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Self- shielding effects in Co-60 production

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Introduction

South African Fundamental Atomic Research Installation (SAFARI-1) is a 20 MW plate type material testing reactor and is utilized for radioisotope production through in-core sample irradiation. Isotopes are produced in specific in-core position based on the activity required and irradiation time. This take place in different core configuration and core depletion states. This work presents the self shielding effects during the production of ^{60}Co sources in the Hydraulic Rabbit of SAFARI-1. ^{60}Co sources are widely used in the medical equipment and pest insect sterilization, as radiation source for radiotherapy and industrial radiography. It is produced by neutron activation of ^{59} Co (occur naturally).

Activation nuclear reaction of cobalt: ^{59}Co (n,r)^{60}Co and $T_{1/2}$=5.27 yrs

Activity simple equation: $$A_2 = \lambda_2 N_2 = N_1 \sigma_1 \phi \left(1 - e^{-\lambda_2 t_{irr}}\right) e^{-\lambda_2 t_{dec}}$$

A is the activity in Bq, N is the atomic density (atoms/sec),
ϕ is the total flux in (n/cm^2.s), σ is the absorption cross section [cm^2],
λ is the decay constant in [s^{-1}], t is the irradiation and decay time

Method

Co-59 cylindrical pellets of different sizes were developed and placed in an Aluminum canister (Fig.2) for placement in the Hydraulic Rabbit (Fig.3) of the SAFARI-1 Reactor MCNP model (Fig.4). Flux spectrum of the Cobalt samples inside the canister were sampled and used in FISPACT for activity calculations. The sample was subdivided into several cylindrical regions to test the shielding effect where the flux spectrum for each region was sampled individually and that of a complete ^{59}Co cylinder. The cylindrical pellets were segmented based on mean free path, the average distance that a neutron can travel between collision.

Also, a simple MCNP model of ^{59}Co was developed, and surrounded by huge amount of water sphere as shown in Fig.1, (isotropic source was assumed). Similarly, the flux spectrum for each segment and of a whole cylindrical pellet were sampled and used as an input to FISPACT for activity calculations.

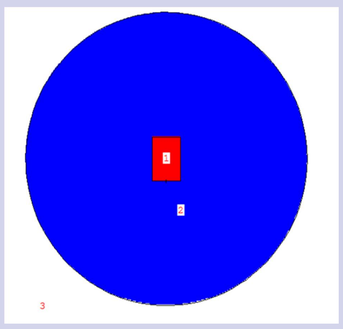


Figure 1: ^{59}Co sample in a water sphere

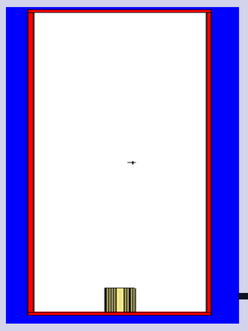


Figure 2: ^{59}Co sample in Al Canister

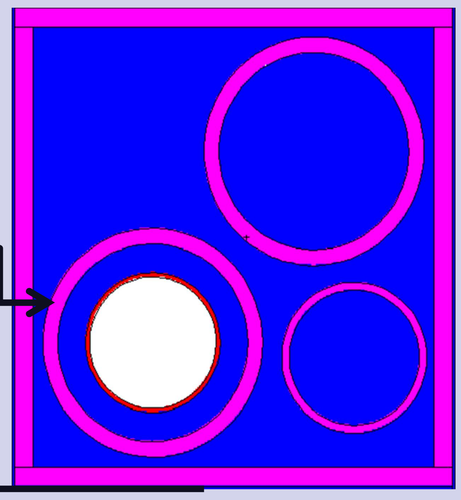


Figure 3: Hydraulic Rabbit

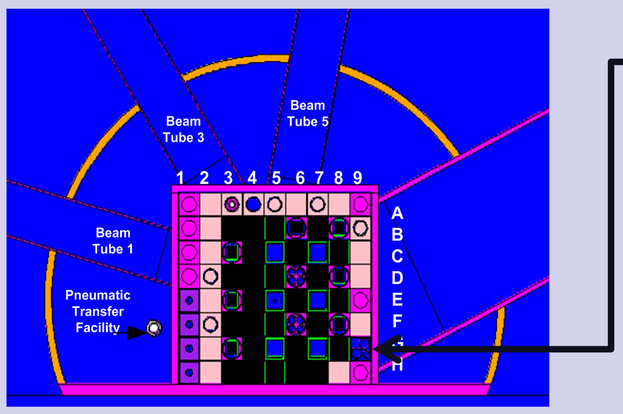


Figure 4: SAFARI-1 Reactor

Results

^{59}Co, 20mm by 40 mm

^{59}Co	Hydraulic Rabbit	
segment	Tot Flux	Activity(Bq)
0.05	1.209505E+14	1.56000E+11
0.15	1.21111E+14	4.73000E+11
0.25	1.22241E+14	8.17000E+11
0.35	1.22241E+14	1.22000E+12
0.45	1.23770E+14	1.67000E+12
0.55	1.25171E+14	2.28000E+12
0.65	1.27472E+14	3.09000E+12
0.75	1.32127E+14	4.33000E+12
0.85	1.38905E+14	6.43000E+12
0.95	1.51714E+14	1.09000E+13
total	1.28570E+15	3.13660E+13
whole	1.33327E+14	3.72000E+13
% difference	18.6	

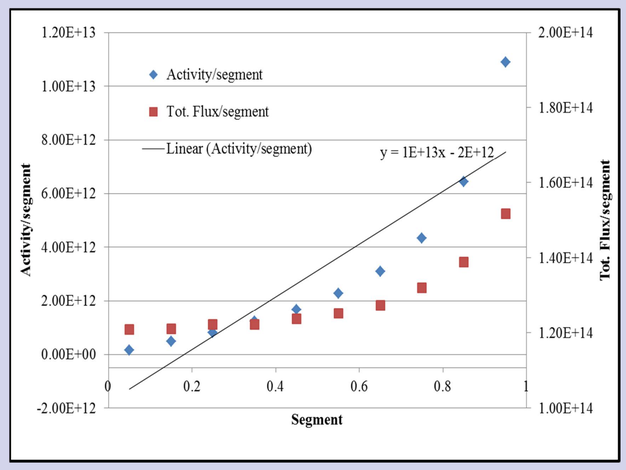


Figure 5: Total flux(n/cm^2.s) and activity (Bq)

Results

^{59}Co, 4mm by 6mm

^{59}Co	Simple model	
Segment	Total flux	Activity
0.0125	9.20328E+16	3.67130E+11
0.0375	9.22638E+16	1.10280E+12
0.0625	9.27597E+16	1.84130E+12
0.0875	9.35360E+16	2.58460E+12
0.1125	9.46600E+16	3.33410E+12
0.1375	9.62305E+16	4.08920E+12
0.1625	9.84742E+16	4.84740E+12
0.1875	1.02065E+17	5.59880E+12
total	9.70154E+16	2.37653E+13
whole		2.38300E+13
% difference	0.27	

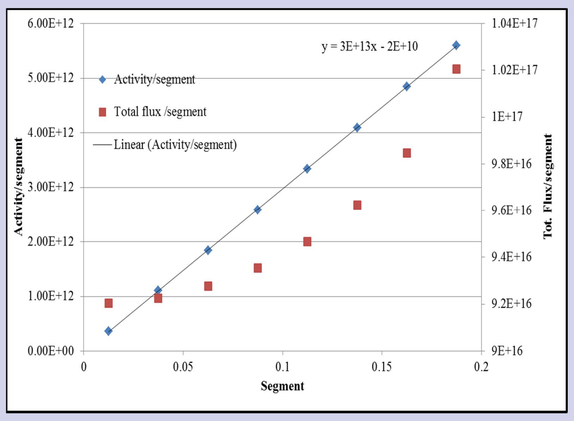


Figure 6: Total flux(n/cm^2.s) and activity (Bq)

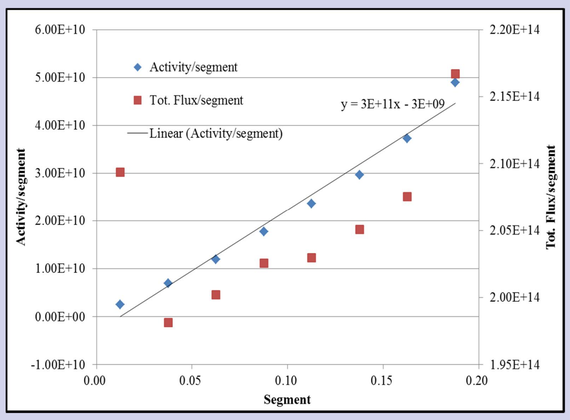


Figure 7: Total flux(n/cm^2.s) and activity (Bq)

^{59}Co	Hydraulic Rabbit	
Segment	Tot Flux	Activity(Bq)
0.01250	2.09370E+14	2.50360E+09
0.03750	1.98144E+14	6.96870E+09
0.06250	2.00207E+14	1.19020E+10
0.08750	2.02544E+14	1.76710E+10
0.11250	2.02969E+14	2.35700E+10
0.13750	2.05073E+14	2.96110E+10
0.16250	2.07534E+14	3.72450E+10
0.18750	2.16684E+14	4.88970E+10
Total	1.64252E+15	1.78368E+11
RT(whole)	2.07083E+14	1.78380E+11
% difference	0.0065	

Discussion

About 18% self shielding was observed for 20mm by 40mm cylindrical pellets

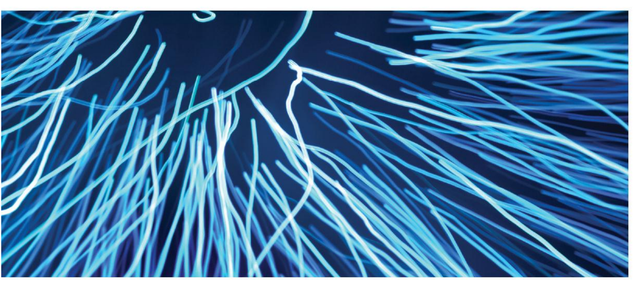
Self shielding was insignificant for 4mm by 6mm cylindrical pellets

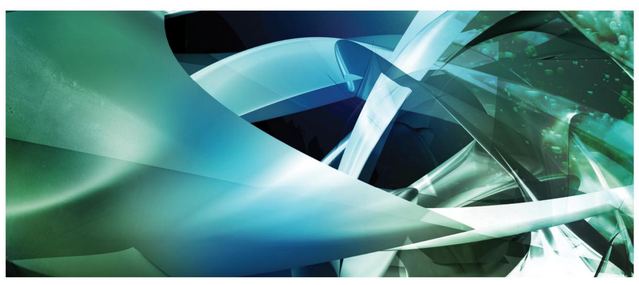
More analysis and experiments are in progress to determine effective ^{60}Co sources to achieve specific activities required for different specific uses.

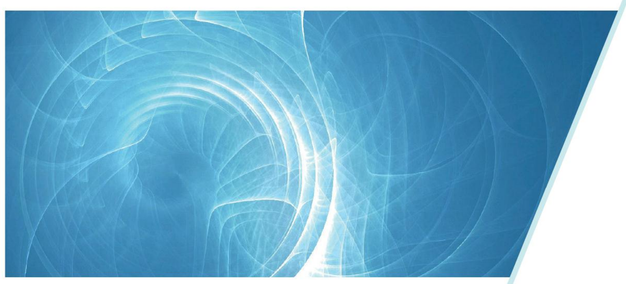
References

MCNP5, General Monte Carlo N-Particle Transport Code version5, Los Alamos National Laboratory, USA

FISPACT, Fuel inventory code, in the European Activation System (EASY), EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, UK.







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