Jurnal Sains Nuklear Malaysia, 2015, 27(2): 16-22
ISSN: 2232-0946

SHIELDING AND CRITICALITY ANALYSIS FOR SPECIAL NUCLEAR MATERIAL (SNM) VAULT IN FUEL REPROCESSING PLANT (FRP) OF FAST REACTOR FUEL CYCLE FACILITY (FRFCF)

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ABSTRACT

Fuel Reprocessing Plant (FRP) which is a part of Fast Reactor Fuel Cycle Facility (FRFCF), under construction, will be dedicated to recover the unburnt and bred fissile material from fast reactor (Prototype Fast Breeder Reactor) spent fuels. The purified finished oxide product of FRP will be stored in its Strategic Nuclear Material (SNM) vault. The radiations emitted due to the inherent nature of the product and the residual fission products are to be shielded. These shielding requirements have been estimated using the 3D transport code MCNP4B (Monte Carlo N Particle Transport Code-version 4B). The SNM vault contains 18 cylindrical containers with each having 6 kg of PuO_2*.Each such container is kept in a concrete pit. Total dose rates (neutron & gamma) have been estimated at various locations inside and outside the SNM vault and to reduce it below 1 μSv/hr at all locations, 7 cm mild steel plus 3 cm polyethylene extra is required as lid for the pit. Near the single pit, additional 5 cm thick concrete is required near the surface facing inside. Criticality analysis carried out for SNM vault confirms that the present arrangement of 18 containers with shield is critically safe.*

Keywords: Criticality, FRP, PFBR, shielding, SNM

INTRODUCTION

The Prototype Fast Breeder Reactor (PFBR) is a 500 MWe fast breeder nuclear reactor presently being constructed in Kalpakkam, India. For India, with its 2nd largest thorium reserve in the world, fast reactor technology would be economically more viable to potentially deploy its thorium resource for power production. PFBR would use uranium-238 not thorium, to breed new fissile material, in a sodium-cooled fast reactor design. The surplus plutonium (or uranium-233 for thorium reactors) from each fast reactor can be used to set up more such reactors and grow the nuclear capacity in tune with India's power requirement.

India will set up its Fast Reactor Fuel cycle Facility (FRFCF) alongside PFBR in Kalpakkam. The FRFCF would reprocess the spent fuel to separate the unburnt and bred plutonium and uranium from the fission products. The fissile material thus purified and separated will be refabricated and recycled to PFBR thus closing the PFBR fuel cycle. The fuel reprocessing plant, which is a part of FRFCF, is designed to reprocess the irradiated fuel subassemblies and radial blanket subassemblies from PFBR and deliver PuO_2 and U_3O_8 powder to Fuel Fabrication Plant (FFP) and Reprocessed Uranium Plant (RUP) respectively for fabrication of fuel subassemblies and radial blanket subassemblies. The reprocessing plant will also receive the MOX and axial blanket rejects from FFP and UO_2 rejects from RUP for processing and conversion to PuO_2 and U_3O_8. The SNM vault is of dimension 1466 x 700 x 765 including 80 cm thick concrete shield on all sides of the vault. The vault is just a buffer space for storing the finished Pu product of FRP before sending it to FFP for fabrication which ensures smooth and safe transfer of the product from FRP to FFP without affecting the normal functioning of the two plants. Hence the vault is designed to accommodate PuO_2 generated during a specific period of time which is fixed as per the site's safety requirement. To ensure minimum manrem exposure while handling the finished product, the vault has to be designed with sufficient shielding to reduce the dose rates to safe limits. At the same time the arrangement must be critically safe. The PuO_2 containers are also to be arranged in a specific array to ensure criticality safety of the vault with maximum storage capacity (Dunn and Shultis, 2012).

MATERIALS AND METHODS

Geometric Description

SNM vault contains 18 cylindrical containers each holding 6 kg of PuO_2 (Fig. 1). The diameter and length of PuO_2 container are 14 cm, 30 cm. Each container is surrounded by 10 cm mild steel and 20 cm polyethylene respectively on all sides. Each shielded containers are kept inside 80 cm x 80 cm concrete pit with wall thickness 20 cm. Top of the pit is covered with 5 cm thick mild steel and at the bottom 80 cm thick concrete is provided (Fig. 2). The shield requirements are estimated to meet the design limit of 1 µsv/h outside the SNM vault (Shanthi et al., 2006).

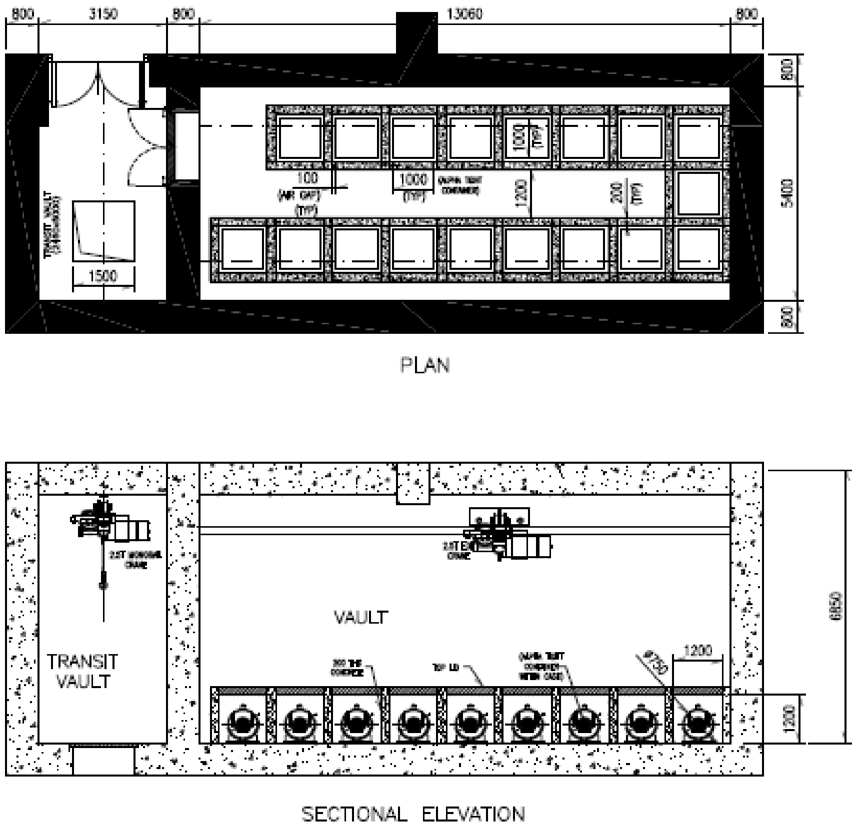

Figure 1: Plan and sectional view of SNM vault

Radiation Sources: Neutron and Gamma

The neutron sources in PuO_2 powder are from (α, n) reaction and spontaneous fission (Pandikumar and Gopalakrishnan, 2010). With the known isotopic composition of Plutonium in PFBR spent fuel, 6 kg PuO_2 powder is estimated to have neutron source strength of the order of 2.45 x 10^6 n/s. For total 18 containers it is about 4.42 x 10^7.

The sources of gamma radiation are fission product activity, actinides, spontaneous fission (Baskar et al., 2009). Among these, gamma radiations from fission products and actinides are the major source of radiation. Considering all sources, the gamma source spectrum has been calculated (Table 1).

Table 1: Gamma source spectrum

Energy (MeV)	**No. of .gammas/kg of PuO_2**
Soft γ < 130 keV	5.58E+11
0.13 <1 MeV	7.10E+08
1 -2.62 MeV	5.57E+07
2.62 - 6MeV	2.56E+06

Calculation Details

The shield requirement for the SNM vault has been estimated using the 3D transport code MCNP4B and ENDF/B-VI cross-section library has been used (Fig. 3). The PuO_2 containers, with cylindrical MS & polyethylene shields, concrete pits and SNM vault are modeled exactly. To account for water content loss in 40 yrs. time, walls are assumed to be made up of 2.256 g/cc concrete. For energy ≥ 100 keV, the total gammas source strength of 108 (=18 x 6) kg PuO_2 powder is 8.29E+10 γ/s. the total neutron source strength of 108 (= 18 x 6) kg PuO_2 powder is 4.42 E+7 n/s. Neutron and gamma dose rates on the all sides and at the centre of SNM vault at an elevation 140 cm and at 100 cm above the floor have been estimated by carrying out neutron and gamma transport calculations separately. Importance sampling, Splitting and Russian roulette has been employed to reduce the statistical uncertainty less than 5% with a runtime approximate 6 hours. The total dose rate has been estimated using point detector tally. The spectrum used for neutron is a combined (spontaneous fission + (α, n) contribution) multi-group spectrum.

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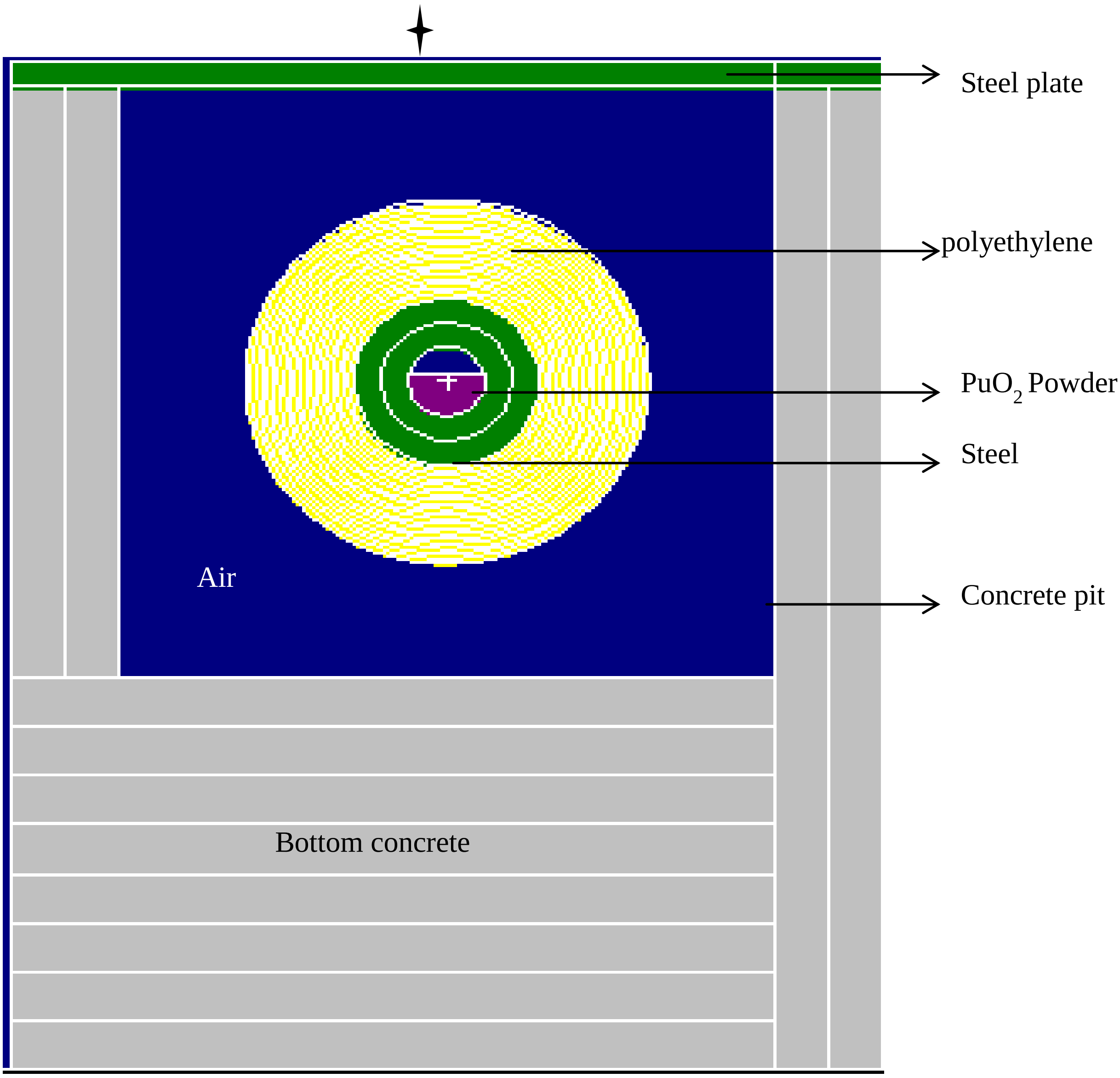

Figure 2: Sectional view of single concrete pit

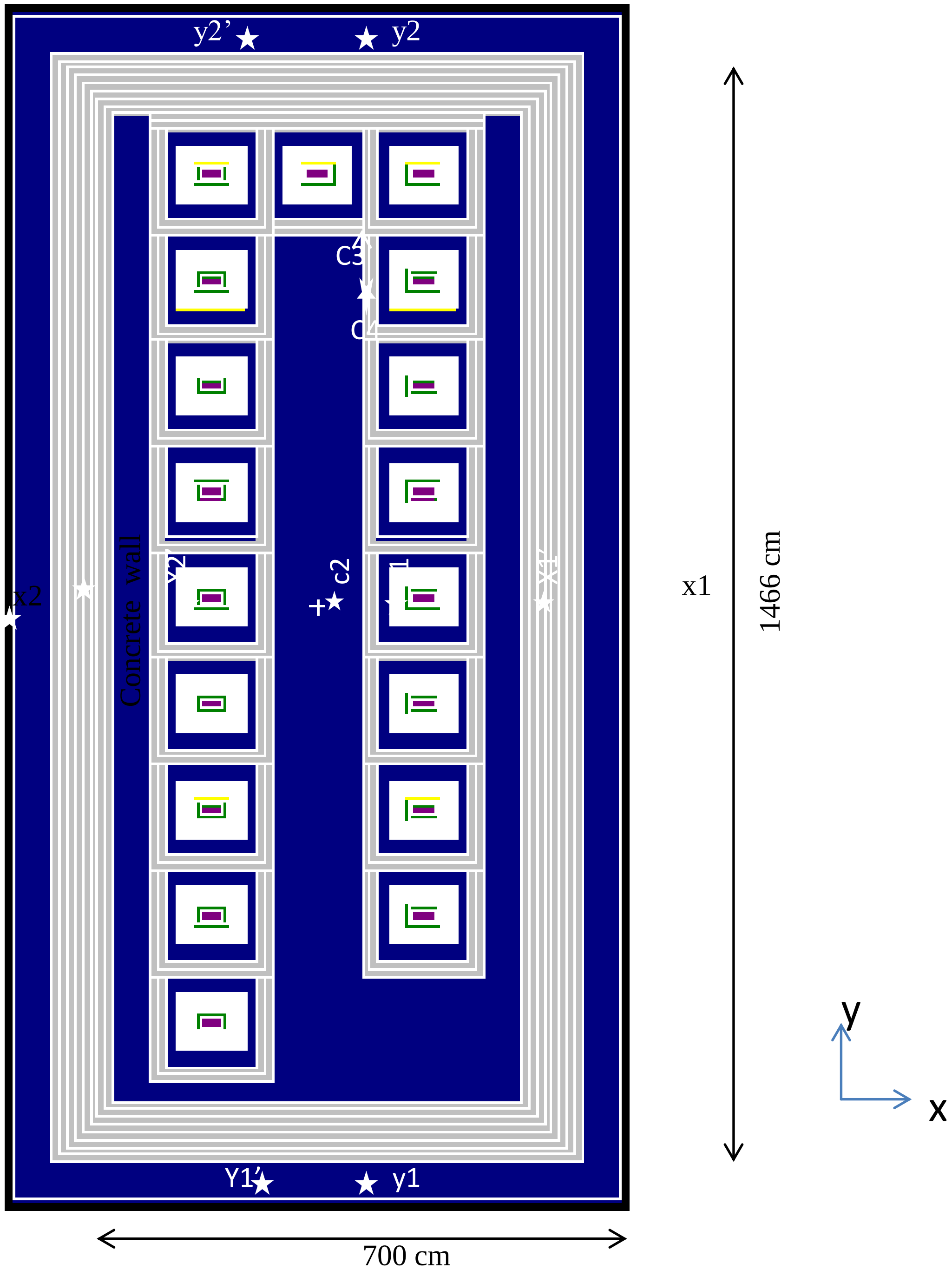

Figure 3: Plan view of SNM vault simulated by MCNP

RESULTS AND DISCUSSION

Criticality

To ensure safe storage of fissile materials in the storage room, criticality analysis has been carried. Effective multiplication factor (keff) has been estimated even in water flooded condition, assuming the entire vault with the concrete pits and SNM container to be immersed in water completely as shown in Fig. 4. The estimated keff values are given in Table 2. It is observed that even in water flooded condition the estimated keff value is below 0.9 which validates the criticality safety of the SNM vault with its present layout.

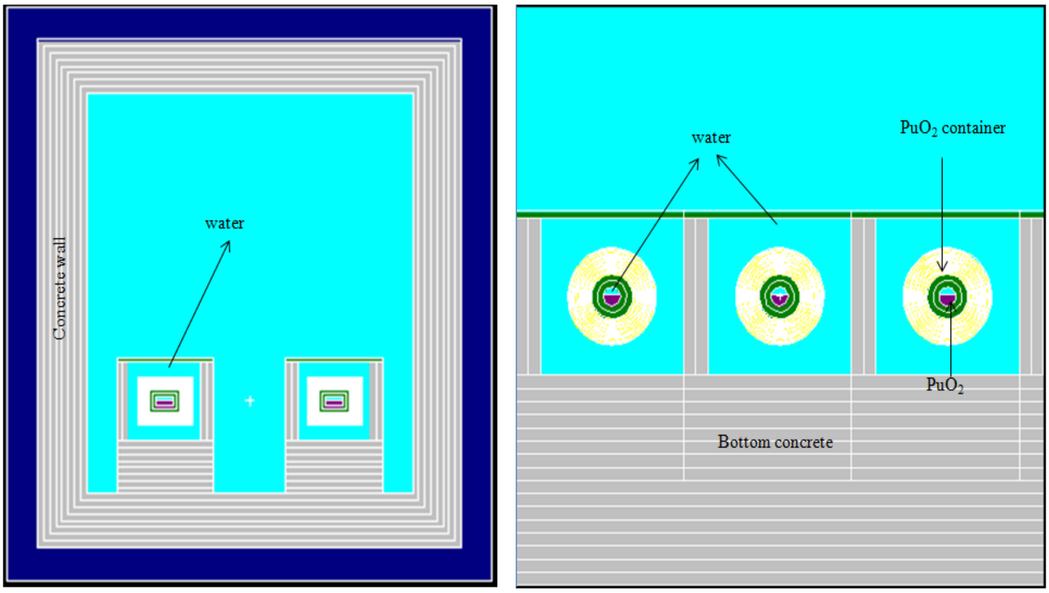

Figure 4: Sectional view if SNM vault in water flooded conditions

Table 2: Estimated values of K_{eff}

Serial No.	**Description**	**K_{eff} SNM Vault**
1	With air	0.2166
2	Water flooded	0.32787

Shielding

With the proposed shield (sec 2.0), the total dose rates at the center and outside the SNM vault have been estimated. The estimated dose rates are presented in Table 3. It is observed that the estimated dose rates inside and outside of SNM vault are less than the desired dose rate of 1 µsv/hr, except on the top of the steel plate at the center of the container (Fig. 2) and near the detector location C3 (Fig. 3). Hence to reduce the dose rates at all locations less than 1 µsv/hr, plus 3 cm polyethylene plus 7 cm mild steel is required as lid for the pit. Near the detector location C3, additional 5 cm concrete is required. With this shield the dose rates inside and outside SNM vault will be less than 1 µsv/hr.

Table 3: Estimated dose rates inside and outside SNM vault

	Inside SNM Vault				Dose Rate (μsv/hr)	
Detector location	**Vertically at the mid-plane of the container(μsv/hr)**		**1m above the floor**		**Container Mid-plane**	**1m above the floor**
	Neutron	**Photon**	**Neutron**	**Photon**		
Mid-plane of 8 containers rack (both sides)	0.43	0.30	0.24	0.08	0.73	0.32
	0.51	0.40	0.34	0.14	0.92	0.48
Centre of SNM vault	0.34	0.17	0.30	0.13	0.51	0.43
Mid-plane of 9 containers rack (both sides)	0.54	0.37	0.34	0.16	0.91	0.5
	0.42	0.29	0.24	0.09	0.71	0.33
Top of mild steel plate	**Neutron**		**Photon**		**Total**	
	1.30		8.21E-01		2.12	
Positions	**Outside of the SNM vault**					
X1	5.21E-04	3.26E-05	4.17E-05	4.56E-05	5.54E-04	4.63E-04
X2	6.14E-04	2.39E-05	3.83E-04	2.37E-05	6.38E-04	4.07E-04
Y1	2.96E-04	6.98E-06	3.02E-04	5.47E-06	3.03E-04	3.07E-04
Y2	1.34E-03	9.49E-05	1.17E-03	4.32E-05	1.43E-03	1.21E-03

ACKNOWLEDGEMENTS

We would like to thank, Dr. R.S. Keshavamurthy, Head, Reactor Physics Division, FBTR, P. Puthiyavinayagam, Director, Core Design Group (CDG), Dr. P. Chellapandi, Director, Reactor Design Group (RDG) & all members of RSDD for their fruitful discussion and support in carrying out this work.

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