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Research Article

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Radiological Evaluation of an Alternative Path to Transport Cobalt Device after Irradiation in Open Pool Type Reactor

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Abstract This study suggests an alternative path to transport the cobalt device after irradiation in open-pool-type reactor from the reactor core to the cobalt cell. The cobalt transport process in current path depends on using heavy shielded cask, 1500 Kg weight, under water surface of spent fuel storage pool which may cause a missile impact of spent fuel accident (Falling of heavy load into spent fuel storage pool). To avoid using the shielded cask, an alternative path is suggested depending on transporting the cobalt device through the hot cells of the reactor; the testing and the cobalt cells. The expected radiation dose rate rise associated with the alternative transport path must be evaluated at positions which the worker will be found during transport process. MCNP simulation code was used to determine the dose rate levels along the suggested transport path; over spent fuel storage pool water surface, and around testing and cobalt cells. The calculated results show rise in radiation dose levels more than the permissible dose rate limits around testing cell. Suggested procedures are presented in this study to decrease the received dose by worker found around testing cell during transport process. The results obtained using MCNP5 were validated by comparing them to those obtained using Microshield5.05 code. Results of these comparisons are presented and discussed.

Keywords MCNP code; radiation dose; open pool reactor; cobalt production; hot cell; ALARA principle

1. Introduction

Cobalt-60 is an artificial isotope has a half-life of 5.3 years produced in nuclear reactors from ^{59}Co by neutron absorption. Although, cobalt device is a fixed and in-core experiment in open-pool-type material testing reactor (MTR), of average neutron flux of 1.4E14 n/cm^2.s, but it still being irradiated to reach the required specific activity suitable for medical and irradiation applications demands. It needs 455-days of neutron irradiation time to reach the activity of 3.7E14 Bq which has not been verified till now. Transporting the cobalt device inside the reactor after irradiation is an important process and must be planned and optimized previously to achieve better performances with keeping the best level of safety. The cobalt device is clamped in the reactor core which located at depth of 10 m under the main pool water surface. After reaching the required activity, the device is removed from the core during reactor shutdown mode and transferred from main pool to auxiliary pool (spent fuel storage pool) and then delivered to the cobalt cell for preparing to different applications. Although, the current path of the device transport has not been used before but due to the risks associated with loading the device into the shielded cask under pool water surface, an alternative path was proposed in this study to avoid using the shielded cask during transporting the cobalt device from auxiliary pool to cobalt cell for the sake of ensuring safety of members of the public and occupational workers as well as protection of environment.

The radiological dose levels associated with the alternative transport path were calculated to assess the radiation dose received by the workers during cobalt device transport process. MCNP5 code [1] was used in this study to estimate the predicted radiation dose rates at positions that the worker would be located during transport process in MTR; over the auxiliary pool surface, and around testing and cobalt cells. Microshield code [2] was also used to validate the MCNP5 results.

2. Methods

2.1. Description of MTR

The MTR facility is an open pool type reactor of 22 MW thermal power core. The reactor contains main and auxiliary pools connected with transfer channel to enable transporting radioactive materials and spent fuel between the two pools [3]. The main pool houses the core, at depth of 10 m under water surface, which represent sufficient radiological shielding during normal operation. The auxiliary pool contains spent fuel element storage racks covered with more than 4 m of water. The core is built on a supporting grid having 6×5 positions available for placing fuel or irradiation boxes. The core consists of 29 fuel elements (FE) and irradiation position for cobalt device irradiation. The cobalt device is a fixed and in-core experiment, clamped at the bottom of MTR reactor core, and cooled by upward water coolant. The cobalt device is irradiated by thermal neutron flux of 2.4×10^{14} n/cm^2.s in irradiation box. The cobalt device has a holder made of aluminum with length 36 cm, containing cylindrical tubes of radius 0.77 cm [4] as shown in fig. 1.

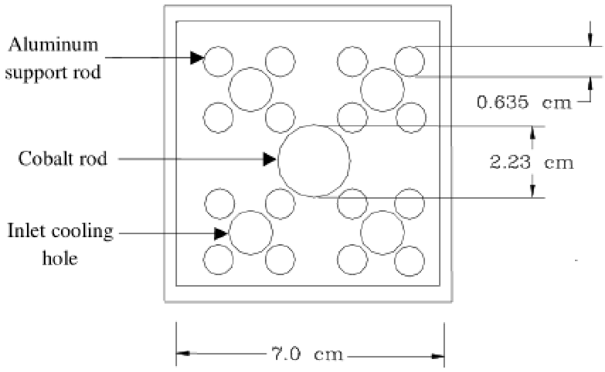

Figure 1: Cross section of cobalt device

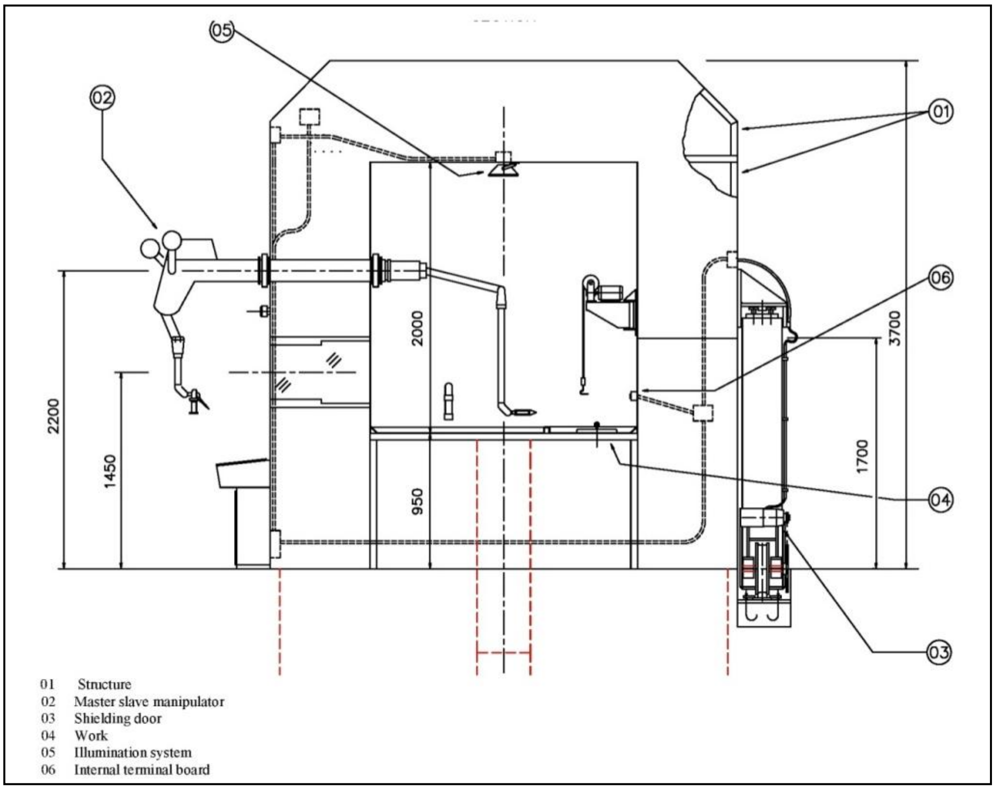

Figure 2: Testing cell

The core is optimized for production of 3.7E14 Bq of ^{60}Co for each transport route. Different hot cells are available in the reactor facility. They include the testing cell, the transfer cell, and the cobalt cell. Testing and cobalt cells are the main cells that would be used in the alternative path for transporting cobalt device. The testing cell is used in the alternative path as an intermediate station for cobalt device before delivering to the cobalt cell. The testing cell is located inside the reactor hall at the second floor beside the auxiliary pool. It is connected to the auxiliary pool by means of a conduct provided with a sample holding cart. The testing cell, as shown in fig. 2, has dimensions of 2.5 × 2.5 m and a height of 3 m [5].

The shielding walls of the testing cell are made of heavy concrete of thickness of 80 cm with a lead glass view window of 45.7 cm wide by 45.7 cm height and a thickness equivalent to 80 cm of heavy concrete [5]. . The testing cell is provided with an iron shielded door of 30 cm thickness for access of personnel and containers. The cobalt cell is located at the ground floor and has dimensions of 2.2 × 2.7 m and a height of 3.5 m as shown in fig. 3.

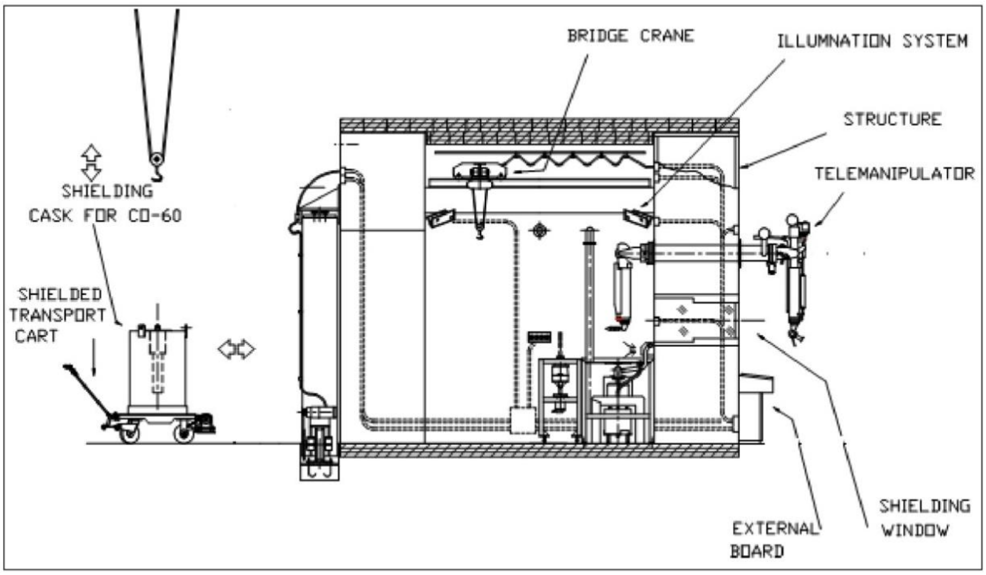

Figure 3: Cobalt cell

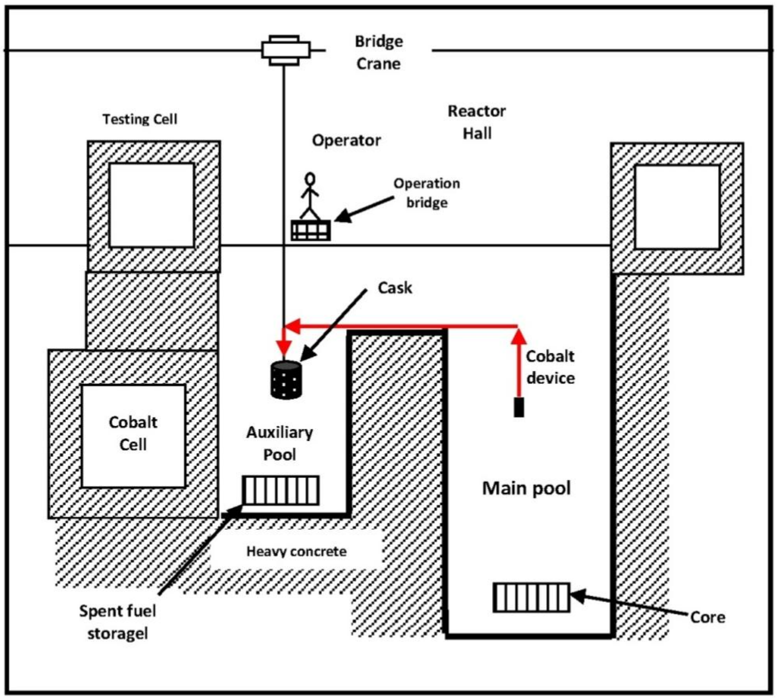

Figure 4: The current path for cobalt device (red line)

The shielding walls of the cobalt cell are made of heavy concrete of thickness of 105 cm with a lead glass view window of 40 cm wide by 70 cm height and a thickness equivalent to 105cm of heavy concrete. The cell is provided with an iron shielded door of 43 cm thickness for access of personnel and containers. The cells are provided with master and slave telemanuipulators to enable the correct handling of elements, as well as to accomplish the tasks which would be carried out in these cells.

2.2. The Current Path of Cobalt Device Transport

As shown in fig. 4, the current path of transporting the irradiated device is divided into three stages:

- Removing the cobalt device from the core and transporting it from the main pool to the auxiliary pool via the transfer channel connecting the two pools using handling tools operated from the operation bridge.
- Using the reactor hall bridge crane, a shielded cask of 1500 Kg is lowered under water surface in the auxiliary pool to load the cobalt device.
- The transport cask is then raised from the auxiliary pool and transferred through vertical opening that connects the reactor hall to the ground floor, where it is unloaded on a cart to transport it to the cobalt cell.

Failure of the electric motor or the hoist brake, breaking off the sling cable, and interruption in the electrical power supply, can lead to cask-drop accident with occurrence probabilities of 3×10^{-5}/h, 1×10^{-3}/h, 1×10^{-6}/h, and 10/yr consequently [5]. Falling of an object would cause an impact on one or more spent fuel elements [6] and so, a heavy cask drop on the auxiliary pool would certainly cause damage on spent fuel elements and an eventual release of fission products could result in offsite doses that exceed permissible limits.

Therefore, an alternative path is suggested in this study to avoid such accident may be occurred during the current transport path.

2.3 The Alternative Path of Cobalt Device Transport

In the proposed path, as shown in fig. 5, the device would be transported by using handling tools to the testing cell through the transfer channel that connects the auxiliary pool with the testing cell under water surface. Then, the device would be delivered to the cobalt cell at ground floor through a duct within the surrounding concrete. The duct connects the testing cell at the reactor hall with the cobalt cell on ground floor as shown in fig. 5.

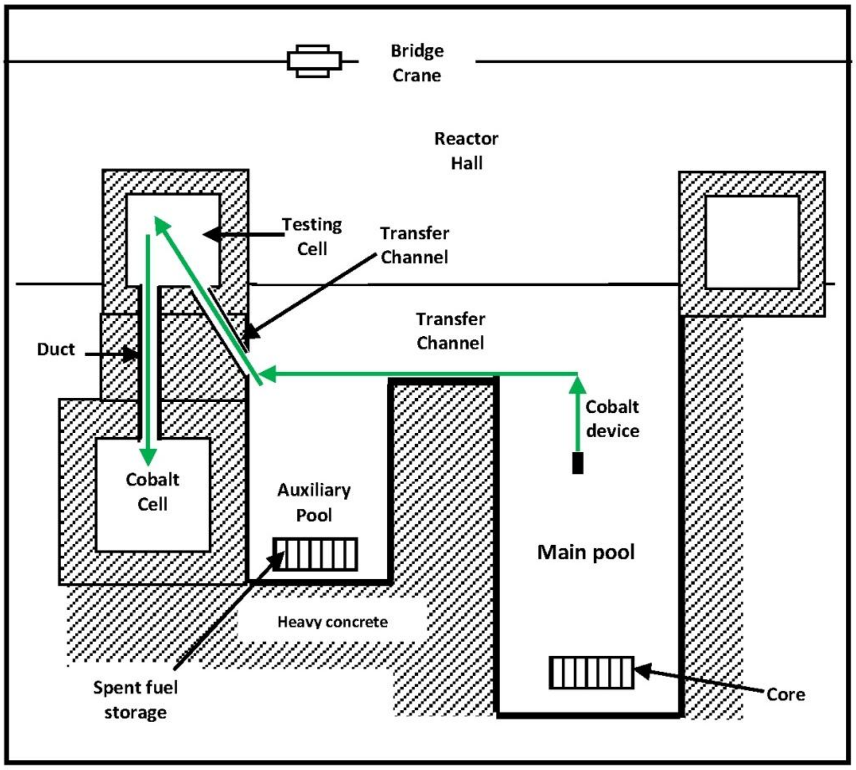

Figure 5: The proposed path for cobalt device (green line)

The testing cell would be used, in the alternative path, as an intermediate station for the cobalt device before delivering to the cobalt cell and so, there is no need to use the shielded cask. The dose rate associated with the proposed path needs to be evaluated to ensure personnel safety.
The cobalt device, along the proposed path, will be found mainly in three different positions;

- Inside the auxiliary pool under water surface of 304 cm depth.
- Inside the testing cell.
- Inside the cobalt cell.

So, the radiation dose rates must be evaluated at positions where the operators would be found during the transport process; over the auxiliary pool surface, around testing cell, and around the cobalt cell. In the alternative path, the operators would work mainly at the front of lead-glass windows of the testing and cobalt cells.

2.4. MCNP5 Simulation

MCNP5 code was used in this study to calculate dose rate for different stages of the alternative transport path of the cobalt device. The auxiliary pool was presented as a cylindrical surface and the testing and cobalt cells were presented by rectangular parallelepiped surfaces. Dimensions were taken from the architectural drawings of the reactor. The source was isotropic and defined as a cylindrical volume with tabulated energy distribution simulated with SI1 and SP1 cards to represent the energies and frequencies of gamma-ray of ^{60}Co. Phantoms of cylindrical shapes with dimensions of 170 cm length and 23 cm diameter were used to simulate workers at the following positions:

- On the bridge crane over the auxiliary pool water surface.
- At the front of the lead-glass window of the testing cell.
- At the front of iron door of the testing cell.
- At the front of the lead-glass window of the cobalt cell.
- At the front of iron door of the cobalt cell.

A soft tissue composition in ICRU report-44 [7] was used to simulate the phantom composition.
The F4 tallies, in conjunction with a dose function [8] card and a FM multiplier card for the cobalt device activity (3.7E+14 Bq), were used to calculate the dose rates for the phantoms.

2.5. Microshield V5.05 Code Simulation

Microshield v5.05 code was used to evaluate dose rates around the testing and cobalt cells, a source of cylindrical side-shielded model was used to simulate the cobalt device of height of 36 cm and radius of 0.77 cm with activity of 3.7E14 Bq. The walls of testing and cobalt cells were modeled as slab of heavy concrete of thicknesses of 80 cm and 105 cm respectively. A source of cylindrical end-shielded model was used to simulate cobalt device under pool surface. Slab of water, of different thicknesses, was used to simulate the different depths of cobalt device under pool water surface. The calculated dose rates for each stage were compared with the results of MCNP5 code as shown in table 2.

3. Results and Discussion

Table 1 shows the calculated dose rates received by phantoms resulting from transporting cobalt device under pool water surface, and inside each of the testing and the cobalt cells using MCNP5 and MS5 codes. Investigation of table 1 reveals that the calculations provided by MS5 and MCNP5 codes were in a good agreement. Table 1 shows that the results provided by MS5 code were higher than MCNP5 code in some points of calculations and the ratio (between MS5 and MCNP codes) reached 1.3 and 1.6 for heavy concrete thickness of 105 cm and water thickness of 260 cm respectively. Radiation dose rates mainly arise in MS5 results from buildup factors where, for high shield thicknesses, the deviance increases due to photons scattered in the shields. The MS5 user guide mentioned that the maximum percentage error in MS5 code calculations was 30% which I considered in this study.

Table 1: Calculated dose rates resulting from the cobalt device for positions of under the pool surface, inside the testing cell, and inside the cobalt cell.

Cobalt device positions		Phantom positions	MCNP5 dose rate, Sv/h	MCNP5 Errors	MS5 dose rate, Sv/h	MS5 Errors	MS5/MCNP5 Ratio
Cobalt device depth under auxiliary pool water surface, cm	30	At 50-cm over the auxiliary pool water surface	5.3	5%	5.411	30%	1.02
	60		0.667	7%	0.7542	30%	1.13
	90		0.1	9%	0.105	30%	1.05
	120		1.33E-2	10%	1.5E-2	30%	1.13
	150		2.1E-3	11%	2.16E-3	30%	1.08
	180		2.66E-4	11%	3.14E-4	30%	1.18
	210		4.0E-5	12%	4.5E-5	30%	1.125
	230		6.9E-6	15%	8.35E-6	30%	1.2
	260		7.69E-7	20%	12.3E-7	30%	1.6
Cobalt device inside testing cell	At 25-cm from the testing cell window	At 40-cm from lead-glass window	2.40E-4	10%	2.69E-4	30%	1.1
		At 20-cm from iron door	2.96E-4	10%	3.5E-4	30%	1.2
Cobalt device inside cobalt cell	At 25-cm from the cobalt cell window	At 40-cm from lead-glass window	6.E-6	10%	7.8E-6	30%	1.3
		At 20-cm from iron door	3.3E-6	10%	4.E-6	30%	1.2

MCNP5 code results were adopted in this study because of sophisticated simulations and accurate calculations. Transporting cobalt device under auxiliary pool surface, the dose rate calculations were carried out for different depths of the cobalt device to determine the suitable depth to conduct the transport process at a radiation dose level less than permissible limit as defined in ICRP60 [9]. Table 1 shows the calculated dose rates over the auxiliary pool water surface versus the cobalt device depth and it is obvious that at depth of 230 cm, a worker would receive a dose rate less than the permissible dose rate limit [10.E-6 Sv/h]. The transfer channel connecting auxiliary pool and testing cell locates at depth of 304 cm from auxiliary pool surface and so the dose received by a worker located over the auxiliary pool surface would be less than the permissible limits.

In the second stage of alternative path and during transporting the device inside the testing cell, the worker always located at front of lead-glass window to receive the device from the auxiliary pool to deliver it into the cobalt cell using telemanupulators. Table 1 shows that the worker at front of lead-glass window would be exposed to dose rate, of 2.4E-4 Sv/h, which is higher than the permissible limit. The worker, located rarely at the front of iron door, would be exposed to dose rate, of 2.9E-4 Sv/h, which is higher than the permissible limit.

The accumulated dose received by worker located at front of the lead-glass window of the testing cell could be minimized by applying ALARA (As Low As Reasonable Achievable) principle; minimizing the time of radiation exposure in this stage by sharing the radiation exposure among multiple workers, and minimizing dose rate level by using additional shielding materials without affecting the vision and the flexibility of the operation. Where, the permissible annual radiation dose for worker is 20 mSv, as recommended by ICRP60, then the permissible dose rate, for 2000 working hours per year, is 20 mSv/2000 h = 10 µSv/h or 80 µSv/day. And so, the time of exposure for each worker should not exceed [80 µSv/ 240 µSv/h = 20 min/day] to avoid exceeding the permissible limit. The second suggestion was adding additional shielding; two rows of bricks of heavy concrete of dimensions of 20 cm×10 cm×10 cm cladding with layer of lead (available in the facility) could be sufficient to decrease the received dose by worker in this position to permissible limit.

In the third stage of alternative path, inside cobalt cell, the worker, located at front of the lead-glass window, would spend long time in receiving and preparing the cobalt pellets before delivering to consumers. Table 1 shows that the workers located at front of the lead-glass window and iron door of cobalt cell would be exposed to dose rates of 6.E-6, and 3.3E-6 Sv/h respectively (lower than the permissible dose rate limits).

Finally, a comparison between the calculated dose rates for present and alternative paths are presented in the table 2.

Table 2: Expected dose rate for the current and suggested paths

Cobalt device positions	Worker positions	Expected dose rate for current path	Expected dose rate for Suggested path	
			Applying ALARA	Without ALARA
Under pool surface at depth of more than 260 cm	Over the pool water surface	~ 1 μSv/h	~ 1 μSv/h	~ 1 μSv/h
Inside the shielded cask	Around the cask	Less than 10 μSv/h	----	----
Inside the testing cell	At front of testing cell	-----	Less than 80 μSv/day for exposure time of 20 min.	240. μSv/h
Inside the cobalt cell	At front of cobalt cell	Less than 10 μSv/h	2.3 μSv/h	6 μSv/h

Although, table 2 shows that radiological dose rates associated with the present path for each stage were within the permissible limits and lower than those associated with alternative path, but the risk associated with present path and applying of ALARA principle in alternative path makes it preferable to use the alternative path.

4. Conclusions

A path for transporting the irradiated cobalt was presented as an alternative path to avoid the cask-drop accident probably occurred during the current path. MCNP5 simulation has been performed to compute the dose rate levels during cobalt device transport from the core to cobalt cell. Although, the calculated dose rates levels associated with the alternative transport path were higher than the permissible dose limits around testing cell but, it is more safe and acceptable compared with consequences resulting from the cask-drop accident. Applying ALARA principle was suggested to decrease the radiation dose received by worker located at front of the lead-glass window of the testing cell. Adding more shielding bricks of heavy concrete and minimizing time of operation were suggested to reduce the worker accumulated dose to values within the permissible limits.

References

[1]. X-5 MONTE CARLO TEAM, 2003. MCNP- A General Monte Carlo N-Particle Transport Code", Version 5, Vol. 1 & 2, LANL.

[2]. Microshield v5.05 code User Manual, 1996, Grove Engineering, http:/radiationsoftware.com/microshield.

[3]. Abdelhady, A., 2013. Determination of the maximum individual dose exposure resulting from a hypothetical LEU plate-melt accident. Ann. Nucl. Energy 56, 189–193.

[4]. Abdelhady, A., 2016. Radiation dose distributions due to sudden ejection of cobalt device, Applied Radiation and Isotopes 115(2016)208–211.

[5]. FSAR: Final Safety Analysis Report of open pool reactor, 1999. INVAP SE, Argentina.

[6]. U.S. Nuclear Regulatory Commission, 1980. Control of heavy loads in nuclear power plants. USNRC Report NUREG-0612.

[7]. ICRU (1989), Tissue Substitutes in Radiation Dosimetry and Measurement, Report 44 of the International Commission on Radiation Units and Measurements (Bethesda, MD).

[8]. ANSI/ANS-6.1.1-1991, 1992. Neutron and Gamma-Ray Fluence-to-Dose Factors. American Nuclear Society, ANSI Standard, La Grange Park, Illinois.

[9]. ICRP International Commission on Radiation Protection, 1991. Recommendations of the International Commission on Radiation Protection. Pergamon Press, Oxford, England, ICRP Publication 60.