Transactions of the Korean Nuclear Society Autumn Meeting
Pyeongchang, Korea, October 30-31, 2014

A Preliminary Study on the Air and Concrete Activation Analysis for RAON ISOL-Bunker

Do Hyun KIM [a], Song Hyun KIM [a], Myung Sub SONG [a], Gi Yeong HAN [a], Che Wook YIM [a], Jae Yong LEE [a], Chang Ho SHIN [a,*], and Shin Woo NAM [b]
[a]*Department of Nuclear Engineering, Hanyang University, 222, Wangsimni-ro, Seongdong-gu, Seoul, 133-791, Korea*
[b]*Institute for Basic Science, 1689, Yuseong-daero, Yuseong-gu, Daejeon, 305-811, Korea*
[*]*Corresponding author:gemini@hanyang.ac.kr*

1. Introduction

The Institute for Basic Science (IBS) in Korea has designed a heavy ion accelerator which is called as RAON [1]. Before constructing the radiation facility, radiation effects should be evaluated for the radiation safety. There are two radiation analysis field; (i) prompt radiation and (ii) residual radiation. The residual radiation is generated from materials irradiated from the high energy prompt radiation. The dose of the residual radiation is relatively lower than that of the prompt radiation; therefore, the analysis is usually performed after turn-off of the accelerators. In this study, radioactivity analyses were performed to establish the strategy of the activation analysis in ISOL facilities of RAON. To estimate the residual radiation dose calculation, the rigorous-two-step method (R2S) [2] was used with coupling the MCNPX 2.7 [3] and SP-FISPECT-2010 code [4].

2. Methods and Results

2.1 Calculation Method

The activation analysis using SP-FISPECT-2010 code can be performed with the particle having energy less than 20 MeV. Hence, the nuclide generation information with the reactions of the high energy particle (over 20 MeV) should be obtained from the physics model in the particle transport codes. In MCNPX 2.7 code, there is a HISTP option to get the isotope production information based on physics model with Bertini intra-nuclear cascade model and ORNL fission evaporation model. In this study, to get the isotope production information, the JENDL/HE-2007 [5] nuclear library was used for particle transport calculation. The lower energy boundary to use the physics model was set to 20 MeV. For the residual dose calculation, R2S method was used as following step:

A. Particle transport simulation is performed to obtain neutron flux and high energy nuclide production.
B. Activation is estimated with the data of Step A to get the amount of isotope and photon source information.
C. Residual gamma transport calculation is pursued to evaluate the dose distribution.

2.2 Overview of ISOL-bunker Geometry

The cross sectional view of ISOL-bunker is given as shown in Fig. 1. There are beam line, target, shielding, and air in the ISOL-bunker. The ISOL system can use proton beam 70 kW (70MeV with 1 mA intensity) in maximum. To generate heavy ions, the proton beam was induced into the cylindrical UC_2 target which has 6 cm diameter and 3.77 cm height. At the end of the target, 1 cm carbon dump is located. The target was located at 150 cm height from the bottom. To protect the prompt radiation, ISOL-bunker was surrounded by concrete shields as shown Table I. And, the information of the material density was given in Table II.

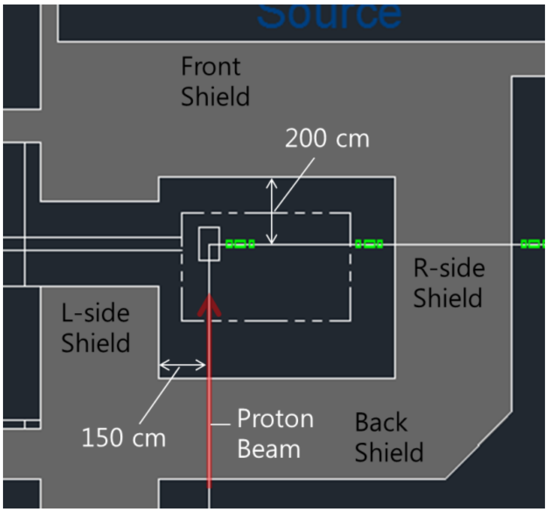


Fig. 1. Cross Sectional Drawing of ISOL-bunker

Table I: Thickness of Concrete Shield

	Front	R-side	L-side	Back	Roof	Bottom
Thickness (cm)	405	300	345	207	325	345

Table II: Densities of materials at ISOL-bunker

	UC2 (Target)	Carbon (Dump)	Concrete	Air
Density (g/cm^3)	2.5	1.8	2.3	1.2048×10^{-3}

Table IV: Specific Activation at 1 Hour and 15 Day Decay Time

	10MeV		20MeV		50MeV		70MeV	
Humidity	1 Hour Decay	15 Day Decay	1 Hour Decay	15 Day Decay	1 Hour Decay	15 Day Decay	1 Hour Decay	15 Day Decay
0%	5.444E+08	5.327E+08	2.489E+09	3.097E+08	1.604E+10	3.313E+09	1.795E+10	5.192E+09
30%	5.421E+08	5.304E+08	2.480E+09	3.088E+08	1.606E+10	3.318E+09	1.794E+10	5.172E+09
40%	5.413E+08	5.296E+08	2.477E+09	3.086E+08	1.608E+10	3.322E+09	1.793E+10	5.173E+09
50%	5.405E+08	5.289E+08	2.473E+09	3.083E+08	1.609E+10	3.324E+09	1.793E+10	5.177E+09

2.3 Air Activation Analysis

The main radiation for the air activation is the prompt neutrons generated by the proton induced target reactions. When the neutrons react with the nuclides in the air, ^{3}H, ^{7}Be, ^{11}C, ^{14}C, ^{13}N, ^{15}O, and ^{41}Ar radioisotopes are generated. Each radioactivity isotope was generated by spallation reaction excepting ^{41}Ar which is produced by (n,γ) reaction. To analyze the air activation, the composition of air can be important such as humidity of the air. For analysis of humidity effect, air activation during 14 days was calculated according to the humidity changes at spherical air which has 60 cm radius. The mono-energetic neutrons, which have 10 MeV, 20 MeV, 50 MeV and 70 MeV, were used with the conditions as given in Table III.

Table III: Information of Air Compositions and Densities as Humidity

	Composition (wt%)			
Humidity	0%	30%	40%	50%
^{1}H	-	5.8006E-07	7.7341E-07	9.6677E-07
^{12}C	1.4761E-07	1.4761E-07	1.4761E-07	1.4761E-07
^{13}C	1.7793E-09	1.7793E-09	1.7793E-09	1.7793E-09
^{14}N	9.0994E-04	9.0994E-04	9.0994E-04	9.0994E-04
^{16}O	2.7925E-04	2.8385E-04	2.8539E-04	2.8692E-04
^{40}Ar	1.5454E-05	1.5454E-05	1.5454E-05	1.5454E-05
Density (g/cm^3)	1.2048E-03	1.2100E-03	1.2117E-03	1.2134E-03

Fig. 2 is one of the activation results generated by 10 MeV neutrons. At 0 % humidity, the activity has highest value than the other conditions. However, there are no specific differences of the activities within 0.8 % as shown Table IV. It shows that the effect of the humidity is relatively lower than the other variables.

In this study, 0 % humidity was selected as a standard composition for the air activation in ISOL-bunker. For the conservative analysis, the concrete shielding is surrounded without any streaming. The air activation was pursued during 14 days, and then the activity was calculated as the change of the decay times.

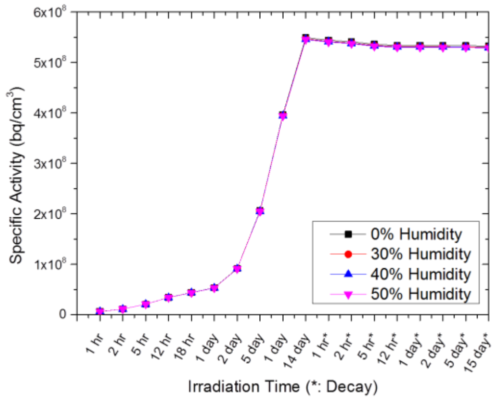


Fig. 2. Specific Activity Generated by 10 MeV Neutrons

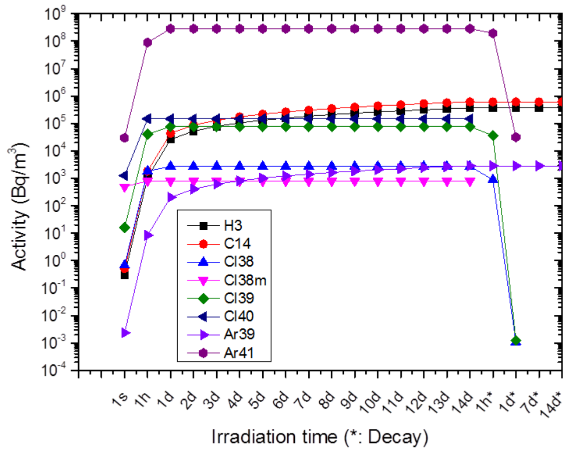


Fig. 3. Activities of Major Radioactive Nuclide as the Irradiation and Decay Times

Fig. 3 is the results of the activities for each produced nuclides after the air activation. It shows that the activities of ^{3}H, ^{14}C, ^{41}Ar, and ^{39}Cl exceed the regulation limits which are Derived Air Concentration Limit (DACL) and Emission Standard (ES). Especially, due to the long decay time, there are extremely small changes of ^{3}H and ^{14}C activities after 14 days.

Table V: Results of Air Activation for Each Nuclide

Nuclide	DACL	ES	0 Sec*	14 Day*
	Bq/m^3	Bq/m^3	Bq/m^3	Bq/m^3
^{3}H	3E+05	3E+03	3.67E+05	3.66E+05
^{7}Be	2E+05	1E+03	-	-
^{11}C	3E+06	2E+04	-	-
^{14}C	1E+04	1E+02	6.11E+05	6.11E+05
^{39}Ar	2E+07	2E+05	2.85E+03	2.85E+03
^{41}Ar	5E+04	5E+02	2.82E+08	-
^{38}Cl	2E+05	3E+03	2.72E+03	-
^{39}Cl	2E+05	3E+03	7.65E+04	-

2.4 Concrete Activation Analysis

Generally, for the concrete activation analysis, the concrete is divided to sub-regions. Therefore, the accuracy of the activation analysis depends on the division strategy of the concrete region. In this section, to establish the division strategy of the concrete structures in ISOL-bunker, the activity using R2S method was evaluated by dividing the concrete to 10 cm and 20 cm unit lengths. To get the flux information, the front shied was chosen and the neutron spectra were estimated. The activation calculation was pursued for the 50 years. During the activation period, the 14 days irradiation and 10.3 days decay were repeated. An infinite slab was used to calculate the residual dose. The Table VI is result of this calculation. The dose results in the target room caused by the residual radiations agree well within 0.8 % for the division strategies. Also, it shows that the dose caused by the residual radiation at out of the target room can be negligible for the radiation safety analysis. Analysis shows that the 20 cm division length can be appropriately utilized for the activation analysis.

Table VI: Residual Doses on each Side of Concrete Wall

	Inside of Target Room		Outside of Target Room	
Division Length	10 cm	20 cm	10 cm	20 cm
Dose (μSv/h)	1.723E+04	1.711E+04	1.507E-04	1.946E-04

In concrete activation, it is well known that the impurities, which are ^{6}Li, ^{59}Co, ^{58}Ni, ^{62}Ni, ^{133}Cs, ^{151}Eu, and ^{153}Eu, are potentially the major gamma sources [7-9] after the transmutations to ^{3}H, ^{60}Co, ^{58}Co, ^{63}Ni, ^{134}Cs, ^{152}Eu, and ^{154}Eu isotopes. Thus, the concrete composition including impurities (given in Table VI) was used for residual dose calculation. For the activation analysis, each side of the walls were divided as shown in Fig. 4. The, with the given condition, activation calculation was performed. The Fig. 5 is the result of residual dose map at (a) 0 sec (b) 30 day (c) 1 year (d) 5 year decay times. Also, the maximum doses in ISOL-bunker were calculated as shown Table VII. Fig. 6 shows the activities of 10 major nuclides after 5 year decays. It shows that the concrete was activated with having lots of long half-life nuclides.

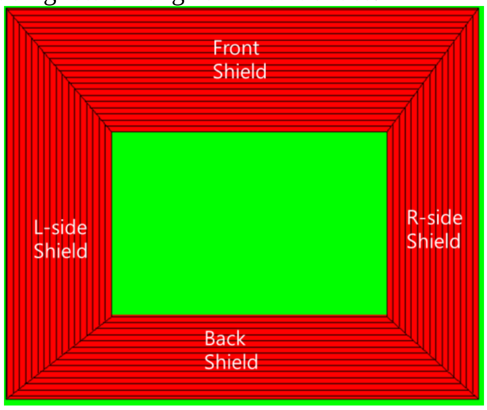


Fig. 4. Cross Sectional View of Geometry Modeling

Table VI: Concrete Composition Including Impurities

Nuclide	Weight Raito	Nuclide	Weight Raito
H*	0.013	O*	1.171
Si*	0.742	Ca*	0.194
Na*	0.040	Mg*	0.006
Al*	0.107	S*	0.003
K*	0.045	Fe*	0.029
^{6}Li	6.525E-06	^{133}Cs	8.678E-06
^{59}Co	3.208E-05	^{151}Eu	3.038E-06
^{58}Ni	9.461E-05	^{153}Eu	3.328E-06
^{62}Ni	7.417E-06	^{133}Cs	8.678E-06

*: natural nuclide

Table VII: Maximum Dose in ISOL-bunker

Decay Time	Maximum Dose (μSv/h)	Relative Error
0 sec	2.034E+06	0.007714
1 day	5.378E+05	0.007924
30 day	5.061E+04	0.011625
90 day	4.947E+04	0.009831
180 day	4.799E+04	0.009867
1 year	4.571E+04	0.009906
5 year	3.275E+04	0.010503

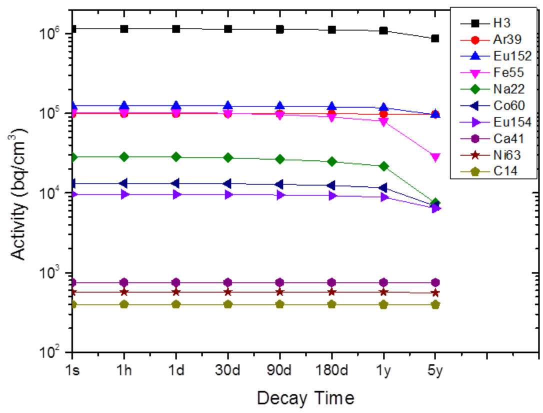
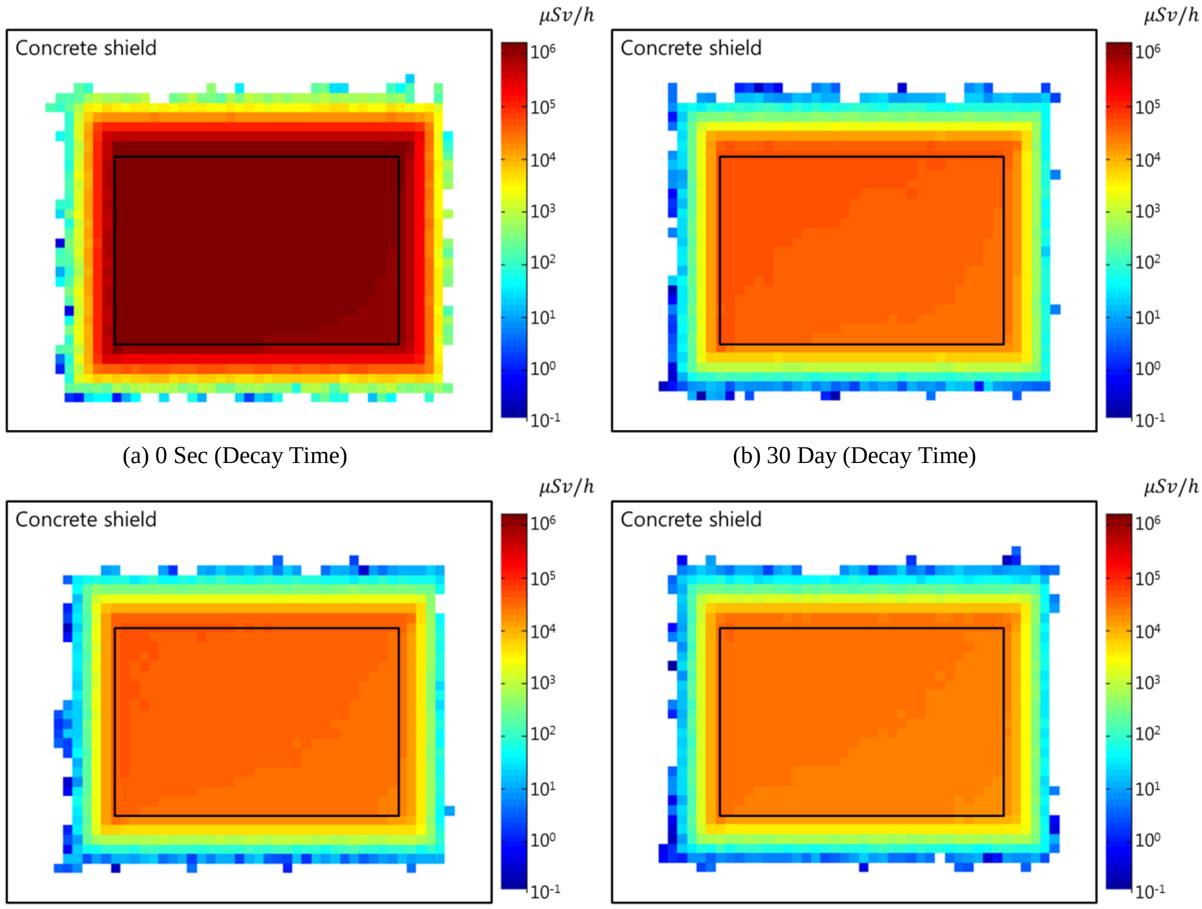


Fig. 6. Produced Long Life Nuclide in First 20cm of Front Wall



(a) 0 Sec (Decay Time)

(b) 30 Day (Decay Time)

(c) 1 Year (Decay Time)

(d) 5 Year (Decay Time)

Fig.5. Residual Dose Map in ISOL-bunker as the Change of the Decay Time

3. Conclusions

In this study, a preliminary study for the air and concrete activation in ISOL-bunker was evaluated using the MCNPX 2.7 and SP-FISPACT-2010 codes. For the air activation, humidity effect was first evaluated; then, the air composition was determined. Also, a calculation procedure of the air activation was established. For the concrete activation, the strategy of dividing the concrete wall was constructed. And then, residual dose distribution and long life nuclide were calculated. These results can be used as the reference data to design the ISOL facility with considering radiation safety.

Acknowledgement

This work was supported in part by Project on Radiation Safety Analysis of RAON Accelerator Facilities grant funded by Institute for Basic Science (Project No.: 2013-C062) and Innovative Technology Center for Radiation Safety (iTRS).

REFERENCES

[1] J. K. Ahn, et al., Baseline Design Summary, Rare Isotope Science Project, IBS, August, 2012

[2] C. Yixue, W. Yican, and U. Fischer, The Rigorous-2-step Calculation of Shutdown Dose Rates for Nuclear Fusion Devices, Nuclear Techniques, Vol.26, P. 763, 2003

[3] D.B Pelowitz, editor, MCNPXTM User's Manual, Version 2.7.0, LA-CP -11-00438, Los Alamos National Laboratory, 2011.

[4] R. A. Forrest, FISPACT 2007 User Manual, UKAEA FUS, Vol. 534, 2007.

[5] Y. Watanabe, T. Fukahori, K. Kosako and et al., Nuclear Data Evaluations for JENDL High-energy File, International Conference on Nuclear Data for Science and Technology, Santa Fe, US, Vol. 769, 24 P. 326-331, 2005

[6] Korean criteria of radiation protection, Notification No 2013-49 of Nuclear Safety and Security Commission, Attached Table 3, 2013

[7] T. ZAGAR, M. BOZIC, M. RAVNIK, Long-lived Activation Products in TRIGA Mark II Research Reactor Concrete Shield: Calculation and Experiment, Journal of Nuclear Materials, Vol. 335.3, P. 379-386, 2004

[8] K. Masumoto, and et al., Evaluation of Radioactivity Induced in the Accelerator Building and its Application to Decontamination Work. Journal of Radioanalytical and Nuclear Chemistry, Vol. 255.3, P. 465-469, 2003

[9] G. Hampel, F. Scheller, W. Bernnat, and et al., Calculation of the Activity Inventory for the TRIGA Reactor at the Medical University of Hannover (MHH) in Preparation for Dismantling the Facility, Waste Management 2002 Symposium, Feb 24-28, 2002, Tucson, AZ (US)