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ARTICLE

Low-Activation Multilayer Shielding Structure of Light Water Reactor Using Various Types of Low-Activation Concrete

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Low-activation multilayer shielding structure of light water reactor has been designed using various types (1/10, 1/100, 1/1,000 and 1/10,000) of low-activation concrete composed of low-activation raw materials. The term “1/10 of low-activation concrete” denotes that the activity reduction rate to ordinary concrete is designed to be 1/10. As an example, iterative calculations of induced activities and $\sum$Di/Ci (Di: concentration of radionuclide i, Ci: clearance level of radionuclide i) values of multilayer model for the Japan Power Demonstration Reactor (JPDR) have been performed by using a discrete ordinate code. It is concluded that most of the shielding concrete of JPDR would be classified below clearance level on decommissioning by adopting such low-activation multilayer shielding structures.

KEYWORDS: low-activation, concrete, neutron irradiation, induced activity, clearance level

I. Introduction

Inner part of biological shielding concrete wall around a reactor is classified as radioactive waste in terms of its clearance level recommended by the International Atomic Energy Agency (IAEA-RS-G-1.7[1)]). Here, “clearance” denotes the radioactive classification permissible for disposing of material as non-radioactive waste. Reutilization of this concrete after decommissioning will be indispensable in the management of radioactive waste disposal operations. For that reason, various types (1/10, 1/20, 1/30, 1/50, 1/100, 1/300, 1/1,000, 1/3,000 and 1/10,000) of low-activation concrete (LAC) composed of low-activation raw materials have been developed.[2),3),4)] These types of low-activation concrete have been developed to reduce generation of residual radioactivities in “onion” type of steel plate concrete structure. The aim of this study is to estimate the ability of low-activation for such multilayer shielding structures.

II. Low-activation concrete for multilayer shielding structure

Table 1 shows low-activation raw materials and reference low-activation concrete. The term “1/10” type of low-activation concrete denotes that the activity reduction rate to ordinary concrete is designed to be 1/10. This reduction ratio of ΣDi/Ci (Di: concentration of radionuclide i, Ci: clearance level of radionuclide i, cited from IAEA-RS-G-1.7 , assuming the neutron flux of an inner part of the BWR biological shield, 40 yr of operation, and 6 yr of cooling) is normalized to the andesite concrete, which is considered to be an “average concrete”.

Mixing works of various types (1/10, 1/20, 1/30, 1/50, 1/100, 1/300, 1/1,000, 1/3,000 and 1/10,000) of low-activation concrete have been performed based on the data obtained in the screening tests of raw materials. In this project, a new type of low-activation cement, that is, “low-activation low-heat Portland cement”[5)] and also a new type of low-activation additive, that is, “low-activation calcium-aluminates-silicate (CAS) additive,[6)] have been developed. The ingredients of major and minor elements for 1/10, 1/100, 1/1,000 and 1/10,000 types of low-activation concrete and for the Japan Power Demonstration Reactor (JPDR) concrete are listed in **Table 2**. For almost types of specimens, chemical analyses were adopted for determining the concentrations of major and minor elements. The water content of JPDR concrete was adjusted to 9.0 w% according to previous study.[7)]

III. Activation analyses of multilayer low-activation concrete using JPDR experiment

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Table 1 Low-activation raw material and reference low-activation concrete

Item		Name of material	
Low-activation raw material	Aggregate (Coarse, Fine)	Ordinary, Dunite, Serpentite, Limestone, Colemanite, Baryte, High purity limestone, Quartzite, silica sand, Fused alumina, B_4C sand[a], etc.	
	Cement	Ordinary Portland, Moderate-heat Portland, Low-heat Portland, White cement, Low-activation low-heat cement[b], High alumina cement, etc.	
	Additive	Fly ash, Blast furnace slag, Low-activation limestone powder, Low-activation silica fume, Low-activation CAS additive[c] , B_4C powder[a], etc.	
Reference low-activation concrete	Name of concrete	Reference compositions	∑D/C [d]
	(Andesite concrete)	(Andesite aggregate + ordinary Portland cement)	1
	1/10 low-activation concrete	Limestone aggregate + low-heat or moderate-heat or ordinary Portland cement, etc	1/10
	1/20 low-activation concrete	Limestone aggregate + low-heat or moderate-heat or ordinary Portland cement + silica fume and/or limestone powder, etc	1/20
	1/30 low-activation concrete	Limestone aggregate + low-activation low-heat [b] or white Portland cement, etc	1/30
	1/50 low-activation concrete	Limestone aggregate + low-activation low-heat [b] or white Portland cement + silica fume and/or limestone powder, etc	1/50
	1/100 low-activation concrete	Limestone aggregate + low-heat or moderate-heat or ordinary Portland cement + B_4C powder, etc	1/100
	1/300 low-activation concrete	Fused alumina aggregate + high alumina cement + low-activation CAS additive, etc	1/300
	1/1,000 low-activation concrete	Limestone aggregate + low-activation low-heat [b] or white Portland cement + B_4C sand and/or powder, etc	1/1,000
	1/3,000 low-activation concrete	Limestone or quartzite aggregate + high alumina cement + low-activation CAS additive + B_4C powder, etc	1/3,000
	1/10,000 low-activation concrete	Fused alumina aggregate + high alumina cement + low-activation CAS additive + B_4C sand and/or powder, etc	1/10,000
	L2→L3 low-activation concrete	Dunite or Fused alumina aggregate + low-activation low-heat [b] or white Portland cement, etc	-
	L2→L3 low-activation heavy mortar	Dunite or Fused alumina aggregate + high alumina cement + low- activation CAS additive, etc	-

a) (0.03-3) $\times 10^{21}/cm^3$ of natural boron. b) Low-activation low-heat Portland cement developed in this project (2007) (Ref. 5). c) Calcium-aluminates-silicate additives developed in this project (2007) (Ref.6). d) Calculated assuming the neutron flux of an inner part of the BWR biological shield, 40 yr of operation and 6 yr of cooling. The radionuclides of ^{3}H, ^{14}C, ^{36}Cl, ^{41}Ca, ^{54}Mn, ^{55}Fe, ^{60}Co, ^{59}Ni, ^{63}Ni, ^{65}Zn, ^{94}Nb, ^{125}Sb, ^{133}Ba, ^{134}Cs, ^{137}Cs, ^{151}Sm, ^{152}Eu, ^{154}Eu and ^{155}Eu are used in this calculation.

Table 2 Ingredients of major and minor elements for reference low-activation concrete and JPDR concrete

×1.0E+24/cm^3

Element	1/10,000 low-activation concrete	1/1,000 low-activation concrete	1/100 low-activation concrete	1/10 low-activation concrete	JPDR concrete
	Type WA-CAS -1.0B	Type HA-W -1.0B	Type HA-L -0.1B	Type HA-L -0.0B	
H	1.67E-02	1.24E-02	1.17E-02	1.17E-02	1.400E-02[a]
B	1.02E-03	1.02E-03	1.02E-04	0.00E+00	0.0000E+00
C	6.16E-06	1.05E-02	1.09E-02	1.09E-02	0.0000E+00
O	5.18E-02	4.32E-02	4.34E-02	4.34E-02	4.5134E-02
Na	7.29E-05	2.17E-05	2.20E-05	2.20E-05	8.4026E-04
Mg	2.17E-05	1.57E-04	1.79E-04	1.79E-04	0.0000E+00
Al	2.56E-02	2.25E-04	1.56E-04	1.56E-04	2.6571E-03
Si	9.27E-04	9.22E-04	9.93E-04	9.93E-04	1.6072E-02
Ca	2.87E-03	1.32E-02	1.32E-02	1.32E-02	2.5612E-03
Fe	1.17E-05	1.04E-05	1.02E-04	1.02E-04	4.8571E-04
Li (g/g)	7.40E-07	1.13E-06	3.51E-06	3.51E-06	1.40E-05
N (g/g)	2.00E-05	9.00E-06	5.77E-05	5.77E-05	4.00E-05
Cl (g/g)	1.03E-05	6.37E-05	3.03E-05	3.03E-05	5.00E-05
Co (g/g)	5.98E-08	3.92E-07	1.47E-06	1.47E-06	6.20E-06
Ni (g/g)	1.85E-05	8.90E-06	3.00E-06	2.93E-06	1.30E-05
Zn (g/g)	7.00E-06	5.61E-06	7.14E-05	7.14E-05	6.92E-05
Nb (g/g)	6.80E-07	3.00E-07	4.70E-07	4.70E-07	1.20E-05
Sn (g/g)	8.10E-06	0.00E+00	8.30E-07	8.30E-07	2.00E-06
Ba (g/g)	2.40E-06	1.20E-05	3.33E-05	3.33E-05	4.00E-04
Cs (g/g)	1.08E-08	1.60E-07	2.90E-07	2.90E-07	2.00E-06
Sm (g/g)	3.10E-06	1.60E-07	2.30E-07	2.30E-07	5.00E-06
Eu (g/g)	1.06E-08	4.94E-08	1.15E-07	1.15E-07	5.90E-07
U (g/g)	7.30E-07	6.20E-07	1.11E-06	1.11E-06	-
g/cm^3	2.81	2.34	2.34	2.34	2.30

a) Adjusted value cited from Hayashi K., et al. (Ref.7).

The neutron transport and activation calculations for the JPDR experiment[8)] were performed to evaluate the ability of low-activation regarding 1/10 and 1/100 types of low-activation concrete just prior to this calculation. **Figure 1** presents the maps of calculated total and thermal neutron fluxes for two-dimensional geometry of JPDR. [9)] The neutron transport calculation was performed by using two-dimensional S_N code DORT[10)] with the MATXSLIB-J33T10 library[11)] which was prepared for activation calculation to obtain correct thermal energy spectrum. The MATXSLIB-J33T10 library was processed from evaluated cross section library JENDL 3.3 by using NJOY 99.83[12)]. This figure indicates that the thermal neutron flux is overwhelmingly dominant in the concrete shield.

Figure 2 illustrates the estimated maps of low level wastes for JPDR shield wall, comparing ordinary concrete with 1/10 and 1/100 types of low-activation concrete. Activation calculation was performed using the obtained neutron flux and MATXSLIB-J33T10 activation cross section library and ORIGEN-79 code[13)]. The Japanese regulations of low level radioactive waste, such as LLW class 2, LLW class 3 and clearance class, were applied for classification. This figure shows that the area of LLW class 3 decreases distinctly by adopting 1/10 or 1/100 type of low-activation concrete, and especially that almost all the area of LLW class 2 disappears by adopting 1/100 type of low-activation concrete.

We next tried to simulate the most appropriate multilayer structure by using one dimensional (1-D) S_N code ANISN[14)] and the geometry as shown in **Fig. 3**. The case 1 is for the JPDR concrete and the case 2 is for the reference multilayer shielding structure as arranged 1/10,000, 1/1,000, 1/100 and 1/10 types of low-activation concrete and JPDR concrete. Source spectrum and flux density were cited from Sukegawa T, et al. [Ref.8]. For the JPDR concrete, the 1-D calculation using DLC-23F cross section library[15)] was performed, as illustrated in **Fig. 4**, to adjust to the 1-D source condition. Under the same source condition, we calculated $\sum$Di/Ci values of the JPDR concrete and the reference multilayer low-activation concrete, as plotted in **Fig. 5**. The area of "LLW class 3" decreases drastically and also the area of "LLW class 2" disappears completely by adopting such multilayer low-activation concrete. A notable fact is that the total neutron flux of the concrete surface for Advanced Boiling Water Reactor (ABWR) or Advanced Pressurized Water Reactor (APWR) is not exceeded that for JPDR, therefore almost all the shielding concrete of ABWR or APWR will be classified below clearance level on decommissioning by adopting such low-activation multilayer shielding structures.

IV. Conclusion

Low-activation multilayer shielding structure of light water reactor has been designed using various types (1/10, 1/100, 1/1,000 and 1/10,000) of low-activation concrete composed of low-activation raw materials. As an example, iterative calculations of induced activities and $\sum$Di/Ci values of multilayer model for JPDR have been performed by using a discrete ordinate code. It is concluded that most of the shielding concrete of JPDR would be classified below clearance level on decommissioning by adopting such low-activation multilayer shielding structures.

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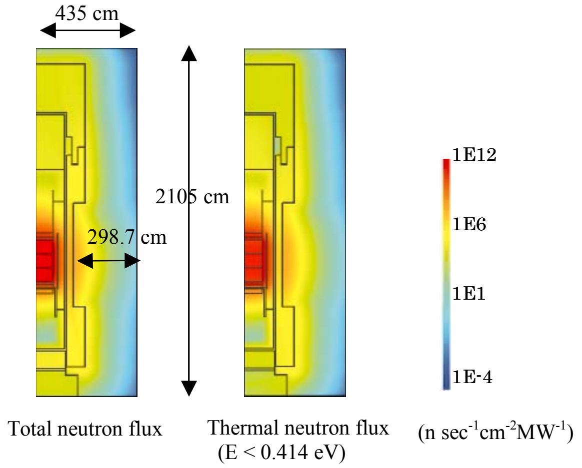
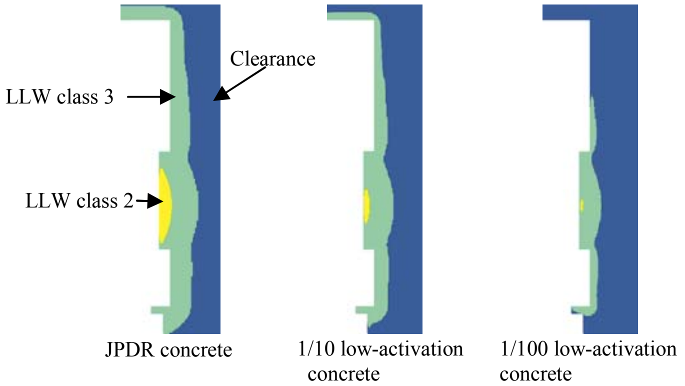


Total neutron flux

Thermal neutron flux (E < 0.414 eV)

(n sec^{-1}cm^{-2}MW^{-1})

Fig. 1 Calculated total and thermal neutron fluxes of JPDR [Ref.9]



JPDR concrete

1/10 low-activation concrete

1/100 low-activation concrete

Fig. 2 Comparison of estimated maps of low level wastes between ordinary concrete and reference low-activation concrete for JPDR shield wall [Ref.9]

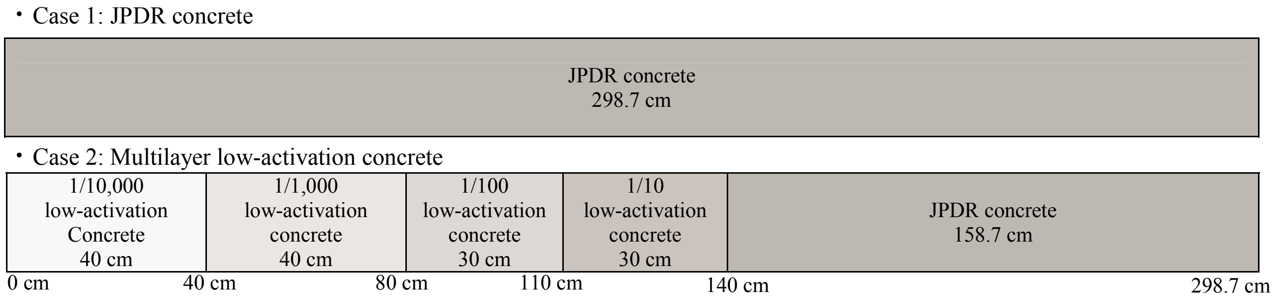


Fig. 3 Reference one dimensional geometry of JPDR shield wall

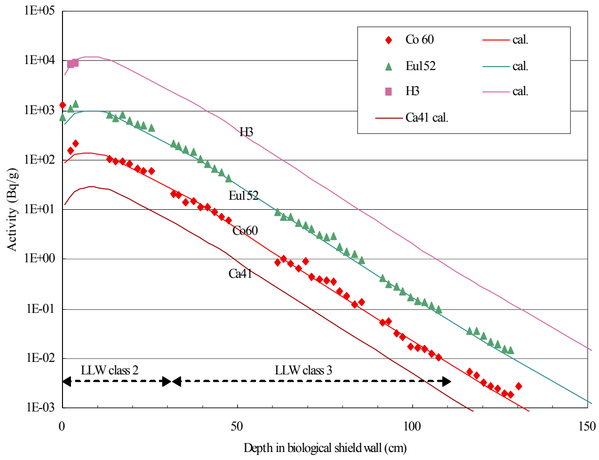


Fig. 4 Comparison of measured [Ref.8] and calculated radioactivities

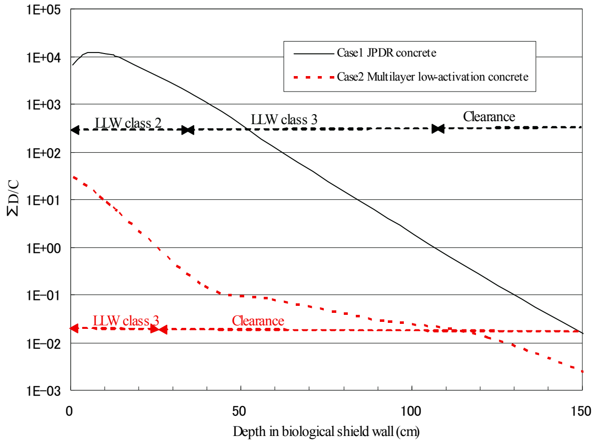


Fig. 5 Comparison of JPDR concrete and multilayer low-activation concrete