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Measurement of dose rate profile and spectra through a cylindrical duct vis-à-vis Monte Carlo simulation studies for optimisation of reactor shield design

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Abstract

In the design of a nuclear reactor, penetrations are provided in the top shield to carry out some essential operations. Radiation streaming is envisaged through such penetrations. To avoid radiation streaming, complementary shielding is provided. Optimisation of complementary shielding is carried out by performing calculations using MCNP code. Uncertainties in the calculations are taken care of by incorporating a safety factor. The assumption of the safety factor, while designing the reactor shielding, has been validated by undertaking experimental measurements on a similar geometry vis-à-vis the computed values obtained using MCNP code. The results of the present work agree with the safety factor of two assumed during the shield design. The details of gamma spectral measurements carried out with high purity germanium detector to understand the pattern of the scattered spectrum are also presented.

1. Introduction

Radiation streaming through duct is often encountered during the design of shielding for reactor or spent fuel storage locations. Complementary shielding is provided at the exit of the duct to keep the radiation level at the accessible locations within the design limit. Optimising shield requirement for radiation streaming through duct is an involved task since the energy and angular distribution of the emerging radiation outside the duct is different from the source at the exit point of the duct. The situation becomes more complicated as one approaches the locations outside the duct, which are away from the duct centreline, where the total fluence rate is predominantly dictated by the scattered component. The general approach to solve such problem is by modelling the exact geometry and using the same in the calculations by Monte Carlo method. Literature survey reveals a number of publications in which the streaming of γ rays and neutrons through straight and bent ducts are discussed and empirical formulations provided (Muira and Sasamoto, 1983; Shin, 1988a,b) The formulations are useful to calculate the dose rate along the axis of the ducts at various depths. But the data on distribution of dose rate profile outside the duct in a three dimensional space domain are sparse (Theodore Rockwell, 1956; Zolotukhin, 1968).

During the shield design of some of the reactor components, radiation streaming through penetrations is envisaged. Shield design is optimised by computing dose rates at the accessible locations using MCNP code (Briesmeister, 1993). While using the MCNP code for Prototype Fast Reactor (PFBR) related shield design studies, a safety factor of two is provided while estimating the dose rates to take into account the variations in the computed values. The use of the safety factor and dose rate values obtained using MCNP code has to be validated by carrying out a radiation streaming experiment through a duct. Such an experiment has been carried out in one of the discharge pit locations of the Fast Breeder Test Reactor (FBTR), where the irradiated subassembly is temporarily

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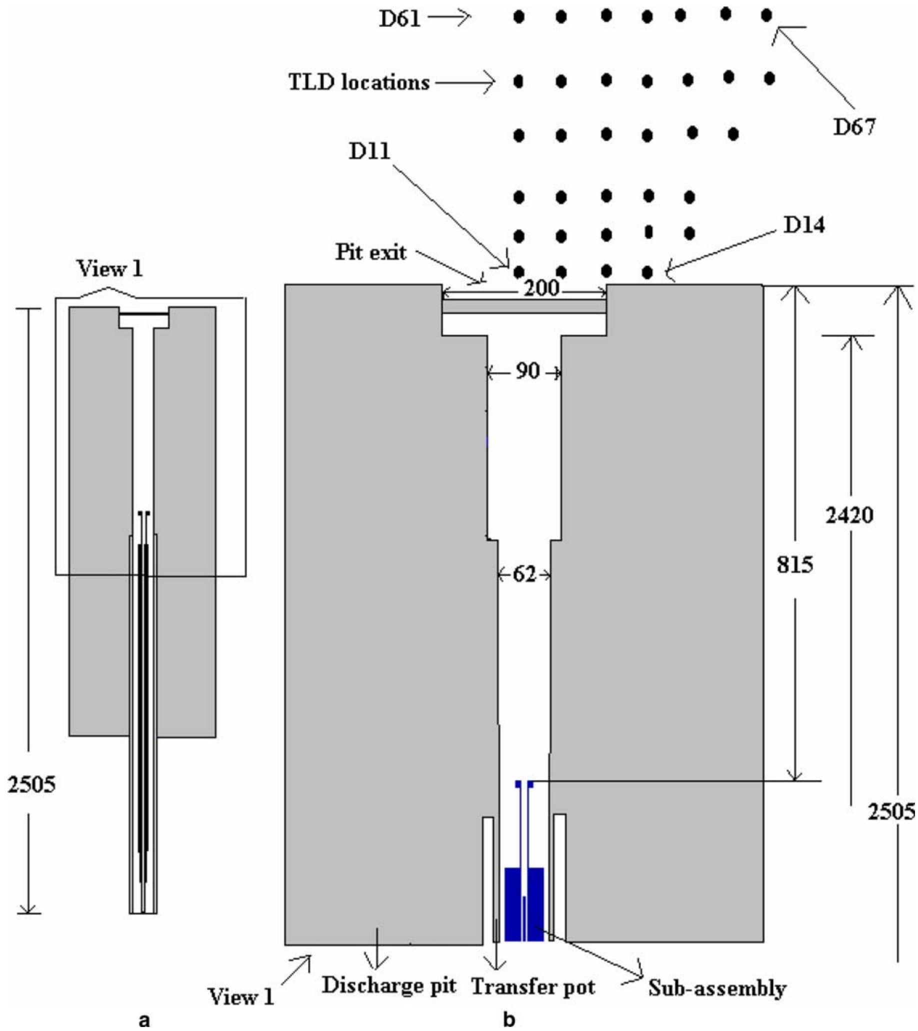

Fig. 1. Sketch of the discharge pit and nickel sub-assembly.

stored. An irradiated nickel reflector subassembly (SA) removed from the reactor served as the source. The objectives of the present work are: (a) comparison of dose rates between experiment and computations at various locations and (b) gamma spectral measurements to identify the predominant source energies and magnitude of scattered components.

2. Experimental arrangement

An experimental set-up in the form of discharge pits in FBTR (1983), wherein irradiated (SA) is being stored was identified (FBTR). Discharge pits are cylindrical in shape but have decreasing radius along the depth and cast iron slabs provide biological shielding. The total depth of the

Table 1
The main activation products in nickel subassembly

Parent nuclide	Nuclear reaction	Produced nuclide	Half life	Gamma energy in MeV (yield %)
Activation products in nickel				
^{58}Ni	(n,p)	^{58}Co	70.8d	0.511 (30), 0.810 (100)
^{60}Ni	(n,p)	^{60}Co	5.26y	1.173 (100), 1.332 (100)
Activation products in steel (AISI 316)				
^{54}Fe	(n,p)	^{54}Mn	312d	0.834 (100)
^{58}Fe	(n,γ)	^{59}Fe	44.5d	1.099 (56), 1.291 (44)
^{58}Ni	(n,p)	^{58}Co	70.8d	0.511 (30), 0.810 (100)
^{60}Ni	(n,p)	^{60}Co	5.26y	1.173 (100), 1.332 (100)
^{59}Co	(n,γ)	^{60}Co	5.26y	1.172 (100), 1.332 (100)