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Study of Radiation dose Rates around Open Pool Type Reactor Building due to LOCA

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Abstract: Loss of coolant accident (LOCA) is one of the anticipated accidents that may occur in the open pool type reactor. LOCA results in decreasing the water level above the reactor core and consequently may cause an increase in the radiation dose rate level. Determining the radiation dose rate levels around the reactor building due to the LOCA is the objective of this study. KENO-VI code was used to model the reactor building structure. ORIGEN-S code was used to evaluate the neutron and the photon spectrums and their intensities after the reactor shutdown assuming the maximum burnup of the discharge for conservative calculation.

MAVRIC code was used to calculate the dose rate distributions around the reactor during LOCA. Then, the distances from the reactor which correspond to the permissible dose rate limit were determined along the water level drop. The study focused on determining the water level above the reactor core, 144 cm, that achieves a dose rate lower than or equal to the permissible limit for any position around the reactor building.

Keywords: Radiation dose rate, Open pool reactor, LOCA, KENO-VI code, ORIGEN-S code, MAVRIC code.

1 Introduction

Studying the radiological conditions resulting from different anticipated accidents for nuclear reactors is very important for expecting the radiation dose that would be received by the persons who located around the reactor building during the accident. Loss of coolant accident (LOCA) is one of the anticipated accidents in the nuclear reactors that may occur due to breakage in the reactor coolant circuits. LOCA in open pool type reactor would result in decreasing the water level in the reactor pool that contains the reactor core and consequently shut down the reactor. Decreasing the water level in the pool would result in decreasing the water shielding thickness above the reactor core and consequently may increase the radiological dose level inside and outside the reactor building.

The second Egyptian test and research reactor (ETRR-2) is an open pool reactor consisting of underground and three floors. The main pool contains the core and the storage pool contains the racks that were constructed to store the spent fuel elements after discharge from the core.

Studying the radiological dose rate level inside ETRR-2 building due to LOCA has been investigated before [1]. Focusing on evaluating the dose rate level outside the ETRR-2 building is the objective of the present study. During LOCA, the dose rate levels around the ETRR-2 would not result directly from the core, as shown in figure 1, but from reflecting the emitted neutrons and photons from the core by the reactor building structure and the atmospheric air above the reactor.

So, the dose rate calculations need a three dimension massive code that has the capability for optimizing deep penetration shielding problems for achieving low relative uncertainties in short computing times. MAVRIC code [2] is a Monte Carlo dependent program effective and proper for calculating the dose rate for this type of problem. The dose rates would be calculated along a distance of 900 m from the reactor building during dropping the water level in the pool due to LOCA.

2 ETRR-2 and LOCA descriptions

ETRR-2 is a material testing reactor of 22 MW power and the core is a grid of 6×5 positions available for receiving fuel elements or irradiation boxes. The core consists of 29 fuel elements (FE) and in-core irradiation position. Each FE consists of 19 fuel plates (FP) and each plate has a meat made by a dispersion of U_3O_8 particles with an enrichment of 19.97 wt% in ^{235}U, in a continuous matrix of pure aluminum and sandwiched between two thin AL6061 plates. The reactor core is placed in a 4.5 m diameter stainless steel tank at a water depth of 11 m [3].

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The main pool of ETRR-2 is a cylinder of 13 m height and 4.5 m diameter constructed of stainless steel surrounded with heavy concrete to verify safe radiological conditions in radial direction [2]. The water is dematerialized water that represents radiological shielding in the vertical direction for personnel in the reactor hall area. ETRR-2 is provided with the core and the pool cooling systems which are capable of transferring the heat generated from the core and the auxiliary structure to the secondary cooling system.

Loss of water inventory through the connected systems can be caused by a leakage through pump seals, neutron irradiation tubes, heat exchanger cracks, cracks or breaks in the piping. In case of occurrence of water leakage simultaneously with loss of the water backup system, the water level in the main pool would decrease and consequently the reactor would be shut down.

Decreasing the water level in the reactor pool may result in increasing the radiological dose rate outside the reactor building depending on the water level value and the source (the core) strength. Studying the radiological dose rate levels is important for the sake of estimating the radiation dose that is exposed by the persons who locate around the reactor building during LOCA. The radiation dose rate would be calculated along a distance of 900 m from the reactor building during dropping of water level in the main pool.

3 The sequence of dose rate calculations

The sequence of dose rate calculations includes the determining the geometry and the description of the reactor building, the source (the core geometry, energy spectrum, and the neutrons/photons intensity), the proper variance reduction technique for the shielding problem, and the tally used to determine the dose rate with the conversion coefficient.

KENO-VI code [4] was used to model the reactor structure including the pool that contains the water above the core at different levels to simulate the LOCA. ORIGEN-S code [5] would be used to calculate the neutrons and the photons energy spectrums including the intensities.

MAVRIC input file would be developed to model the source, the conversion coefficient, and the tally. The core would be modeled as a rectangular parallelepiped with the same dimensions of the core.

3.1 The reactor building model

KENO-VI is a Monte Carlo program used for calculating the effective multiplication factor (k_{eff}) of three-dimensional systems as well as for modeling the problem of concern. KENO-VI has been used in this study to simulate reactor building structure (the surfaces and the geometries) including the pool, reactor hall, control room, first floor, ground floor, underground floor, and the core as shown in figure 1. The used materials are the specific materials of the reactor components. The atmospheric air above the reactor building is involved in the KENO-VI model to consider the skyshine reflection of the neutrons and the photons to the persons who locate around the reactor building during LOCA.

Fig.1: Vertical section of the reactor building model using KENO-VI.

3.2 The core radiation source

It was assumed that the reactor was at full power, 22 MW, until shutdown resulting from LOCA, and during this time, the photon and neutron intensities are dropping rapidly and can be well characterized by the photon and neutron decay libraries for spent fuel. In this model, the decay photon and neutron spectrums were applied for the core. The photons and neutrons source was calculated using the isotope generation and depletion code, ORIGEN-S, considering that each FE has 404.7 g of ^{235}U. A continuous irradiation during 275 days to a power of 22 MW was considered, and a burn-up of 103.1 GWd/MTU is achieved which corresponds to the maximum discharge.

The photon and neutron source intensities were calculated assuming no decay time (t= 0) after shutdown for conservative calculations. The photon and neutron spectrums were determined using the ORIGEN-S energy structure as shown in figures 2 and 3. These photon and neutron source intensities data, 5.278E+18 p/s and 6.45E+05 n/s respectively, were then introduced into the MAVRIC model to calculate the photon and neutron fluxes around the reactor building.

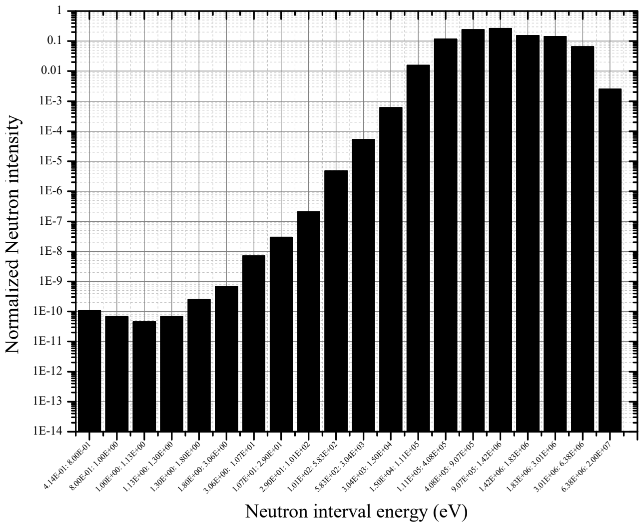

Fig.2. Neutron spectrum at time of LOCA.

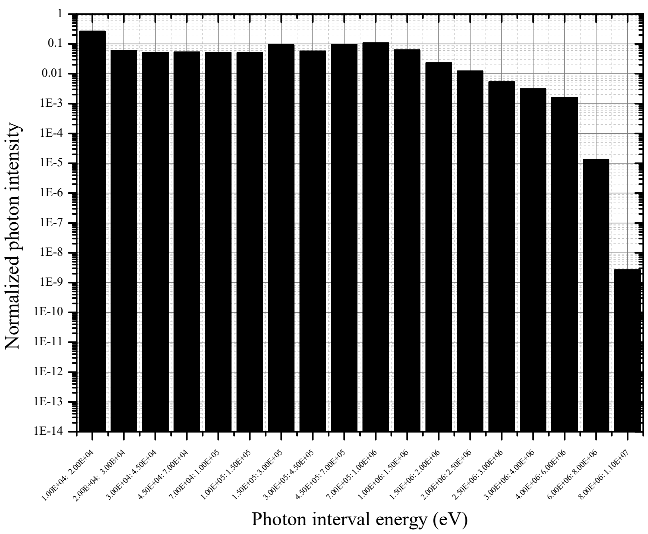

Fig. 3. Photon spectrum at time of LOCA.

3.3 The dose rate estimation

The MAVRIC code was used for analyzing the dose rates outside reactor building during LOCA. MAVRIC contains automated variance reduction techniques based on the CADIS and FW-CADIS methods that are effective for optimizing deep penetration Monte Carlo shielding problems for achieving low relative uncertainties in short computing times. MAVRIC uses the Denovo [6] discrete ordinates code to compute importance maps and biased source terms for the Monaco fixed-source Monte Carlo code, which can use multi-group or continuous-energy cross section data. Estimating the dose rate outside the reactor building depends on the water level above the core as well as the reactor building structure. The water level above the reactor core would be the variable parameter in the dose rate calculation. The source is isotropic and simulated as a rectangular parallelepiped shape with the real dimensions of the core (54.9 cm × 43.8 cm ×19 cm). The delayed neutron and photon spectrums that were calculated using ORIGEN-S are provided in the MAVRIC code. ICRU-57 conversion coefficients [7] would be used to convert the neutrons and photons fluxes to dose rate in Sv/h. Point detectors tally, multiplied by the photons and neutrons intensities, would be used to determine the dose rate at 13 positions distributed along the distance of 900 m from the reactor building.

4 Results and the discussion

The dose rates profiles around the reactor building during LOCA accident are illustrated in figure 4 considering the maximum burn up of the reactor core for conservative calculations. The horizontal line in figure 4 represents the radiological dose rate permissible limits, (1.0E-05 Sv/h) [8], considering that all the persons inside the 900 m distance are workers. The dose rate distributions around the reactor would be studied at the following water levels; 20, 40, 70, 120, 150, 170, 220 cm as shown in figure 4.

The dose rates around the reactor are equal to the permissible limits at the intersection points between the dose rate distribution curves with the horizontal line that represents the permissible limit. The intersecting points, at each water level, represent the positions around the reactor building at which the worker would be exposed to the permissible dose rate. The workers located at distances less than the intersecting points, for each water level, would be exposed to dose rate more than the permissible limit and vice versa.

Radiation dose rate profiles around the reactor building would be studied during loss of water level above the core resulting from LOCA. More than water level of 220 cm, the resulting dose rate would be less than the permissible limit as shown in figure 4. So the water level that ranges between 120 and 150 cm would be the critical level and the persons who locate outside the reactor building at any distance would be exposed to dose rate close to the permissible limit. For investigating the critical level in detail, figure 5 would be introduced to determine the water level that achieves the permissible limit outside the reactor at any distance.

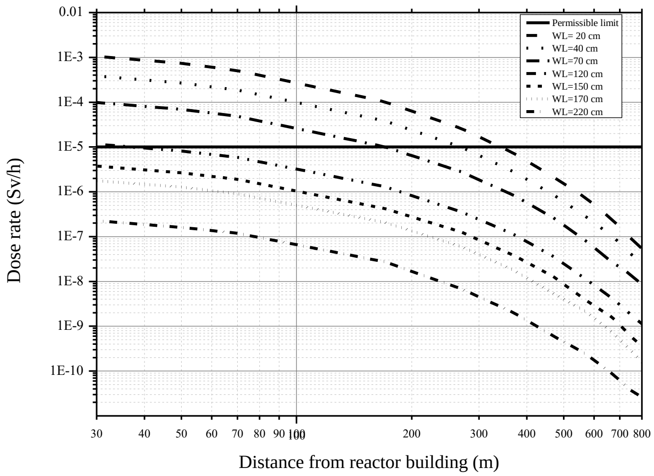

Fig.4. Distributions of dose rates outside the reactor during LOCA.

Figure 5 is isodose rate curves were plotted for the relationship between the water level and the distance from the reactor. This chart shows that the zone at which the dose rate would be higher than the permissible limit is the region under the dashed line (1.0E-5 Sv/h). In this zone, the person would be exposed to overdose rate and its value depends on the distance from the reactor building and the water level above the core.

The worker located at a distance more than 370 m would be exposed to a dose rate lower than the permissible limit at any aforementioned water levels. The worker who locates outside the reactor building at any position would be exposed to dose rate less than permissible limit if the water level above the core is more than 144 cm. Since, the water level of 144 cm is a sufficient shielding to protect the persons outside the reactor from exposure to overdose rate limit. So, constructing a cuboid structure above the reactor core to retain a water column of length equal to or more than 144 cm is essential for protecting the persons who locate outside the reactor from exposure to overdose as well as protecting the core from melting down due to the anticipated LOCA.

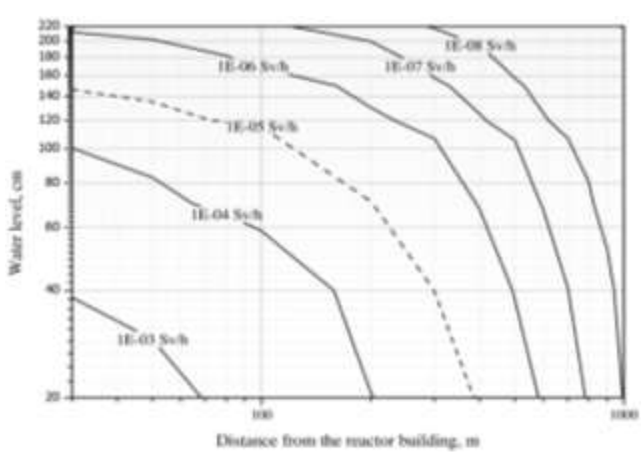

Fig. 5: The dose rate contours during LOCA.

5 Conclusions

A loss of coolant accident in an open pool type reactor was modeled in order to determine the distributions of dose rates around the reactor building using MAVRIC code. The model was applied conservatively at the maximum burnup of the core. The dose rate distributions around the reactor building were calculated during dropping of water level above the reactor core during LOCA and consequently, the positions that verify the permissible limit were determined. A chart of isodose rate curves were plotted to determine the positions at which the worker would be exposed to dose rate higher or lower than the permissible limit. Consequently, the received dose by the worker could be evaluated depending on the time of exposure during the accident. From the radiological safety viewpoint, the study focuses on the importance of constructing a cuboid structure to retain water above the core during LOCA. It shows that a cuboid structure height of 144 cm is sufficient to reduce the dose rate at any distance around the reactor building to lower than or equal to the permissible limit during LOCA.

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