International Conference on Applications of Radiation Science and Technology
(ICARST 2017)
24 to 28 April 2017, Vienna, Austria

Core Neutronic and Source Strength Analyses of Co-60 Production in Local Power Reactors

Aamir Ihsan, M. Kamran Chughtai

Directorate of Nuclear Power Engineering Reactor (DNPER), Pakistan Atomic Energy Commission

Abstract A detailed analytical study on the feasibility of local production of Cobalt-60 in power reactors, C-1 & C-2 (Chashma Nuclear Power Plant, unit-1/unit-2), has been made by irradiating metallic pencils of Cobalt-59 in-core and out-of-core locations. Four fresh fuel assemblies with 4 guide tube locations per fuel assembly have been selected for in-core Co-59 loading, whereas the four vacant locations on the outer surface of Reactor Core Barrel, which were earlier occupied by the Surveillance Capsules Assemblies (SCAs), have been selected as out-of-core locations for Co-60 production. The total activity of Co-60 produced at these locations for the two schemes over a period of two fuel cycles is presented. Detailed neutronic and safety analysis of C-1/C-2 core was also carried out to determine the effect of samples irradiation upon core performance.

Background

Cobalt-60 sources need to be recouped after every 3-4 years. Transportation or import from other countries is expensive. It is the only radioisotope used as gamma irradiation source to kill pathogens and microbes. It can be produced by thermal neutron irradiation of natural cobalt (Co-59) metal in NPPs.

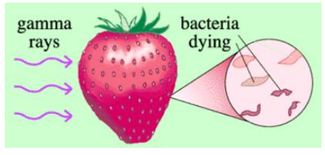
Objective

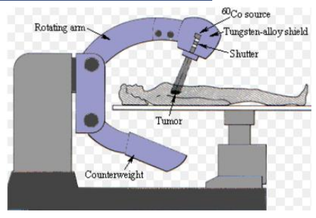
Indigenous production of Cobalt-60 to meet country's industrial and medical requirement.

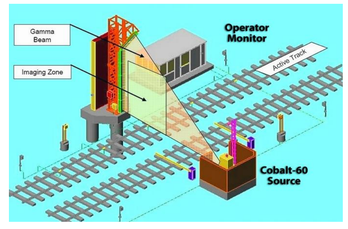
Basic Concept

Utilization of thermal neutron flux of existing nuclear power plants without any major change in core configuration and performance. Two different irradiation locations are selected, i.e., incore and out-of-core locations.

Applications & Benefits

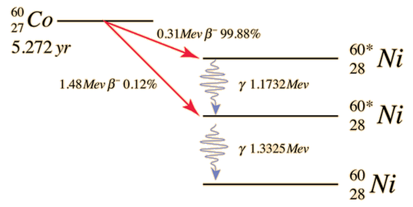






Principle of Co Production

$$^{59}_{27}Co + ^{1}_{0}n \rightarrow ^{60}_{27}Co \rightarrow ^{60}_{28}Ni + ^{0}_{-1}e + \gamma\ (photon)$$



Methodology

$$\frac{dN_m}{dt} = N_o\sigma_m\phi e^{-\sigma_T\phi t} - \lambda_m N_m - N_m\sigma_c^m\phi$$

$$\frac{dN}{dt} = N_o\sigma_o\phi e^{-\sigma_T\phi t} - \lambda_o N - N\sigma_c\phi + \lambda_m N_m$$

$$N = N_o\sigma_o\phi\left(\frac{e^{-\sigma_T\phi t} - e^{-(\lambda_o+\sigma_c\phi)t}}{(\lambda_o+\sigma_c\phi-\sigma_T\phi)}\right) + N_o\sigma_m\phi\left(\left(\frac{e^{-\sigma_T\phi t} - e^{-(\lambda_o+\sigma_c\phi)t}}{(\lambda_o+\sigma_c\phi-\sigma_T\phi)}\right) - \left(\frac{e^{-(\lambda_m+\sigma_c^m\phi)t} - e^{-(\lambda_o+\sigma_c\phi)t}}{(\lambda_o+\sigma_c\phi-\lambda_m-\sigma_T\phi)}\right)\right)$$

Irradiation of Co-59 at Incore Locations

Four fresh fuel assemblies with 4 guide tube locations per fuel assembly have been selected for in-core Co-59 loading. The typical reactor core of C-1/C-2 is shown in Fig-1 and the locations for Co-59 loading in the fuel assembly is shown in Fig-2. A total of about 296000 curies of Co-60 are produced in these locations over a period of two fuel cycles (~ 770 days). The estimated specific activity of cobalt pencil at the end of 2 years is 37.3 Ci/g.

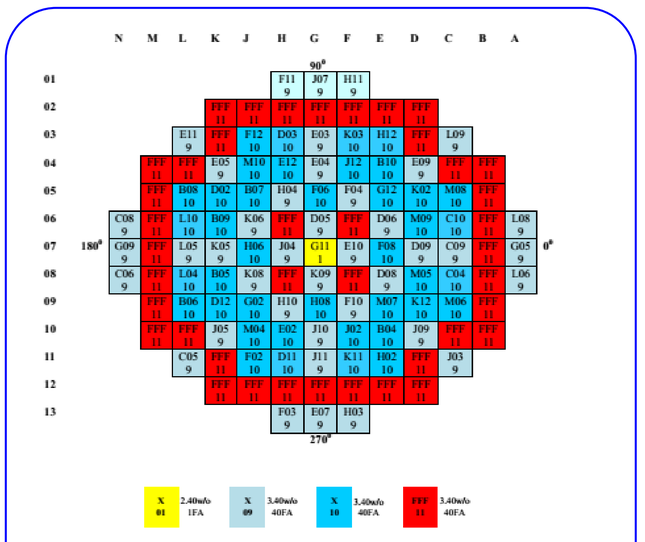


Fig. 1. Core loading pattern of C-1 with 4 fresh fuel assemblies at core centre.

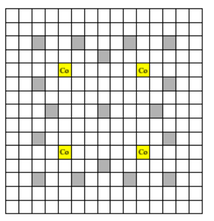


Fig. 2. Central fresh fuel assembly with the loading of 4 Co-59 pencils

Diameter of pencil (cm)	0.842
Length of pencil (m)	1.0
Mass of pencil (g)	495
Density of Co-59 (g/cc)	8.9

Table 1. Geometrical data of single pencil of target Co-59

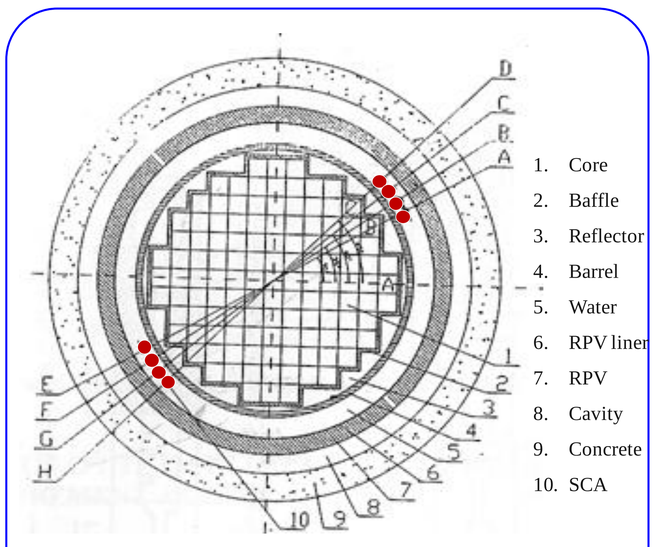


Fig. 3. Out-of-core locations for loading of Co-59 pencils

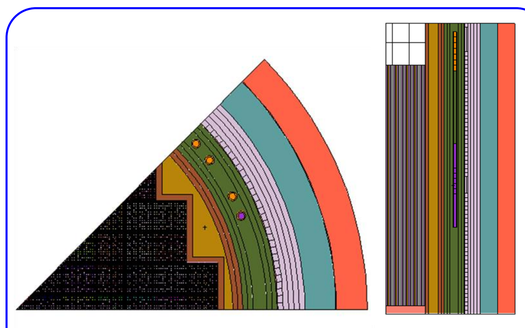


Fig. 4. Ex-core locations of Co-59 pencils

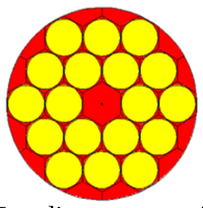


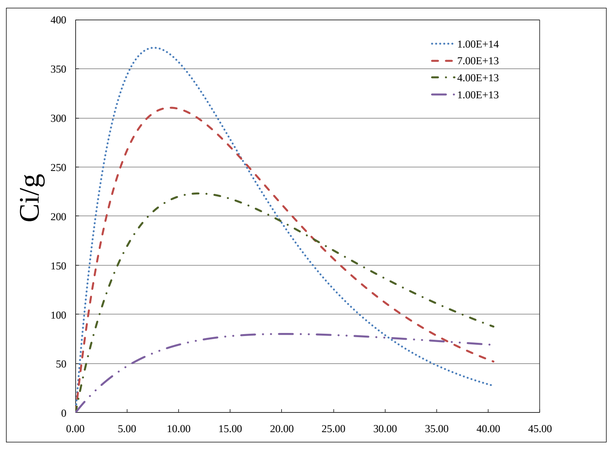
Fig. 5. Loading pattern of Co-59 pencils at Ex-core locations

Irradiation of Co-59 at Ex-core Locations

Four out-of-core vacant locations on the outer surface of Reactor Core Barrel, which were earlier occupied by SCAs, have been selected for Co-60 production (Fig. 3~5). In this scheme four bundles in the form of stainless steel tube, each tube containing 18 concentric cobalt pencils would be loaded in SCA hanger assemblies. An estimated 31300 curies of Co-60 are produced in these locations over two core cycles.

Conclusion

Feasibility of production of cobalt-60 at the in-core and out-of-core vacant locations of SCAs in power reactor has been demonstrated. For the loading of Cobalt metal at incore locations, core performance is slightly affected with the shortening of cycle length just by 1 day. For the out-of-core scheme, the effect on core reactivity is much smaller. There is no adverse impact on plant safety and economy in both the cases.



Summary of Results

Activity (Source Strength) at In-Core Locations									
Location	Total Pencils Loaded	Co Weight (Kg)		Thermal Neutron Flux ($n.cm^{-2}.s^{-1}$)	Time of Irradiation	Activity (Ci)		Specific Activity (Ci/g)	Change in Reactivity (pcm)	Change in Cycle Length (Days)
		01 pencil	16 pencil			Single pencil	16 pencils			
4 Fuel assemblies	16 (4 per fuel assembly)	0.495	7.92	4.1E+13	02 Fuel Cycle (770 days)	1.85E+04	2.96E+05	37.37	-57	0.8
Activity (Source Strength) at Ex-Core Locations										
Location	Total Pencils Loaded	Co Weight (Kg)		Thermal Neutron Flux ($n.cm^{-2}.s^{-1}$)	Time of Irradiation	Activity (Ci)		Specific Activity (Ci/g)	Change in Reactivity (pcm)	Change in Cycle Length (Days)
		01 pencil	72 pencil			Single pencil	72 pencils			
4 Out of core vacant SCA locations	72 (18 per location)	0.495	35.6	9.0E+11	02 Fuel Cycles (770 days)	4.35E+02	3.13E+04	0.88	-25	0

Table 2. Activity (Source Strength) at In-Core and Out-of-Core Vacant SCA Locations