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Proposition of innovative and safe design of grid plate for Tehran research reactor

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ABSTRACT

The purpose of this paper is to propose an innovative and safe design of grid plate for Tehran research reactor (TRR) without any reduction in its performance in comparison with the current operation. The new grid plate consisted of two joined cubic with empty walls which are place of fuels and heavy water, respectively. The proposed design is such that the reactor core is divided into two distinct parts using the heavy water. The heavy water is inserted in the walls of the new grid plate. The new design of grid plate by keeping the characteristics of the previous version creates the possibility of shutting the reactor down in critical condition. In this paper, at initial step, a simulation of acceptable benchmark for Tehran research reactor is performed which could be considered reliable and comparable with SAR (Safety Analysis Report) data. In the next step, two different designs are proposed for grid plate and then are applied to reactor core using simulation tools. For the proposed design: core excess reactivity, shutdown margin, control rod worth, neutron flux and kinetic parameters are calculated. Furthermore, the transient analysis was performed for the new design to check the status of reactor safety. Obtained results show that all neutronic parameters for the first operating core and the new design are comparable, and there is no reduction in the efficiency of reference core. Moreover, in the current design, a diverse and independent shutdown system for TRR was included. Nuclear reactor analysis codes including MTR-PC package were employed to carry out these calculations.

1. Introduction

Reactor plant has been developed from the early work where the aim was to demonstrate that a nuclear reactor was feasible to the present time where safety is a foremost consideration (Green, 1996). For a nuclear reactor to be licensed, the reactor designer should demonstrate that the technical objectives (IAEA, 2005) for the reactor safety are fulfilled. Requirements for the safety of nuclear research reactors are the same as or similar to those for nuclear power reactors. In view of the most important differences between power reactors and research reactors and between the different types of research reactors, these requirements are to be applied in accordance with the potential hazards associated with the reactors. For example, most research reactors have a small potential for hazards to the public in comparison with power reactors, but they may pose a greater potential for hazards to operators.

In order to ensure that technical safety objectives are fulfilled, two main facts must be considered; the shutdown of the reactor, and the adequate core cooling capacity. It means that both neutronic and thermohydraulic aspects must be analyzed. In neutronic point of view, some safety features are common to all power ranges like negative feedback reactivity coefficient and a shutdown system. At least one automatic shutdown system shall be incorporated into the design. The provision of a second independent shutdown system may be necessary, depending on the characteristics of the reactor and this shall be given due consideration (IAEA, 2005; Jalali et al., 2015). However, these safety systems should not have a devastating effect on reactor performance in normal operation. For example, for a research reactor, the safety is the first aspect that must be considered. Therefore, it needs to use variant protection and safety systems. This work should not disorder the other aspect of research reactor such as neutron flux. Research reactors provide a neutron source for neutron scattering, non-destructive testing, analysis and testing of materials, production of a radioisotope, research and public outreach and education. Indeed, the safety systems should not reduce the neutron flux in research reactor or have a negative effect on the reactor core. Thus, neutron economy and safety systems should be considered together in optimum condition.

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Achieving this goal depends on exact calculation and innovative design that should be conducted by nuclear engineers. Heretofore, a considerable number of safe research reactors with good performance were designed and operated. In this paper, in continuation of previous works, an innovative and safe design for the core of Tehran research reactor is proposed. This design can be used by any research reactor, but here it was especially investigated and analyzed for TRR.

TRR is a 5 MW pool-type light-water moderated, heterogeneous solid fuel reactor in which the water is also used for cooling and shielding (AEOI, 2009). For the control of reactivity, two types of control rods are used in TRR: one of which is made out of Ag-In-Cd alloy (80, 15 and 5 wt.% respectively) and the other is made of stainless steel. Both have a set of 2 control plates firmly screwed to a knuckle. If this system fails, there is no another protection system to shut it down and protect reactor core from damage. Experiences have shown that the current safety practiced in the design of TRR is sufficient. However, one must always plan for additional safety measures. Hence, this paper presents a new and feasible design for TRR based on reactor safety. The proposed design is such that the reactor core is divided into two distinct parts using the heavy water. This water is inserted in the walls of the new grid plate. Two separate parts of the core are subcritical and when D_2O is added to the system, it becomes critical. More details about this design will be provided in the further sections.

In the following, the organization of the paper is as follows:

In the next section, we are describing the TRR as a case study and benchmark calculation. Description of the proposed design for grid plate is given in Section 3. In Section 4, calculation tools and method of analyses are expressed. In next step, neutronic calculations for the first operating core (FOC) of TRR are investigated and results are compared with Safety Analysis Report (SAR). Once we achieved to acceptable benchmark, all neutronic parameters would be calculated again with the new grid plate. It will be shown in Section 6 that the presented design is capable for shutting and holding the reactor down from critical point to subcritical state. In the last section, results and conclusion with a discussion about neutronic and safety aspects of the new design are presented.

Obtained results show that all neutronic parameters of the new design and safety analysis satisfy the safe operation criteria.

2. Brief description of Tehran research reactor

Tehran research reactor is a 5 MW pool-type research reactor located in Tehran-Iran. This reactor consists of MTR low enriched uranium (LEU) fuel type (Zareian Ronizi et al., 2015). The reactor core is cooled by downward forced flow of light water. Table 1 lists the general characteristics of the TRR. Its core configuration contains MTR-type fuel elements that are arranged in 9×6 grid plate assembly. The grid plate of TRR is a high-purity Aluminum plate, 12.7 cm thick, bolted to the core support angles and is aligned with the drive mechanism mounting plates on the core support bridge. A series of fifty-four holes, capable of accommodating the end fittings of the fuels are arranged in a 9×6 rectangular lattices (6×7.7089 in the x-direction and 9×8.1 in Y-direction) on the plate. There are forty smaller holes (diameter: 2.2 cm) between the holes which provide additional passages for cooling water flow passed between the side plates of the fuel assemblies during operation. Fig. 1 shows a schematic of current grid plate in TRR. Fig. 2 shows the first operating core configuration implemented by the Argentinean constructor. It refers to the first configuration which allows the reactor operation at maximum power level (5 MW). This core is consist of 14 standard fuel elements (SFEs), 5 control fuel elements (CFE) and with light water is reflected. As mentioned, two types of control rods are used in the TRR. One made out of Ag-In-Cd which have large reactivity worth and are suitable for reactor control and shutdown. These group also called Shim Safety Rod (SSR) and there are four of them in the core. The second is made of stainless steel and has less reactivity worth and is suitable for regulation power in a limited range. This rod called Fine Regulation Rod (FRR) and there is one of them in the core. Therefore, CFE is divided into two categories, SSR and FRR.

The utilization of nuclear reactors are essentially for research, training and production of radioisotopes. The average thermal neutron flux for the first operating core of the reactor is 3.1E+13 n/cm^2·s which in irradiation box reaches to 6.0E+13 n/cm^2·s.

Table 1
General characteristic of Tehran research reactor.

Parameter	Description
Thermal power	5 Mw
Fuel	20% U_3O_8, MTR-type, Al clad
Avg. thermal neutron flux at 5 Mw (n/cm^2·s)	3.1×10^{13}
Core dimension (cm)	$40.5 \times 38.54 \times 89.7$
Coolant inlet temperature (°C)	37.8
Coolant outlet temperature (°C)	46
Cladding thermal conductivity (W/m·K)	167
Fuel thermal conductivity (W/m·K)	10
Grid plate (dimension in cm)	6×9 array, pitch 7.71×8.1 Al-1100 (thickness: 12.70) 54 holes (diameter: 6.17–6.19) 40 holes (diameter: 1.90–2.20)
Number of plate per fuel element	19 for SFE, 14 for CFE
Passing cooling water cross section (cm^2) at CFE	25.81
Passing cooling water cross section (cm^2) at SFE	33.92
Clad thickness (cm)	0.04
Water channel (cm)	0.27
Meat thickness (cm)	0.07
Meat width (cm)	6.0
Meat length (cm)	61.5
Upper fuel plate (cm)	76

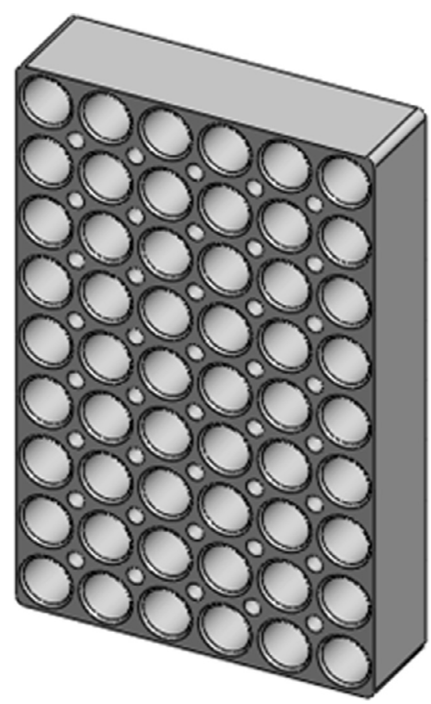

Fig. 1. Schematic figure of grid plate in Tehran research reactor.