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A liquid injection based Second Shutdown System for a typical material testing research reactor

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ABSTRACT

Many research reactors are used all over the world. There is a higher probability of accidents in nuclear research reactors compared their wide applications in a broad spectrum of sciences and industries. Material Testing Reactor (MTR) type is one large species of nuclear research reactors. Safety criteria are of main concern issues in the entire nuclear research reactor lifetime to satisfy the defense in depth criteria. In this paper, the main focus is on Second Shutdown System (SSS) as an Engineered Safety Feature (ESF) considered to enhance safety which will transfer the reactor to a subcritical state at actuation of any command circuits when a specific parameters exceeds some pre-established set points. Tehran Research Reactor (TRR) is selected as an MTR case study and one SSS is designed and studied in detail using MCNPX 2.6.0 code with regard to its requirements. It turns out that this SSS improves the overall reactor safety, and has not considerable penalties on different capabilities and characteristics of the reactor such as neutronic characteristics, safety criteria, and performance applications.

1. Introduction

Research reactors have numerous applications in various fields of sciences, life, medicine, environmental, chemistry, material, nano and engineering. As these facilities are usually placed in hospitals, residential and university regions, any accident in them can cause numerous radiological and mental damages to a wide range of people including facility personnel and the public. The persistence of IAEA and other responsible organizations is considering to comply with the highest level of safety standards in design, construction, operation, etc., at the whole lifetime of nuclear facilities.

For research reactors, engineered safety features such as containment, confinement and cooling systems, shielding and also in some cases Second Shutdown System (SSS) are considered for enhancing the reactor safety (IAEA, 2005). A shutdown system is a part of RPS which consists of the material and equipment used for reactor startup, operation, shutdown, and keeps it in a safe permanent subcritical state in the case of anticipated operational occurrences and accidents. In some reactors, another part of RPS is duplicated for safety enhancement such as second trip system in NRU. This reactor was originally designed in the early 1950s and commissioned in 1957. It is a heavy-water moderated and cooled, high flux reactor. Light-water is used as a secondary coolant and as a reflector which surrounds the reactor vessel (Tseng, 1994; Staff, 1960). Each of First Shutdown System (FSS) or SSS of the reactor is supported with some signals such as signal from the neutron instrumentation system, the process instrumentation system and the process radioactivity monitoring system (IAEA, 1997). The existence of SSS is necessary for power reactors (IAEA, 2012), also IAEA recommends to considering second shutdown system as an engineering safety feature for research reactors (IAEA, 2005a,b, 2012, 2014).

Characteristics of each research reactor such as age, site place, financial problems, different designs and features should be considered for implementing a second shutdown system. For example, the aging effect and degradation of structures strength should be considered in old reactors, as the IAEA database in April 2016 showed from 243 operational research reactors about half of them are over than 40 years old (Association, 2016).

In overall, there are some types of second shutdown system in research reactors. As a first case, absorber rods and string are used for SSS such as CONSORT, HANARO, JRTR, KJRR, FRMII and GHARR-1 (Bond et al., 2003; Kim et al., 2012, 2015; Nuding et al., 2000;

Abbreviations: MTR, Material Testing Reactor; SSS, Second Shutdown System; ESF, Engineered Safety Feature; TRR, Tehran Research Reactor; RPS, Reactor Protection System; FSS, First Shutdown System; FOC, First Operating Core; SFE, Standard Fuel Element; CFE, Control Fuel Element; GR, Graphite box; IR, Irradiation box; SRF, Safety Reactivity Factor.

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Boffie and et al., 2012). As a second method, injection of neutron absorber solution into the reactor core is used for SSS such as ETRR2 (Hussein et al., 2011). The third type is using heavy water as a reflector which is contained within a reflector tank in normal condition and dumping it in accident condition for SSS such as the new research reactor of Vietnam (Nguyen et al., 2012), CRCN/RPM-1 reactor in Brazil (Barroso et al., 1998), OPAL in Australia (Kim, 2006), CHTR and CIRUS in India (Dwivedi et al., 2010), RA-8 in Argentina, ZEEP and MAPLE in Canada, DIORIT in Switzerland and DIMPLE in UK.

In this paper, we consider Tehran Research Reactor as a typical MTR medium power for designing a new SSS. Recently, the two different types of SSS have been considered for TRR. In one use of heavy water as reflector tank around the reactor core was selected as the optimum system for TRR, but the study was limited to the FOC of TRR and the selected method requires major changes to the existing core structure and grid plate that in the present work as a requirement we avoid it as much as possible (Jalili et al., 2015). In the other work an effective approach to designing an SSS based on neutron absorber solution injection into the existing core was taken, but that design passes the safety margin of 1000 pcm narrowly (Boustani et al., 2016). In the present work using the same approach as taken in Boustani et al. (2016), a new design of SSS for the TRR is presented such that the shutdown margin is much more bigger than the obligatory worth.

The article is organized as follows. At first, in Section 2 a concise explanation about SSS, MTR type reactors and MCNPX code are given. This section also addresses the fundamental functional requirements and limitations for designing one SSS and the designs are presented. The obtained results for considered parameters with a discussion on these are given in Section 3 and finally Section 4 is devoted to the conclusion.

2. Materials and method

2.1. Second shutdown system

The basic safety functions to be performed in a research reactor are shutting down the reactor, cooling, and confining radioactive material. Incidents and accidents may occur whenever a failure, malfunction or incorrect operation of a system or component challenges the fulfillment of one of these basic safety functions (IAEA, 2008).

ESFs are designed for control or mitigation of consequences of postulated accidents in nuclear reactors. These are provided which are capable of maintaining the reactor in a safe condition under all anticipated operational conditions. They constitute the third level of “defense in depth” and are designed to prevent incidents from developing into accidents. They comply with fail-safe and reliability safety criteria and are qualified to withstand the environmental conditions arising from all operational states and all accident conditions for which they are required to function (INVAP, 2014). Some of ESFs are FSS, SSS, core cooling by natural convection, reactor pool coolant boundary and containment. The SSS is a part of RPS which the important duty of it is an interruption of fission chain reaction in the reactor core in case that the FSS fails. The existence of FSS for almost many of research reactors such as MTR type is necessary. The existence of SSS depends on reactor characteristics such as existing safety features, reactivity feedback coefficients, etc. The implementation of any SSS must have a minimum defect on reactor reactivity feedback coefficients and its performance quality as much as possible. Another point which must be considered in designing this feature is the ability for shutting down the reactor when it partially operates. Designing one SSS for the TRR medium power reactor with the downward coolant direction has its appropriate limitations and requirements.

Table 1
Some major parameters of one typical MTR.

Parameter	Quality\Quantity
Type of reactor	Open pool
Reactor power (MW)	5
First criticality	11th Nov 1967
Number of fuel assemblies in equilibrium core array	33
Safety rods and moving direction	5, downward
Core dimensions (cm × cm × cm)	47 × 73 × 100
Flow direction throw the core	downward
Moderator and coolant	Light water
Reflector	Graphite
Reactor cooling mode	Below 100 kW natural convection Above 100 kW forced convection
First shutdown system operating time (ms)	700
Grid array	6 × 9
Active fuel length (cm)	61.5
Control rods drive location	Above core
Average extraction burn-up (%)	30
Maximum extraction burn-up (%)	65
Fuel type	19.75% enriched, U_3O_8Al
Absorbing material	Ag-In-Cd
Core refueling interval (full power)	About 30 days
Fuel type	Plate
Number of fuel plates per fuel assembly	19 for SFE and 14 for CFE
External plate thickness (mm)	1.5
Internal plate thickness (mm)	0.7
Cladding material	Al 6061
Power peaking factor (PPF)	<3
Reactor pool inventory (m^3)	About 500
Average thermal neutron flux ($cm^{-2}.s^{-1}$)	2.5e13
Maximum neutron flux ($cm^{-2}.s^{-1}$)	1.0e14