COMPARATIVE STUDY OF TRANSIENT ANALYSIS OF PAKISTAN RESEARCH REACTOR-1 (PARR-1) WITH HIGH DENSITY FUEL

M. Iqbal, A. Muhammad, T. Mahmood

Nuclear Engineering Division, Pakistan Institute of Nuclear Science and Technology (PINSTECH)
Nilore, Islamabad, Pakistan

ABSTRACT

To investigate safety of equilibrium core of Pakistan Research Reactor-1 (PARR-1) utilizing high density (4.8 g/cc) low enriched uranium dispersed fuel (U_3Si_2-Al) against fast reactivity insertion transient, analysis was carried out at proposed power i.e 9 MW. Calculation reveals that fast reactivity insertion is limited to 1.4 $ per 0.5 sec. Reactivity of a single in-pile experiment is limited through operating policy to 0.5 % $\Delta k/k$ in 0.023 sec at PARR-1was also investigated. Computer code PARET/ANL and RELAP5 MOD 3.4 were utilized to calculate peak power, maximum fuel centre line temperature, maximum clad temperature and maximum coolant temperature. Calculation reveals that results of both codes are in good agreement and PARR-1 can be safely operated with proposed core at 9 MW with high density fuel.

1. Introduction

Reactivity insertion transient analysis is very important from reactor safety point of view. Different types of transients have already been simulated for earlier PARR-1 cores. Among those transients analysis are; Sensitivity of reactivity insertion limits with respect to safety parameters in typical MTR [1], LEU-MTR transients under reactivity insertion, loss of flow conditions [2], analysis of reactivity induced accidents at Pakistan Research Reactor-1[3], simulation of burn-up effect on inherent safety parameters and reactivity insertion transient analysis of Pakistan Research Reactor-1 considering the xenon free reference operating core of PARR-1[4]. In the current study reactivity insertion transient analysis has been carried out for proposed equilibrium core utilizing Low Enriched Uranium high density fuel (U_3Si_2-Al fuel with 4.8 g/cc of U). The core was proposed in our previous study on improved performance base [5]. The proposed core containing 15 standard and 4 control fuel elements is shown in Fig 1.

Pakistan Research Reactor-1 (PARR-1) is basically a swimming pool type material testing research reactor (MTR), having a parallelepiped core comprising LEU (U_3Si_2-Al) fuel, containing 19.99% ^{235}U. Demineralized light water is used as coolant and moderator. One side of the parallelepiped core is reflected by graphite, i.e. thermal column, while opposite side is reflected by a blend of graphite reflector elements and light water. The bottom side is reflected by a combination of aluminum and water. Rest of the three sides, i.e. top and two lateral sides, are reflected by light water only. At PARR-1, five (Ag-In-Cd alloy) control rods are employed for reactor operating power level control and safe shut down in normal or any anticipated accidental condition [6]. PARR-1 core provides numerous irradiation facilities, which include water boxes, graphite thermal column, pneumatic rabbit tubes, beam port tubes, dry gamma cell, a bulk irradiation area and hot cell.

2. Methodology

Reactor response to transients depends upon kinetic and inherent safety parameters. Kinetic, inherent safety parameters, peaking factors and various other parameters used for this study are listed in table 1. Two channels model approach was adopted i.e hottest plate with associated flow channel and other being an average plate with associated flow channel. Axial peaking profiles, represented by 21 equidistant mesh points calculated through deterministic neutronics calculation; were incorporated in this study. Engineering hot channel factor of 1.584 was incorporated using the conservative multiplicative method [3] to account for the: Uncertainties in coolant temperature rise due to manufacturing tolerances in the coolant channel spacing, uncertainties in film temperature rise due to uncertainties in the heat transfer coefficient and in-homogeneities in ^{235}U distribution and uncertainties in the calculated power distribution.

It is assumed that 90% of the total fission energy is deposited in fuel section, about 4% in moderator, about 1% in other reactor materials and remaining 5% is carried away by neutrinos [7]. Reactivity transient calculations have been performed with coolant inlet temperature of 38 ^{0}C and inlet pressure of 1.712 bar. Only high power trip at 10.35 MW with delay of 27 msec has been considered to be actuated after introduction of reactivity induced transient [4]. Using the conservative approach, all other trips present at the reactor have been assumed to be non functional. Fast reactivity insertion transient (1.4 $ in 0.5 sec) and removal of in-pile experiment accident were analyzed utilizing computer codes RELAP5/MOD3.4 [8] and PARET/ANL [9].

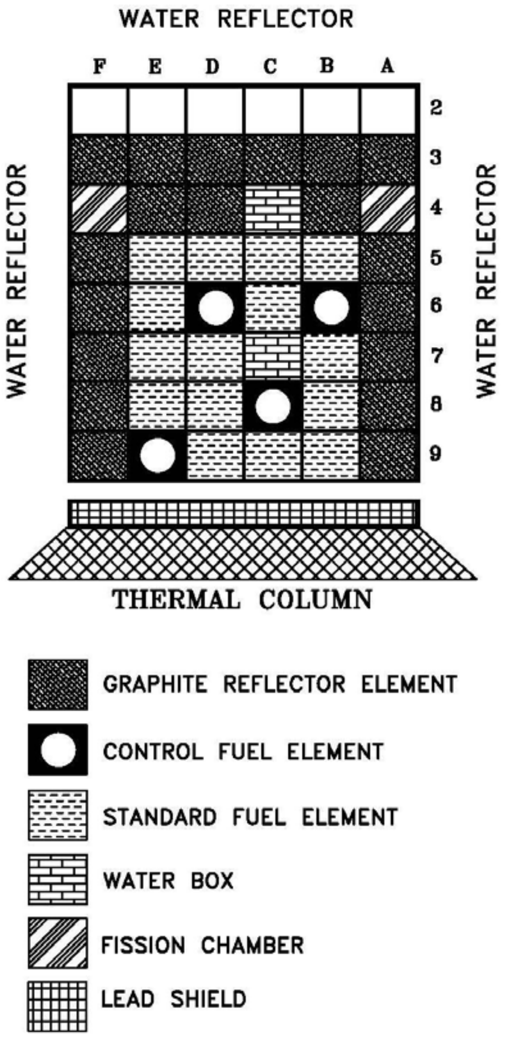

Fig. 1. Proposed equilibrium core

Parameter	Value
Radial peaking Factor	1.951
Axial peaking factor	1.567
Engineering Peaking factor	1.584
Total Peaking Factor	4.843
Flow (m^3/h)	950
Coolant velocity (m/sec)	4.23
Delayed neutron fraction	0.00753
Prompt neutron generation time (s)	3.25×10^{-5}
Fuel temperature reactivity coefficients ($\frac{\partial k}{k\partial T_f} \times 10^{-5}$)	-2.09
Moderator temperature reactivity coefficients ($\frac{\partial k}{k\partial T_m} \times 10^{-5}$)	-8.795
Moderator voids reactivity coefficients ($\frac{\partial k}{k\%voids} \times 10^{-3}$)	-2.337

Tab. 1: Parameters used for reactivity insertion transient analysis

3. Results and Discussions

3.1 Fast Reactivity Insertion Transient

A compact proposed core utilizing high density fuel with comparatively harder neutron flux spectrum having low prompt neutron generation time, fast reactivity ramp was limited to 1.4 \$ per 0.5 sec due to limiting condition of clad temperature i.e 580 ^{o}C. Utilizing RELAP5 code maximum fuel centre line, clad and coolant temperatures were calculated and results were compared with PARET/ANL shown in table 2.

Parameter	RELAP5	PARET
Peak power (MW)	173.66 (0.602 s)	165.76 (0.603)
Maximum Fuel centre line Temperature (^{0}C)	553.0	518.0
Maximum Clad Temperature(^{0}C)	551.75	517.86
Maximum coolant Temperature(^{0}C)	69.17	89.7

Tab. 2: Transient response to fast ramp reactivity insertions (initial power = 1 watt)

It is clear from table 2 that peak power, fuel centreline and peak clad temperatures are somewhat higher as estimated by RELAP5 than PARET/ANL. But maximum coolant temperature calculated by RELAP5 is less than PARET/ANL estimation. In Fig 2 and 3, trend of power and energy released are shown during this transient, while Fig 4 displays the trend of clad temperature.

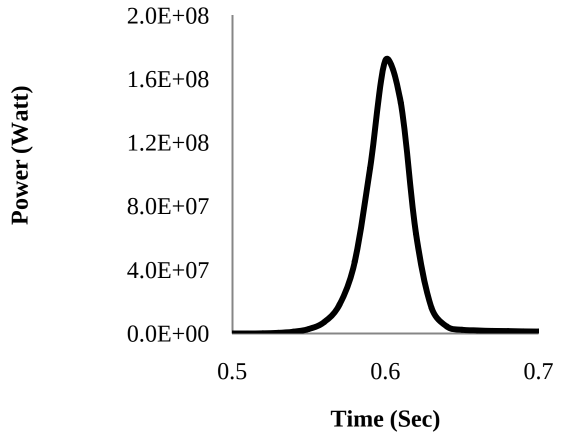

Fig. 2: Time behaviour of in fast reactivity insertion (1.4 $per 0.5 sec)

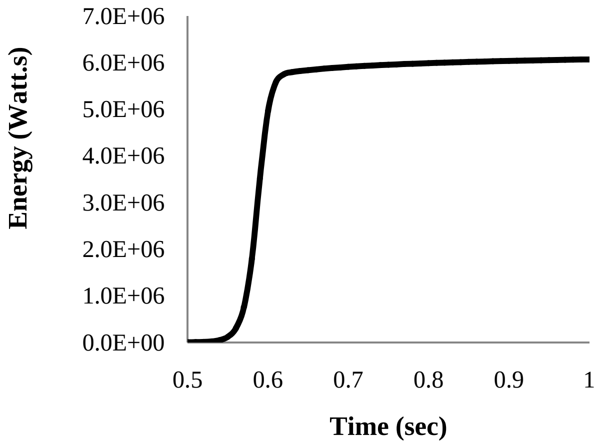

Fig. 3: Time behaviour of energy release in fast reactivity insertion (1.4 $per 0.5 sec)

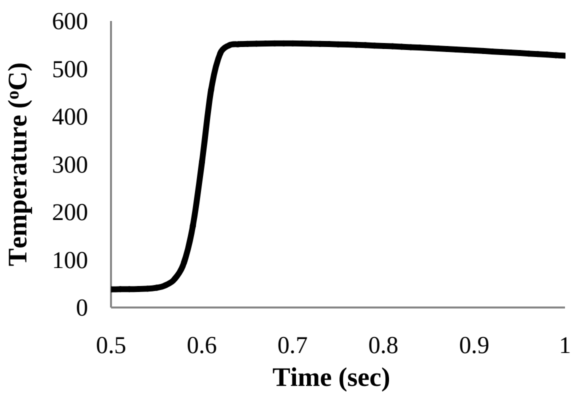

Fig. 4: Time behaviour of clad temperature in fast reactivity insertion (1.4 $per 0.5 sec)

3.2 Removal of In-Pile Experiments

Reactivity of a single in-pile experiment at PARR-1 is limited to 0.5 % $\Delta k/k$. It is assumed that this amount of reactivity will be added to reactor core in 0.023 sec [4, 6]. Postulated reactivity accidents at PARR-1 include drop of a fuel element on the core, removal of in-pile experiment, empty beam tube flooding with water and movement of core towards thermal column. Clad temperature attains maximum value in the case of removal of in-pile experiment [5] when reactor is operated at full power. Therefore removal of in-pile experiment accident has been modelled in this study utilizing RELAP5 and results have been compared with PARET in table 3.

Power history and energy released during this transient are shown in Fig 5 and 6 while time behaviour of clad temperature is shown in Fig 7 to demonstrate the trend.

Parameter	RELAP5	PARET
Peak power (MW)	19.74 (0.040 s)	22.31 (0.038 s)
Maximum Fuel centre line Temperature (^{0}C)	147.92	147.18
Maximum Clad Temperature(^{0}C)	135.54	134.7
Maximum coolant Temperature(^{0}C)	77.65	72.0

Tab. 3: Transient response to removal of in pile experiment (initial power = 9 MW watt)

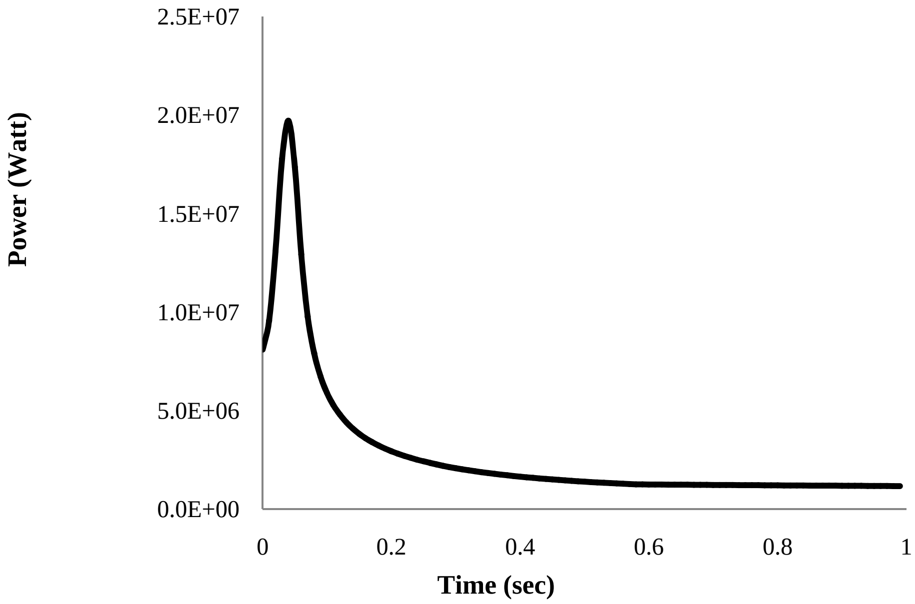

Fig. 5: Time behaviour of power for removal of in-pile experiment

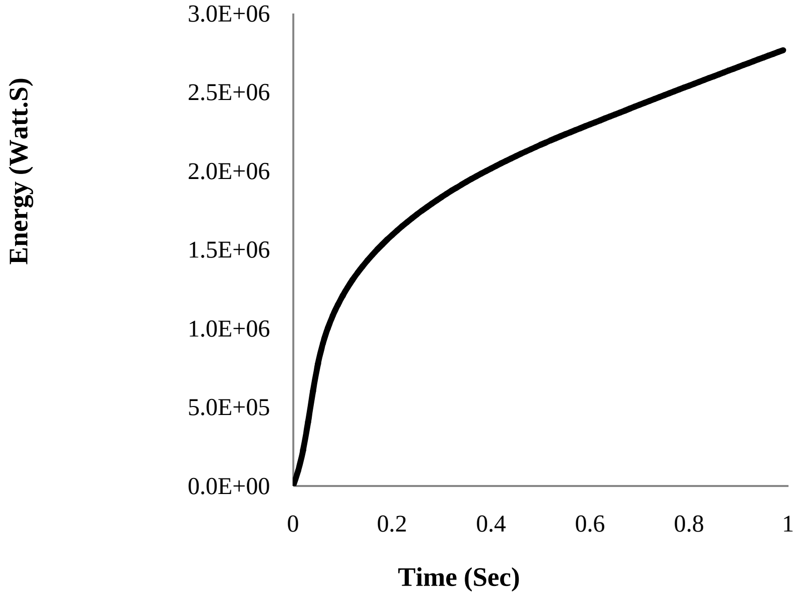

Fig. 6: Time behaviour of energy released in removal of in-pile experiment

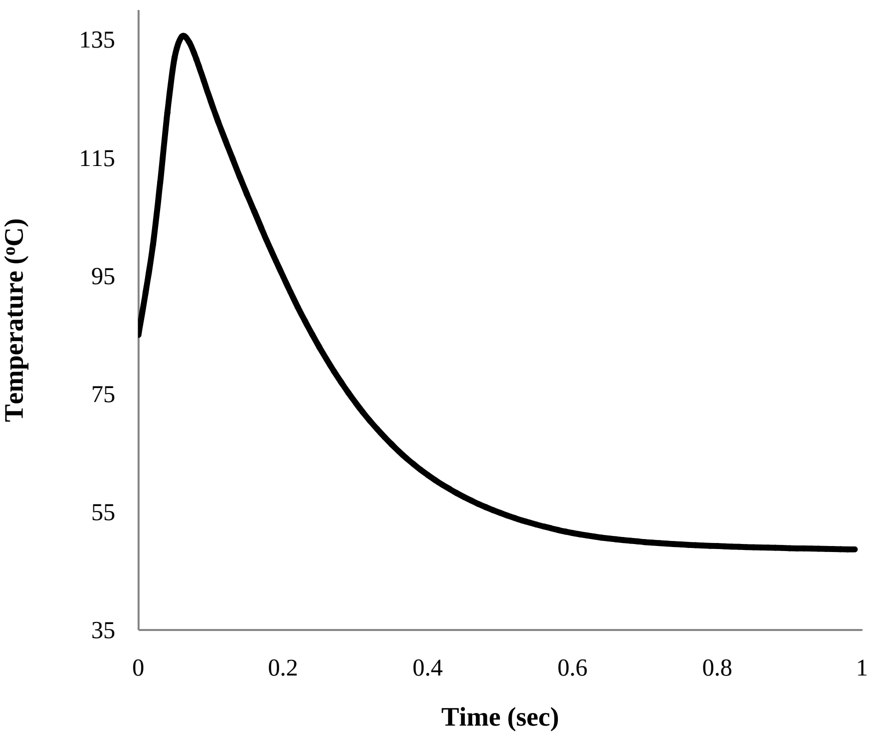

Fig. 7: Time behaviour of clad temperature in removal of in-pile experiment

4. Conclusion

Calculation reveals that the proposed core is safe against startup accident of fast reactivity insertion up to 1.4 $/0.5 sec and reactivity induced by maximum sample removal accident during full power operation (9 MW).

5. References

[1]. Nasir, R., Mirza, N.M., Mirza, S.M., 1999. Sensitivity of reactivity insertion limits with respect to safety parameters in a typical MTR. *Annals of Nuclear Energy* 26, 1517–1535.

[2]. Bokhari, I.H.,Mahmood,T., 2005. Analysis of loss of flow accident at Pakistan research reactor-1. *Annals of Nuclear Energy* 32, 1963–1968.

[3]. Bokhari, I.H., Israr, M., Pervez, S., 2002. Analysis of reactivity induced accidents at Pakistan Research Reactor-1. *Annals of Nuclear Energy* 29, 2225–2234.

[4]. Muhammad, A., Iqbal, M., Mahmood, T., 2012. Burn-up effect on inherent safety parameters and reactivity insertion transient analysis of Pakistan Research Reactor-1. *Progress in Nuclear Energy* 58, 1-5.

[5]. Muhammad, A., Iqbal, M., Mahmood, T., A study on improving the performance of a research reactor's equilibrium core. *Nuclear Technology & Radiation Protection* 28, Volume 28 (2013) No. 4, pp. 362-369.

[6]. FSAR, (2001) Final Safety Analysis Report of PARR-1.

[7]. El-Wakil M.M., 1971. Nuclear Heat Transport, International Textbook Company.

[8]. RELAP5/MOD3, 1995. Code Manual, Volume II: 'User's Guide and Input Requirements. NUREG/CR-5335, INEL-95/0174. Idaho National Engineering Laboratory.

[9]. Woodruff, W.L., Smith, R.S, 2001.A Users guide for the ANL version of the PARET code, PARET/ANL (2001 rev.) Argonne National Laboratory, Argonne, IL 60439-4841 USA.