Activation Analysis of Nuclear Power Plant Internal Structures Based on Neutron Flux Levels and Impurity

Hyuk Han* and Chang Je Park
Nuclear Engineering Dept., Sejong University., 209 Neungdong-ro, Gwangjin-gu, Seoul, Korea 143-747
**22150062@sju.ac.kr*

1. Introduction

As the nuclear power generation project has been in progress for a long time, the demand for decommissioning nuclear power plant is also increasing.[1]

The internal structure of the reactor is irradiated by neutrons due to the operation of the reactor, which means that part of the internal structure becomes radioactive waste. Accordingly, when decommissioning the nuclear power plant, a large amount of radioactive waste is expected to be generated. As for radioactive waste, according to regulations, the generator is obligated to present the results of the evaluation of the amount of isotope inventory for each drum, and the disposal company shall verify the evaluation results.

The activated internal structures are classified into low, intermediate and low, intermediate-level and self-disposal wastes depending on whether the specific activity value of the constituent isotopes exceeds the standard. In general, the closer to the reactor core, the higher the neutron flux to be irradiated, so that more intermediate-level waste is generated, which varies depending on the material of the structure. Likewise, the specific activity value determined by irradiation varies depending on the composition and ratio of impurities contained in the structure.[2][3]

Therefore, this paper summarizes and presents the results of the activation analysis for internal structures of nuclear power plants using computational code and the specific activity evaluation according to the neutron flux level and impurity.

2. Activation Analysis Method

The Oak Ridge Isotope Generation (ORIGEN) code applies an exponential matrix expansion method to perform time-dependent combustion evaluation to provide the content of each nuclide, activity, and radiation intensity and energy spectrum by all isotopes. ORIGEN-S of the SCALE code system was used as the code for activation analysis. [4]

Three materials were selected as the target for the activation analysis, and concrete, stainless steel-304, and vessel steel. The neutron flux was constantly divided into 9 levels from 1E+06 to 1E+14 and was used according to the pure and impurity composition described in NUREG-3474.[5] NUREG-3474 is a report evaluating problems related to reactor decommissioning due to long-life radioactive waste from reactor internal materials. This report also contains information related to impurities in the internal structure of the nuclear power plant. For the calculation of specific activity, 1g is used in the calculation and the calculation result is replaced by Bq/g.

In order to be similar to the conditions of a typical reactor, the calculation conditions in Table I were used, and the cooling time was set to 10 years.

Table 1. ORIGEN-S activation analysis condition.

Total Number of Cycle	32
Day per Cycle	412 days
Cooling Time	10 years
Neutron Flux	1E+06, 1E+07, 1E+08, 1E+09, 1E+10, 1E+11, 1E+12, 1E+13, 1E+14
Material Type	Concrete, SS304, Vessel Steel
Material Weight	1 gram
Impurity Condition	2(with and without)

The same flux was calculated using the same for 32 cycles, and the specific activity results for this were extracted as the isotopes corresponding to Table II with OPUS option.

Table 2. List of isotopes selected using the OPUS option.

H3	Ni63	I129	Mn54
C14	Sr90	Cs137	Mo93
Co60	Nb94	Eu152	Fe55
Ni59	Tc99	Eu154	-

The 15 isotopes in Table II are used as the result using the OPUS option, and these isotopes can be compared to their respective disposal criteria to determine the disposal level of waste.[6]

3. Results and Analysis

R-STUDIO was used to analyze and plot the activation analysis results. Analysis was performed on the isotopes showing the most sensitive results, and the neutron flux sensitivity evaluation results for concrete are shown in Figure 1 and 2.

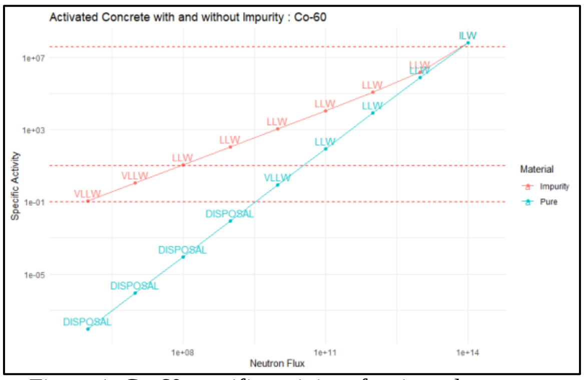

Figure 1. Co-60 specific activity of activated concrete waste by neutron flux.

Concrete waste is most sensitive in Co-60 in the presence of impurities and tends to converge at high neutron flux levels, although the influence of impurities is large at low neutron flux levels. In the presence of impurities, even the neutron flux of 1E+06 exceeded the very-low level waste criteria, but in the absence of impurities, the neutron flux of 1E+10 or more had to be irradiated to exceed the very-low level waste criteria.

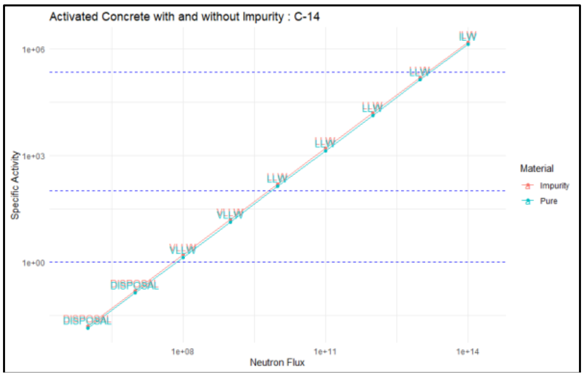

Figure 2. C-14 specific activity of activated concrete waste by neutron flux.

In concrete without impurities, C-14 was calculated to be the most sensitive to neutron flux. Regardless of the presence of impurities, it showed almost similar trends proportional to neutron flux.

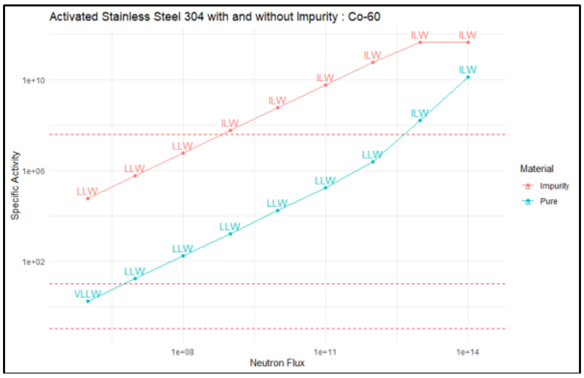

Figure 3. Co-60 specific activity of activated SS304 waste by neutron flux.

SS304 was evaluated as the most sensitive material of Co-60 regardless of the presence or absence of impurities. However, there was a big difference in the waste level depending on the presence or absence of impurities. This is shown in Figure 3.

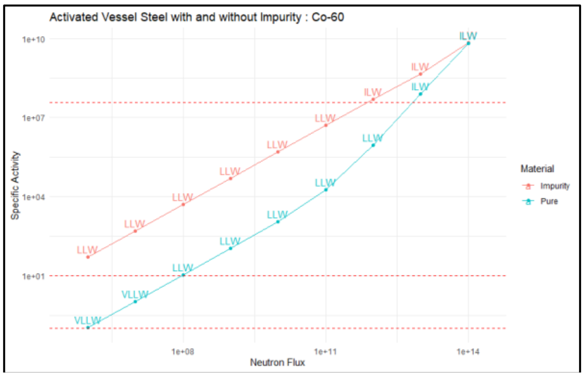

Figure 4. Co-60 production amount of activated vessel steel waste by neutron flux.

Even in vessel steel, co-60 was evaluated as the most sensitive isotope when impurities were present, and it was found that there was not a small amount of influence by impurities. Figure 4 shows this trend.

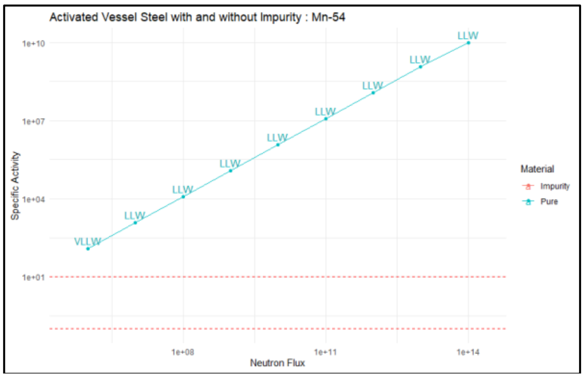

Figure 5. Mn-54 specific activity of activated vessel steel waste by neutron flux.

In the absence of impurities, in the Figure 5, Mn-54 showed the most sensitive tendency, and almost the same trend was observed regardless of the presence or absence of impurities.

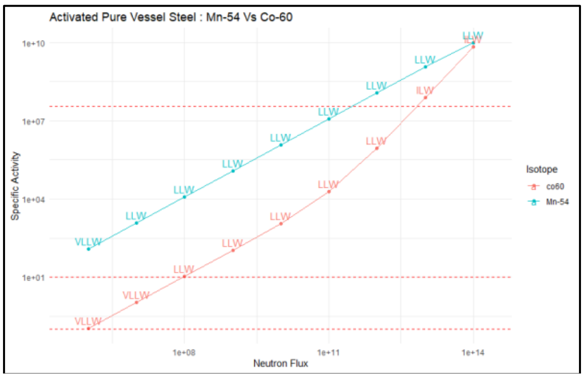

Figure 6. Mn-54 vs Co-60 specific activity of activated vessel steel waste by neutron flux.

However, Mn-54 is not determined by the specific activity value itself, but isotopes that correspond to the low-level criteria are also related. In this case, Co-60 corresponds to this, which is shown in Figure 6.

Finally, the sensitive isotopes in each calculation are summarized in Table III.

Table III. Summary of Sensitive Isotopes according to Activation Analysis Results.

	Impurity	Pure
Concrete	Co-60	C-14
SS304	Co-60	Co-60
Vessel Steel	Co-60	Mn-54, Co-60

Finally, Co-60 was evaluated as the most sensitive isotope in metals, and sensitive isotopes vary depending on impurities in concrete.

4. Conclusion and Summary

In preparation for the decommissioning of the nuclear power plant, the activation analysis was performed on the internal structure materials according to the neutron flux and impurities. As a result of the analysis, waste, not self-disposal, is generated even at a low flux level depending on the presence or absence of impurities. At a very high flux level, it was found that the results were mainly due to isotopes generated by the main nuclides regardless of the impurities, and the intermediate level waste was also generated.

As a future work, not only the current 15 isotopes, but also those that meet the alpha nuclides and self-disposal criteria will be output and calculated in detail.

Acknowledgement

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Reference

[1] IAEA, Radiological Characterization of Shut Down Nuclear Reactors for Decommissioning, Technical Report Series, No.389, International Atomic Energy Agency, Vienna 1998

[2] Sohn, H.D., Soo Park, K., Woong Kim, H., Woo Kim, C., Hwan Hwang, Y., Young Yoon, J., 2020. The study for activation analysis on activated structures in nuclear power plant with 40 years operation history. Ann. Nucl. Energy 141, 107305.

[3] Seung Uk Yoo, Dong Hyeok Park, Ki Ho Park, Chang Je Park, Coupled module of radioactive waste analysis for CANDU reactor based on the Monte Carlo method, Ann. Nucl. Energy 192, 109978.

[4] Wieselquist, et al, W.A., 2020. SCALE Code System, ORNL/TM-2005/39, Version 6.2.4, April 2020

[5] NUREG-3474-Long-lived activation products in reactor materials, Evans, J.C, 1984

[6] Regulations on classification of radioactive waste and self-disposal standards, Nuclear Safety Commission Notice No. 2023-7(KOREA), 2023