Improving the safety of one typical research reactor with regarding gamma radiation hazards of uncovered core

Boustani E.[1], Hasanzadeh M.[1*]

[1]Reactor and nuclear safety school, Nuclear Science and Technology Research Institute (NSTRI), P.O. Box:143995113, Tehran, Iran

**Email: mhasanzadeh@aeoi.org.ir*

Abstract

Establishing reactor coolant is important in shutdown conditions. Core uncovering accident analysis is essentail for reactor safety considering recommendations after the Fukushima Daiichi disaster. Plate-type research reactors are one of the main groups of research reactors. In this study, Tehran research reactor as an open pool and medium power reactor is investigated which following 30 days operation in 5 MW and 24 h cooling after shutdown. The gamma dose is calculated using MCNPX and ORIGEN codes as there is no water in beam tubes and pool. The amount of dose is highly depends on gamma source and other accident conditions. The dose rate is up to 80 Svh^{-1} for some under containment areas which is considerable and exceeding from allowable exposure limits. The reactor is equipped with an emergency make-up system to prohibit individuals' exposure and core damage during the loss of coolant accident.

Keywords: Radiation safety, gamma dose, medium power research reactor, uncovered core.

Introduction

The establishment of cooling in a shutdown reactor is necessary for heat removal and attenuation of gamma rays. Some investigations are done for the study of the contamination of damaged cores in different research reactors involving miniature reactors to pool types, but the accident of core uncovering in undamaged core did not analyzed yet [1, 2, 3]. Also, the beyond reactor containment absorbed dose is investigated where the in-containment dose is neglected in all of them. In this research, some calculations are done for validation at first. Then, the core uncovering accident without core damage is investigated with the calculation of doses in some specific under-containment points using MCNPX 2.6.0 and ORIGEN 2.1 codes which used ENDF-VI and ENDF/B-IV libraries, respectively [4, 5, 6].

Preparation of the materials

Tehran Research Reactor (TRR) is as a medium power and open pool research reactor involving fuels with 19.75% enrichment of ^{235}U which is selected for analysis. The core, pool, infrastructures, and containment are exactly simulated using MCNPX 2.6.0 code and source terms of all fuel elements are calculated using ORIGEN 2.1 code. The equilibrium core consists of 54 locations for Standard Fuel Element (SFE), Control Fuel Element (CFE), Regulating Rod (RR), Graphite box (GR), and Irradiation position (IR). The maximum power of the core is 5 MW submerged in a pool with about 9.5 m height. The complete core uncovering accident is conceivablem, which necessitates this accident analysis. The importance of some engineering features such as emergency hold-up tank in reactor safety are studied in this research. Some of the main important TRR characteristics are given in Table 1. The considered core has 28 SFEs, 5 CFEs, 8 IRs, and 13 GRs. The necessity of a lag time between the initiating accident and complete core uncovering have been demonstrated recently.

Table 1- Main characteristics of the TRR

Quantity	Value	Quantity	Value
Pool volume	500 m^3	Internal diameter of containment	29.92 m
SFE Plates	19	Height form beam tube to upper containment	23.45 m
CFE Plates	14	Containment wall height	18.55 m
U mass in plate	76 g	Pool wall thickness	1.7 m
Concrete, density (gcm^{-3})	Baryot, 2.7	Clad, density (gcm^{-3})	Al6061,1.27
Coolant, density (gcm^{-3})	Water, 0.9984	Fuel, density (gcm^{-3})	U_3O_8Al, 4.76

The worst-case scenario as the 30 days operation with 5 MW power before happening accident is studied. It is worth mentioning that the relative error of the MCNPX results are less than 1%.

Results and discussion

The source terms calculations are involving emitted photon rates for core inventory. The validation of source terms was done at first whereas cooling was estabished during one day after shutdown. The source terms are given in 18 groups from 1.0e-2 to 9.5 MeV for different fuels' burnup.

The source terms and produced radionuclides of equilibrium core with 28 SFEs are calculated for 295 days operation in 5 MW. Also, obtained data are compared against the results of the Safety Analysis Report (SAR) of the TRR that shows in Table 2 [7].

Table 2- Source terms and radionuclides activity

Source term /Radionuclide	Activity (Ci) Calculation	Activity (Ci) SAR	Relative diff. (%)
Activation Products	3.03e+05	3.00e+05	1.00
Actinides and Daughters	8.11e+05	8.00e+05	1.31
Fission Products	2.36e+07	2.37e+07	-0.59
Xe-135	7.81e+04	7.63e+04	0.02
I-131	1.20e+05	1.20e+05	0.01
I-136	1.24e+05	1.25e+05	-0.01

As a good agreement exists between calculation and reference in Table 2, thus, it is the rationale for using the proposed method.

The gamma spectra are calculated for fresh the fuels to 55% burnup. The variations of Actinides and Daughters (ADs) are given in Figure 1 as emitted photon per second for some of fuels as an example.

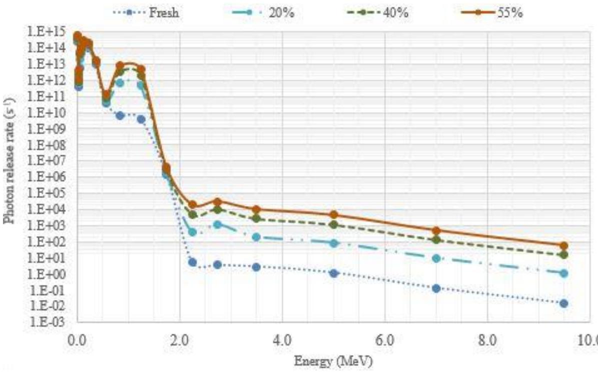

Figure 1. ADs activity for different burnups

As could be seen from Figure 1, ADs have distinctive activity in less than 1.5 MeV that should be considered for shielding calculations.

The amounts of gamma dose for different positions in the under containment region have been calculated for dewatered pool and beam tubes scenario. This scenario is the worst case in which the bared core is in contact with air and there is not any shielding around it. The results are given in Table 3 in which the core is in the center of the coordinates. As the height of all points from the ground is 60 cm, it is omitted from the points coordinates of the table.

As could be seen from Table 3, the values of absorbed dose rate for some points are much higher than the permitted limits. This necessitates preventing from happening accident and also considering appropriate protecting actions before and after the accident.

Table 3- Calculated gamma dose rate

Location (x,y) (cm, cm)	Dose rate ($mSvh^{-1}$)	Location (x,y) (cm, cm)	Dose rate ($mSvh^{-1}$)	Location (x,y) (cm, cm)	Dose rate ($mSvh^{-1}$)
(500, 0)	0.2	(0, 500)	7.9 e +04	(360, 360)	27.6
(650, 0)	0.6	(0, 650)	5.5 e +04	(500, 500)	17.3
(800, 0)	0.6	(0, 800)	3.7 e +04	(650, 650)	13.5
(950,0)	0.5	(0, 950)	2.6 e +04	(800, 800)	10.3
(1100, 0)	0.4	(0, 1100)	1.9 e +04	(950, 950)	7.7
(1250, 0)	0.4	(0, 1250)	1.4 e +04	(1100, 1100)	5.9

Conclusions

The main goal of this research is to reveal the hazards of gamma radiation of uncovered core for operating personnel and others in one typical research reactor such as the TRR. The reactor core would be undamaged due to the establishment of the core cooling during one day after the accident. The under-containment dose of gamma for regions with direct radiation from the core is in the range of 80 Svh^{-1}, which gives rise to much more exposure than permissible occupational absorbed dose of 50 Svy^{-1}. One emergency make-up system has been designed and located in the reactor which is a suitable approach for coping this challenge.

References

[1] Anvari, A. and L. Safarzadeh, (2012), Assessment of the total effective dose equivalent for accidental release from the Tehran Research Reactor. Annals of Nuclear Energy. 50: p. 251-255.

[2] Foudil, Z., B. Mohamed, and Z. Tahar, (2017). Estimating of core inventory, source term and doses results for the NUR research reactor under a hypothetical severe accident. Progress in Nuclear Energy. 100: p. 365-372.

[3] Muswema, J., et al. (2015), Source term derivation and radiological safety analysis for the TRICO II research reactor in Kinshasa. Nuclear Engineering and Design. 281: p. 51-57.

[4] IM J, B. (1973), ORIGEN-The ORNL Isotope Generation and Depletion Code. ORNL-7628, Oak Ridge National Laboratory.

[5] LANL (2008), MCNPXTM User's Manual. Los Alamos National Laboratory, USA.

[6] ENDF/B-IV Library Tapes 401-411 and 414-419, available from the National Neutron Cross Section Center, Brookhaven National Laboratory, 1974.

[7] AEOI (2009), Safety Analysis Report for Tehran Research Reactor. Atomic Energy Organization of Iran, Tehran, Iran.