly inventory of FPs accumulated during normal operation
- <u>MELCOR</u>: to simulate the FPs behaviors inside the reactor pool, the building, and leakage into the environment
- <u>Microshield10</u>: to identify the radiation shielding effect of reactor building materials (concrete, lead)
- <u>SafeHanaro</u>: to predict the atmospheric dispersion and the ground deposition, and to assess individual exposure dose

2.3 Radiological Environmental Impact Assessment

2.3.1 Radiation Source Term

Table I lists the amounts of radioactive materials released into the environment obtained from MELCOR code. Based on the estimated source term, environmental impact assessment was conducted with the SafeHanaro program, which developed on the basis of the Gaussian Plume atmospheric dispersion model at KAERI.

2.3.2 Exposure Pathway from the Gaseous Effluents

Since the release duration of radioactive materials into the environment is only approximately two hours, the representative exposure pathways for workers and the public were selected as follows:

- Internal Exposure
  - Plume Inhalation (inhalation of radioactive materials in air)
- External Exposure
  - Cloud shine (resulting from the radioactive plume)
  - Ground shine (from deposited materials on the ground)

2.3.3 Meteorological Data

Figure 1 represents arithmetic mean values of regional meteorological data (2017~2019) extracted from website of the Korea Meteorological Administration (KMA) [6]. The variations of weather conditions and dominant wind direction in the Daejeon area are observed. It implies that the occurrence time of the HANARO DBA can affect the trends of atmospheric dispersion and ground deposition.

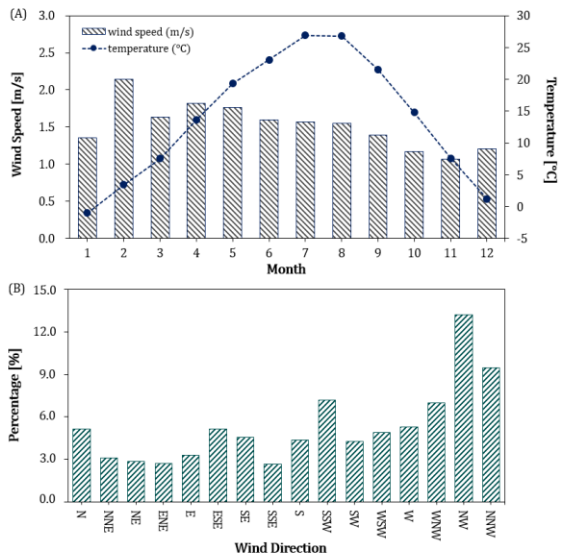

Fig. 1. Arithmetic mean values of meteorological data measured at the Daejeon site for recent three-years. (A) Monthly wind speed and temperature (B) Annual distribution of wind direction

Table I: Radiation source-terms released into the environment [Bq/sec]

Radionuclides		Stack (68m)	Ground (Building Leakage) (10m)					
		H+00:12-00:13	H+00:13-00:23	H+00:23-00:31	H+00:31-00:35	H+00:35-00:42	H+00:42-01:01	H+01:01-02:30
	Xe-127	9.26E+01	1.60E-05	1.41E-04	6.79E-03	3.33E-02	9.06E-02	1.29E-03
	Xe-129	1.48E+04	2.55E-03	2.24E-02	1.08E+00	5.31E+00	1.44E+01	2.06E-01
	Xe-131m	3.59E+08	6.19E+01	5.44E+02	2.63E+04	1.29E+05	3.50E+05	5.00E+03
	Xe-133	8.61E+10	1.48E+04	1.30E+05	6.28E+06	3.08E+07	8.37E+07	1.19E+06
	Xe-133m	2.67E+09	4.57E+02	4.02E+03	1.94E+05	9.51E+05	2.58E+06	3.65E+04
	Xe-135	9.40E+09	1.58E+03	1.38E+04	6.59E+05	3.21E+06	8.63E+06	1.16E+05
Noble Gas (Xe, Kr)	Xe-135m	1.57E+10	1.06E+03	6.86E+03	2.45E+05	9.79E+05	1.67E+06	5.19E+03
	Xe-138	8.17E+10	5.13E+03	3.24E+04	1.13E+06	4.44E+06	7.29E+06	2.10E+04
	Kr-83m	6.92E+09	1.05E+03	8.82E+03	4.09E+05	1.95E+06	4.96E+06	5.32E+04
	Kr-85	9.98E+07	1.72E+01	1.52E+02	7.33E+03	3.59E+04	9.78E+04	1.40E+03
	Kr-85m	1.61E+10	2.63E+03	2.27E+04	1.08E+06	5.22E+06	1.38E+07	1.75E+05
	Kr-87	3.23E+10	4.61E+03	3.81E+04	1.73E+06	8.16E+06	2.01E+07	1.92E+05
	Kr-88	4.56E+10	7.22E+03	6.18E+04	2.91E+06	1.40E+07	3.65E+07	4.31E+05
	I-128	8.87E+04	2.02E+00	9.97E+00	2.85E+02	1.03E+03	1.42E+03	5.13E+00
	I-129	1.61E-01	6.42E-06	3.84E-05	1.33E-03	5.43E-03	9.86E-03	1.02E-04
	I-130	3.98E+05	1.56E+01	9.28E+01	3.19E+03	1.30E+04	2.34E+04	2.31E+02
	I-131	3.24E+07	1.29E+03	7.74E+03	2.68E+05	1.09E+06	1.98E+06	2.05E+04
	I-132	5.07E+07	1.83E+03	1.06E+04	3.54E+05	1.41E+06	2.44E+06	2.01E+04
	I-133	7.62E+07	3.01E+03	1.80E+04	6.19E+05	2.52E+06	4.56E+06	4.60E+04
Halogens (I, Br)	I-134	8.60E+07	2.63E+03	1.44E+04	4.55E+05	1.75E+06	2.79E+06	1.65E+04
	I-135	7.12E+07	2.75E+03	1.62E+04	5.55E+05	2.25E+06	4.02E+06	3.83E+04
	Br-80	1.20E+01	2.14E-04	9.70E-04	2.55E-02	8.72E-02	1.07E-01	2.77E-04
	Br-80m	6.53E+00	1.16E-04	5.26E-04	1.38E-02	4.73E-02	5.81E-02	1.50E-04
	Br-82	7.52E+04	2.98E+00	1.78E+01	6.15E+02	2.51E+03	4.55E+03	4.63E+01
	Br-83	5.87E+06	2.13E+02	1.23E+03	4.12E+04	1.65E+05	2.85E+05	2.37E+03
	Br-84	1.09E+07	2.80E+02	1.44E+03	4.30E+04	1.59E+05	2.33E+05	1.01E+03
	Cs-132	1.23E+03	9.22E-02	5.52E-01	1.91E+01	7.78E+01	1.41E+02	1.46E+00
	Cs-134	1.69E+05	1.26E+01	7.56E+01	2.61E+03	1.07E+04	1.94E+04	2.01E+02
	Cs-134m	2.30E+05	1.59E+01	9.24E+01	3.11E+03	1.25E+04	2.18E+04	1.88E+02
	Cs-135	3.82E-01	2.86E-05	1.71E-04	5.92E-03	2.42E-02	4.40E-02	4.55E-04
	Cs-135m	6.18E+04	3.55E+00	1.94E+01	6.13E+02	2.36E+03	3.77E+03	2.23E+01
Alkali Metal (Cs, Rb)	Cs-136	1.04E+05	7.74E+00	4.63E+01	1.60E+03	6.54E+03	1.19E+04	1.23E+02
	Cs-137	2.28E+05	1.71E+01	1.02E+02	3.53E+03	1.44E+04	2.62E+04	2.72E+02
	Cs-138	2.42E+07	1.17E+03	6.02E+03	1.80E+05	6.66E+05	9.78E+05	4.29E+03
	Rb-86	6.96E+03	5.20E-01	3.12E+00	1.08E+02	4.40E+02	8.00E+02	8.27E+00
	Rb-88	1.26E+07	4.27E+02	1.95E+03	5.18E+04	1.78E+05	2.21E+05	5.86E+02
	Rb-89	1.63E+07	4.85E+02	2.11E+03	5.35E+04	1.78E+05	2.08E+05	4.67E+02

It suggests that emergency response strategies for the radiation protection of employees and residents ought to be coordinated at the point of the accident date.

Accordingly, the accident was assumed to be occurs at noon on the 15th of every month, and then environmental dose assessment was performed by using the averaged values of the meteorological data of that day as input data. The meteorological data measured at the 70m and the 10m height above ground were adopted to evaluate the results of stack release and ground release, respectively.

3. Results and Discussion

Figure 2 illustrates the estimated individual effective dose by the accident date and the down-wind distance from the HANARO. It was revealed that a temporary evacuation (50-500 mSv in 2 days) is required to be taken for workers and residents up to a radius of 50m, and sheltering (5-50 mSv in 1 week) is needed up to a radius of 70m. The most severe exposure-induced accident date was turned out to be as November accident. Furthermore, the maximum exposure doses observed at points around the reactor chimney (NNE, 40m) and the boundary of the fence on the north side of the reactor (N, 60m), in which points have the maximum deposition density.

Effective dose and thyroid dose for the maximum exposed individual and their own time-dependent dose contributions, in case of the November accident, are shown in **Figures 3** and **4**, respectively. In both cases, the dose contribution by each exposure pathway was found to be decreased in the following order of ground shine, plume inhalation, and cloud shine.

The main exposure pathway in the initial phase of the accident (0~2 hours) was found to be as plume inhalation, which was the major cause of thyroid dose. Thyroid dose contribution resulting from inhalation was accounted for more than 45.03% of the total thyroid dose. Meanwhile, the effective dose resulting from inhalation accounted for 4.03% of the total effective dose. This result indicates that the protective measures for workers and inhabitants need to be applied appropriately depending on time sequence after the accident. That is, the urgent protective strategies such as dose of stable iodine, sheltering and temporary evacuation should be considered in the early stage of the accident when the radioactive plume passes through

Meanwhile, for the intermediate- and long-term stage (8 hours ~), the major exposure pathway was identified to be as the ground shine which accounted for more than 84.33% of the total effective dose and 47.72% of the total thyroid dose. After the passage of radioactive plume, the longer-term protective strategies including permanent relocation, agricultural protective measures, environmental restoration work and decontamination, should be implemented because the deposited radioactive nuclides cause external exposure doses in the intermediate- and long-term phases.

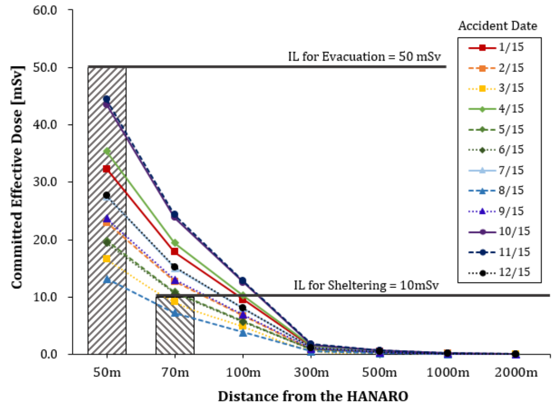

Fig. 2. Individual effective dose according to accident occurrence time and the down-wind direction from the HANARO

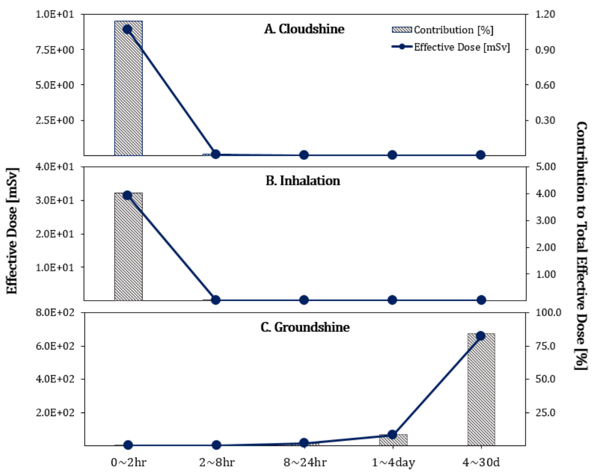

Fig. 3. Contributions of exposure pathways to effective dose

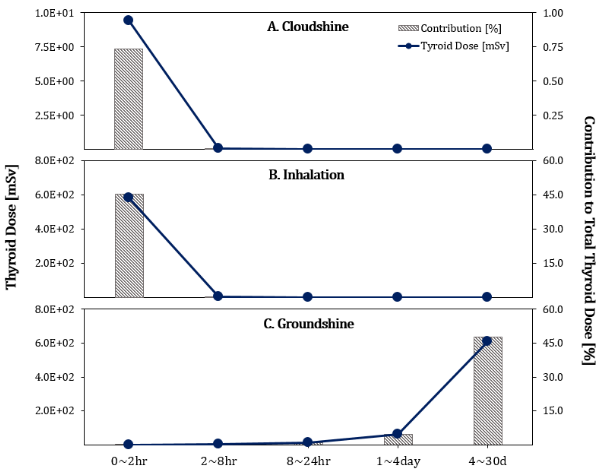

Fig. 4. Contributions of exposure pathways to total thyroid dose

4. Conclusions

Off-site consequence according to the occurrence time of the HANARO DBA was analyzed by combining the estimated radiation source-term with the current site-specific meteorological data. The most severe exposure-induced occurrence date was confirmed to be November. In addition, the most severe exposure-induced pathways for initial phase of (0~2 hours) and the intermediate- and long-term phase (4~30 days) were found to be as plume inhalation and ground shine arising from the deposited materials, respectively. It was confirmed that the radiological protective measures should be implemented by the accident occurrence date and the elapsed time after the accident. In conclusion, the results will be used as the background data to establish the plans for the HANARO nuclear emergency response integrated exercise in 2020.

5. Acknowledgments

This study has been conducted as a part of the project of emergency preparedness for nuclear research facilities in KAERI.

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