# INVESTIGATION OF WASTE MANAGEMENT OF CONTROL ROD, IRRADIATION BOXES, AND STEEL LINING OF TEHRAN RESEARCH REACTOR AFTER DECOMMISSIONING


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## ABSTRACT

Prediction of the radioactive behaviour of different components of a research reactor during the cooling time is important regarding their waste management and decommissioning. The present work investigate the radioactivity behaviour of control rod, aluminium irradiation box and steel lining of Tehran Research Reactor during the cooling times after the reactor shutdown. MCNPX and ORIGEN computational codes were used to estimate the behaviour. A benchmark study was done to evaluate the conformity of the experimental measurement with the simulation data. The carried out study showed the aluminium parts would be easily handled after at least 6 months after the reactor shutdown by means of the usual shield are used to transfer the radioactive components to the spent fuel pool or radioactive waste storage sites.  In the case of the steel lining also after 6 months of cooling the gamma dose rate decreases noticeably. The gamma dose rate of control rods are very high and decreases slowly during the years after the reactor shutdown.



***Keywords:*** *Gamma dose rate, decommissioning, waste components, Tehran Research Reactor*


## 1 INTRODUCTION

Decommissioning of a nuclear facility is an important process. When each part of a nuclear facility has a problem and the problem cannot be solved satisfactorily within a reasonable time, a decision may be made to discharge that part. The radioactive material decommissioning is a technical process and needs great attention to assure the minimization of the risks to both the public and the workers involved in the process. The IAEA has developed some guidance documents on decommissioning [1-3]

In this work, the future decommissioning of some core components of TRR has been investigated.

## 2 MATERIAL AND METHODS

### 2.1 Description of TRR

TRR is an open pool, MTR- type, light water moderated reactor. The core consists of fuel elements, graphite boxes as reflectors and irradiation boxes. TRR is a 5 MW reactor with 20% enriched fuels and 500 m3/h flow rate. There are two types of fuel elements, i.e. Standard Fuel Element (SFE) and Control Fuel Element (CFE). First of all the control rod of

TRR modelled using the MCNPX code and its radial neutron flux was calculate along its height then the flux was used in ORIGEN code to calculate the rod decay behaviour (Fig.1).

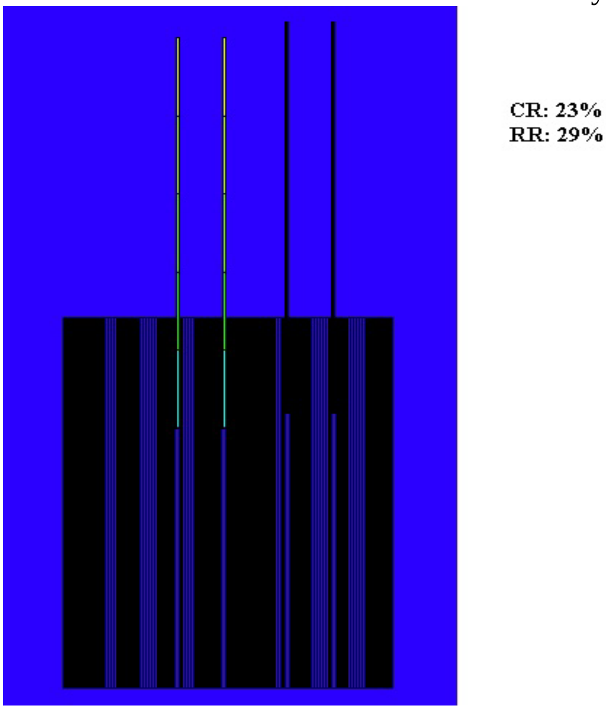


Figure 1: schematic view of TRR core and its control rods.

## 2.2 Simulation

In this study MCNPX 2.6.0 have been used as a powerful particle transport code with the ability to calculate deposited power and dose calculation [5]. In addition to MCNPX code, Origen 2.1 code [6] has been used to determine the photon spectrum. The TRR core with the control rods and its total containment has been modelled using the MCNPX.2.6 code. The spectrums of photons after 50 years of reactor operation time and in different cooling times have been determined on the surface of the control rod, central irradiation box and the hottest section of the steel lining of the research reactor using two ORIGEN and MCNPX codes. Dose calculations have been performed at the End Of Irradiation (EOI) using DE and DF cards and flux to dose conversion coefficients to the ICRP38 which is available in the MCNPX code appendix.

# 3 RESULTS AND DISCUSSION

The Ag-In-Cd control rods with precise dimensions and length of 65 cm were modelled according to Fig.2 using MCNPX code. An average of 23% of control rods and 29% of regulatory rods were assumed to be used inside the core in any operation. Consumption of rods from 2002 to 2015, is equivalent to 7300 MWD. The control rod decay behaviour on the cooling time is shown in Fig.2. As the figure shows the decay behaviour is tightly dependent to the neutron flux exposure the control rod and after 10 years of cooling its reduction is slow.

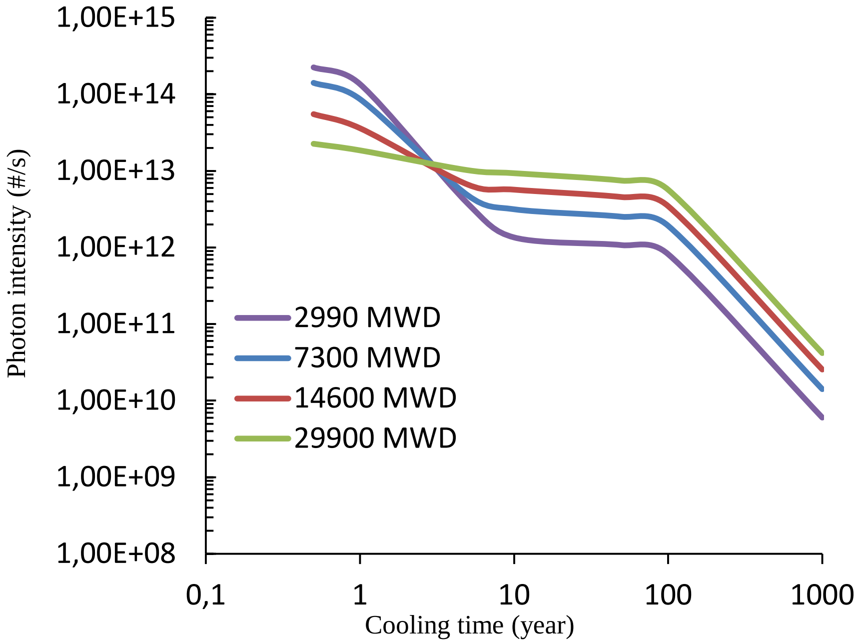


Figure 2: the gamma intensity variation of the activated control rod during the cooling time.

The gamma spectra variation of the radioactive control rod exposed to a neutron flux from a 7300 MWD TRR operation showed after the cooling times the gamma spectra shape does not change noticeably.

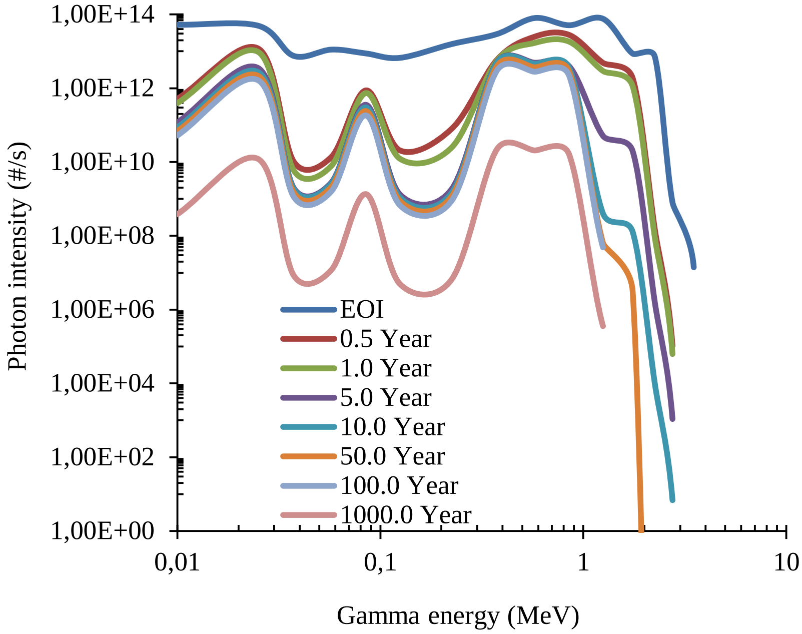


Figure 3: Comparison of Gamma spectra of the radioactive control rod at different cooling times and EOI.

To investigated the decay behaviour of one section of the control rod (13 cm) which is the internal ones in the TRR core during its operation, the received neutron flux by it was used in the ORIGEN code and the produced radioisotopes inside it was reported in Table 1.

Table 1: Investigation of radioactivity behaviour of the first part of the irradiated control rod at 7300 MWD at different cooling times

| Radio-isotope | End OF IRR | .5YR | 10.0YR | 50.0YR | 100.0YR | 1000.0YR | BR (%) | Particle | Energy (MeV) |
|---|---|---|---|---|---|---|---|---|---|
| **RH104** | 1.57E-02 | | | | | | | | |
| **RH106** | 1.01E-02 | 2.64E-14 | 3.84E-17 | 4.35E-29 | | | | | |
| **PD107** | 8.10E-09 | 8.10E-09 | 8.10E-09 | 8.10E-09 | 8.10E-09 | 8.10E-09 | | | |
| **PD107M** | 1.87E-05 | | | | | | | | |
| **PD109** | 5.98E+00 | | | | | | | | |
| **PD109M** | 9.69E-02 | | | | | | | | |
| **PD111** | 1.52E-01 | | | | | | | | |
| **PD111M** | 2.12E-02 | | | | | | | | |
| **AG106** | 3.13E-01 | 1.07E-07 | | | | | | | |
| **AG108** | 4.26E+03 | 7.17E-01 | 6.81E-01 | 5.47E-01 | 4.17E-01 | 3.07E-03 | 97.00 | β | 1.65 |
| **AG108M** | 8.08E+00 | 8.06E+00 | 7.65E+00 | 6.15E+00 | 4.68E+00 | 3.45E-02 | 92.00 | γ | 0.72 |
| **AG110** | 1.87E+04 | 8.31E+00 | 5.49E-04 | 1.38E-21 | | | | | |
| **AG110M** | 1.04E+03 | 6.25E+02 | 4.13E-02 | 1.04E-19 | | | | | |
| **AG111** | 2.50E+01 | 1.04E-06 | | | | | | | |
| **AG111M** | 1.25E+01 | | | | | | | | |
| **AG112** | 4.07E-03 | | | | | | | | |
| **CD107** | 9.93E-02 | | | | | | | | |
| **CD109** | 5.57E+00 | 4.24E+00 | 2.38E-02 | 7.90E-12 | 1.12E-23 | | 100.00 | γ-β | 0.088-0.125 |
| **CD111M** | 3.28E+00 | | | | | | | | |
| **CD115** | 2.19E+01 | | | | | | | | |
| **CD115M** | 1.88E+00 | 1.10E-01 | 4.16E-25 | | | | | | |
| **CD117** | 6.53E-01 | | | | | | | | |
| **CD117M** | 2.49E-02 | | | | | | | | |
| **IN114** | 1.14E+02 | 3.67E+00 | 2.94E-21 | | | | | | |
| **IN114M** | 4.95E+01 | 3.84E+00 | 3.08E-21 | | | | | | |
| **IN115** | 5.13E-11 | 5.13E-11 | 5.13E-11 | 5.13E-11 | 5.13E-11 | 5.13E-11 | | | |
| **IN116** | 5.69E+03 | | | | | | | | |
| **IN116M** | 4.48E+03 | | | | | | | | |
| **IN117** | 3.50E-01 | | | | | | | | |
| **IN117M** | 6.18E-01 | | | | | | | | |
| **SN117M** | 4.72E+01 | 5.60E-03 | | | | | | | |
| **SN119M** | 1.28E-04 | 7.64E-05 | 4.17E-09 | 4.68E-27 | | | | | |
| **SUMTOT** | 3.45E+04 | 6.58E+02 | 8.42E+00 | 6.70E+00 | 5.10E+00 | 3.75E-02 | | | |

The mass of the control rod is approximately 455 grams, as the calculations of the ORIGEN code show that the activity of cadmium-109 after 10 years of cooling is about 0.19E+07 Bq/g. In general, cadmium-109, silver-108 and silver-108m are important radiobiological contaminants of the control rod. After 50 years of cooling of the rod, the amount of cadmium activity per unit mass of the rod reaches 0.0006 Bq/g, while the values of silver -108 dose not reach to the free release limit even after 1000 years (24×104 Bq/g >>0.02 Bq/g).

The measurements showed after 4 years of cooling the highest gamma dose rate of the control rod in 60 cm distance between the detector and the control rod in water is about 37 mSv/h. The simulation data showed the gamma dose rate value is about 480 mSv/h at 1 m of air after 6 months of cooling.

The irradiation boxes of TRR are made of Al6061. The 50-years irradiation was considered for the central Aluminium irradiation box, which is imposed in front of the highest neutron flux. The gamma source distribution on the irradiation box is shown in Fig.4.

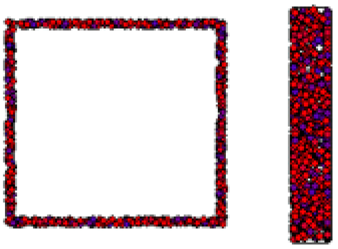

Figure 4: The gamma source distribution on the irradiation box using MCNPX code.

The gamma intensity variation of the radioactive irradiation box was determined by using the ORIGEN code. As Fig.5 shows after 0.5 year, the total gamma intensity reaches to 4.37E+08 #/s. the intensity was used to calculate the box dose rate.

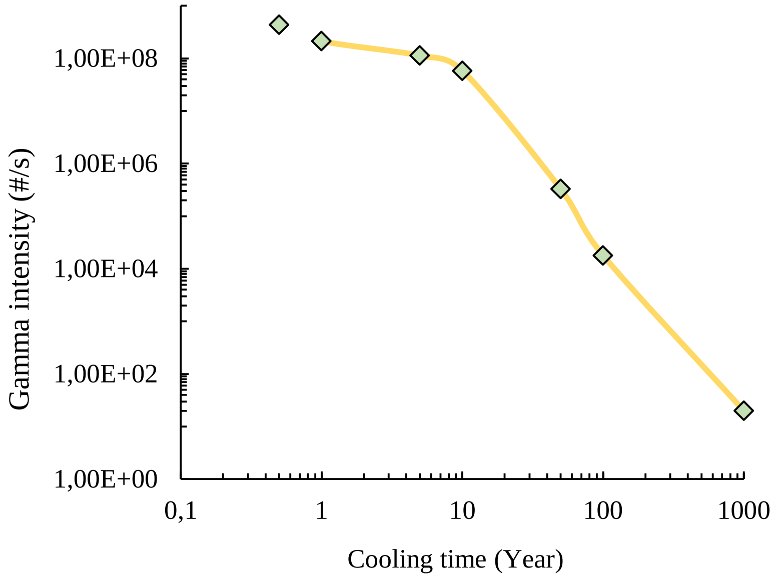


Figure 5: variation of Gamma intensity of the radioactive irradiation box on the cooling time.

In addition, the box gamma spectra of radioactive box were compared for the 6 months cooling time and EOI. As Fig.6 shows after 6 months of cooling the gamma spectra would be noticeable softer and high-energy gammas are not in the spectra so it is predictable the gamma dose rate decreases noticeably than EOI.

Clearly, the total intensity would decrease in order of 10000 after 6 months cooling. Calculations show that after 6 months of cooling, the maximum dose of the irradiated box at the box surface will be about 3.5 mSv/h. The dose at a distance of 1 m from the surface of the irradiated box in the air is about 35 µSv/h. Calculations show that nickel-63 is one of the most important problems of this box and its value will be about 20 Bq/g after 1000 years.

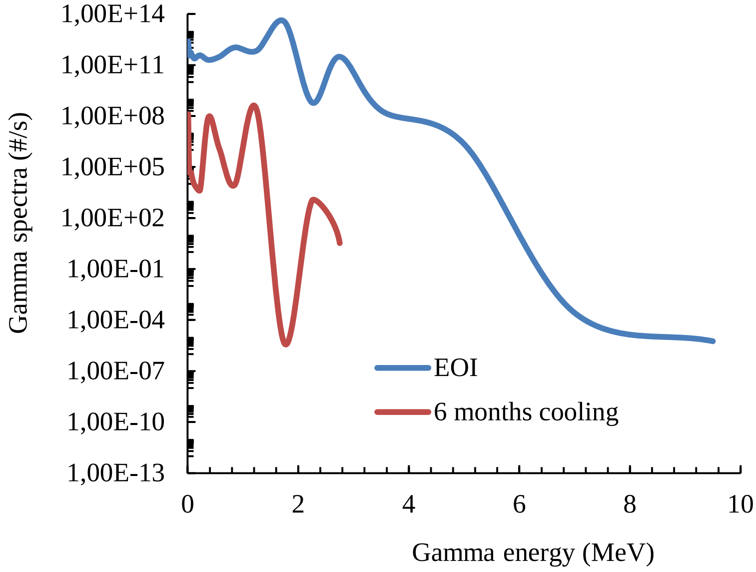


Figure 6: Comparison of Gamma spectra of the radioactive irradiation box at 6 months cooling time and EOI.

The highest radioactive section of the steel lining of the TRR pool wall was selected to calculate its radioactive behaviour. It's received neutron flux was calculated using MCNPX code and its mass and flux was used in the ORIGEN code to calculate its radioactive behaviour.

Calculations show that the gamma intensity emitted from the shutdown time to 6 months after the reactor shutdown decreases by about 55-fold and continues to decrease even up to 1000 years of cooling (Figure 7). At the time of 1 year after cooling, the gamma intensity of this piece of steel is in the order of 106 #/s, which its dose rate will be at a distance of 1 m in the order of nanosievert. It should be noted that in all these calculations, the share of the stabilized surface contamination on this calculation is not considered. Figure 8 shows that the gamma spectrum of this piece of steel which is severely softened after 6 months of cooling, and high-energy gammas are removed.

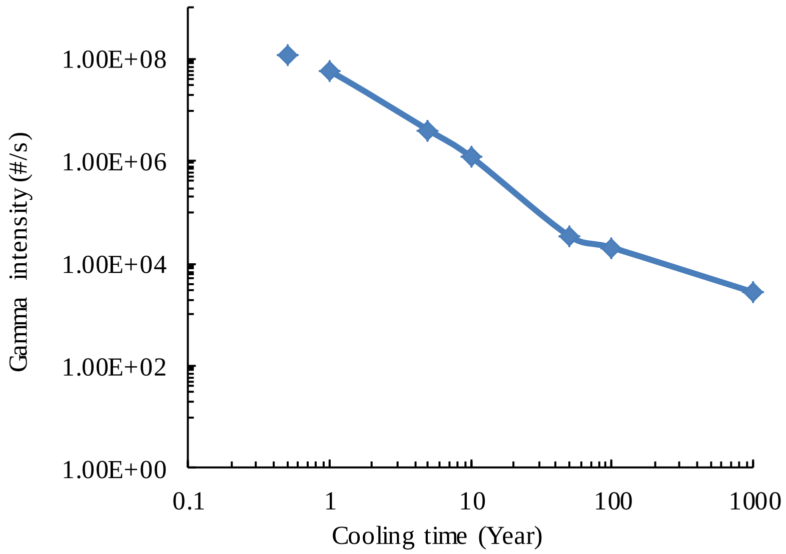


Figure 7: variation of Gamma intensity of the radioactive steel lining piece on the cooling time.

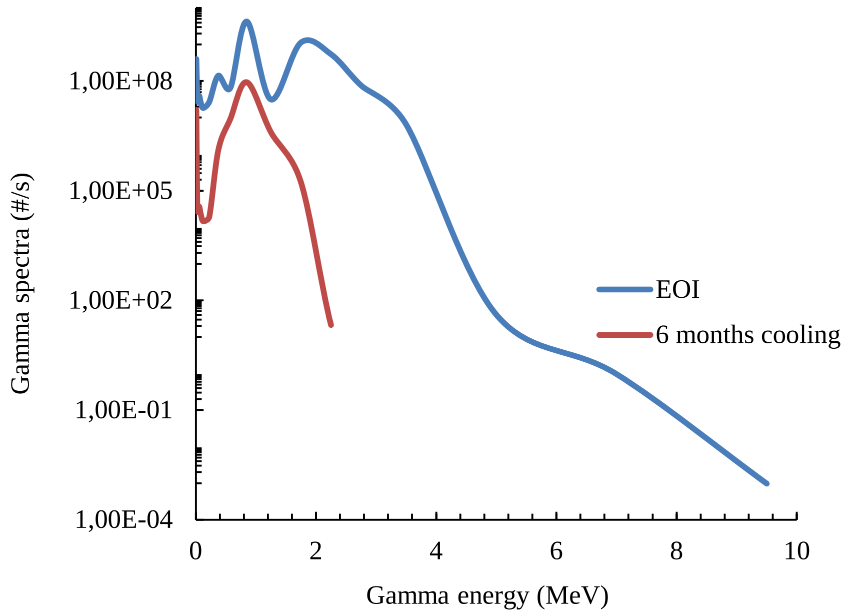


Figure 8: Comparison of Gamma spectra of the radioactive steel lining piece at 6 months cooling time and EOI.

Calculations show that the surface dose of this part after 6 months of cooling is 3.5 mSv/h. In the measurements that were done at the time of repairing the Tehran reactor in 2016, the dose of the steel piece in the most active parts was about 5 mSv/h and 3.7 mSv/h, which shows the consistency of the calculations with the experimental results ( Figure 9). It should be noted that the lead shield hanging in front of the thermal column during repairs was not completely fixed to the wall and was slightly spaced from the right side of the wall, which led to a higher detected dose reading from this side. In addition, since the gamma dose readout belongs to all directions and this value was not only related to the steel layer of the pool wall, it was expected that the measurement value of Figure 8 would be higher than the computational value in this work.

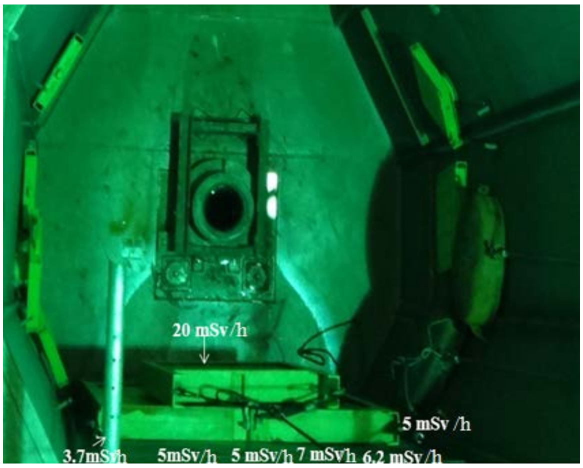


Figure 9: Measurement of gamma dose rate of the steel lining at 2016 year after 6 months of the reactor shutdown.

## 4 CONCLUSION

Waste management of the radioactive parts of a research reactor after its shutdown and during its decommissioning is very crucial concern. The decay behaviour of the activated components would be predicted using computational codes. This procedure could drastically help use to manage the waste components as easily as possible. In the present work, MCNPX and ORIGEN codes were used to estimate the decay behaviour of the Ag-In-Cd control rod, the aluminium irradiation box and the hottest section of the steel lining of the TRR. The calculation showed in the case of the aluminium parts at least 6 months transition time is needed to handle transportation of the radioactive components to storage sites or spent fuel pool. In the case of the steel lining, its gamma dose rate after 6 months of the reactor shutdown would not be noticeably high to impact on the personnel exposure when the reactor pool is empty of water. The calculation data suggests the gamma dose rate of control rods are very high in the first years after the reactor shutdown.

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