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Enhancing Tehran Research Reactor safety through a Second Shutdown System: A probabilistic safety assessment

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ABSTRACT

One of the conceivable safety features for enhancing safety of a research reactor such as the Tehran Research Reactor (TRR) is a Second Shutdown System (SSS). One innovative SSS is designed with considering the TRR requirements and limitations such as safety, operational problems, neutronic and aging problems. The SSS of TRR is a reliable, independent and diverse shutdown system which can actuate and shut down the reactor following the First Shutdown System (FSS) failure. In the present study, the effect of this new option on upgrading the reactor safety is studied with performing level 1 of Probabilistic Safety Assessment (PSA) using the SAPHIRE code based on the selected initiating events. PSA is increasingly being used as a part of the decision making process to assess the level of safety of nuclear reactors. Considering only internal events in this analysis, it is seen that with the existence of the SSS the failure rate of reactor shutdown system decreases at least to 3.20E-04 of its previous value. The core damage frequency conservatively turns out to decrease at least by the half of the value previously reported to be 8.37E-06/y. In order to enhance the TRR, reactor personnel and other public safety, equipping TRR with a SSS is a rational plan. To avoid accidents which can cause mass environmental damage and human loss is the prime advantage of equipping TRR with this engineered safety feature.

1. Introduction

A complete SSS or where this is not possible, some part of RPS is used as a engineered safety feature in many types of nuclear reactors for improving safety, from research reactors to nuclear power plants in which the existence of SSS is compulsory. Design a part of RPS such as the installation of a STS in NRU (Bessada, 1997), or adding one control rod for SSS in the core such as FRM-II (Böning and Blombach, 1995) or other sophisticated designs are some of instances (Fukami and Santecchia, 2000; Glasstone and Sesonske, 1994; IAEA, 2012; Kim, 2006; Sapara et al., 2003; Vanmaercke et al., 2012).

Depending on the specific characteristics of each reactor such as structure, fuel, coolant, moderator, neutron flux spectrum, operational condition etc., there are many variables and dependent parameters that should be taken account in designing one SSS. One SSS is designed regarding the characteristics of TRR with minimum interferences and changes to the existing core structure in order to improve the safety of this reactor.

The aim of this paper is to study the effect of SSS on the TRR with performing level 1 PSA utilizing the SAPHIRE program and to demonstrate that adding the SSS upgrades the TRR safety with illustrating quantitatively decreases in the shutdown system failure rate and the core damage frequency. A description of TRR and its shutdown systems, an explanation of PSA method and also PSA analysis of TRR systems are given in section 2, Section 3 is devoted to the results and discussion. We then conclude in section 4.

2. Materials and methods

2.1. TRR and its first shutdown system

TRR is an open pool and MTR type research reactor that is used for radioisotope production, neutron activation analysis, personnel training, sample irradiation for research activities and etc. The reactor core stands on a grid plate consisting of an array with 9×6 rectangular places. The only existing shutdown system of this reactor is FSS that consists of 4 shim safety rods composed of Ag, In and Cd in 80, 15 and 5 wt percentages, respectively and 1 regulating rod of stainless steel for fine power regulations and flux

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Abbreviation

TRR	Tehran Research Reactor
SSS	Second Shutdown System
FSS	First Shutdown System
PSA	Probabilistic Safety Assessment
RPS	Reactor Protection System
STS	Second Trip System
MTR	Material Testing Reactor
FOC	First Operating Core
IR	Irradiation Box
SFE	Standard Fuel Element
CFE	Control Fuel Element
RR	Regulating Rod
SR	Shim Safety Rod
P&ID	Piping and Instrumentation Diagram
V	Valve
P	Pump

distribution. Being a time-honored reactor (near 50 years), located in an almost crowded region, operating continually and the need for this reactor operation, notice to upgrade the safety of this reactor is indispensable.

TRR core has two limiting characteristics: The first one is having a relatively small core size, where the total outer core dimensions are smaller than 50 cm × 75 cm × 100 cm for length, width and height, respectively which limits any use of its inner space for SSS. The second one is the fact that the surrounding space of TRR core has been filled with beam tubes, thermal column and rabbit system and so use of this region for SSS is impossible without major changes to the core structure. In the light of these two restricting factors, as can be seen from the FOC in Fig. 1 and the other technical and safety issues as mentioned before, one SSS is designed for the TRR.

Some basic characteristics of TRR are brought in Table 1.

Table 1
Some basic characteristics of TRR.

Parameter	Quality/Quantity
Reactor power (MW)	5
Safety rods moving direction	downward
Flow direction throw the core	downward
Moderator and coolant/Reflector	Light water/Graphite
First shutdown system operating time (ms)	≈700
Control rods drive location	Above core
Fuel material	19.75% enriched, U_3O_8Al
Fuel type	Plate
Number of fuel plates per fuel assembly	19 for SFE and 14 for CFE
Cladding material	Al 6061
Reactor pool inventory (m^3)	About 500

2.2. SSS of TRR

A redundant and diverse shutdown system is foreseen and designed for upgrading TRR safety. A comprehensive literature about safety features and detailed characteristics of SSS could be found in Ref. (Boustani et al., 2016). Nevertheless, some main specifications of SSS in TRR are given in Table 2.

The top and overall view of this safety system final plan is shown in Fig. 2 and Fig. 3.

One outstanding point about the SSS performance is that with filling only one of the two SSS boxes, it will shut down the reactor

Table 2
Some main parameters of SSS in TRR.

Parameter	Value
Wall thickness (mm)	2
Material of walls	Al-6061
height (mm)/length (mm)/width (mm)	703/320/30
Total volume of two SSS boxes (liter)	11.49
Neutronic absorber solution	Enriched boric acid
SSS pressure in standby mode (kPa)	20
SSS pressure in actuation condition (bar)	10
Injection time (s)	<4
Shutdown margin (pcm)	>1000

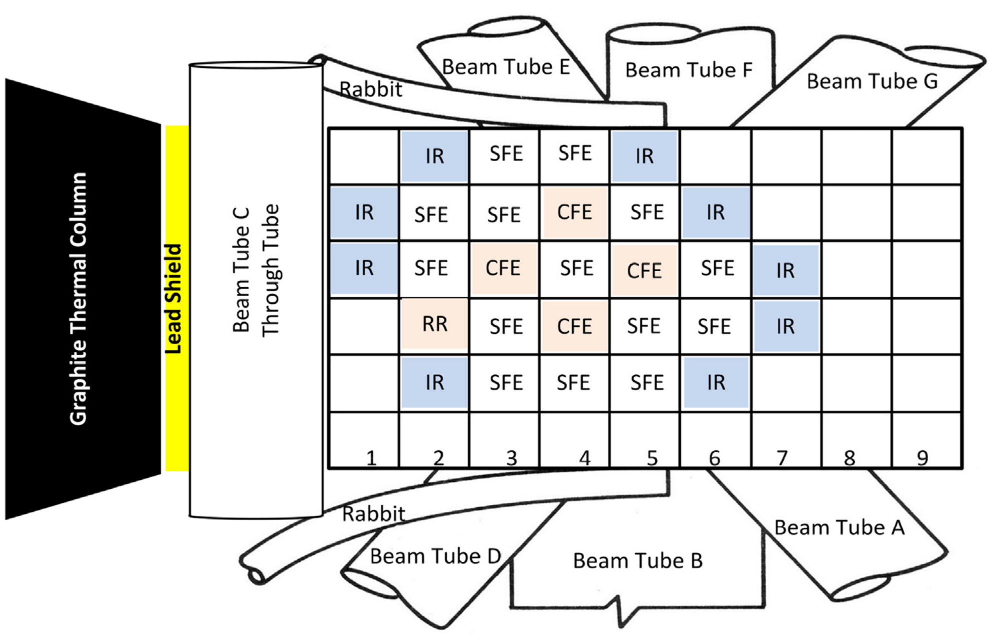

Fig. 1. TRR first operating core and surrounded structures.