iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 4 **Issue:** VIII **Month of publication:** August 2016

DOI:

Volume 4 Issue VIII, August 2016
ISSN: 2321-9653

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Analysis of Individual Fuel Element Burnup and Core Burnup Lifetime of BAEC TRIGA Core Using TRIGAP Code

M Asaduzzaman[1], S. M. A. Islam[2], M. J. H. Khan[3], M. S. Hossain[4]

[1]Lecturer, Dept. of Physics, Bangladesh Army University of Engineering & Technology (BAUET), Qadirabad Cantonment, Natore-6431, Bangladesh

[2]Professor, Dept. of Physics, Jahangirnagar University, Savar-1342, Dhaka, Bangladesh

[3]PSO, Reactor Physics and Engineering Division, Institute of Nuclear Science and Technology, Atomic Energy Research Establishment, Savar, GPO Box 3787, Dhaka-1000, Bangladesh

[4]Associate Professor, Dept. of Physics, Bangladesh Army University of Engineering & Technology (BAUET), Qadirabad Cantonment, Natore-6431, Bangladesh

Abstract* - The 3 MW TRIGA Mark II research reactor of Bangladesh Atomic Energy Commission (BAEC) has been operating since 1986 without any reshuffling or reloading yet. The key objective of this study was to calculate the core burnup lifetime at 700 MWd of the BAEC TRIGA Low Enrichment Uranium (LEU) fresh core and it is an important characteristic of the in-core fuel management. The core burnup lifetimes at 2 MW power condition was calculated using TRIGAP code. The calculated results were compared to the three dimensional MVP-BURN result and also the reference data of Safety Evaluation Report (NUREG-1282). It was found that the calculated core burnup lifetime shows a good agreement to the MVP-BURN result. By analyzing the results it might be concluded that the TRIGAP code shows a good performance for core burnup lifetime calculation of the LEU fresh core of 3 MW TRIGA MARK II research reactor, which reflects that the TRIGA model is simulated properly by TRIGAP code.

***Keywords*— Fuel Element Burnup, TRIGAP, Core Burnup Lifetime, LEU Fuel, TRIGA, NUREG**

I. INTRODUCTION

Burnup calculations are based upon the assumption that nuclide concentrations can be assumed constant when solving the neutron density distribution. They are formulated around two central equations in reactor physics, which are the neutron transport equation and the burnup equations. The TRIGA MARK II research reactor was commissioned at the Atomic Energy Research Establishment, Savar, Dhaka in 1986. The reactor was designed to implement the various fields of basic nuclear research activities like neutron scattering experiments neutron activation analysis and production of radio isotopes [1]. The reactor is a light water cooled; graphite reflected one, designed for continuous operation at a steady power level of 3000 kW (thermal). The fuels are of single type i.e. only LEU fuel (20 wt.% and 19.7% enriched uranium and 0.47 wt.% erbium) [2]. For the economic and efficient use of the reactor like increased isotope production, burnup calculations and in-core fuel managements are necessary. For this purpose individual fuel element burnup information is needed. This study aims at establishing the applied technological know-how for burnup analysis of the fuel elements loaded initially in the TRIGA core. The principal objective of this study is to formulate an effective optimal fuel management strategy for the TRIGA MARK II research reactor at AERE, Savar. The core management study has been performed by utilizing four basic types of information; burnup calculation is one of the most important parameter of them. The primary thrust of this study is on the burnup calculations and their analysis [3]. This study represents the results of the burnup calculations for TRIGA LEU fuel elements. The TRIGAP [4] computer code that has already been used successfully elsewhere for the analysis of TRIGA research reactor [5] was applied for this analysis. The analyses which have been performed during this study are: (i) determination of individual fuel element burnup in ring-wise, (ii) formulation of effective multiplication factor and excess reactivity and (iii) calculation of core burnup lifetime [1]. This study reflects that the TRIGAP code simulates the TRIGA model properly and this code is suitable for analysis of Core Burnup lifetime calculation of the LEU fresh core of TRIGA MARK II research reactor [6]. This study contributes valuable insight into the behaviour of the reactor and will ensure better utilization and operation of the reactor in future.

II. TOOLS AND TECHNIQUES

The standard one dimensional diffusion computer code TRIGAP with supporting data bases appropriate was used to calculate the core burnup lifetime of TRIGA LEU core. The burnup calculations were performed using TRIGAP computer program. TRIGAP was developed for research reactor calculations especially for TRIGA type reactors. The program assumes that the reactor has a cylindrical geometry and problems are supplied with appropriate databases consisting mainly of the nuclear constants and the fuel operating history. The expected accuracy of the calculation is 0.5% for k_{eff}, 15% for power distribution and peaking factors and 10% for fuel burnup, which yields practically the same values as is conventionally done by standard power reactor codes [4, 5]. TRIGAP package is based on two-group diffusion equation (group boundary at 1 eV). It is solved in the finite differences approximation by fission density iteration method. A database for the TRIGAP code was generated for the Bangladesh TRIGA MARK II research reactor [7]. The library was created using the WIMS-D/4 code [8]. The original WIMS cross-section library extended for TRIGA reactor specific nuclides (hydrogen bound in zirconium lattice, erbium) is used. According to the generally accepted approach the analysis starts from the basic reactor cell calculations. The cell is composed of a single LEU fuel consisting of a homogeneous mixture of Er–U–ZrH (20 wt% U, 19.7% ^{235}U enrichment and 0.47 wt% Er), cladding (SS-304L) and Zr rod. The non-fuel units consist of dummy graphite element, water channel, void channel, central thimble (CT), pneumatic post and reflector. Normally one unit-cell represents a fuel rod in the centre surrounded by water [1]. The homogenized unit-cell cross-sections are calculated for each fuel element separately as a function of burnup, fuel temperature, water temperature and xenon concentration. The group constants belonging to different unit-cells are homogenized in TRIGAP by volume weighting over each ring. The diffusion calculation is performed in one-dimensional radial geometry. The TRIGA core consists of 100 fuel elements arranged in a concentric hexagonal array within the core shroud. Fig. 1 shows the cross sectional view of the present core configuration of the reactor, which was achieved on October 9, 1986 during reactor start-up at full power operation [9]. Elements are arranged in seven concentric rings and the spaces between the rods are filled with water that acts as coolant and moderator.

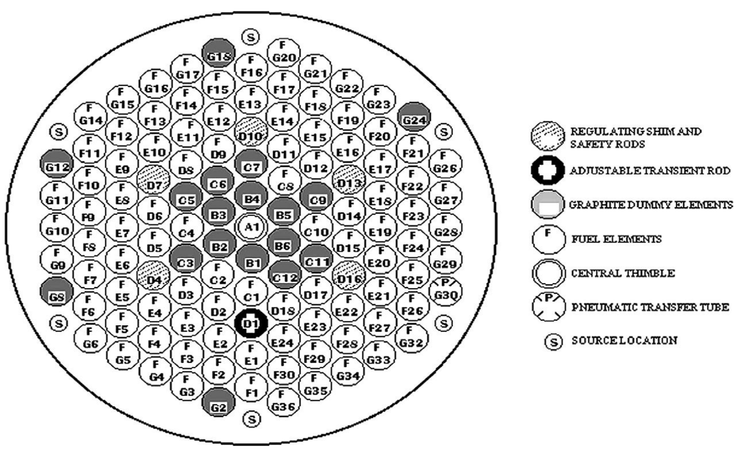


Fig. 1 Core configuration of the 3 MW TRIGA MARK II research reactor

One hundred and twenty one holes of diameter 3.82 cm each are drilled into the top grid plate in six hexagonal bands around a central hole. These holes locate the fuel moderators, graphite dummy elements, control rods and pneumatic tube. Out of the one hundred and twenty one periodic arrangements of holes, the central hole accommodates the central thimble. Eighteen holes are occupied by the graphite dummy elements, six control rods, and one pneumatic tube and the rest ninety five single cells filled with the fuel-moderator material. Besides, there are six source locations in the grid plate. The reactor core and reflector assembly are located at the bottom of 2 m diameter aluminum tank 8.2 meter deep. About 6.4 meter water upon the core acts as vertical shielding [10]. Fig. 1 [1] describes the cutaway view of the TRIGA reactor core. As described before 19 cm thick graphite radial reflector surrounds the core.

III. BURNUP CALCULATION

The principal objective of this study was to calculate the core burnup lifetime of 3 MW TRIGA Mark II Research Reactor and it was calculated by one dimensional diffusion code TRIGAP at 2 MW power level. This study explains not only the core burnup lifetime but also the following important neutronics parameters of the in-core fuel management of 3 MW TRIGA LEU core. The following neutronics parameters are analysed such as a) Effective Multiplication Factor b) Excess Reactivity and c) Core Burnup

Lifetime.

a) The effective multiplication factor, k_{eff} is the most important benchmark integral parameter of 3 MW TRIGA Mark II Research Reactor. Because it consists of all reactor physics parameters of the physical problem: geometry, isotopic composition, cross sections of all isotopes, spectrum etc. For this reason it is very sensitive to the TRIGAP input modelling. The effective multiplication factor was calculated by one dimensional diffusion code TRIGAP at zero power (50 W) and it was shown in Table I with experimental value [11].

TABLE-I

Shows the Comparison between the Calculated Values of Effective Multiplication Factor (K_{eff}) by TRIGAP Code with Experiment

Effective Multiplication Factor (k_{eff})	Calculated	Experimental
	1.07744 (-0.002)*	1.07746

*Error in % = [(Calculated-Experiment)/Experiment] x100

From above table it was found that the calculated effective multiplication factor shows a good agreement to the experiment and hence it might be concluded that the TRIGAP code shows a good performance for TRIGA modelling, which reflects that the effective multiplication factor (k_{eff}) is generally well predicted by the TRIGAP code within the 0.002 % less difference from experiment.

b) The excess reactivity was calculated using one dimensional diffusion code TRIGAP at zero power (50 W) and it was shown in Table II with experiment [11].

TABLE-II

Shows Comparison between the Calculated Values of Excess Reactivity (ρ) with Experiment

Excess Reactivity ($)	Calculated	Experimental
	10.26 (-0.10)*	10.27

*Error in % = [(Calculated-Experiment)/Experiment] x100

From above table it was found that the calculated excess reactivity shows a good agreement to the experiment. By scrutinizing the results it might be concluded that the TRIGAP code predicted the excess reactivity well within the 0.10 % less difference from experiment.

c) The core burnup lifetime of 3 MW TRIGA LEU core at different power levels was calculated with the help of one dimensional diffusion code TRIGAP based on the generated library TRIGAP.LIB [12]. The calculated value of core burnup lifetime was 700 MWd or 16800 MWh at 2 MW power level. It was compared to the 3-dimensional MVP-BURN result (700 MWd) [13] at 2 MW and also the reference value of Safety Evaluation Report (NUREG-1282) [14]. By comparing the results it was found that the calculated core burnup lifetime shows a good agreement with MVP-BURN result and also the value of Safety Evaluation Report (NUREG-1282). Based on the above core burnup lifetime the value of effective multiplication factor (k_{eff}) and burnup of fuel element (in per cent of ^{235}U) for each ring at 2 MW power level was analysed. The calculated burnup of fuel element (in per cent of ^{235}U) versus different rings are summarized in below fig. 2.

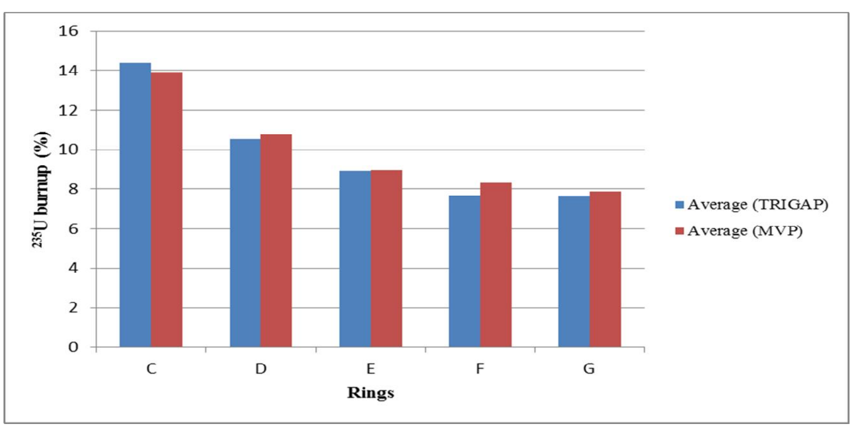


Fig. 2 Comparison of the TRIGA fuel burnup (% ^{235}U depletion) results calculated by TRIGAP at different locations of the core with this of MVP-BURN

Hence it was found that the burnup of U-235 (%) for each same ring at power level 2 MW is approximately equal and this burnup (of U-235 in %) values were around 14.2227, 10.4105, 8.7979, 7.5699 & 7.5356 for C, D, E, F & G ring respectively, which reflects that the operating power does not affect the average burnup of U-235 in % for each ring. The individual burnup of TRIGA fuel and fuel-follower elements calculated by TRIGAP (% ^{235}U depletion) during the period of 1986–2005 (total energy produced up to December 31, 2005 was 8585.594 MWh) are tabulated in Table III.

TABLE-III:
Individual TRIGA LEU Fuel Element Burnup at 700 MWD at 2 MW Power Level

Fuel ID	Fuel ID no	% of ^{235}U burnup (TRIGAP)	% of ^{235}U burnup (MVP-BURN)	Fuel ID	Fuel ID no	% of ^{235}U burnup (TRIGAP)	% of ^{235}U burnup (MVP-BURN)
C1	9457	14.392	12.47	F8	9409	7.66	8.311
C2	9397	14.392	13.853	F9	9443	7.66	8.348
C4	9442	14.392	14.361	F10	9438	7.66	8.116
C8	9420	14.392	14.47	F11	9363	7.66	8.024
C10	9412	14.392	14.457	F12	9430	7.66	7.832
D2	9372	10.5344	10.161	F13	9405	7.66	8.481
D3	9456	10.5344	10.626	F14	9389	7.66	8.499
D5	9367	10.5344	10.427	F15	9431	7.66	8.415
D6	9369	10.5344	10.532	F16	9432	7.66	8.382
D8	9360	10.5344	11.363	F17	9446	7.66	8.073
D9	9358	10.5344	11.535	F18	9387	7.66	8.703
D11	9355	10.5344	10.662	F19	9386	7.66	8.652
D12	9419	10.5344	10.524	F20	9364	7.66	8.653
D14	9370	10.5344	10.462	F21	9371	7.66	8.527
D15	9403	10.5344	10.508	F22	9447	7.66	8.025
D17	9382	10.5344	11.473	F23	9380	7.66	8.73
D18	9357	10.5344	10.962	F24	9375	7.66	8.441
E1	9455	8.9026	8.611	F25	9449	7.66	8.201
E2	9366	8.9026	9.252	F26	9450	7.66	7.912
E3	9425	8.9026	9.764	F27	9426	7.66	7.728
E4	9415	8.9026	9.112	F28	9374	7.66	8.417
E5	9453	8.9026	8.369	F29	9373	7.66	8.43
E6	9413	8.9026	8.867	F30	9414	7.66	7.838
E7	9434	8.9026	9.529	G3	9411	7.6257	7.974
E8	9418	8.9026	8.722	G4	9408	7.6257	8.033
E9	9452	8.9026	8.038	G5	9401	7.6257	7.84
E10	9451	8.9026	8.655	G6	9402	7.6257	7.81
E11	9445	8.9026	9.572	G9	9400	7.6257	7.856
E12	9454	8.9026	8.804	G10	9398	7.6257	7.391
E13	9448	8.9026	8.345	G11	9396	7.6257	7.697
E14	9444	8.9026	8.954	G14	9439	7.6257	7.562
E15	9362	8.9026	9.839	G15	9395	7.6257	7.753
E16	9361	8.9026	9.121	G16	9394	7.6257	8.105
E17	9440	8.9026	8.498	G17	9393	7.6257	8.44
E18	9417	8.9026	9.108	G20	9441	7.6257	7.921
E19	9365	8.9026	9.735	G21	9436	7.6257	8.001
E20	9416	8.9026	8.965	G22	9392	7.6257	8.283

Volume 4 Issue VIII, August 2016
ISSN: 2321-9653

E21	9435	8.9026	8.077	G23	9391	7.6257	8.648
E22	9424	8.9026	8.662	G26	9406	7.6257	8.064
E23	9359	8.9026	9.693	G27	9390	7.6257	7.966
E24	9356	8.9026	9.099	G28	9381	7.6257	8.127
F1	9368	7.66	8.212	G29	9379	7.6257	8.236
F2	9427	7.66	8.335	G32	9437	7.6257	7.194
F3	9423	7.66	8.598	G33	9378	7.6257	7.516
F4	9422	7.66	8.641	G34	9377	7.6257	7.789
F5	9428	7.66	8.074	G35	9376	7.6257	7.452
F6	9429	7.66	8.302	G36	9404	7.6257	7.15
F7	9421	7.66	8.383				

IV. CORE BURNUP LIFETIME

The core burnup lifetimes were calculated power level 500 kW using TRIGAP code. The calculated values of core burnup lifetimes by different methods were given in table IV.

TABLE- IV
Comparison between the calculated values of core burnup lifetime (MWd) with different methods

Core Burnup Lifetime (MWd)	Calculated by TRIGAP Code	MVP-BURN Code result	NUREG-1282
	1250 (4.20)*	1200	1200

*Error in % = [(Calculated –Reference)/Reference] x100

From above table it was found that the calculated core burnup lifetime is 1250 MWd and this value was taken from the graph of excess reactivity vs. core burnup (fig. 3). In below figures fall of excess reactivity ($) are shown in relation with core burnup (MWh).

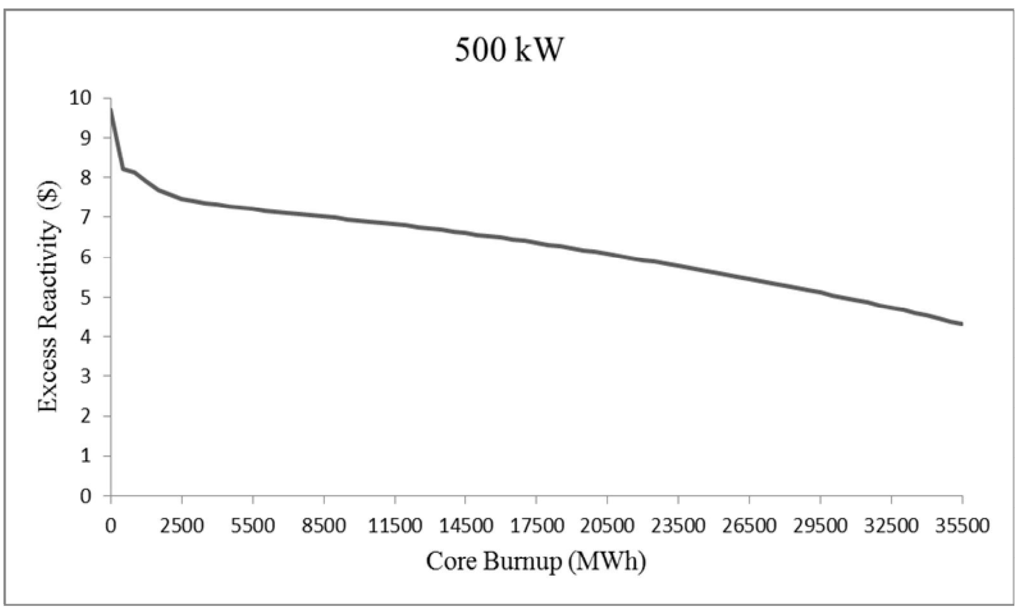


Fig- 3 Details of the initial fall of reactivity in relation to burnup at Xe and Sm equilibrium for power level 500 kW

According to the Safety Analysis Report (SAR) [10] by General Atomic (GA), on initial start-up of the core about 7 % (~10 $) excess reactivity in necessary to compensate for equilibrium xenon, the reactivity loss due to heating of the fuel, and the build-up of ^{149}Sm during the initial few months of full-power operation. After that, the operation can continue to operate the reactor until the core access reactivity fall below the value of about 5 $ which is needed to override the Cold-to-Hot reactivity change. Since excess reactivity 5 $ is minimum needed for sustainable operation at critical condition. According to the calculated core excess reactivity loss curve (fig. 3), the reactor can be operated up to 1250 MWd in total without refuelling or reshuffling the initial loaded core of 3 MW TRIGA Mark II Research Reactor. The calculated result was compared to the three dimensional code MVP-BURN result and also the reference data of Safety Evaluation Report (NUREG-1282). By scrutinizing the results it might be concluded that the TRIGAP code predicted the core burnup lifetime well within the 4.2 % more difference from the reference.

V. RESULT AND DISSCUSSIONS

The physical insight gained from this study would enable us to understand the behaviour of this reactor and thereby ensure better utilization and operation of the reactor. The analysed parameters are:

A. In case of Multiplication factor (k_{eff}) the calculated effective multiplication factor shows a good agreement to the experiment which has been shown in Table I.

B. In case of Excess reactivity (ρ) the calculated excess reactivity shows a good agreement to the experiment which has been shown in Table II.

C. In case of Ring wise U-235 Burnup (%) at 2 MW power level it was found that the burnup of U-235 (%) for each same ring is approximately equal to the 3-dimensional MVP-BURN result (700 MWd) at 2 MW and also the reference value of Safety Evaluation Report (NUREG-1282) which has been described by fig. 2.

D. In case of Core burnup lifetime the calculated parameter was compared to the MVP-BURN code result as well as the reference data of Safety Evaluation Report (NUREG-1282) which has been described in table IV and fig. 3.

VI. CONCLUSIONS

The analysed neutronics parameters of 3 MW TRIGA fresh core are investigated using one dimensional diffusion code TRIGAP. The most important findings of this analysis are as follows:

A. Effective multiplication factor calculated at 50 Watt is 1.07744 compared to 1.07746 experimental value.

B. Excess reactivity calculated at 50 Watt is 10.26 $ compared to 10.27 $ experimental value.

C. The k_{eff} is almost linear function of burnup after the Xe, Sm and temperature effects reach equilibrium.

D. Core life varies approximately linearly with power level.

E. The burnup of U-235 (%) for each same ring at power level 2 MW is approximately equal which reflects that the operating power does not affect the average burnup of U-235 in % for each ring

F. The calculated core burnup lifetime 1250 MWd by TRIGAP code at power level 500 kW comply with MVP-BURN result 1200 MWd at 2 MW and NUREG-1282 value 1200 MWd. Due to limitation of TRIGAP code at high power levels such as 1 MW, 2 MW and 3 MW from the excess reactivity loss vs. core burnup figures it is found that the excess reactivity drops sharply due Xe and temperature effect. If this effect would overcome then the core burnup lifetime complies with the MVP-BURN result as well as NUREG-1282 value at higher power levels.

From the analysis of the above parameters it might be concluded that TRIGAP code simulate the TRIGA model properly. And all these parameters will contribute significantly for safe operation and best utilization for the core; also this study can give insight to redesign a better core configuration than the present one using the same fuel elements.

VII. ACKNOWLEDGEMENT

The authors would like to thank DG of AERE, and Director of INST for their kind permission to perform this work at RPED of INST. The authors also express their thankfulness to members of RPED, INST, AERE, Savar for their supportive suggestions to improve this work.

REFERENCES

[1] Mahmud, M. S. et al., 2013. Optimum burnup of BAEC TRIGA research reactor. Annals of Nuclear Energy 55 (2013) 225-229

[2] Bhuiyan, S. I. et al., 1990. Analysis and Core-Life Calculation of 3-MW TRIGA MARK II Research Reactor Including Effects of Central Thimble Modifications, Proc. Int. Conf. Physics of Reactors: Operation, Design and Computations, Marseilles, France, Vol. 4, p. 114.

[3] Khan, M.J.H., Sarker, M.M., Islam, S.M.A., 2013. Analysis of kinetic parameters of 3 MW TRIGA Mark-II research reactor using the SRAC2006 code system. Annals of Nuclear Energy 60 (2013) 181–186

[4] Huda, M.Q., et al., 2008. Burnup analysis and in-core fuel management study of the 3 MW TRIGA MARK II research reactor. v Annals of Nuclear Energy 35 (2008) 141-147

[5] Bhuiyan, S.I., Sarker, M.M., Rahman, M., Shahdatullah, M.S., Huda, M.Q., Chakrobortty, T.K., Khan, M.J.H., 2000. Criticality and safety parameter studies of

a 3MW TRIGA MARK II research reactor and validation of the generated cross-section library and computational method. Nucl. Technol. 130, 111–131

[6] Huda, M.Q., Rahman, M., Sarker, M.M., Bhuiyan, S.I., 2004. Benchmark Analysis of the TRIGA MARK II Research Reactor using Monte Carlo Techniques. Annal. Nucl. Energ. 31 (11), 1299–1313

[7] Mele, I., Ravnik, M., 1985. TRIGAP - A Computer Programme for Research Reactor Calculations. IJS-DP-4238. Josef Stephan Institute, Ljubljana, Slovenia

[8] Ravnik, M., Zgar, T., Persic, A., 1999. Fuel element burnup determination in mixed TRIGA core using reactor calculations. Nucl. Technol. 128, 35–45

[9] Mahmood, M. S. et al., 2010. Calculation for Core Life Estimation and Extension of the TRIGA MARK-II Research Reactor of BAEC. Technical Report (INST), Atomic Energy Research Establishment, Savar, Dhaka, Bangladesh

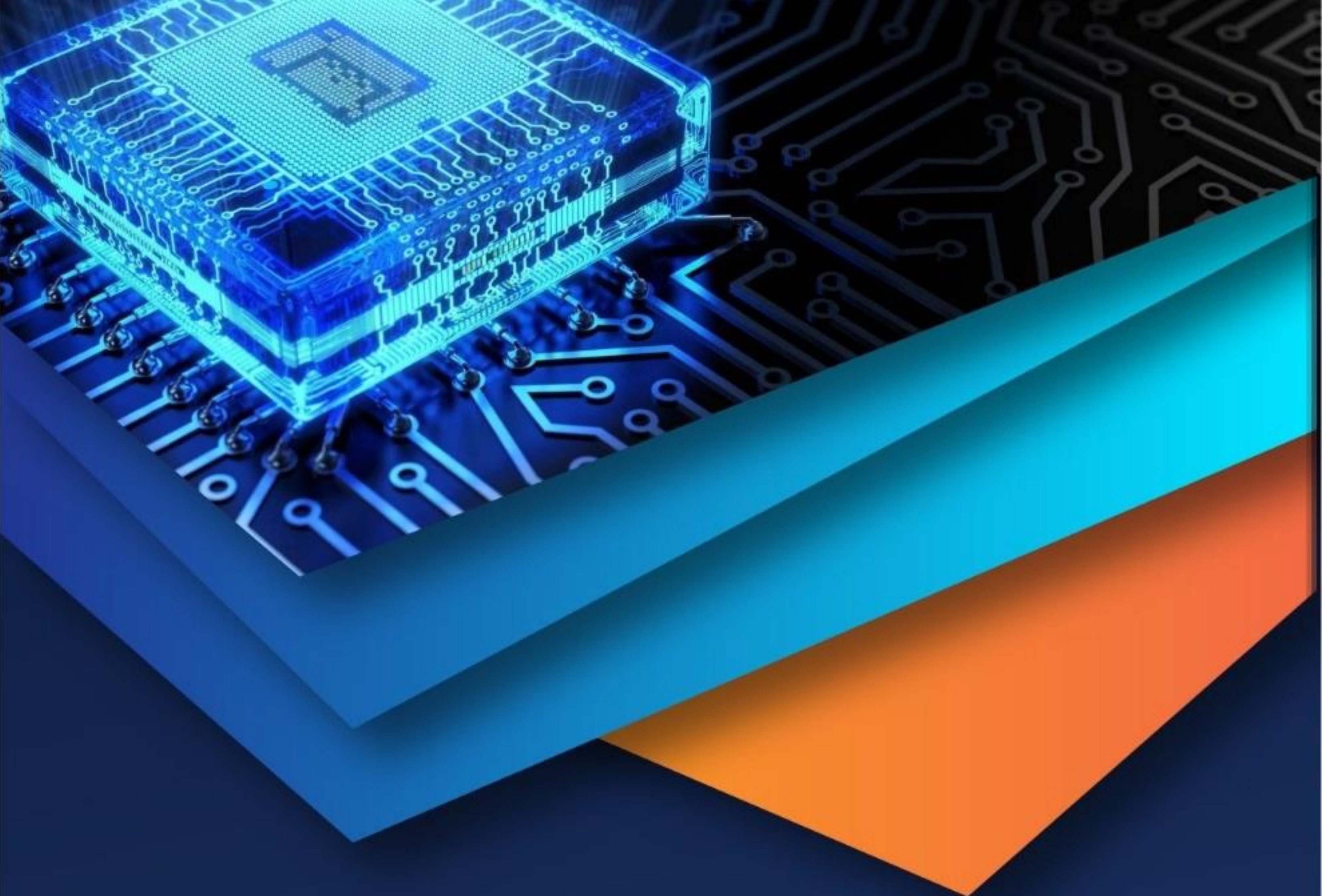
[10] U.S. Nuclear Regulatory Commission, 1987. Safety evaluation report on high- uranium content, low-enriched uranium–zirconium hydride fuels for TRIGA reactors, NEUREG-1282

[11] Rahman, M. et al. 2007. Evaluation of the MVP Model Developed for the TRIGA Mark-II Research Reactor at AERE, Savar, through Criticality and Reactivity Analysis. Internal Report, Institute of Nuclear, Science and Technology, INST- 113/RPED-25

[12] General Atomics, 1981. Safety Analysis Report (SAR) for the 3000-KW Forced-Flow TRIGA MARK II Reactor, E-117-990

[13] Ravnik, M. 1987. Burnup Calculations of TRIGA Reactor Core. IAEA Interregional Training Course on the Application of Small Computers to Research Reactor Operation Ljubljana

[14] Bhuiyan, S.I., Khan, A.R., Sarker, M.M., Rahman, M., Ara, Z.G., Musa, M., Mannan, M.A., Mele, I., 1992. Generation of a library for reactor calculations in core and safety parameter studies of the 3MW TRIGA MARK II. Res. React. Nucl. Technol. 97, 253–263



10.22214/IJRASET

INDEX COPERNICUS
45.98

IMPACT FACTOR:
7.129

TOGETHER WE REACH THE GOAL

IMPACT FACTOR:
7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY