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Calculating the Out-core Radioactivity in VVR-S Reactor after Shutdown

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Abstract

The results of coupled nuclear codes, WIMS-CITATION-ANISN-ORIGEN/MCNP-ORIGEN, and gamma spectrometry measurements of representative samples are compared. Based on this methodology, the radiation level of the reactor block materials at 4050 days after shutdown could be estimated. The aluminum and graphite are the most activated waste material. Iron cast and concrete are radioactive wastes, too.

Keywords: ANISN, CITATION, MCNP, ORIGEN, VVR-S reactor, WIMS

1. Introduction

An important consideration in the design of nuclear reactors is providing access to the reactor system for maintenance and repair[1]. The radiation monitoring purpose in reactor site is determining the radioactive source that arises outside the core. Sources outside the core are gammas from the capture of thermal neutrons, gamma from inelastic scattering of fast neutrons, gammas from activated materials, and photo-neutrons[1]. Operation of nuclear fission reactors results in a significant formation of actinides and fission products. Several technical computer codes are available that will permit calculating of the actinides and fission products[2].

In this study, by different computer codes, university and research codes, out-core radioactivity determines in VVR-S 2MWth research reactor after reactor shutdown. The results of the codes i.e. coupled codes compare with experimental results of different sampling points.

2. Reactor Description

The VVR-S is a tank-in-pool type research reactor which uses enriched uranium as fuel, light water as coolant and moderator. The reactor block is mainly composed of reactor vessels, experimental channels, reactor core, mobile thermal column, upper rotating lids, in-core fuelling mechanism and biological shield[3]. All these parts are made of four types of materials, aluminum, cast iron, concrete and graphite. A summary of the design and thermal-hydraulic parameters of the VVR-S reactor is given in Table 1.

Figure 1 shows VVR-S reactor block cross section. Since this reactor is a research reactor it has different irradiation sites vertically and horizontally.

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Table 1. Design and thermal-hydraulic parameters of the VVR-S reactor

Parameter		Description
Plant		
	Reactor type	Pool type
	Neutron flux	2×10^{13} (n cm^{-2} s^{-1})
	Reactor power level	2 (MW Thermal)
	Cooling system	Forced convection
	Water level	5750 (mm)
Fuel element		
	Fuel material	UO_2+MgO
	Fuel type	EK-10 (Enriched 10% in ^{235}U) used in the first cycle
		C-36 (Enriched 36.6% in ^{235}U) used combined with EK-10 in rest cycle
	Diameter of fuel pellet	6 (mm)
	Cladding material	Aluminum
	Clad thickness	2 (mm)
	Active Length	500 (mm)
	Total Length	560 (mm)
Core		
	Active zone diameter	645 (mm)
	Fuel assemblies array shape	Square
	Pitch of fuel assemblies	70 (mm)
	Pitch of fuel rods	17.5 (mm)
	Number of fuel assemblies	36 (first cycle), 51 (second cycle)
	Number of control rods	8 B_4C, 1 SS
	Irradiation sites	16 (vertical experimental channels), 9 (horizontal experimental channels), 3 (biological channels), 1 (thermal column)
	Reflectors	Graphite+H_2O
	Thickness of reflectors	426 (mm) at top, 130 (mm) at bottom
	Coolant inlet temperature	34 (°C)
	Coolant outlet temperature	36 (°C)
	Maximum clad outside temperature	91.7 (°C)
	Coolant inlet pressure	0.207 (MPa)
Vessels		
	Central Vessel	Aluminum material, Inside diameter 2245 (mm), Thickness 20(mm), Height 5700 (mm)
	Middle Vessel	Aluminum material, Inside diameter 1100 (mm), Thickness 14 (mm), Height 5700 (mm)
	Outer Vessel	Aluminum material, Inside diameter 670 (mm), Thickness 12 (mm), Height 1825 (mm)

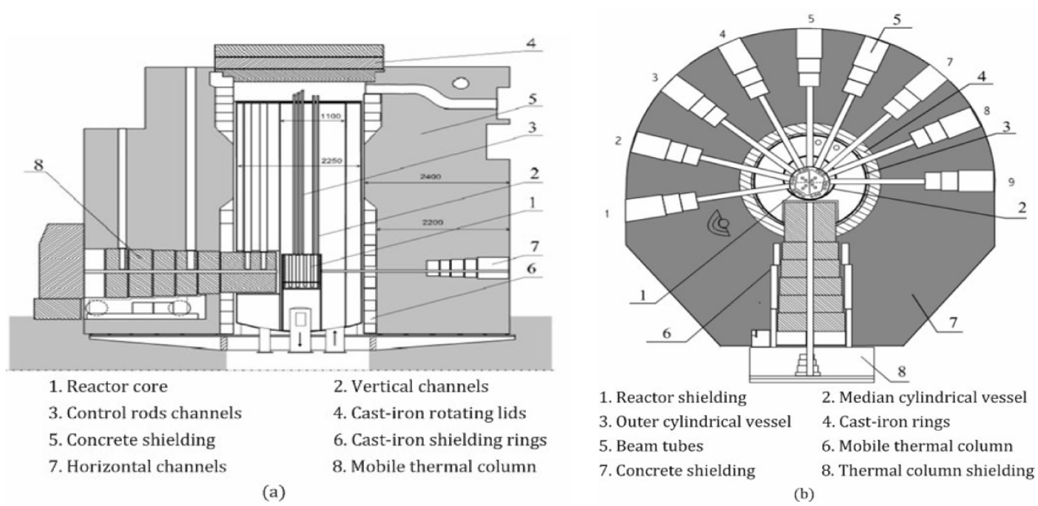

Figure 1. The VVR-S reactor block a) vertical cross section, b) horizontal cross section.

3. Methodology

In this study, two strategies are applied to coupling the nuclear codes. By these approaches out-core radioactivity in the VVR-S is determined. Then, the results compare by experimental sampling information.

Common code in the two methods is COBRA-EN code, as a light water reactor core analysis code[4]. COBRA-EN thermal hydraulic code calculates the temperature distribution in reactor meshes in each time step. Although, some other codes like RELAP code is used[5]. Next, power and neutron flux distribution in different zones can be estimated.

In the first strategy by combining calculation of WIMS-CITATION codes and ANISN code the power and neutron flux are determined.

WIMS, a general lattice cell program which uses transport theory, calculates effective cross-section as a function of energy and position in the core cells. Then, using CITATION code and incorporating parameters related to transport equation which result from WIMS code the neutron flux and power distribution can be determined[6]. The details of VVR-S reactor modeling by WIMS-CITATION codes can be studied in[7]. Out-core neutronic cross sections and neutron flux can be estimated by ANISN, a shielding purpose code.

In the second method, the reactor geometry and characteristics are carried out in MCNP code. The VVR-S reactor assumed in critical state then by KCODE in input deck and proper tally power and neutron flux can be computed[8].

The final attempt in the two above mentioned strategies is the running of ORIGEN code. The primary function of ORIGEN code is to compute time-dependent concentrations and source terms of many nuclides that are simultaneously generated or depleted through neutronic transmutation, fission, radioactive decay, input feed rates, and physical or chemical removal rates[9].

So activation calculations were performed with ORIGEN code using as input space-energy distribution of the neutron flux (computed by two following approaches), nuclear and decay data, material composition (impurities), and the history of operation.

The flowchart of these two strategies is shown in Figure 2.

4. Result and Discussion

The reactor block made of many materials, so the out-core activity comes from them. The main experimentally sampling points are aluminum vessels, cast iron lids, cast iron shields, concrete, graphite reflectors, and numbered points. These components consist of different isotopes and elements which applied into codes as input structural material. The detail of elements can be found in[10].

Figure 3 shows the activity of Co-60, Fe-55, Ni-63, Ni-59, Eu-152, Eu-154, Eu-155 in aluminum, cast iron, Concrete, and graphite materials 4050 days after

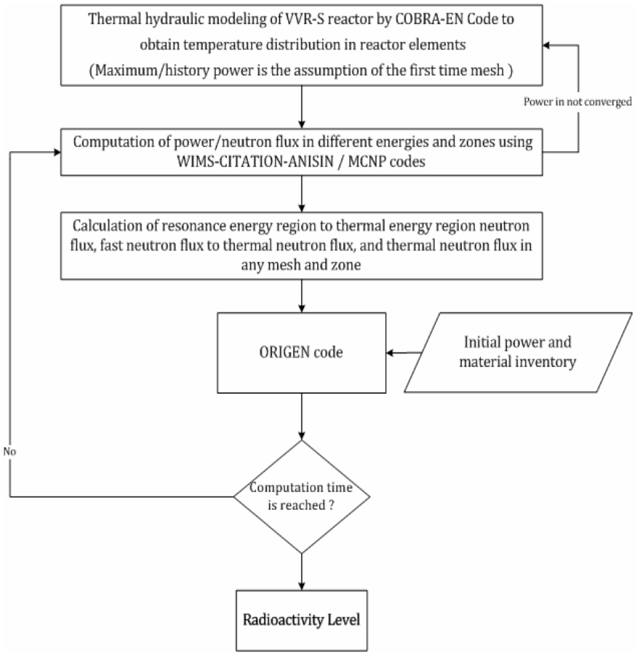

Figure 2. Flowchart of radioactivity calculation in out-core of VVR-S.

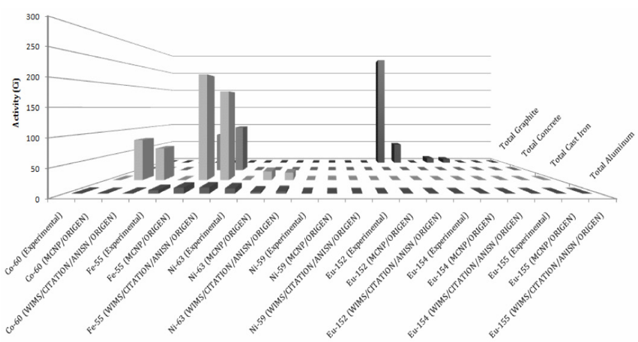

Figure 3. Activity in different VVR-S reactor blocks.

shutdown. The isotopes activity (in Ci) are calculated by two methods and compared with experimental data.

Besides reactor blocks, the radioactivity levels in some sampling points compare with the outputs of the codes. Figure 4 shows the radioactivity levels in sampling points No; 593, 594, 595, 597, 598, 599, 600, 601, 602, 603, 604, 605, and 606.

Although the theoretical calculations, based on two approaches and the ORIGEN code, were affected by large errors due to inaccuracy of data on impurity concentrations and the use by ORIGEN code of effective cross sections specific to LWR cores, we have obtained a set of conservative preliminary estimations by taking the maximal values of all impurity concentrations used in the calculations.

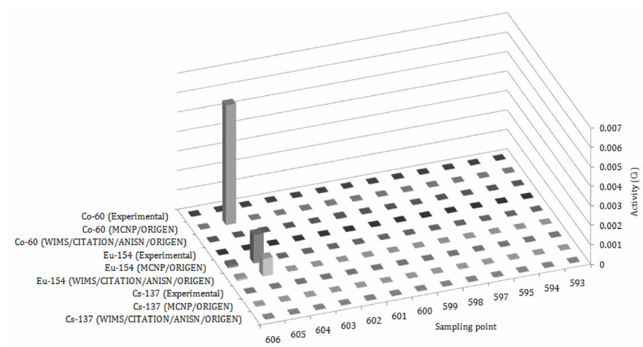

Figure 4. Radioactivity level in different out-core sampling points of VVR-S reactor.

5. Conclusion

VVR-S reactor block is the major contributor to the overall radioactive inventory of the reactor. According to experimental and codes results, aluminum and graphite activated wastes, which contains Fe-55 and Eu-154, must be stored in the storage facilities in the radioactive waste treatment plant. However, cast irons and concrete included highly radioactive material theoretically. In summary, the radioactivity levels of the reactor block provide useful results for planning and performing the decommissioning programs of the VVR-S research reactor.

6. References

1. Rockwell T. Reactor Shielding Design Manual. US atomic energy commission. Paperback. III ed. US Dept of Energy; 1956.
2. Omar H, Ghazi N. Time dependent burn-up and fission products inventory calculations in the discharged fuel of the Syrian MNSR. Ann Nucl Energ. 2011; 38:1698–704.
3. Ionescu E, Gurau D, et al. Decommissioning of the VVR-S research reactor - radiological characterization of the reactor block. Romanian Journal of Report Physic. 2012; 64(2):387–98.
4. Rahgoshay M, Hashemi-Tilehnoee M. Optimizing a gap conductance model applicable to VVER-1000 thermal-hydraulic model. Ann Nucl Energ. 2012; 50:263–7.
5. Rahgoshay M. Computation of concentration changes of heavy metals in the fuel assemblies with 1.6% enrichment by ORIGEN code for VVER-1000. Nukleonika. 2006; 51(3):161–7.
6. Tashakor S, Javidkia F, et al. Neutronic analysis of generic heavy water research reactor core parameters to use standard hydride fuel. World J Nucl Sci Tech. 2011; 1:46–9.

7. Rahgoshay M, Noori-Kalkhoran O. Calculation of control rod worth and temperature reactivity coefficient of fuel and coolant with burn-up changes for VVRS-2 MWth nuclear reactor. Nucl Eng Des. 2013; 256:322–31.
8. Hashemi-Tilehnoee M, Hadad K. Optimizing the performance of a neutron detector in the power monitoring channel of Tehran Research Reactor (TRR). Nucl Eng Des. 2009; 239:1260–6.
9. Rahgoshay M, Hashemi-Tilehnoee M. Calculating the inventory of heavy metals in the fuel assemblies of VVER-1000 during the first cycle. Ann Nucl Energ. 2013; 58:33–5.
10. Biro L, Rapenu S, et al. Elemente suport pentru dezafectarea reactorului nuclear de cercetare VVR-S. Romanian, CNCAN. 2003.