Rods extraction sequence to optimize the neutron flux in irradiation facilities at Peruvian Research Reactor RP-10

Mariano Vela mvela@ipen.gob.pe, Rolando Arrieta rarrieta@ipen.gob.pe, Alberto Salazar, Agustín Urcia, Dionisio Canaza, José Félix, Emilio Veramendi, Edgard Ovalle, Roberto Giol, Luis Zapata, Fernando Ramos

Dirección de Instalaciones, Instituto Peruano de Energía Nuclear, Av. Canadá 1470, Lima 41, Perú

Resumen

En este trabajo se evalúa el efecto de dos secuencias diferentes de extracción de las barras de control y seguridad sobre la distribución de flujo neutrónico en el núcleo del Reactor Peruano de Investigación RP-10. El método aplicado consiste en irradiar pequeñas hojuelas de oro en las facilidades internas de irradiación para llevar a cabo la reacción nuclear $^{197}Au(n,\gamma)$ ^{198}Au. Posteriormente, usando un sistema de espectrometría gamma y el formalismo de Westcott se obtuvo el valor de flujo neutrónico. Los resultados confirman el efecto favorable de las diferentes configuraciones de las barras de control y emergencia, incrementando el flujo neutrónico tanto térmico como epidérmico en 25 % en la facilidad de irradiación central y hasta 50 % en las otras facilidades de irradiación. Los resultados permiten conocer mejor la distribución de flujo neutrónico para cierta configuración de las barras de control y seguridad; de modo que podamos optimizar el flujo de neutrones y el tiempo de irradiación para ciertas potencias de operación y consecuentemente economizar energía y ahorro de combustible.

Abstract

In this work we evaluate the effect of two different extraction sequences of control and emergency rods on neutron flux distribution in core at Peruvian Research Reactor RP-10. The method applied was to irradiate small gold foils in the irradiation facilities of the core to carry out the nuclear reaction $^{197}Au(n, \gamma)^{198}Au$; then using a gamma spectrometry system and the Westcott formalism we obtained the neutron flux. The results confirm the favourable effect of the configuration of emergency and control rods, increasing the neutron flux both thermal and epithermal neutron flux; near to 25 % in the central irradiation facilities and near to 50 % for the other irradiation facilities. The results entail to know better the neutron flux distribution for certain control and emergency rod configuration; so we can optimize the neutron flux and irradiation time for a certain power of operation and consequently to economize energy and fuel consumption.

1 Introduction

Peruvian Research Reactor RP-10 is a light water moderated and cooled, graphite reflected, pool type reactor with thermal output of 10 MW. The core reactor consist of 29 fuel elements (MTR type), and we may build different suitable configurations. Since the first critically was achieved, RP-10 has been operated safely for utilization such as radio isotope production, nuclear activation analysis, neutrography and reactor school training.

The routine work of the RP-10 is basically to irradiate samples in: 1) the central place of the core, E5, B4 and H4 positions; 2) peripheral places of the core, pneumatic irradiation system and conduits of irradiation. The central positions are influenced by the control rods near that position, D3 and F3, (configuration 1, see Fig. 1); and the peripheral ones by the other bars, also near them, D6 and F6 (configuration 2, see Fig. 2).

For the neutron flux optimizing process it is necessary to even get commitment in the selection rods to extract; such rods must fulfill a safety roll (totally extracted), small neutron absorption effect in the zone of interest, and in addition one, fulfills the requirements of margin of shutdown and excess of reactivity; so it has been determined two different sequences for the extraction of rods, increasing until 25 % the specific activity of the samples for each configuration.

2 Theoretical background

The method is based on activation of small foils of a certain material, placed in irradiation facilities of interest followed by its absolute activity measurements in a gamma detection system and applying the Westcott formalism we can get the neutron flux value.

Westcott Formalism

To determine the thermal and epithermal neutron flux in a given position, it is irradiated two foils, one bare foil and the other is covered with cadmium. The activity reached at the end of the irradiation period is proportional to the intensity of the flux and is given by [1]:

$$\phi_W = \frac{A_{sb}}{\sigma_w} \qquad (1)$$

where

ϕ_w: is the Westcott neutron flux

A_{sb}: is the saturation absolute activity of the bare foil,

σ_w: is the Westcott's microscopic effective neutron cross section, given by

$$\sigma_W = g(T)\cdot\sigma_{th}\left(G_{th} + r_W \cdot\sqrt{\frac{T}{T_0}}\cdot S_0 \cdot \frac{G_{epi}}{g(T)}\right) \qquad (2)$$

where

$g(T)$: is the parameter that represents the departure of cross-section from the 1/v law in the thermal region ($g(T)=1$ if the nuclide obeys the 1/v law in this region).

σ_{th}: is the activation microscopic cross section of the target isotope

G_{th}: is the thermal self-shielding factor of the bare foil, and is given by

$$G_{th} = \frac{1-(1-x_b)\cdot e^{-x_b}}{2x_b} \qquad (3)$$

with

$$x_b = \frac{\sigma_{th} N_b\, \rho e_b}{M_b} \qquad (4)$$

where N_b, σ, e_b, M_b : represent number of atoms, density, thickness and mass of the bare foil, respectively, and r_w: is the Westcott spectral indices, given by

$$r_w = \frac{G_{th}\cdot\sqrt{\frac{T_0}{T}}}{(R_{Cd}\cdot F - 1)S_0\frac{G_{epi}}{g(T)} + R_{Cd}\left(\frac{4}{\sqrt{\pi}}\cdot\sqrt{\frac{E_0}{E_{Cd}}} - \frac{F}{g(T)}\cdot\frac{2}{\sqrt{\pi}}\cdot\frac{I_r}{\sigma_{th}}\right)} \qquad (5)$$

where

R_{cd} : is the cadmium ratio, given by [2]

$$R_{Cd} = \frac{A_{sb}}{A_{sCd}} \qquad (6)$$

F : factor that considers the thermal neutrons absorbed by cadmium

S_0: parameter that represents the epithermal resonance integral, excluding the contribution 1/v and thermal cross section

E_0: neutron energy in thermal equilibrium (0.0253 eV)

E_{Cd} : cadmium cut of energy [2]

I_r : epithermal resonance integral [3] (1560 ± 40b)

T_0: is the temperature in thermal equilibrium (293.6 °C)

T: is the temperature where the sample is placed

G_{epi}: epithermal self-shielding factor of the foil covered by cadmium, given by

$$G_{epi} = \frac{1}{\sqrt{1+\frac{2\sigma_{epi}\, N_{Cd}\, \rho e_{Cd}}{M_{Cd}}\cdot q}} \qquad (7)$$

where

σ_{epi}: is epithermal activation microscopic cross section of the target at resonance energy

$N_{Cd}, \sigma, e_{Cd}, M_{Cd}$: represents the number of atoms, density, thickness and mass of the foil covered by cadmium, respectively

q: is a statistical factor

The thermal neutron flux is determined from

$$\phi_{th} = \frac{2}{\sqrt{\pi}} \cdot \sqrt{\frac{T}{T_0}} \cdot \left(1 - \frac{4}{\sqrt{\mu \cdot \pi}} \cdot r_w\right) \cdot \phi_w \quad (8)$$

and the epithermal neutron flux is determined from

$$\phi_{epi} = \frac{\phi_{th}}{\frac{1}{r_w} - \frac{4}{\sqrt{\mu \cdot \pi}}} \quad (9)$$

where

μ: is the connection factor between thermal and epithermal regions

The expression that relates the activity of the irradiated foils and the resulting net area of the photopeak for a given photon energy in a gamma spectrometry system is approximated by

$$A_{sb} = \frac{C_{\gamma b}}{(F_i)(F_{eb})(F_{mb})(\varepsilon_\gamma)(I_\gamma)(N_b)} \quad (10a)$$

$$A_{scd} = \frac{C_{\gamma cd}}{(F_i)(F_{ecd})(F_{\mathrm{mcd}})(\varepsilon_\gamma)(I_\gamma)(N_{cd})} \quad (10b)$$

where

A_{sb}, A_{sCd}: is the gamma activity [Bq] of the bare and cadmium covered foils respectively

$C_{\gamma b}, C_{\gamma Cd}$: is the resulting net area [cps] under the photopeak for ^{198}Au from the bare and cadmium covered foils respectively

F_i : is the saturation factor owing to irradiation time.

F_e, F_m: are the waiting and measurement time factors respectively

N_b, N_{Cd} : is the number of atoms of the bare and cadmium covered foils respectively

ε_γ : photopeak efficiency of the gamma spectrometry system.

I_γ: is the gamma-ray abundance for the ^{198}Au isotope

Replacing equations (10) in equation (6) we obtain the cadmium ratio and then replacing in equations (5) and (4) and finally in equation (2) we get the neutron flux value. With this and equations (5) and (9) we get the epithermal flux.

Experimental procedure

Two foils of gold (isotope ^{197}Au, and mass 8 mg) were irradiated in every irradiation facilities of the core, one bare foil and the other covered with cadmium of 1.0 mm thick. Having the three safety rods 100% extracted and with the reactor in sub critical state, the irradiation assemblies containing the samples were placed. The irradiation time was 60 minutes and the reactor power was fixed at 28 kW for both cases. Finally the reactor was shut down inserting simultaneously all the rods. To measure the activity of the foils, a GeHP detector associated to a gamma spectrometry chain S100 and spectrum processing software GENIUS 2000 were use; and the data were treated using a mathematical processor Mathcad 2000 where it has been elaborated the Westcott formalism ant the neutron activation equations.

	A	B	C	D	E	F	G	H	I	J
1	NT	GE	IP	GE	GE	GE	IP	GE		
2	GE	BE	FE	FE	FE	FE	FE	GE	GE	
3	GE	BE	FE	CR	FE	CR	FE	GE	GE	FC
4	GE	IP	FE	FE	FE	FE	FE	IP	GE	
5	GE	BE	FE	FE	IP	FE	FE	GE	GE	
6	GE	BE	FE	ER	FE	ER	FE	BE	GE	
7	GE	BE	FE	FE	ER	FE	FE	BE	GE	
8	GE	GE	GE	GE	GE	IP	FC	GE	GE	
9	IP	GE	GE		GE	GE	GE	GE	IP	
10								FC		

Figure 1. Core configuration N° 1 for radioisotopes production at RP-10 reactor.

	A	B	C	D	E	F	G	H	I	J
1	NT	GE	IP	GE	GE	GE	IP	GE		
2	GE	BE	FE	FE	FE	FE	FE	BE	BE	
3	GE	BE	FE	ER 100%	FE	ER 100%	FE	BE	GE	FC
4	GE	IP	FE	FE	FE	FE	FE	IP	GE	
5	GE	BE	FE	FE	IP	FE	FE	BE	GE	
6	GE	BE	FE	CR 0%	FE	CR 43%	FE	BE	GE	
7	GE	BE	FE	FE	ER 100%	FE	FE	BE	GE	
8	GE	GE	GE	GE	GE	IP	FC 0%	GE	GE	
9	IP	GE	GE		GE	GE	GE	GE	IP	
10								FC		

Figure 2. Core configuration N° 2 for neutron activation analysis at RP-10 reactor.

Legend: FE: fuel element, ER: emergency rod, CR: control rod, FCR: fine control rod, IP: irradiation position, GE: graphite element, BE: beryllium element, NT: pneumatic tube, FC: fission chamber.

3 Results

In Figure 3 we show the thermal and epithermal neutron flux distribution for the central irradiation facility E5. We see that for configuration N° 1, the neutron flux has been increased up to 25% compared to configuration N° 2. Similar results are obtained for irradiation facilities B4 and H4.

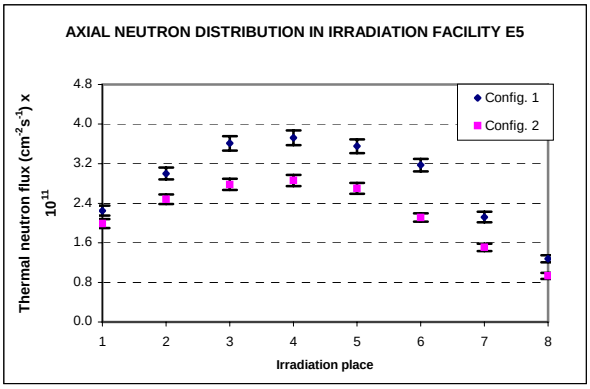

Figure 3a. Thermal neutron flux distribution in irradiation facility E5**.**

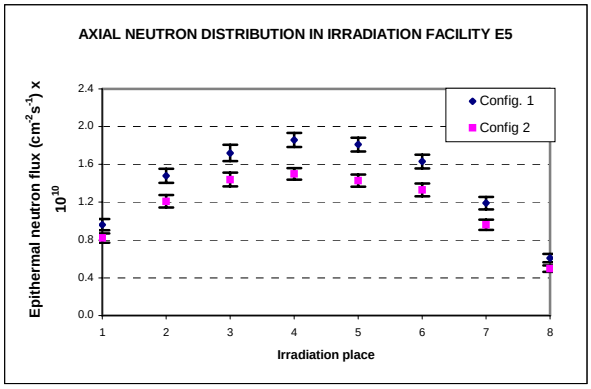

Figure 3b. Epithermal neutron flux distribution in irradiation facility E5.

In Figure 4, we see that the increase in neutron flux take place for configuration N° 2, here the thermal neutron flux is increased up to 40 %; similar behaviour is observed for irradiation facility G1. In Figures 5a and 5b, we see that in the Thermal Facility, which is located at about 1.2 meters from the centre of core, thermal and epithermal neutron flux has been increase up to 50 %.

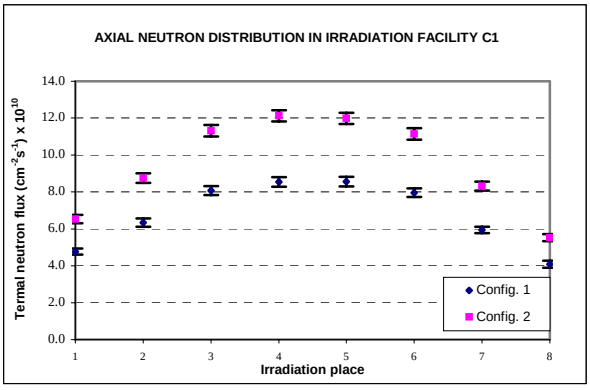

Figure 4. Thermal neutron flux distribution in irradiation facility C1.

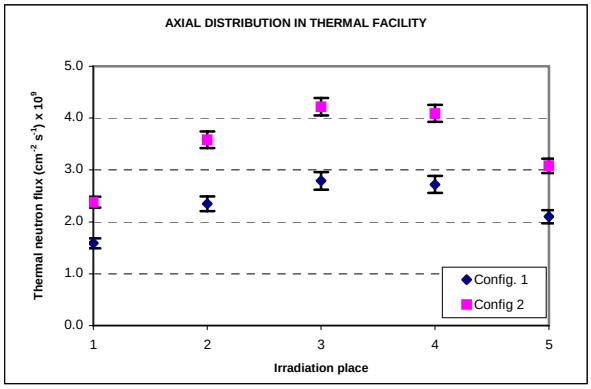

Figure 5a. Thermal neutron flux distribution in Thermal Facility.

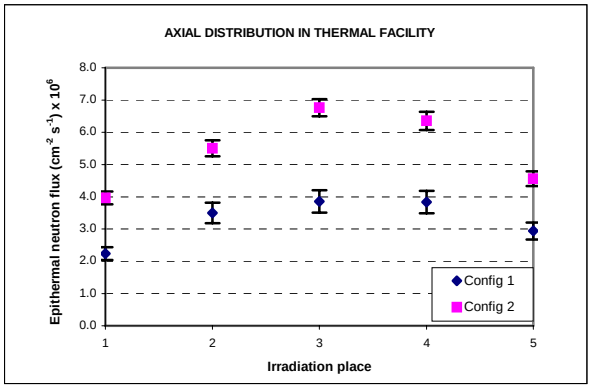

Figure 5b. Epithermal neutron flux distribution in Thermal Facility.

4 Conclusions

The results entail to know better the neutron flux distribution for certain control and emergency rod configuration; so we can optimise the neutron flux and irradiation time for a certain power of operation and consequently to economize energy.

The impact this results is having on operations at RP-10 is that we have improved the specific activity of radioisotopes produced for medical applications, such as: ^{131}I, ^{99}Tc, ^{153}Sm, and ^{192}Ir; in this case as the samples are placed in central facilities (E5, B4 and H4) we use configuration N° 1. On the other hand for investigation by neutron activation analysis which samples are place in (C1, G1, A9 and pneumatic tube), we use the configuration N° 2; by this way we reduce significantly the irradiation time and as a consequence of this we save the nuclear fuel.

5 References

[1] International Atomic Energy Agency. Handbook on Nuclear Data. Technical Report Series N° 273; Vienna: Austria; 1987.

[2] International Atomic Energy Agency. Neutron Fluency Measurements, International Atomic. Technical Report Series N° 107; Vienna: Austria; 1970.

[3] Erdtmann G. Neutron Activation Tables, Kernchemie in Einzaldarstellungen, Vol. 6; 1976.