Radiological characterization of the GRR-1 pool

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Abstract. The GRR-1 inspection and refurbishment plan involves inspection of the reactor's primary cooling circuit and pool, thus it requires drainage of the pool water. Purpose of the present work is the evaluation of the gamma radiation fields inside and around the GRR-1 pool during the inspection procedures. The Monte Carlo neutron and photon transport computer code MCNP5 was employed in order to predict gamma radiation levels during pool drainage. The code enabled simulation of the pool and activated components within the pool i.e. experimental tubes with in pile collimators, beryllium blocks, reactivity control rods, lead shields and irradiation rigs. The MCNP predicted gamma dose rate results were calibrated against experimental measurements performed using a submersible GM detector. The dose rate profile data derived will be used in order to set the radiation protection requirements, during the inspection and refurbishment operations, such as implementation of certain procedures, removal of activated components from the pool or manufacture and placement of special shielding arrangements.

1. Introduction

GRR-1 is a 5MW open pool type research reactor with MTR-type fuel elements cooled and moderated by light water with beryllium reflectors at the two opposing sides of the core. Six radial horizontal beam tubes are available, of which three contain in-pile collimators for neutron scattering instruments. A graphite thermal neutron column is adjusted to one side of the core. Several irradiation devices are employed for material irradiations, radioisotope production and neutron activation analysis. The reactor is currently out of operation for inspection and refurbishment purposes. The core has been dismantled and the fuel elements are stored in the used fuel storage tank. The GRR-1 inspection and refurbishment plan involves inspection and eventually replacement of the reactor's primary cooling circuit.

The health physics procedures to be implemented during the inspection program of the pool and main water outlet are divided in three stages: a) pool dose rate survey from pool top, b) pool drainage by decreasing water level in steps and c) inspection of the pool lining and water main outlet. The evaluation of the gamma dose rate profiles in the reactor pool is very important to plan the ALARA actions that must be taken in order to decrease the collective doses received by exposed professional workers. Nevertheless, acquisition of experimental dose rate data is difficult because the measurements have to be performed in hard-to-access locations in the presence of high dose rates. Moreover, these measurements need to be repeated after any change in experimental conditions resulting in further increase of personnel collective doses.

In the present work, the Monte Carlo code MCNP-5 [1] was employed in order to predict gamma radiation levels during pool drainage. The code enabled simulation of the complex geometry of reactor pool and activated components within the pool i.e. reactivity control rods, beryllium blocks, lead shields and irradiation rigs. The actual photon sources depend upon alloy, impurity content, neutron spectrum, reactor operation history, and decay time. Since GRR-1 was out of operation for over three years, it was assumed that the most important activation nuclide in the pool is ^{60}Co due to its long half-time of 5.27 y. The MCNP predicted gamma dose rate results were calibrated against experimental measurements performed using a submersible GM detector.

2. Method

2.1. Experimental measurements

The radiation survey was performed from the pool top. Contact gamma dose rate measurements were performed using a submersible Thermo Electron™ UWDS FHZ 312 Geiger Muller type detector. The measuring range of the detector expanded between 100 μSv/h to 100 Sv/h. It is noted that this survey was performed without having removed any activated components stored in the reactor pool and with the reactor bridge-support tower- gridplate assembly being in position.

2.2. Simulations

The Monte Carlo neutron and photon transport code MCNP5, with cross sections from ENDF/VI data library, was employed to predict gamma radiation levels during pool drainage. The three dimensional geometry of the reactor pool and activated components modeled with the MCNP code is schematically given in Fig 1. Activated materials in the pool included reactivity control rods (Ag-Cd-In alloy 80%-5%-15% respectively), core gridplate (Al), beryllium reflector boxes (Be), graphite pile lead shields, irradiation devices and rigs (stainless steel Al and Pb) and control rod sock absorbers (stainless steel). The pool dimensions are 10.3 m × 3.3 m × 9.0 m.

The source of ^{60}Co gamma rays was assumed homogeneously distributed inside the volume of activated materials. This assumption is considered acceptable for the preliminary estimation of the gamma doses for radiation protection purposes. Nevertheless, a detailed activation calculation will be performed taking into consideration the actual neutron source and operating history of the reactor. The results of the gamma dose rate survey in the pool were used to adjust the relative source probabilities in the MCNP input file. Dose modified track length estimate tallies, f4, using photon flux-to-dose rate conversion coefficients from ICRP 74 [2], were used to calculate the dose equivalent rate in several positions in the reactor pool. The results of the simulations were calibrated against the experimentally measured dose rates on the surface of the activated materials in the filled with water reactor pool.

3. Results and discussion

Fig. 2 shows the MCNP predicted gamma dose rates, as a function of pool water height, at the top of the pool (z= 9 m). A (x,y) detector position array (7 × 3) was assumed at the top level of the pool. It can be observed that the gamma dose rate decreases with increasing water height, as water acts as shielding for gamma radiation. The variation in gamma dose rate between the several detectors depends on the varying relative contribution of the different photon sources in the pool. Moreover, the maximum gamma dose rate at the pool top with an empty pool is derived to be 6 mSv/h.

Fig. 3 shows the MCNP predicted gamma dose rates, as a function of pool water height, above the water level in the pool (water height varying between 0 and 3 m). From the data shown in this figure it can be observed that the maximum gamma dose rate value was estimated to be 1 Sv/h.

Fig. 4 shows the predicted gamma dose rate profiles at three height levels in the pool (a) at the pool bottom (z=0) (b) at the mid-height of the reactivity control rods (z= 1.8 m) and (c) at the top of the pool (z= 9 m) under dry pool conditions. From the data presented in Fig. 4(a) it can be observed that the estimated gamma dose rates are significantly high (up to 1.6 Sv/h) at the bottom of the pool. From Fig. 4(b) it can be derived that the gamma dose rates at the control rod mid-height reach the value of 8 Sv/h near the rod location.

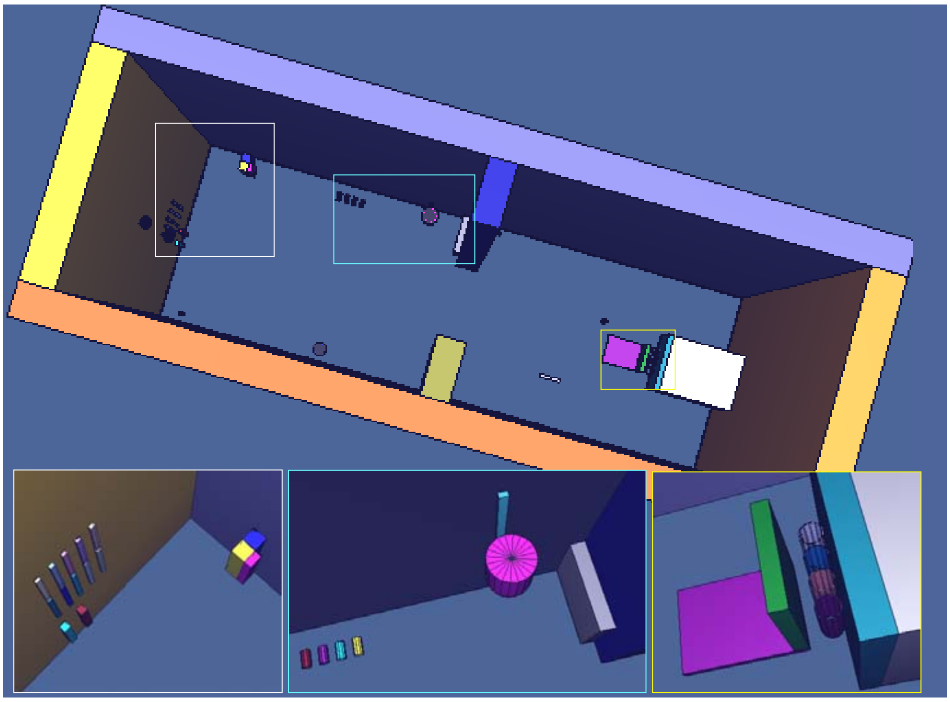

FIG. 1. MCNP simulated geometry

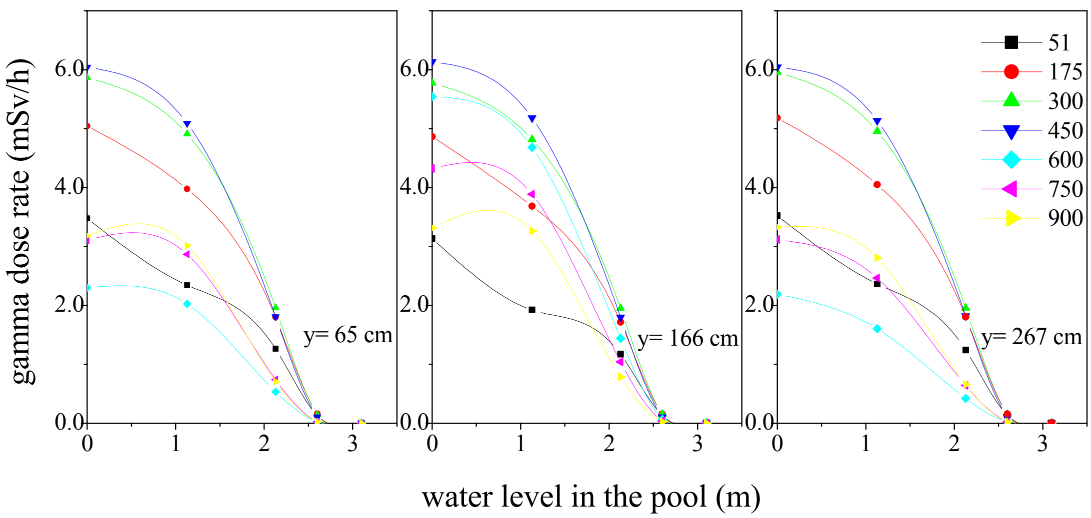

FIG. 2. MCNP predicted gamma dose rates at the pool top as a function of the water level in the pool, for several x and three y positions over the z=9 m plane

The results shown in Fig. 4(c) indicate a maximum dose rate value of 7 mSv/h at the pool top. These results clearly reveal the necessity to remove the activated components from the reactor pool and transfer them at an interim shielded storage area before performing the planned reactor inspection and modification program in order to reduce personnel radiation doses to acceptable levels.

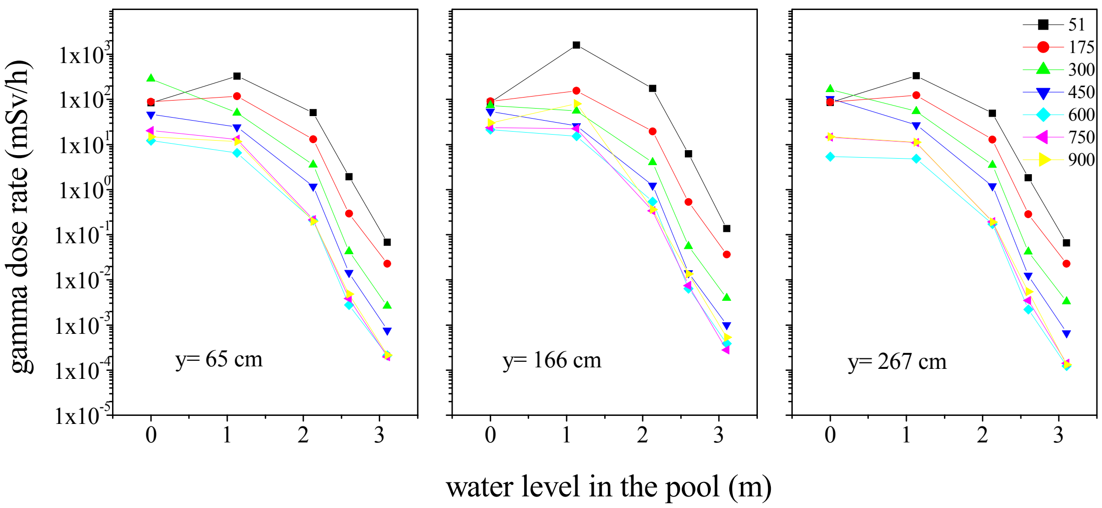

FIG. 3. MCNP predicted gamma dose rates as a function of the water level in the pool, for several x and three y positions over the water level

4. General discussion and future work

The GRR-1 inspection and refurbishment plan involves inspection and eventually replacement of the reactor's primary cooling circuit. The health physics procedures to be implemented during inspection of the main water outlet include: a) pool dose rate survey from pool top, b) pool drainage by decreasing water level in steps and c) inspection of the water main outlet.

Nevertheless, acquisition of experimental dose rate data during pool drainage is difficult because the measurements have to be performed in hard-to-access locations in the presence of high dose rates and be repeated after any change in experimental conditions resulting in further increase of personnel collective doses. Since the radioactive source geometry in the pool is rather complicated it would be convenient to apply a versatile calculation solution, such as the Monte Carlo method, for the estimation of the gamma radiation field in the pool. The Monte Carlo neutron and photon transport computer code MCNP has been employed by other workers to estimate gamma dose rates [3], [4] and internal pipe contamination in nuclear reactors [5].

In the present work, MCNP was applied to estimate the radiation field in the GRR-1 pool during drainage, arising from activated components, so as to take appropriate actions and adapt the procedures of next inspection stage. The evaluation of the gamma radiation field in the reactor pool was based on a detailed model of the reactor pool and activated components. Preliminary calculations of the gamma dose rate profiles in the reactor pool for several drainage stages were presented. The calibration of computational results was based on experimental gamma dose rates acquired using a submersible GM detector.

The Monte Carlo method has proven to be a powerful tool for the simulation of activated components in the reactor pool and prediction of the gamma radiation levels in the pool under several experimental conditions. The MCNP predicted dose rate profile data will be used in order to set the radiation protection requirements, during the inspection and refurbishment operations, such as implementation of certain procedures, removal of activated components from the pool or manufacture and placement of special shielding arrangements.

Our future work will be directed towards: (a) detailed activation calculations of several components taking into consideration the actual neutron source and operating history of the reactor and (b) calculations to provide the required gamma shielding to limit the dose from non-removable activated components. These data will furthermore allow establishing records of the cumulative activation of materials and gamma dose rates for regulatory and decommissioning purposes.

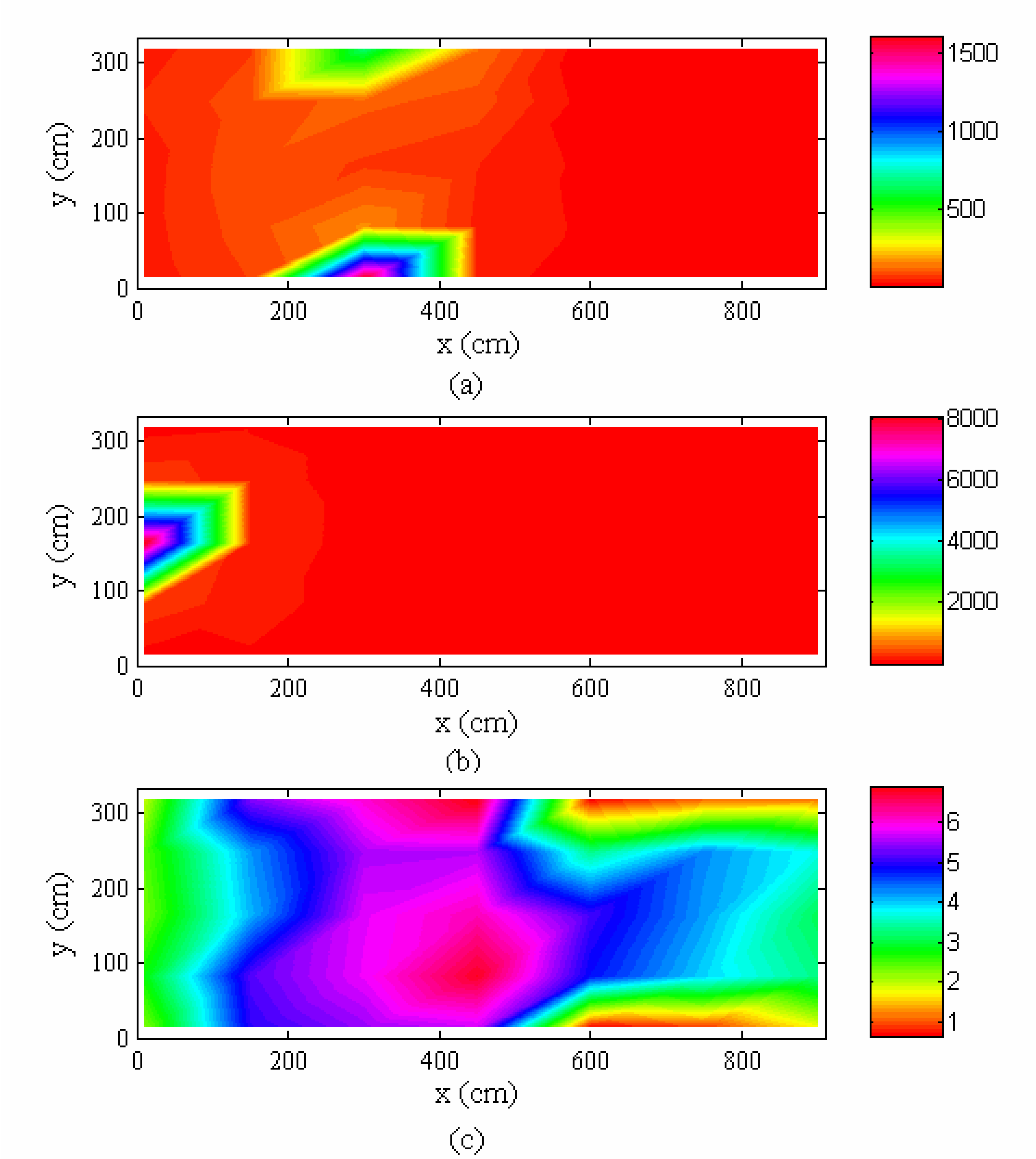

FIG. 4. MCNP predicted gamma dose rate profile, in mSv/h, at (a) bottom (b) z=182 cm control rod mid-height and (c) 9m top planes of the pool under total drainage conditions

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