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Calculation of Dose Rates in Loss of Coolant Accident Due to Double Ended Rupture of the Experimental Tangential Irradiation Beam Tube of MTR Reactor

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ABSTRACT

The doses and dose rates following a LOCA in a MTR reactor have been studied. A MTR reactor is an open water pool reactor type. The water pool serves as a shield from radioactive radiations.

The most serious accident in this type of reactors is the Loss of Coolant Accident (LOCA) due to rupture either of a primary coolant pipe or of any experimental beam tube. In the present work, it has assumed that pool water drains out due to double ended rupture of the tangential irradiation beam tube (TIC) which has a diameter 150 mm. For an operating power level of 22 MW, the equilibrium core would enter into melting conditions if the pool drain time is less than one hour.

It was also assumed that Emergency Core Cooling System (chimney water injection system and siphon effect breaker were not working. Therefore conservatively a severe damage (~80%) is expected to occur to the core, either by a core uncover situation following extended boiling operation, or by a core covered situation with extended boiling.

The reactor building, reactor hall and control room, have been modeled using the Monte Carlo N-Particle Transport code (MCNPX 2.7.0). The source term has been determined using the ORIGEN-2 code. The doses and dose rates calculations in different places of operator (as phantom of Tissue-Equivalent Material) inside of the reactor building were determined using the Monte Carlo N-Particle Transport code (MCNPX).The results show that the dose rate in the control room would be 5.24557 SV/h, the dose rate in the reactor hall above the pools on the gate would be7.20137 SV/h and the dose rate in the emergency control room would be 2.68239 SV/h. These dose rates are extremely high and would lead to fatal doses in short time.

1. INTRODUCTION

Averting high radiation dose exposure is necessary for the operation of a nuclear reactor. High radiation dose rates that the operator would receive cause an accumulated dose which may exceed the allowable annual limit. That is why some important locations in the reactor are inaccessible. The radiation dose level in the open-pool reactor may rise due to the following complex accident composed by: melt down of the fuel elements in the reactor core, expulsion of radiation materials from the reactor core, [1] and decreasing of the water level in the reactor pools due to the loss-of-coolant accident (LOCA). In the present calculations, the radiation dose levels resulting from radioactive materials, which are released from the core have been studied. [1]

The dose rates in different reactor locations as a consequence of LOCA have been determined. A multipurpose reactor (MTR) is an open pool type reactor, the reactor in the present study is the Egypt Second Research Reactor (ETRR-2) which is located at the Inshas Nuclear Center of the Egyptian Atomic Energy Authority, about 60 km from Cairo. ETRR-2 has a nominal power of 22 MW, light water moderated and cooled, designed and manufactured by INVAP,

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a company in Argentina. It has two pools, the main pool and an auxiliary pool. The main pool contains the reactor core, the irradiation grid, a part of the core cooling circuit and pool cooling system, and the radial and tangential irradiation tubes, as shown in Figure (1) [2]. The two pools are connected by a transfer channel that is used to transport the irradiated materials and spent-fuel from the main pool to the auxiliary pool underwater to avoid increasing the radiation doses during the transport processes. A shielding water layer of 4.6-m thickness is enough to keep the radiation dose rate in the reactor building at a lower level than the permitted limit. Decreasing in the water level, due to malfunction or accidents, results in raising the radiation dose rate in the reactor building.[2] LOCA is an accident that may occur in nuclear reactors as a result of rupture or breaking in cooling system pipes or neutrons irradiation tubes. This leads to the decrease in the level of water in the reactor pools [2] and, consequently, raising the radiation dose levels that would prevent access to the reactor building, reactor hall and the control room. The collected dose rate depends on the time that operator stays in the reactor and on the activity of the fission products gases released during LOCA. [12].

The Monte Carlo N-Particles Transport code (MCNPX-2.7.0) [5] was used to calculate the dose rates in the reactor building, especially in the reactor hall and the control room, resulting from breakage in tangential irradiation tube. If the tangential beam tube(TIC) is broken while being used without the blind flange or inner metallic cover “glove finger”, the core will be successfully shutdown (either manually or in an automatic way by a low pool water level signal). Reactor automatic shutdown is expected between 2 min to 10 min after the breakage occurrence [4] .Thus, while the water level drops in the main pool, the dose above the main pool will increase; when the dose exceeds 250µSv, the reactor will SCRAM (shut down), the water level in the main pool would continue to drop until it reaches the level of TIC tube (located above the core by 60cm) and the dose continues to decrease [2, 6].

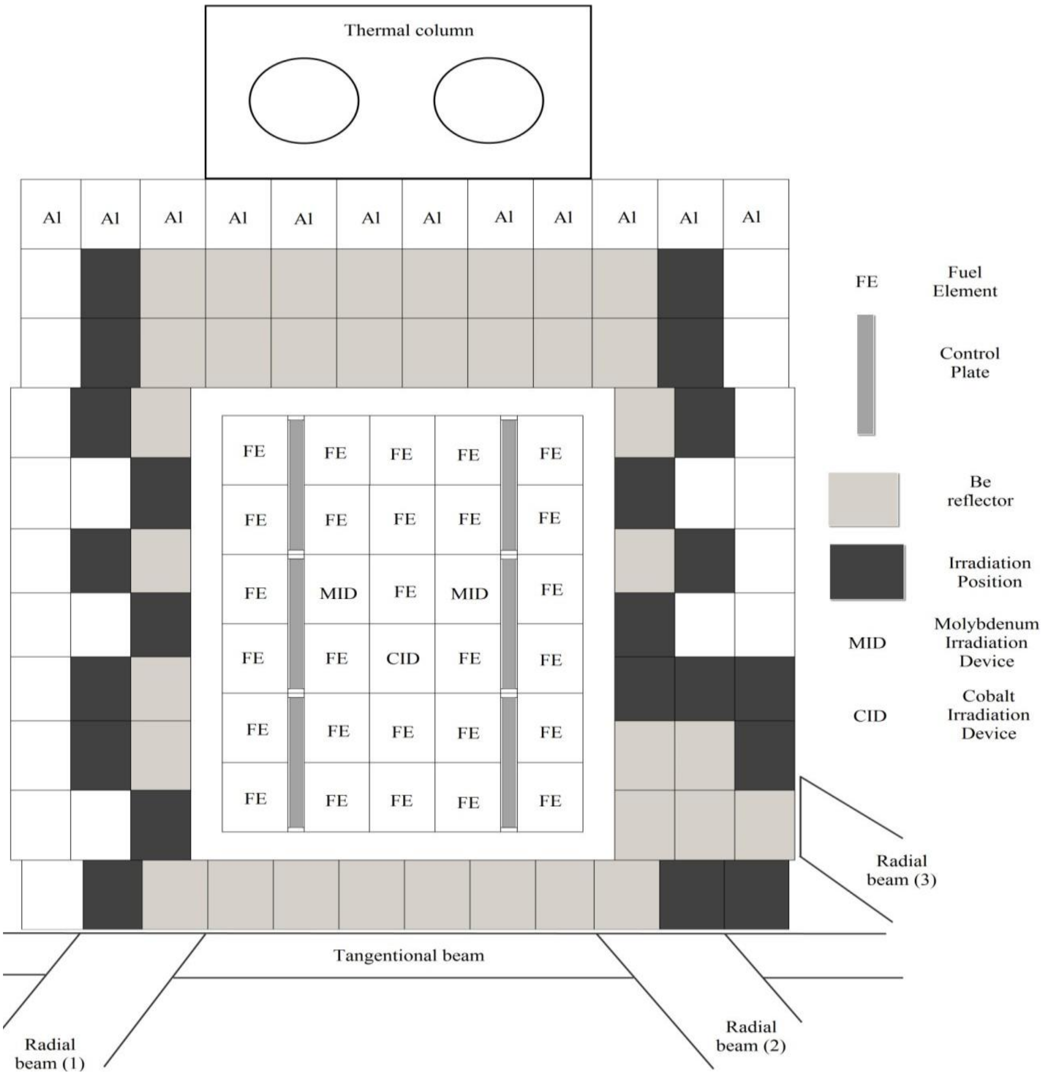

Fig. (1): ETRR-2 core and beam tube

1.1. Description of loss coolant due to breakage in tangential irradiation tube TIC

The tangential beam is a cylindrical aluminum tube with an external diameter of 200 mm, internal diameter of 150 mm. and length of about 4000 mm. Stainless steel ends are flanges, placed in the tank internal wall. One of the ends has stainless steel bellows for component shortening during installation. A pneumatically operated tool produces component shortening. A beryllium block is screwed at the tube central area. The tube traverses twice through the reactor tank wall. The tangential beam connects the tank penetration to the concrete shielding external face that supports the beam shielding box. This component consists of a stainless steel tube of 8" externally covered with a 2 mm thick Cadmium sheet. The shielding box holds the beam end, closed by an aluminum cover with lodging for a ring seal, pressed by an articulated arm with fastening pivot screw as shown in Fig. (2).[2,3]

1.2. Accident scenario description

In the following, the description of the accident scenario sequences will be given:

(I)The reactor is operating at full power (22MW thermal) with two core cooling pumps (2000m^3/h).

(ii) A hypothetical event breakage in tangential irradiation channel (TIC) occurs.

(iii) The reactor will be scrammed when the water level in the main pool drops to 100 cm below the normal level. This leads to an increase of the dose on the main pool surface above the scram safety limit value;

(iv) Emergency Core Cooling System (chimney injection system) fails to operate;

(v) The reactor operator makes no attempt to save the core by moving it to the healthy section of the pool and isolating it by using the pool dividing gate;

(vi) The reactor core is partially/fully exposed to air after 36 min (using Bernoulli's equation)[6].

(vii) The temperature of the clad will be increased because of the decay heat and will reach the melting temperature of clad alloy.

(viii) The fission products gases will be released. [4]

From these emissions, activity of radioactive iodine I ^{131} was considered to be of interest for this study, it is photons energy branch [9] which fill the reactor hall. To calculate the inventory of I ^{131}, ORIGEN2 code was used [7].

The ETRR-2 fuel element consists of U3O8-Al with 19.7%.^{235}U enrichment. There are different types of fuel elements with different masses of ^{235}U as the reactor was assumed to operate for a total of 195 days at maximum power of 22 MW, the burn up level 120000 MWD/TU being achieved, which corresponds to the maximum fuel burn up [2]. The inventory of I ^{131} before decay was determined to be 3.828×10^{16}Bq. All fuel elements in core were considered at the maximum burn up at the time of the accident, for conservative calculations [8]. This activity together with the tally multiplication factor are used to calculate the total iodine source, which is then introduced into the MCNPX model to calculate the dose rates in the reactor hall, control room and other places in the reactor building.

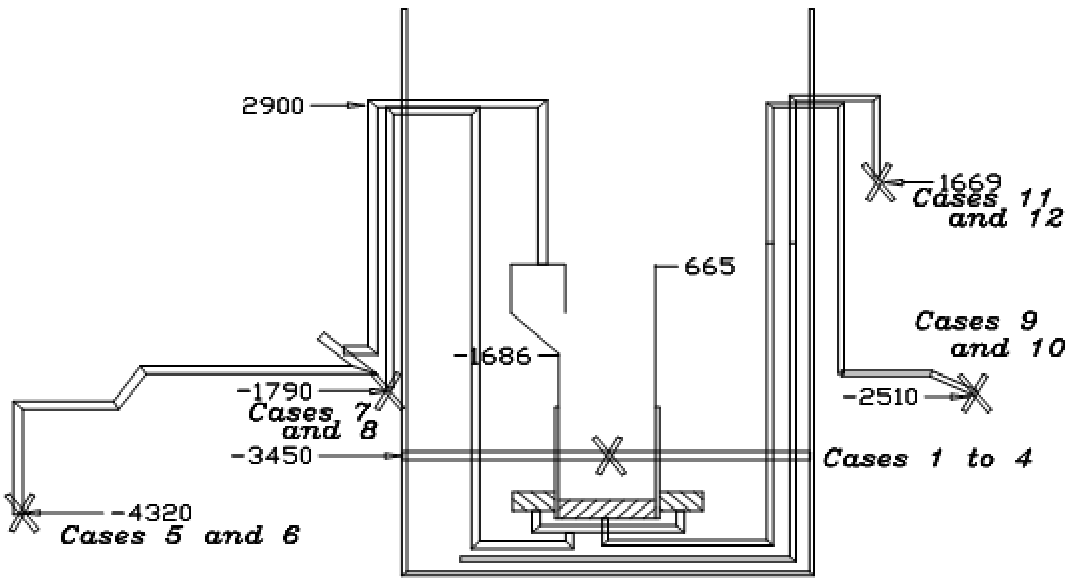

Fig. (2): Location of tic channel

2. The Monte Carlo N-particle transport model

The MCNP model for ETRR-2 includes the reactor building, reactor hall and control room which is filled with radioactive I^{131}. The reactor hall contains the two pools (main pool and auxiliary pool). The fuel elements are immersed in water and distributed in the main pool, which has a cylindrical wall of stainless steel and heavy concrete in radial direction. The source term of radioactive I^{131} distributed in the main pool and reactor hall was calculated to have an activity of 3.828×10^{16}Bq. The source distribution in the reactor was modeled by MCNPX as shown in Figure (3). From this activity together with the tally multiplication factor, the total source was calculated to be 2.3×10^{10} photon/cm^3. [2]

The dose rates were determined in the situation of the core partially uncovered of water. By the rupture of TIC beam tube, the water level in the main pool decreased to the minimum level at which the water layer could drop due to LOCA, and the reactor core remains partially uncovered. The dose rate calculation was performed for phantoms chosen in important locations in the reactor building, depending on the locations in which the operators may exist. The higher dose rates for phantoms expected that in reactor hall and this dose is much higher than the permissible limit of deterministic health effects, it is 500mSV/h. [9, 10, and 11]

According to MCNP capabilities, the F6 tally was used to calculate the energy deposition in units of MeV/g per source of phantom for 19 different locations in the control room, reactor hall, lab and other places in the reactor building. The phantom refers to a person in the selected locations having 170cm in height, 11.5 cm in diameter, and consists of Tissue-Equivalent Material, as shown in Figure (4). The Figure shows the phantoms from the reactor hall, main pool and auxiliary pool in xz diagram, the phantoms from the facility lab (neutron activation analysis lab) in yz diagram, and the phantoms from the reactor hall, control room and the two pools in xy diagram. In order to obtain the results for the dose rates in units of **(SV/h),** the dose function DF6 card was used. [5] The relative errors for the dose rate collected by the phantoms were often <6%.

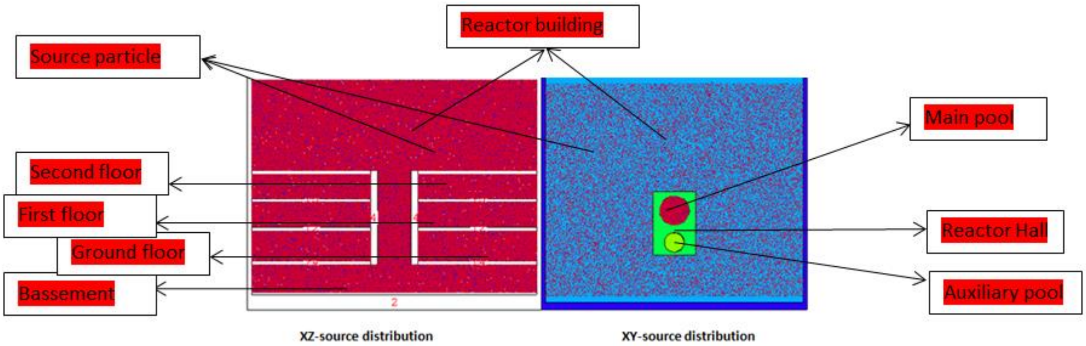

Fig. (3): Source distribution of I^{131} in the ETRR-2

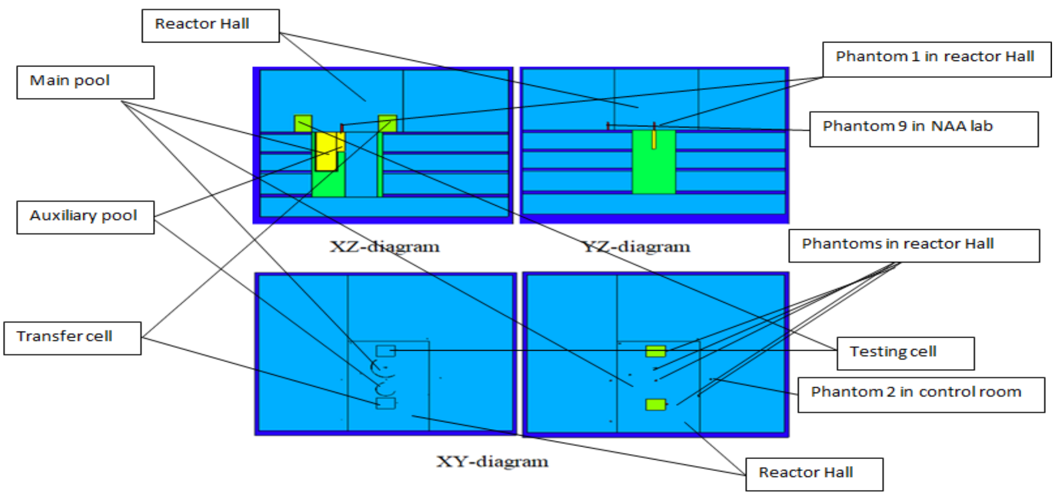

Fig. (4): the phantoms in the reactor building in different distributions

3. RESULTS AND DISCUSSIONS

The expected dose rate in ETRR-2, during normal operation, must be determined in order to ensure the radiological safety of the reactor design. During abnormal operation and during accidents similar to the one under investigation in this study, the water drains from the main pool, the reactor core are either totally or partially uncovered. Consequently, the doses obtained in the locations from the reactor building considered in the present work rise to extremely high levels. It was found that the dose rate registered on the gate between the main pool and the auxiliary pool, in the reactor hall, was 7.20137 Sv/h, and the dose rate in the control room was 5.24557 Sv/h, both are much higher than the permitted dose rate limit (10 µSv/h).[9]

Table (1) presents the dose rates received by the different phantoms considered in the reactor building, including the reactor hall, control room, emergency control room, facility labs and offices. The statistical errors in the dose rates are also shown in the Table.

Table (1): dose rates collected by the phantoms considered in the reactor building

Phantom no and place	Dose rate(SV/h)	Error
phantom 1 in control room	5.24557E+00	0.0318
phantom 2 between main pool and auxiliary pool	7.20137E+00	0.0242
phantom 3 reactor hall (topaz loading test)	5.96126E+00	0.0304
phantom 4 reactor hall (transfer cell)	3.16165E+00	0.0440
phantom 5 reactor hall (test cell)	3.62893E+00	0.0406
phantom 6 reactor hall (enter)	5.13006E+00	0.0312
phantom 7 reactor hall (exit)	5.77801E+00	0.0308
phantom 8 in training room	5.84710E+00	0.0308
phantom 9 in lab	5.72054E+00	0.0306
phantom 10 in (HPFA)	4.10685E+00	0.0370
phantom 11 in radiation protection lab	3.07695E+00	0.0424
phantom 12 electronic maintenance lab	2.61236E+00	0.0470
phantom 13 in head office	2.80865E+00	0.0439
phantom 14 in IT and maintenance office	2.97733E+00	0.0433
phantom 15 treatment 520 Emergency door	2.62624E+00	0.0442
phantom 16 in Emergency control room	2.68239E+00	0.0449
phantom 17 in neutron activation lab	2.79035E+00	0.0435
phantom 18 in reactor building exit door	1.68266E+00	0.0583
phantom 19 in the basement, near mechanism door (waste tank)	2.54609E+00	0.0420

In the control room, the dose rate is considered a scattered dose rate, since there is no direct connection between the operator located in the control room and the reactor hall.

As one can see in Table (1), the dose rate on the gate between the main pool and the auxiliary pool was 7.20137 SV/h, the dose rate in the control room was 5.24557 SV/h and the dose rate in emergency control room was 2.68239 SV/h. Those were registered for phantoms 2, 1, and 16, respectively. Figure (5) shows the variation of the dose rates with the time for phantoms considered in the control room, reactor hall and the emergency control room. After 10 min, phantom 1 in the control room receives a dose of 874 mSv, phantom 2 in the reactor hall receives a dose of 1.207 Sv, and phantom 16 in the emergency control room receives 447 mSv, as shown in before mentioned Figure. These doses will be high enough to cause deterministic health effects, considering that such effects begin to appear at approximately 500 mSv. Indeed, for emergency planning, these doses may be compared to the existent standards allowing emergency workers to perform certain lifesaving or protecting actions [9].

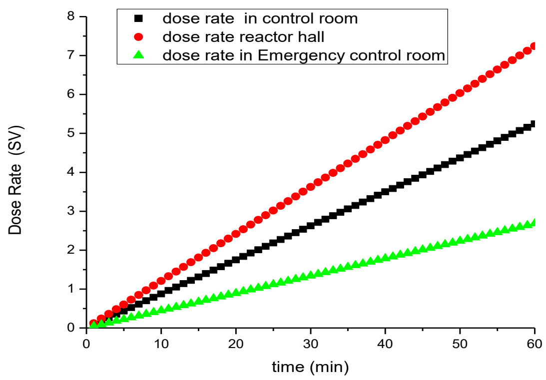

Fig. (5): External photon dose rate to phantoms in three positions for a I^{131} gas cloud with time

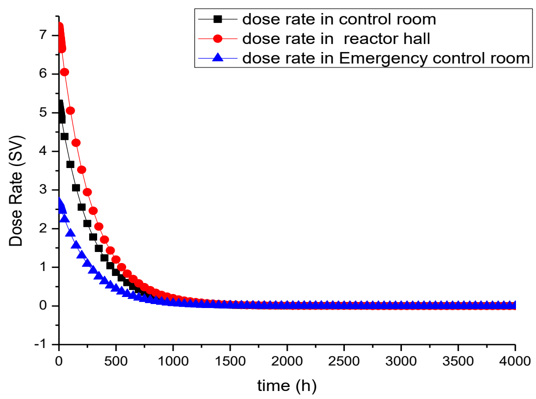

Fig. (6): External photon dose rate decay in three positions decay for a I^{131} gas cloud dispersed throughout the reactor hall with time

Figure (6) shows the dose rate decay evolution with time in the ETRR-2 control room, reactor hall and emergency control room. The calculation is useful to determine the time when the emergency workers can enter the reactor after this accident and show the decay of the dose resulting from the release of I^{131} during core meltdown. In ETRR-2, the dose rate is calculated by decay equation $\mathbf{D = D_0\ EXP\ (\lambda t)}$, where λ is decay constant I^{131}.

In the three important positions, as shown in Figure (6), the dose rate in the control room was 5.24Sv/h, after 50 days (=1200 hours) the dose rate becomes 50 mSv/h and for this dose rate level the emergency workers can enter the reactor control room for necessary purposes only. After 127 days (=3050 hours), the dose rate will be less than 100 μSV/h, at this time a worker being able to enter the reactor and work, but only for one hour a day. The dose rate in control room becomes less than the permitted limit of 10 μSv/h after 152.08 days (=3650 hours), at this time a worker is able to enter the reactor control room and work.

In the reactor hall, the calculation for the position between the two pools (on the gate) gives the dose rate of 7.24 Sv/h, the highest dose rates registered for this study. The dose rate in this location will be 96.3 mSv/h after 50 days (=1350 hours), and after 56.25 days (=1350 hours) days becomes 56.132 mSv/h at this level a worker is able to enter the reactor control room for necessary purposes only. After 130 days (=3120 hours), the dose rate will be less than 100 μSV/h, at this time a worker is able to enter the reactor and work, but only for one hour a day. The dose rate in reactor hall reaches the permitted limit, i.e. becomes less than 10 μSv/h, after 156.25 days (=3750 hours), at this time a worker is able to enter the reactor hall and work.

In the location from the Emergency control room, the dose rate obtained from calculations is 2.68 Sv/h. After 50 day (=1200 hours), the dose rate in the emergency control room becomes 35.6 mSv/h, at such dose rate a worker is able to enter the reactor Emergency control, if needed only. After 118.75days (=2850 hours), the dose rate will be less than 100 μSv/h, at that time a worker is able to enter the reactor and work, but only for one hour a day. The dose rate in the emergency control room becomes within the permitted limit, i.e. less than 10 μSV/h after 143.7days (=3450 hours), at that time a worker is able to enter the reactor and work.

The calculations of dose rate decay helps the decision makers to take the appropriate actions in the specified times.

4. CONCLUSIONS

- Radiological consequence resulting from water level drop from the reactor main pool due to LOCA resulting from rupture of TIC beam was studied using the MCNP code. The dose rates were conservatively calculated by assuming that partial core meltdown occurs and the core becomes uncovered by the water layer.
- In present study, the calculations of the dose rate in ETRR-2 during LOCA accident due to I^{131} release show that the dose rate received by the operator in the control room (represented by phantom1) would be 5.2455 Sv/h, the dose rate for the operator in the reactor hall (represented by phantom 2) positioned between the main pool and the auxiliary pool (on the transfer gate) would be 7.20137 Sv/h, and the dose rate for operator in the emergency control room (represent by phantom16) would be 2.6829 Sv/h.
- If the operator stays 10 min in the ETRR-2 reactor, the calculations give that the accumulated dose for operator in the control room (represented by phantom1) would be 874 mSv, and for the operator in the reactor hall (represented by phantom 2) between the main pool and the auxiliary pool (on the transfer gate) would be 1.2 mSv, and for the operator in the emergency control room (represented by phantom16) would be 447.15 mSv.
- The decay of the dose rate in the reactor hall which results from I^{131} cloud due to LOCA accident takes a lot of time to reach the permitted limit allowing workers to enter for any action dealing with accident remedy. The permitted limit is 10 μSv/h, and as one can see from Figure (6), it takes 152.08 days (=3650 hours) to reach this limit in the control room, and 156.25 days (=3750 hours) to reach this limit in the reactor hall.
- Finally, all the time periods have been determined based on the dose rates collected by phantoms during a severe accident calculations. Hence, in a real case, the doses may be higher than the calculated ones.

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