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Evaluation of Disposal Waste Production from AGN-201K Reactor as a Preliminary Decommissioning Plan

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1. Introduction

With the recent revision of the Korean regulation, preliminary assessments of decommissioning should be conducted for all reactors currently operating and planed. Various evaluation items may be included such as decommissioning waste, decontamination activities, fire protection, remediation, and etc. Maybe the most important and basic one is the production of decommissioning waste. In this paper, a preliminary study of the decommissioning waste generated was done for the AGN-201K, a research and education reactor in the Kyung Hee University.

The AGN-201K reactor is a zero power reactor, in which neutron flux level is very low. In general, it is considered that radioactivity is negligible for the area where neutron flux is low. In fact, AGN-201K has no radioactive waste generated during operation. Short-lived isotopes may be considered mainly during normal operation. However, for decommissioning plan, long-lived radioisotopes should be calculated. That is why reactor should be cooled-down for a few years before decommissioning actions. This difference makes different trend of radioactive waste in both conditions. Therefore, mid- or long-lived isotopes will be considered and analyzed dominantly in this paper.

2. Evaluation Model & Method

The AGN-201K reactor is a research and educational reactor. It is called zero power reactor because power is very low. It had been licensed as 0.1 watt of power in 1978, and raised power has been licensed up to 10 watt of power in 2007. It is lower than commercial reactors about billion times. It is expected to be negligible activation because of very low neutron flux.

2.1 Evaluation Method

The most accurate and easiest way to evaluate activation is a measurement of activity of radioactive samples. But in case of AGN-201K reactor, it may be hard to measure radioactivity due to its very low neutron flux. So numerical calculation has done. The Monte Carlo code, MCNP6, and activation code, ORIGEN 2.1, are used [1, 2]. The methodology by connecting the MCNP and ORIGEN code is a well-known method for evaluation of material activation.

The MCNP code is used for generation of neutron cross-sections of isotopes and calculation of neutron flux in the material. The cross-sections and neutron flux are condensed to one-group. The cross-sections are already weighted the neutron energy spectrum in the material. The reason of one-group condensation of neutron energy is for the ORIGEN 2.1 code. Only one-group condensed nuclear data can be used in the ORIGEN code version 2.1. In this calculation step, the ENDF/B-VII.1 nuclear library is used.

The ORIGEN code is used for estimation of the radioactivity of material in long-term neutron activation. It is for calculation of radioactivity by neutron irradiation, not burnup of nuclear fuel. It can be assumed that neutron energy spectrum is same for all irradiation-time.

2.2 Evaluation Model

A geometry of AGN-201K reactor is modeled as realistic as possible. Neutron flux and irradiation time is assumed conservatively. Whole model including concrete confinement and door is shown in figure 1, and expanded model focusing on the reactor is shown in figure 2.

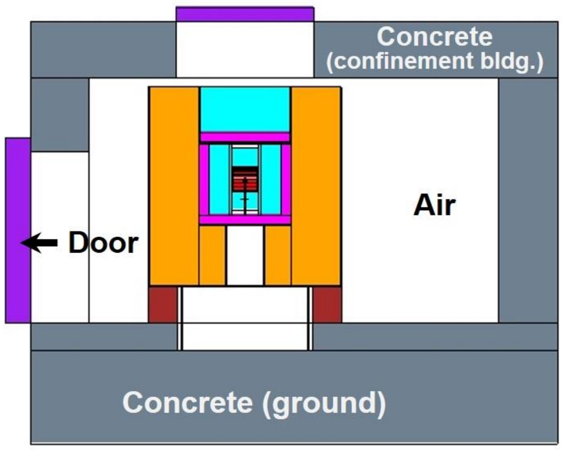

Fig. 1. Whole geometry model of AGN-201K including confinement concrete and doors (for MCNP calculation)

The reactor has licensed as 10 watt of power. But in real experiment, the reactor is usually operated from a few dozen watt to a few hundred watt of power level. Therefore, the reactor power is assumed 1 watt for conservative calculation. Meanwhile, the AGN-201K reactor has operated about 40 years until now. Burnup of nuclear fuel is extremely small, so it could be operated more than a hundred years from now on. But in this paper, operation period of the reactor is assumed 80 years. In other words, it is assumed that the reactor operation will be finished about 40 years later. Annual operating time of the reactor is different for each year, but it is limited less than 500 hours in the technical specification for the AGN-201K. So annual irradiation time is assumed 500 hours. For the more conservative calculation, reactor cooling time between reactor shutdown is not considered.

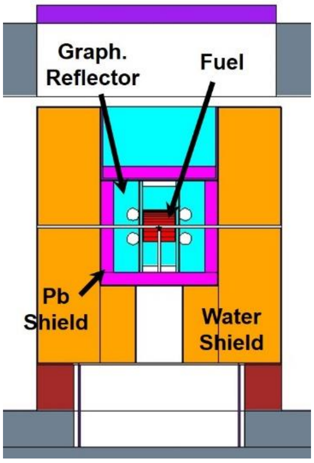

Fig. 2. Expanded view of geometry model of AGN-201K

2.3 Special Characteristic of AGN-201K Reactor

Unlike typical commercial nuclear power plants, graphite is used as a reflector in the AGN-201K. If graphite is irradiated, C-14 isotopes will be produced. It is one of the important things to consider.

Annual operating time is also very different to typical nuclear reactors. The annual operating time is only 500 hours for the AGN-201K. This is only about 21 days of continuous operation. And actual operating time is one year when operating for about 17.5 consecutive years. From it, the AGN-201K reactor may show a different tendency from common sense. Assuming 80 years (40,000 hours) operation as in this study, actual operating time corresponds to about 4.6 years of continuous operating.

3. Regulation

In Korea, the regulatory system [3] sets self-disposal standards based on specific radioactivity. Radioactive waste is defined as specific radioactivity higher than that. If two or more radioactive isotopes are mixed, it will be normalized for the allowable radioactivity of each nuclide to determine rank of radioactive waste. The self-disposal criteria of mixed material is as following equation, where C_i is specific radioactivity of isotope and $C_{i,L}$ is self-disposal criteria.

$$\sum \left({C_i}/{C_{i,L}} \right) < 1.0$$

Under domestic regulation, if $\Sigma(C_i/C_{i,L})$ is greater than 1.0 and less than 100, it is classified as very low level radioactive waste. If $\Sigma(C_i/C_{i,L})$ is greater than 100, it is classified as low and intermediate level radioactive waste. Low and intermediation level radioactive wastes are classified based on the radioactivity of specific isotopes such as H-3 and/or C-14. High level radioactive wastes are identified by special criteria based on radioactivity and heat generation rate.

Since the AGN-201K reactor has very low power level, all materials except nuclear fuel are expected to be able to do self-disposal. If some parts have higher radioactivity than others, but they may be still very low level radioactive waste

4. Result

4.1 Graphite Reflector

High-density and high-purity graphite with a density of 1.7 g/cm^3 is used as a neutron reflector in the AGN-201K. It is very close to the fuel and is expected to have high radioactivity. Radioactive isotope of C-14, which is produced by neutron capture of C-13, is a long-lived radioisotope with a half-life of 5,700 years. Once created, the C-14 will not easily decay-out.

For conservative evaluation, location which have the highest radioactivity is predict, and its radioactive is calculated. Since the graphite is next to the nuclear fuel, it is assumed that the neutron characteristics is same in all directions very near the nuclear fuel. The graphite is cut imaginary sample into 1cm-thick cylinder in the radial direction of the nuclear fuel. Radioactivity of the imaginary sample is calculated.

Table 1. Specific activity and self-disposal feasibility of graphite reflector

Isotope	Activity (C_i) [Bq/g]	Limit ($C_{i,L}$) [Bq/g]	Activity Ratio to Limit (C_i / $C_{i,L}$)
Be-10	8.8615E-06	0.1	8.8615E-05
C-14	5.2466E-03	1	5.2466E-03
Sum	5.2555E-03		**5.3252E-03**

4.2 Lead Gamma-ray Shield

A lead-shield is located just outside the graphite. It may be assumed that the location closest to the fuel is locally most radioactive. For conservative evaluation, the radioactivity of the bottom lead shield closest to the fuel is calculated. The calculated imaginary sample is a cylindrical shape with a height of 1 cm and a radius equal to the fuel. As a result of calculation, its radioactivity is about 1.1 times higher than the radial located sample.

Radioactive isotope of Pb-204 is long-lived radioisotope, which half-life is about 140×10^{15}yr. In generally, the radioactivity is too small, so it may be ignored for radioactivity evaluation. In this calculation, however, the radioactivity of Pb-204 is seemed to be large because the overall radioactivity is so low.

Table 2. Specific activity and self-disposal feasibility of lead gamma-ray shield

Isotope	Activity (C_i) [Bq/g]	Limit ($C_{i,L}$) [Bq/g]	Activity Ratio to Limit (C_i / $C_{i,L}$)
Tl-204	6.3899E-05	1	6.3899E-05
Pb-204	6.3862E-06	0.1	6.3862E-05
Pb-205	1.7682E-05	0.1	1.7682E-04
Sum	8.7978E-05		**3.0459E-04**

4.3 Water Shield for Neutron Shielding

The water is assumed to be continuously flowed and mixed. Therefore, the averaged radioactivity is evaluated for whole water. Because water is liquid, not solid, drainage management standards are used rather than self-disposal criteria [4].

Table 3. Volumetric activity and drainage feasibility of water shield

Isotope	Activity (C_i) [Bq/m^3]	Limit ($C_{i,L}$) [Bq/m^3]	Activity Ratio to Limit (C_i / $C_{i,L}$)
H-3	6.4787E+01	4E+07 (in case of water)	1.6197E-06
C-14	1.3760E+02	1E+06 (in case of labeled organic compound)	1.3760E-04
Sum	2.0239E+02		**1.3922E-04**

4.4 Concrete Confinement Building

The distribution of neutron flux is evaluated for the concrete confinement building. The radioactivity at the largest neutron flux location is calculated. This is based on the following two assumptions; the neutron energy spectrum at each location may not be very different, and therefore the larger neutron flux makes higher radioactivity. Consequentially, the radioactivity is calculated for the reactor bottom concrete surface. Calculated imaginary sample is a rectangular cuboid shaped and a 25 cm × 25 cm × 1 cm sized.

Table 4. Specific activity and self-disposal feasibility of concrete confinement building

Isotope	Activity (C_i) [Bq/g]	Limit ($C_{i,L}$) [Bq/g]	Activity Ratio to Limit (C_i / $C_{i,L}$)
Ca-41	2.4683E-03	0.1	2.4683E-02
Ca-45	1.3290E-01	100	1.3290E-03
Mn-54	1.6376E-03	0.1	1.6376E-02
Fe-55	1.9858E+00	1000	1.9858E-03
Sum	2.1228E+00		**4.4538E-02**

5. Conclusion

In this paper, a preliminary study on the decommission of the AGN-201K reactor after about 40 years later, focused on the disposal waste. The radioactivity of graphite reflector, lead shield, water shield, and concrete are evaluated, but not for the nuclear fuel. The evaluation standard is based on the self-disposal criteria (and drainage management standard for water). The radioactivity is very low in comparison with limitation for each radioactive isotope. As a result, all materials could be done self-disposal or drainage without decontamination.

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