Effect of Concrete Mixture Design On Radiation in Biological Shielding Wall of APR1400

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Overview

1. Background and objective

2. Concrete mix analysis and breakdown

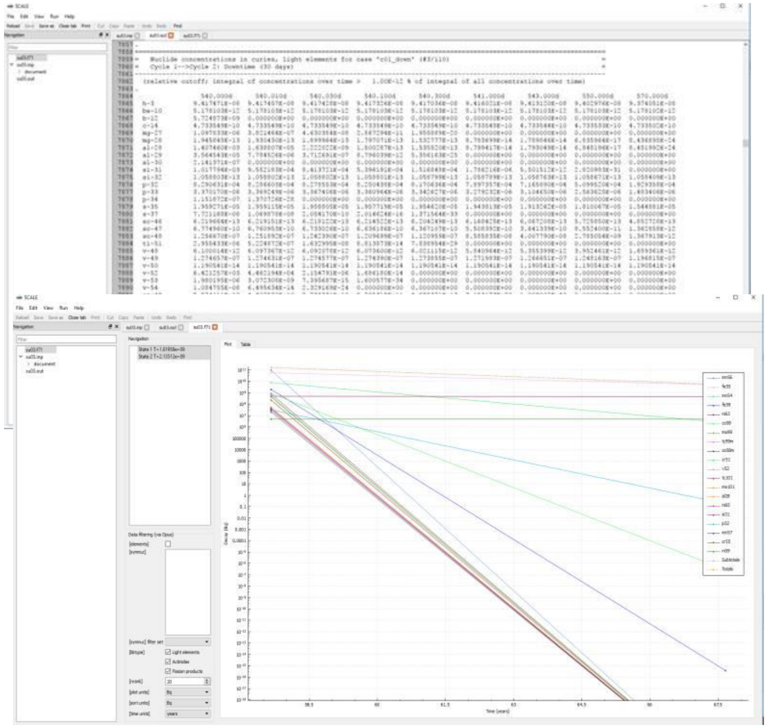
3. Neutron flux calculation and distribution

4. Concrete Irradiation analysis

5.Conclusion

Background

- The evaluation of activation products produced in reactor shielding concrete will:
  - Give a profound knowledge on the method of decommissioning procedure to be followed
  - Guide utility companies in estimating the amount of radiation dose effect on workers and the general public during decommissioning process
  - Assist in determining decontamination methods and,
  - Also assist in the selection of waste disposal methods during transportation and storage
- ORIGEN (Oak Ridge Isotope Generation code) will be used in the simulation process



Objective

- To analyse concrete composition mix and types used in NPP concrete construction for shielding purpose
- To carry out a detailed irradiation decay process on the concrete mix types to determine the various activation products (significant) produced after NPP's active life
- To classify each activation product in order of significance with respect to their half life
- To determine whether a particular concrete mix type could be classified as a radioactive waste or otherwise as well its level of radioactive waste

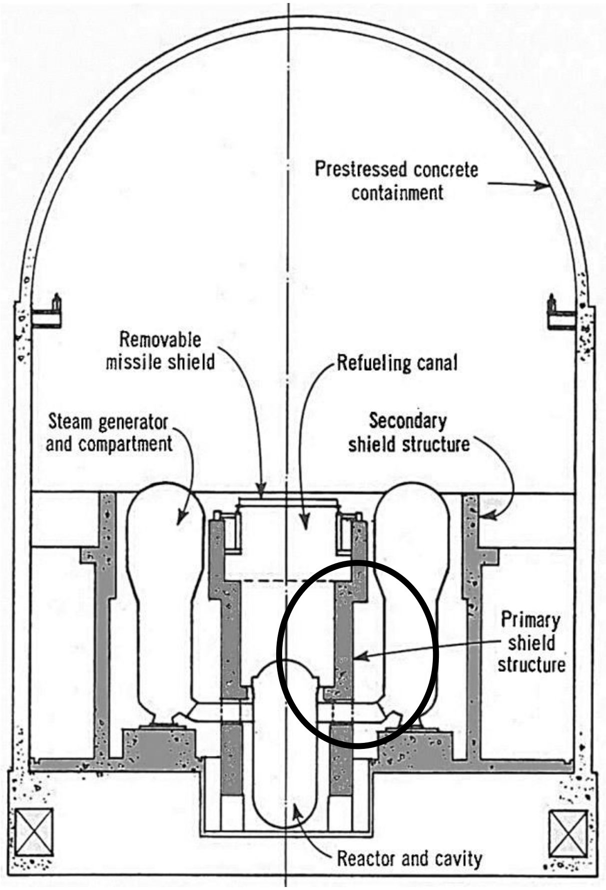


Fig. 1. APR1400 vertical sectional view

Concrete mix analysis and breakdown

- Concrete incorporating three different cement types`:
- Ordinary Portland cement (OPC), Fly ash cement and Slag
- Concrete mixture 1: 100% OPC
- Concrete mixture 2: 80% OPC + 20% Fly ash
- Concrete mixture 3: 60% OPC + 40% slag

Table I: Concrete mixture design

Concrete Mix	Water	Cement	Slag	FA	Crushed sand (1-1/2 &3/4)	Sand	Total(g/cm3)
MIX 1	0.16	0.402	-	-	1.043	0.684	2.289
MIX 2	0.16	0.32	-	0.082	1.043	0.684	2.289
MIX 3	0.16	0.241	0.161	-	1.043	0.684	2.289

Concrete mix analysis and breakdown

- Table II shows the chemical composition of each cementitious material in the mix.
- The compositions given in Tables I and II was analyzed carefully to determine the percentage and mass compositions of each element in the mix
- This was then used as input in the simulation for radiation analysis.

Table II: Chemical Properties of FA and Slag (%)

Chemical composition	FA	Slag
Specific gravity	2.43	2.79
SiO_2	63.5	34.4
Al_2O_3	11.1	9.0
Fe_2O_3	5.2	2.58
CaO	14.7	44.8
MgO	1.98	4.43
SO_3	0.35	2.26
Na_2O	0.48	0.62
K_2O	0.4	0.5
LOI	2.1	1.32

Neutron Flux calculation and distribution

Table III: Neutron fluence and flux value for APR1400 RPV

Radius (cm) (peak values)	Fluence(n/cm^2) (E>1 MeV, 55.8 EFPY)	Flux (n/cm²s)
231.775 @ inside surface	9.5×10^{19}	5.40×10^{10}
237.528 @ ¼ thickness location	5.1×10^{19}	2.90×10^{10}
249.034 ¾ thickness location	1.0×10^{19}	5.68×10^{9}

- The neutron fluence for the APR1400 Reactor Pressure Vessel was referenced from APR 1400-Z-A-NR-14015-NP, Rev.0 jointly published by KEPCO-KHNP using the DORT code and BUGLE cross section library
- The values represents the peak values of the fast neutron flux (E > 1 MeV) over 60 years of operation
- Regression analysis was carried out to evaluate the removal cross section, Σ_t, of the RPV material with regards to the attenuation equation :

$$\varphi_1 = \varphi_0 e^{-\Sigma_t x} \quad (1)$$

Ref: APR 1400-Z-A-NR-14015-NP, Rev.0

Neutron Flux calculation and distribution

Table IV and Fig. 3 shows the flux values evaluated from the regression model which is used to evaluate flux at the outer surface of the RPV.

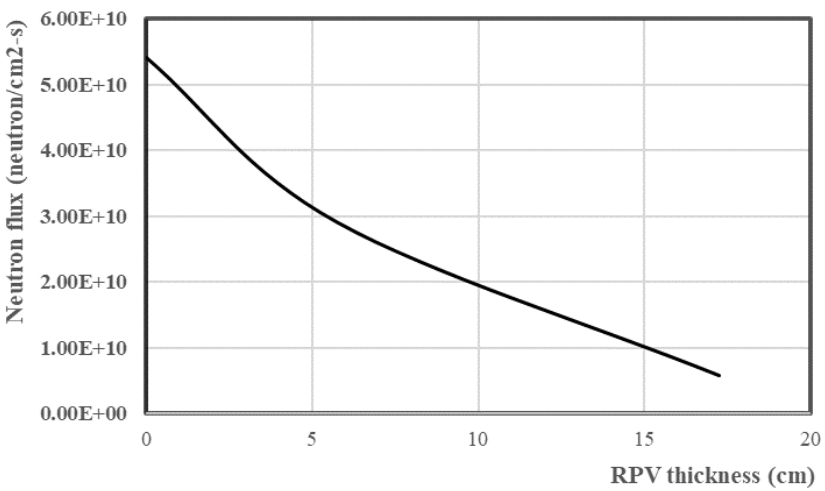


Fig. 3. Neutron attenuation in RPV

Table IV: Regression analysis of flux for APR1400

Radius (cm)	Flux (Regression)	Flux(reference)
231.775 Inside surface	6.00E+10	5.4E+10
237.528 ¼ thickness location	2.82E+10	2.9E+10
249.034 ¾ thickness location	6.30E+9	5.68E+9
Outside surface	2.94E+9	-

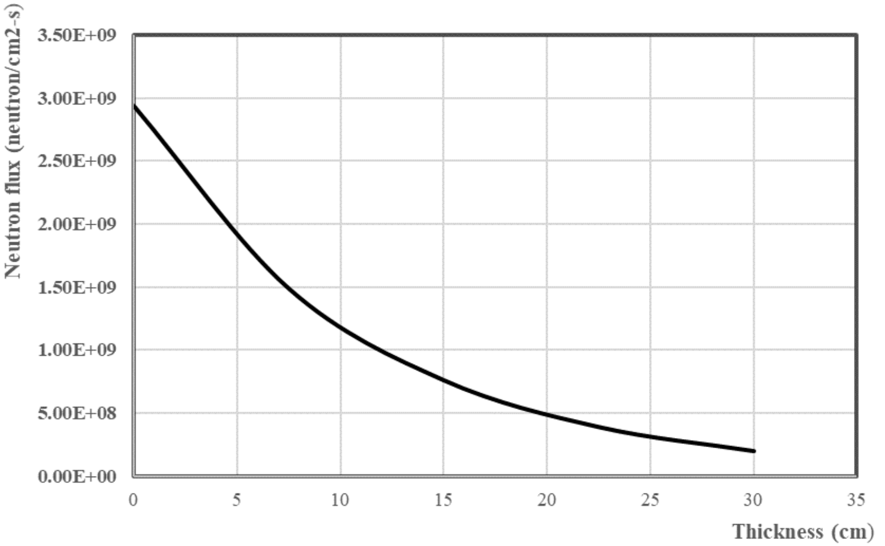
Neutron Flux calculation and distribution

- The distribution of flux levels along the depth in the bio-shielding concrete wall was evaluated with consideration of the removal cross section for concrete

- Table V and Fig. 4 shows the distribution of the flux along the depth in bio-shielding concrete wall.

Table V: Flux distribution in concrete

Concrete depth (cm)	Flux level
0.000	2.94E+09
7.505	1.49E+09
15.01	7.62E+08
22.515	3.91E+08
30.02	2.00E+08



Fig, 4. Neutron distribution in concrete

Concrete Irradiation Analysis

To simulate concrete irradiation in the bio-shielding wall:

- it was assumed that APR1400 was operated for 60 years, 18months cycle length and a cooling down time of 10years
- The suitable cross section library in the ORIGEN code is the ce16x16 library, using fuel with an average enrichment of 3.5 w/o.
- It was also assumed that the reactor operates at 100% power over each cycle and,
- With no power reductions, no reactor trips, or unexpected outages
- The waste level was evaluated with the following equation: $\sum {}^{ci}/_{cl} < 1$ (2)
  where: ci = radioactivity concentration of nuclide i and cl = concentration of radionuclides not emitting $\alpha\ rays$

Concrete Irradiation Analysis

- Using ORIGEN computer code, the irradiation decay for the concrete was calculated
- The calculation was performed with the calculated neutron fluxes along the concrete thickness
- The radioactivity of the most significant radionuclides are presented
- The activity change of the nuclides over cooling time of ten years is presented

Table VI: Significant nuclides with half life after 10 years cooling time

Isotope	half life(years)
h-3	12.3
be-10	1.39E+06
c-14	5700
al-26	7.17E+06
si-32	150
cl-36	3.08E+05
ar-37	35.04
ar-39	2.69E+02
ar-42	32.9
k-40	1.25E+09
ca-41	1.03E+05
ca-48	4.90E+19
mn-53	3.70E+06
fe-55	2.74E+00
co-60	5.27E+00

isotope	Half life (hours)
na-22	15
k-42	12.4
sc-44	3.97
sc-45m	318ms
co-60m	10.4mins
Isotope	Half life (days)
p-32	14.3
p-33	25.3
s-35	87.4
ca-45	162.7
sc-46	83.8
cr-51	27.7
mn-54	312
fe-59	44.495

Concrete Irradiation Analysis

MIX 1

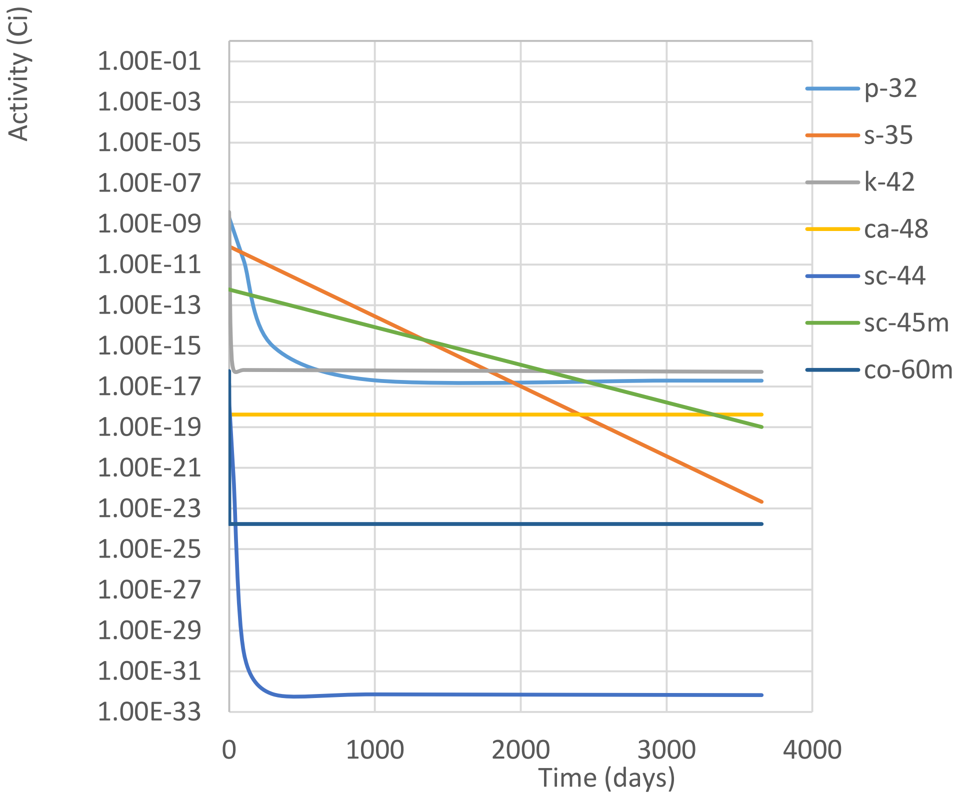


Fig.5a

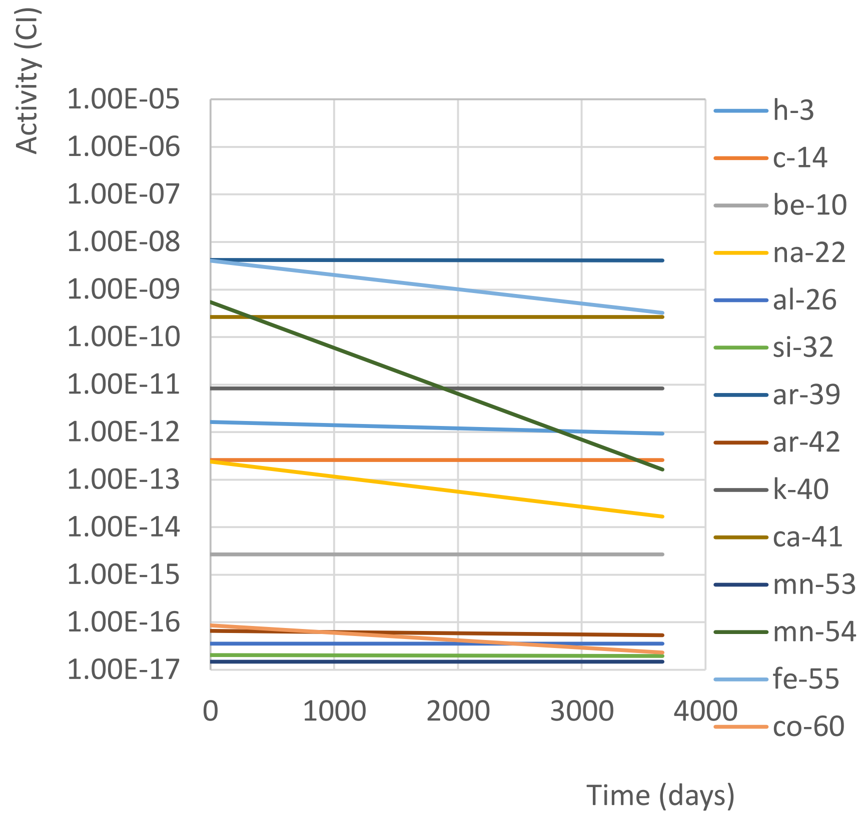


Fig. 5b

Fig. 5a and b: Activity change with time for Long and short lived nuclides

Concrete Irradiation Analysis

- For the three concrete mixture design, the waste level analysis results are presented in Table VII and Fig. 8 along distribution of flux level.

- At surface and back end of concrete, the concentration ratio for each type is < 1 from (2). This indicates that at this point, the structure is considered a waste

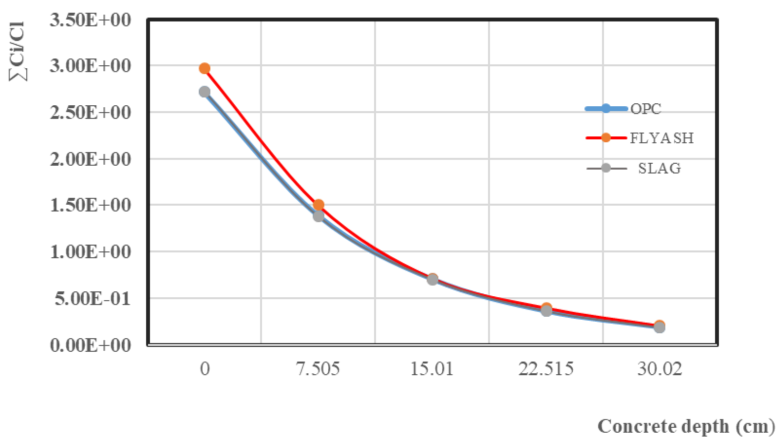


Fig. 8. Concentration ratio against concrete thickness

Table VII: Concentration ratio for mix types

Thickness	OPC	FLYASH	SLAG
Front end Surface	2.720	2.970	2.720
¼ thickness location	1.380	1.500	1.380
2/4 thickness location	0.706	0.713	0.702
¾ thickness location	0.361	0.394	0.361
Backend location	0.185	0.201	0.185

- Also, Slag and OPC showed a bit lower concentration ratio accordingly, specifically with a relatively higher flux compared to FA mix.

Conclusion

- The activation product obtained after a 60 years operation and 10 years cooling of the concrete used in biological shield especially for APR1400 was considered in this project
- The study considered three major concrete mix types incorporating three different types of cementitious material: OPC, FA, and SLAG
- Irradiation was carried out with the ORIGEN code using ce16x16 library, 3.5w% fuel enrichment. The operation and cooling history assumed to be 100% with no reactor trip or sudden shutdown
- The result was used in the evaluation of the level of degradation along concrete thickness for the mix types considered
- The result showed that the concrete mixture design with FA showed higher concentration in comparison with OPC and SLAG
- Through further study, the results in this paper can be useful for decision on how much of concrete should be decontaminated during decommissioning.