Safety assessments of the Tehran research reactor

A.Lashkari[1], M.R.Kardan[1], S.M.Mirvakili[1], B.Rokrok[1], Y.Kasesaz[1]

1) Research school of reactor and nuclear safety, Nuclear Science and Technology Research Institute (NSTRI), Atomic Energy Organization of Iran (AEOI), Tehran 14399-51113, Iran

Corresponding author: alashkari@aeoi.org.ir

Abstract. Research reactors play an important role in the development of nuclear science and technology. They provide a proper source of neutron for research, testing and analysis. They are also used for various applications in the fields of nuclear engineering, nuclear physics, in all of these applications, research reactors must be operated in safe condition. TRR is an old research reactor which has been operating for the last 50 years and needs to be upgraded and improved to satisfy the up-to-date safety requirements in view of the planned lifetime extension. TRR needs to operate safely and efficiently for production of the required radiopharmaceuticals and industrial used radioisotopes according to the national plan. In this situation, the extension of the TRR lifetime through its safety enhancement is of vital importance. This paper and presentation includes the following sections to enhancement of TRR.

- Efforts made by IAEA experts.
- Establishing
- Updating of safety documents
- Training and qualification of personnel
- Minimizing radioactive waste by

Future activities that have to be consider are

- Considering detailed population distribution around the TRR in analysis, simulations and dose estimations.
- Using new detectors on-site for alpha-beta emitters.
- Using online detectors on the top of TRR's stack for online analysis of type and amount of releases from TRR.

Actions being taken after Fukushima accident are

- Refurbishment of Emergency Ventilation System
- Design and installation of a new I&C system
- Review availability of Emergency Power Supply
- An Emergency Core Cooling System(ECCS) for TRR
- Enhancing Emergency Preparedness and Response, including Emergency Equipment, and Emergency Communication
- Seismic Re-evaluation and reinforcement of the SSCs of TRR
- Evaluation of a BDBA(Blackout +LOCA) for TRR
- Stress tests analyses for the Tehran Research Reactor

Nomenclature	
AEOI	Atomic Energy Of Iran
NPP	Nuclear Power Plant
NSTRI	Nuclear Science and Technology Research Institute
SFS	Spent Fuel Pool. Cooling System
TRR	Tehran Research Reactor
LEU	Low Enriched Uranium
HEU	Highly Enriched Uranium
SFE	Standard Fuel Element
CFE	Control Fuel Element
LEU-CFE	Low Enriched Uranium- Control Fuel Element
SAR	Safety Analysis Report
SR	Shim Safety Rod
RR	Regulating Rod
OLC	Operating Limits and Conditions
AMP	Aging Management Program
ER	Environmental Report
EP	Emergency preparedness
RPP	Risk-Informed and Performance-Based Plan
ECCS	Emergency Core Cooling System
BDBA	Beyond Design- Basis Accident
TLD	Thermo luminescent Dosimeter Monitoring
LOCA	Loss Of Coolant Accident
HEPA	High Efficiency Particulate
INRA	Iranian-Nuclear-Regulatory-Authority
SBO	Station Black Out
UHS	Ultimate Heat Sink

1. Introduction

Research reactors play an important role in the development of nuclear science and technology. They provide a proper source of neutron for research, testing and analysis. They are also used for various applications in the fields of nuclear engineering, nuclear physics, radiochemistry, materials sciences, nuclear medicine, agriculture etc. Requests of research reactors fall into four wide-ranging categories: human resource development, irradiations, extracted beam work and testing.[1]. In all of these applications, research reactors must be operated in safe condition. Several activities related to normal operation involve safety evaluation. Generally, any activity or modification that influences Neutronic, thermal-hydraulic and mechanical properties of the reactor should be supported by safety analyses. SS 35-G2[1] Provides guidance on the safety categorization of modification and utilization projects and the associated approval routes. NS-R-4 establishes safety requirements for the utilization and modification of research reactors [2]. The IAEA safety requirements document (NS-R-4) is under revision to incorporate the relevant feedback from the Fukushima Daiichi accident. The experience available from the Fukushima accident is vital for defining and implementing measures to prevent the occurrence of accidents involving a large release of radioactive material at nuclear installations, including at a research reactor.

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[1] Safety Series No, 35-G2, NTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA, 1994

TRR is an old research reactor which has been operating for the last 50 years and needs to be upgraded and improved to satisfy the up-to-date safety requirements in view of the planned lifetime extension. TRR needs to operate safely and efficiently for production of the required radiopharmaceuticals and industrial used radioisotopes according to the national plan. In this situation, the extension of the TRR lifetime through its safety enhancement is of vital importance. Past efforts have addressed the TRR safety issues:

- recommendations made by the Integrated Safety Assessment of Research Reactors (INSARR) mission in 2007
- recommendations made by IAEA experts during implementation of TC project (IRA9022) for enhancing TRR safety (2014-2016)
- Analysis of some experiences of other research reactors that reported in IRSRR and comparing with TRR
- Use of our experiences in previous years during operation, periodic tests, inspections & maintenance, exercises and maneuvers, experiments, incidents and audits
- Recommendations received from INRA site inspections, Audits and reviewing safety documents and procedures

Safety reassessment of TRR is needed in light of the lessons learned from Fukushima accident.

2. Description of TRR

Tehran Research Reactor (TRR) became critical using Highly Enriched Uranium (HEU) that was more than 90% enriched in ^{235}U, in 1967 [3]. In later years, based on the International Atomic Energy Agency Non- Proliferation Treaty (IAEA-NPT), the new fuel with Low Enriched Uranium (LEU), containing less than 20% enrichment in ^{235}U, was used. The TRR is pool type, heterogeneous, solid fuel, light water moderated research reactor, in which the light water is also used for cooling, shielding and reflecting. The reactor has been designed and licensed to operate at maximum thermal power level of 5 MW with forced cooling mode. The reactor core assembly has been located in two-section pool and may be operated in either of two sections of the pool. One of the sections contains experimental facilities like beam tubes, rabbit system, and thermal column. The other section is an open area for bulk irradiation studies. The major components of TRR are the pool (including embedment and accessories), bridge and support structure, core, cooling system, control and instrumentation, ventilation system, and the experimental facilities. The TRR specifications are shown in tabe1. Other details of reactor description and core parameters are given in TRR- Safety Analysis Reports (SAR[2]) [4]. Elements of the reactor core are arranged in a 9 by 6 grid plate structure. The nuetronic and kinetic parameters of first and equilibrium core (core No 51 & 61) are given in this references [5, 6].

The utilization of the reactor is essentially for research, training and production of radioisotopes. The research projects to be undertaken are determined based on the general type of working involved. This would include the following topics: physics, chemistry, Engineering and Industrial use. Summary of Strategy and objectives of the TRR are:

- Fundamental nuclear researches, mainly study of neutron reaction with materials, activation by means of neutron and investigation on its consequences.
- Radioisotope production, being utilized in medicine, industry and agriculture.

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[2] - AEOI, 2001. Safety Analysis Report for the Tehran Research Reactor (LEU), Tehran-Iran.

- Education and training of manpower in the field of nuclear technologies and providing facilities and infrastructures for Ph.D and M.s students projects.

Safety advantages of TRR includes, Passive core cooling system, Flow direction is compatible with decay heat, downward flow aids the scram and N16 doesn't reach pool surface

Table 1: Reactor Specifications

Thermal power	5 MW
Fuel	Low enriched U-235,MTR type, Al Clad
Ave. Thermal Neutron Flux at 5 MW	3.21×10^{13} n/cm^2.s
Number of plates per fuel element	19 for SFE 14 for CFE
Moderator	Light Water
Shielding	Water, Lead, Barite Concrete and regular Concrete
Cooling System	Forced Flow Primary Loop Through Shell and Tube Heat Exchanger, Secondary Loop Dissipates Heat in a Cooling Tower
Coolant	Light Water
Primary Coolant Flow	500 m^3/h (2200 gpm)
Secondary Coolant Flow	522 m^3/h (2300 gpm)
Coolant inlet temperature entering the heat exchanger in 5 MW	37.8 ^{o}C (100 ^{o}F)
Coolant outlet temperature exiting the heat exchanger in 5 MW	46 ^{o}C (115 ^{o}F)
Secondary coolant outlet in 5 MW	39 ^{o}C (102 ^{o}F)
Secondary coolant inlet in 5 MW	30.6 ^{o}C (87 ^{o}F)
Water purification	Continuous demineralisation of a portion of primary water
Demineralizer flow	3.42 m^3/h (15gpm)
Control	4 Silver-Indium-Cadmium Shim Safety Rods (SSR). 1 stainless steel Regulating Rod (RR)
Experimental Facility	Four 6" beam tubes One 8" beam tube One 12" by 12" beam tube One thermal column One double pneumatic rabbit system One 6" through tube One gamma irradiation facility One dry irradiation chamber

3. Major modification and various projects in TRR in recent years:

3.1. Core conversion

Core conversion form HEU (93%) to LEU (20%) was carried out in 1993, causing a striking increase in utilization plan of the TRR. The main safety related modification in this conversion was change of absorber control rods from oval to fork type (*FIG. 1*) To compare between oval and fork type absorbers, it follows that considering the same absorber material and fuel enrichment, fork-type control rods are more effective than oval by a ratio ranging from 1.25 to 1.36. Using the fork-type control rod results in higher excess reactivity than the oval-type. The peaking factor due to oval-type when the rod is extracted is 16% greater than the one obtained with fork-type for LEU-FE cores [4] .

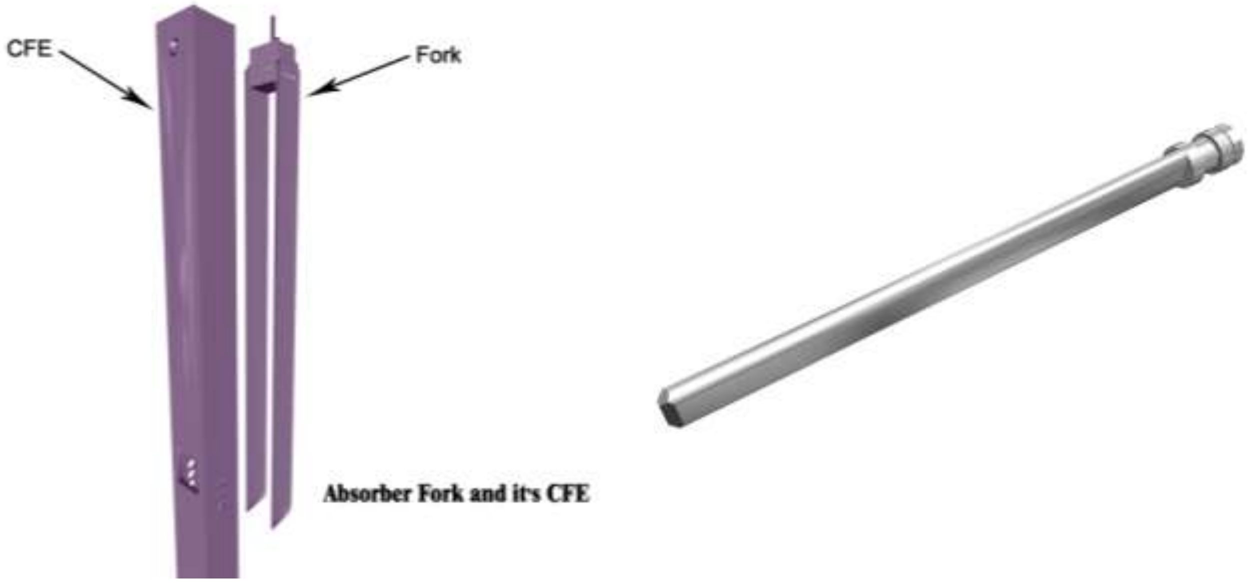

FIG. 1. Oval and fork type of TRR control rods

3.2. Steel lining of the reactor pool and the underground Hold Up Tank

A stainless steel lining is installed inside the reactor pool. The main purpose of lining is to prevent the water leakage from the reactor pool. The lining thickness is 5 mm except for the front of the thermal column and gamma irradiation room where the lining is only 1mm thick in order to allow the maximum possible flux to enter the irradiation facilities (*FIG. 2*).

FIG. 2. Steel lining of TRR

3.3. Design and construction of a spent fuel

The irradiated fuel storage pool is located in the north west of the reactor, in the distance of about 50 meters. The storage pool has steel lining with capacity of 135 fuel assemblies (Figs. 10.2 and 10.3). The demineralized water is provided by the reactor make up system. The pool length, width and depth are 6×4×5 meters respectively. Figure 10.6 show the spent fuel storage facility. The building volume is 750 m3 and the ventilation system is designed to filter and discharge the air from the spent fuel storage building through a three phase exhaust fan with 750 m^3/hr flow rate to atmosphere. The HEPA filters are used either in inlet or outlet ducts. There is a RADOS gamma radiation monitor in the storage pool. The spent fuel storage pool is designed and constructed according to the Iranian national building standards. The lining of the pool is stainless steel (SS-304) with no connecting pipe at the bottom. Thus, abrupt drainage of pool water due to rupture of piping does not sound probable

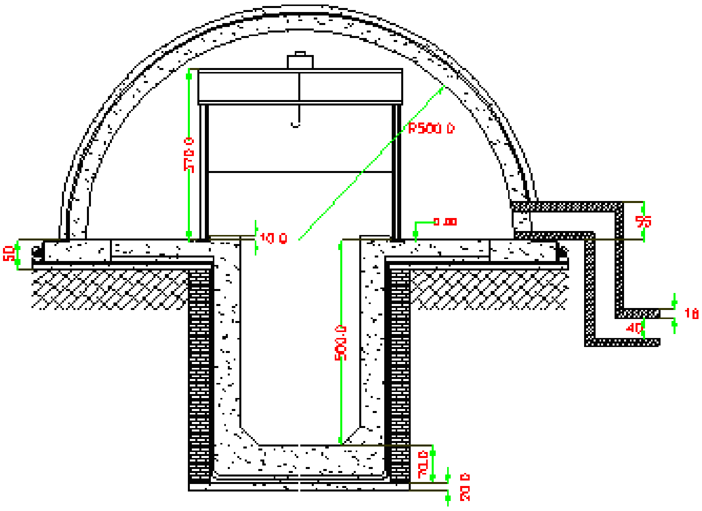

FIG. 3.Spent Fuel Cross Section

3.4. Design and construction of new Control room

As originally described, in order to provide the safety and protect the equipment, a space outside the reactor building is considered for management of the reactor and staff deployment. This space is located on the first floor of new building and access via stairs built on the ground floor. In this floor, required spaces for the deployment of personnel and equipment are predicted on the basis of labor relations and equipment relations. (*FIG.4*).

FIG.4. new control room of TRR

4. Activities for safety enhancement of TRR

Some activities have been done in recent years in TRR to enhancement of safety. These activities are:

- *Establishing quality assurance program based on GS-R-3, Strategic plan for TRR utilization and Process map*
- *Updating of safety documents such as SAR , OLC, AMP, ER, EP, RPP and Operating procedures*
- *on-site environmental dose assessment using TLD detectors*
- *Training and qualification of personnel*
- *Minimizing radioactive waste by training and optimization of method & equipment*

In updating of ER for TRR the latest changes was considered. These changes include:

- Some changes in population, transportation, number of structure and buildings around the TRR.
- Assessment and analysis of probable accidents for another facility on
- Site simultaneously (gamma center, spent fuel storage pool and TRR.
- Some sampling and analyzing of soil plant and air on-site around the TRR.

- *Radiation protection activities include*:

- Establishing an integrated radiation monitoring system for the reactor facility and in the vicinity of TRR in AEOI site that INRA can access online to this data.
- Preparation of RPP
- Establishing and implementing of contamination monitoring program
- Future plan:
  - Development of radiation monitoring system , renewing some monitoring equipment and implementation a post-accident monitoring system

- ***Emergency plan***

  - Establishing a committee for updating emergency preparedness and response of TRR facility in connection with crisis management committee of AEOI
  - Reviewing emergency plan, Updating procedures and attachments, applying assessments of IAEA experts, considering suggestions of regulatory body
  - Establishing alarm and notification system, renewing communication network
  - Planning and performing training maneuvers

5. Safety reassessment of TRR in the light of the lessons learned from Fukushima accident

Safety reassessment of TRR is needed in light of the lessons learned from Fukushima accident. The TRR was constructed decades ago (50 years ago) and is not fully in conformance with up-to-date safety standards. TRR is located near populated areas, and for some of these the leak-tightness of the confinement is inadequate. In many cases, the characteristics of the TRR site and area in the vicinity have changed since the construction of the facility and these changes have not been considered in the safety documents of TRR.

The above elements are not adequately reflected in the SAR of TRR. The experience available from the Fukushima accident is crucial for defining and implementing measures to prevent the occurrence of accidents involving a large release of radioactive material at nuclear installations, including at a research reactor. The actions being taken after Fukushima accident in TRR are

- Refurbishment of Emergency Ventilation System
- Design and installation of a new I&C system
- Review availability of Emergency Power Supply & An ECCS for TRR
- Enhancing Emergency Preparedness and Response, including Emergency Equipment, and Emergency Communication
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6.1. Key points in Fukushima in comparison with TRR

In this section some of key points of Fukushima accident are compared with TRR.

***Loss of Power supply*: ** In Fukushima NPP the loss of offside power and onside AC power, led to a complete station Blackout, which in turn led to fuel overheating and damage but In TRR Downward flow provided by gravitational head continues until natural convection establishes

***Hydrogen Production*:** In Fukushima NPP Overheating of fuel and rapid oxidation of Zirconium cladding led to generation of large amount of hydrogen, But in TRR MTR fuel has Al cladding, and hence Hydrogen explosion is not a force able scenario

***Spent Fuel Storage*:** In Fukushima NPP, Lack of the SFS cooling due to loss of power supply resulted in the release of radionuclides, But In TRR**,** The stored energy and radionuclides inventory are considerably lower than a NPP and SFS is separated from the reactor building with the passive SF cooling and then, The TRR dispersed fuel has a significantly different behavior in terms of fission product retention

***Containment Venting*:** In Fukushima NPP, Due to the station blackout, the operators had to vent the containment to avoid containment over -pressurization some vented gases leaked into the reactor building, resulting in hydrogen explosion but in In TRR, The containment is vented directly to the stack by the ventilation system with backup power supply. It should be emphasized, for a prolonged blackout+ radionuclides release safety function of containment could be threatened.

***Site Layout*:** In Fukushima NPP, Due to the site’s compact layout, problem at one unit created negatively safety-related situations at adjacent units, But in TRR, Only one unit

5.2. Stress tests analyses for the Tehran Research Reactor (TRR)

Identification of weak points of the reactor design, mainly due to external hazards – extreme weather, earthquakes, floods and fires are stress test goals. Assessment of scenarios includes station blackout and ultimate heat sink loss. The analysis was based on simplified power plant guidelines for stress tests. The stress tests were done voluntarily; no requirements came from the regulatory body. UJV/CVR Group will support NSTRI in performing stress tests for TRR. The stress tests will be in line with the practice of the EU countries adopted after the Fukushima accident and will focus on the evaluation of the TRR reactor resistance to internal and extreme external conditions. Report on Stress test for TRR, Safety analysis for definition events, Workshop and training course are the main goal of this stress test analyses. The resulting report may be structured into the following sections. The following activities to be performed by NSTRI:

- The basic design characteristics of the nuclear facility
- History of earthquakes in Iran and in TRR (Tehran) site
- Flooding
- Potential sources of flooding in the neighboring area of TRR
- Resistance of building structures and technological equipment of TRR against flooding
- Loss of Internal sources electric power

The following sections to be performed by UJV:

- Resistance of building structures and technological equipment of TRR against earthquakes
- Extreme weather condition
- Resistance of building structures and technological equipment of TRR against Extreme weather condition
- Disintegration of external grid
- Loss of AC/DC electrical power
- Internal and External Extreme Hazards including Fire, Explosions, Lighting, etc.
- Terrorist Attack (including Aircraft Crash, Missile hit, Software obstructionism)

The following analyses to be perform by CVR:

- SBO analysis for TRR
- Loss of ultimate heat sink (UHS)
- SBO analysis and simultaneous loss of UHS
- Analysis of potential severe accident in TRR and accident management.
- Conclusions, the proposed measures

Building resistance against seismic and extreme meteorological events can be evaluated using the Finite element method analysis of the global building structure. It is also important to quantify margins of the structure and to analyze behavior of the structural system when design values are exceeded. Technological equipment resistance against seismic event review will be focused on safety systems design basis seismic qualification, identification of key and weak equipment, cliff edge effects, function and potential interaction with non- safety systems in case of design basis seismic event. Conditions and consequences of exceeding design basis earthquakes (DBE) will evaluate as well. Design values for all extreme meteorological phenomena typical for the site have to be established based on data from meteorological stations. This relates to air temperatures, wind speed and extreme precipitation (rain, snow). It is also important to investigate possible effects of rare meteorological phenomena, such as lightning, typhoons, tornadoes, etc.

The required inputs for technological equipment are passports of equipment and design basis conditions for the equipment. Based on the inputs the function during extreme conditions and resistance against extreme weather condition will be reviewed. As for the building structures and resistance against other internal and external extreme hazards, the preliminary screening of potential initiating events has to be prepared. Important for stress test is events potentially leading to multiple loss of safety functions. Such hazard may come from near industrial facilities, transportation of hazardous material on roads, etc. Building resistance analysis for aircraft crash and missile hit is also possible using the Finite element method analysis of the global building structure. Pipe ruptures, internal flooding effects will be evaluated. Safety systems protection against safety hazards will be review. Fire concept of TRR shall be analyzed in order to review potential failure of safety systems during fire. The issues of cyber security (software obstructionism) shall be analyzed from a technical point of view as well as a procedural point of view – risk analysis. It covers not only external attacks but also internal hazards like PC access control. Collection of information on potential sources of man made hazard is necessary including evaluation of design basis parameters. As for the terrorist attack, the design basis threat has to be established in cooperation with Iranian regulatory body. Analysis of SBO, Loss of Ultimate Heat Sink (UHS), SBO analysis and simultaneous loss of UHS and potential severe accident in TRR should provide information on accident scenarios development in case of the total loss of external and internal electricity supply or loss of ultimate heat sink or a case of their simultaneous occurring. The key expected outcome is time to the initiation of the core damage (cliff edge effect) along with the potential release of the radioactive substances from the core (source tem). Analyses will have to be done by an appropriate computer code(s). A computer model of the TRR and its technological systems will have to be developed and validated. Input data requirements are, Detailed design data of the TRR, in particular on the active core (fuel, control rods, internals), cooling systems (circuits), confinement, etc.

6. **Conclusions**

TRR is an old research reactor which has been operating for the last 50 years and needs to be upgraded and improved to satisfy in light of the lessons learned from Fukushima accident. TRR needs to operate safely and efficiently for production of the required radiopharmaceuticals and industrial used radioisotopes according to the national plan. The TRR was constructed about 5 decades and is not fully in conformance with up-to-date safety standards. In this situation, the extension of the TRR lifetime through its safety enhancement is of vital importance. In this paper all major modifications of TRR introduced and also all activities for safety enhancement of TRR stated. In this paper some of key points of Fukushima accident are compared with TRR. Although TRR in comparing with Fukushima N.P.P is very safe but we need to analyses stress tests for the Tehran Research Reactor. The stress test will focus on the evaluation of the TRR reactor resistance to internal and extreme external conditions. The analyses of SBO, Loss of ultimate heat sink (UHS), SBO and simultaneous loss of UHS and analysis of potential severe accident in TRR will be perform by NSTRI and UJV/CVR group.

7. References

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