

# **Operational Safety Experience at 14 MW TRIGA Research Reactor from INR Pitesti, Romania**

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**Abstract.** The safe operation of TRIGA-14 MW Core and Annular Pulsed TRIGA Core in the assembly of Research Reactor in Pitesti, Romania for 27 years is presented from historical perspective as well in the light of evolving safety experience. The accomplishment of safety objectives and responsibilities of operating organization is described and sustained with practical examples including management responsibilities, resources of management, performance indicators, measurement analysis and monitoring. Further improvement of safety of Research Reactor through a large refurbishment and modernization program under way is also presented in the paper.

## **CONTINUOUS IMPROVEMENT OF SAFETY OF NUCLEAR INSTALLATIONS**

Mainly the safety of nuclear power plant is improved by utilization of Probabilistic Safety Assessment (PSA). In general, PSA is used to support the system design and configuration decisions and rarely is used to support the operational safety management of plant. With respect to plant safety it should be stressed that risk prevention is more appropriate philosophy rather than consequences mitigation procedure [1]. These ideas are applied to 14MW TRIGA Research Reactor operated by Institute for Nuclear Research Pitesti, Romania.

The initial design of this research reactor were not sustained by results of a specific dedicated PSA, being the result of other 54 TRIGA facilities with smaller power and reduced performances 500 kW to 2000 kW under design construction and operation between 1952 and 1974.

The Safety Report including several Safety Analyses is based mainly on deterministic and qualitative judgements. Each research reactor either designed and built by the same supplier operate in a changing environment which is not possible to be forecasted and modelled during design and consequences – in availability, safety and utilization are different, imposing the monitoring of risk of operation.

During the operation of a given facility each event of operation constitute a valuable information which properly acquired, processed, understood and used in time will increase the safety and availability of facility. The common word is building a database for operation of facility to collect and process all information concerning the configuration and status of facility.

## **OPERATIONAL SAFETY**

The term **Operational Safety** is used on power reactors to describe the safety of the plant, as well as power production through a series of performance indicators. To extend the Operational Safety term to research reactors, this will describe the evolution of nuclear safety of facility, as well the only one indicator related to availability for neutrons production for research and practical purposes.

Considering the above idea, we may define Operational Safety as being the aptitude of Operating Organization to avoid the occurrence of events whose consequences affect the availability of reactor, the systems or equipments and health of personnel [2].

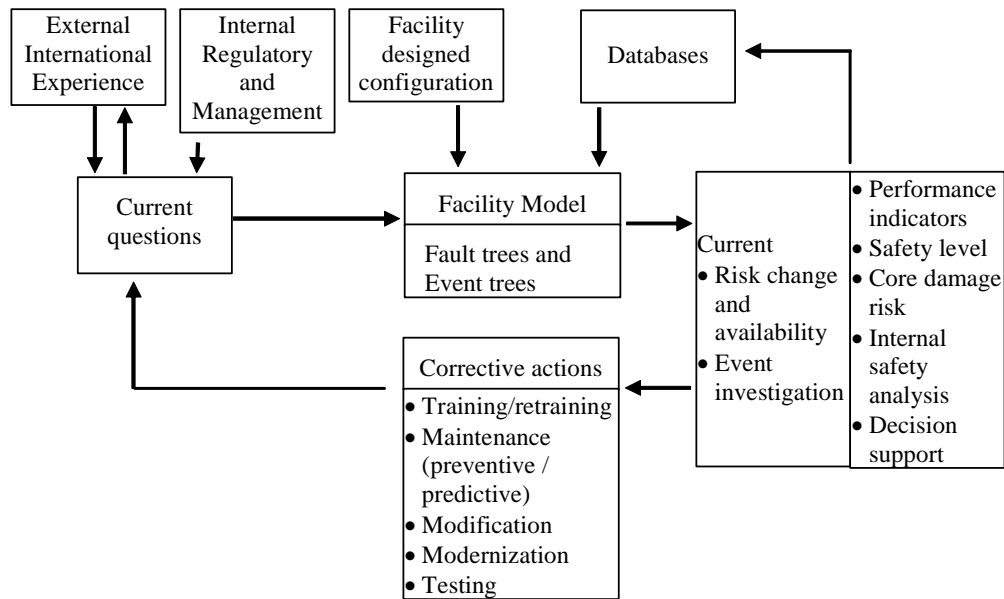


FIG. 1. The flowchart of Operational Safety

The aim of Operational Safety is to minimise or eliminate the risk of injuries or damages to operators, equipment and availability of research reactor utilization. The Operational Safety should be applied through the entire life of facility. Performance indicators philosophy is evolving and in the area of research reactors is a promising beginning. In the last two decades several sets of performance indicators were proposed by IAEA and since 2005 a set of indicators is proposed through IRSRR (International Reporting System for Research Reactors) to be used by research reactors as a prevention tool.

The analysis of operating experience data based on statistical and deterministic models describe the trends of indicators including human and organizational performances. An enhancing experience and a good source of information is the licensee event report starting with the simplest “Unscheduled Shutdown Report” made by Senior Reactor Operator during the shift and Logs Records which are very useful. The analysis of those reports always lead to the root causes of events frequently connected with human performances. The Operational Safety is also correlated with organizational and human performances, safety culture, learning from experience process and research and financial resources.

### OBJECTIVES AND TYPES OF OPERATIONAL SAFETY INDICATORS

Operational Safety Indicators are used by Operating Organization, Regulatory Body and international community to evaluate trends of safety of an individual facility, or type of reactor, the indicators can be used for:

- Definition of goals and targets;
- Follow-up of effectiveness of corrective actions including changes and modernization/refurbishment;
- Identification of improved performances in a specific area;
- Transfer of knowledge and experience;
- Acceptance and appreciation of operation of facility by public and organizations/stakeholders.

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Safety performances indicators of research reactors as proposed by IAEA – IRSRR:

1. availability
2. unscheduled shutdowns
3. radiation doses
4. radioactivity released
5. adequacy of man power and personnel turnover
6. emergency preparedness
7. maintenance of safety systems
8. safety review
9. safety culture
10. completeness of safety documentation
11. quality assurance
12. fuel integrity
13. utilization
14. unusual events records

The safe operation of TRIGA reactor installed in Institute for Nuclear Research in Pitesti, started in 1979 in conditions of existing infrastructure, Regulatory Authority was established in 1962, a 2 MW VVR-S Research Reactor was in operation since 1956 (from 23 years), the University of Bucharest and the Polytechnic University teaching nuclear physics and nuclear engineering.

The Regulatory Authority having the independence for regulation and control, issued the basic norms and regulations for safety of nuclear reactors, radiation protection, transportation of radioactive materials, safeguard, updated in 1996. Cooperation with an experienced supplier of numerous TRIGA Research Reactors ensured the transfer of specific knowledge of core design, safety principles and operation of first 14 MW TRIGA SSR core built by US General Atomics.

The quality assurance for commissioning and operation of the reactor was the formal requirement of Regulatory Authority. In the above presented circumstances, the Institute for Nuclear Research built, commissioned, and operates the TRIGA Research Reactor under IAEA Project and Supply Agreement. The Safety Analysis Report structure and content, was adopted following the IAEA recommendation having in that time 17 chapters. Later, sections concerning Quality Assurance, Emergency Preparedness, Decommissioning, were developed and added.

The continuous development of safety requirements, new standards, guides and norms were reflected in national legislation and lead to a rather complete Legal Regulatory Framework, in this regard, based on Safety Analysis Report and the proposal of Operational Limits and Conditions sustained by Operating Organization, a full formal licensing process was developed and reinforced by the Regulatory Authority in Romania. Continuous development of safety standards and guides by IAEA, development of a new and complete set of internal regulations since 2001 by Regulatory Authority and experience of 20 years of TRIGA reactor operation lead to periodic revision of SAR.

Most of the sections, chapters of SAR were updated considering the modification of the reactor, core conversion, taking advantage of the new computational methods and solutions. Re-evaluation of safety studies with new methods including Probabilistic Safety Analysis, considering real condition of operation, updating the specifications, the procedures, the SAR and the OLC's allow to enhance the safety of TRIGA Research Reactor. The accomplishment of safety objectives of operation and utilization of research reactor operated by an organization which is in the same time Technical Support Organization for Nuclear Activities in Romania is the challenging task correlated with the sustainability of the institute.

The 14 MW TRIGA Research Reactor was commissioned in 1979 and Annular Core Pulsed Reactor was commissioned in 1980. The 14 MW TRIGA Research Reactor is used for:

- experimental fuel rods irradiation to sustain the research program for new fuel and technologies development for power reactors;
- irradiation of structural materials for power reactors;
- simulation of power cycling effect on fuel behaviour in NPPs and some accident conditions;
- production of radioisotopes and services of irradiation;
- neutron scattering two instruments;
- prompt gamma analysis;
- dry and wet neutronography installations;

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➤ devices for standard neutron flux spectrum generation for neutronic measurements.  
The reactor utilization sustains institute research programs and provides some irradiation services for other internal and external users.

Operational safety of TRIGA Research Reactor is sustained by Organization for Operation of Research Reactor Department and overall management at the level of institute. Organization of Quality Assurance evolved in institute since 1978 in agreement with continuous evolution of standards and applications for products and services of institute, lead now to an integrated Quality Management System following ISO 9001/2000 accredited by Lloyds in 2003.

Concept of defence in depth is applied to all activities related to safety organizational, design related, operation, modification and utilization, emergency preparedness. Operational Limits and Conditions of TRIGA Research Reactor are approved by Regulatory Authority with the occasion of Safety Analysis Report updating any time when the license is renewed.

Fulfilment of OLC's requirements in operation ensure the level of prevention, that means that normal operation values of operational parameters and administrative requirements are established with conservative margins, the warning of deviation or/and violation of OLC's will bring the reactor in safe condition.

Program of monitoring, verification and surveillance, testing of equipments and systems, ageing evaluation is reinforced license. The results of program and feedback in the decision of research reactor systems maintenance and modernization are communicated to the Regulatory Body.

A special program for radiological protection, environmental monitoring of releases and effluents is derived from SAR requirements and is applied by the Radiological Protection Department of institute.

A comprehensive Emergency Intervention Plan conceived in correlation with the results of safety analysis of each internal and external initiating event and some events beyond design basis provide means of action for mitigation of accidents in correlation with offsite emergency plans.

### **14 MW TRIGA OPERATION EVENTS**

The reactor operation is performed following the approved procedures in agreement with irradiation facilities and programs. A large experience of operation during 27 years was acquired in terms of events which produced unscheduled scrams concerning 14 MW TRIGA R.R. A systematic collections of recorded data from Control Room logs allow to compute the reactor operation time and availability. The data tables contain [3]:

- equipment or component that caused failure;
- failure type (mechanical, electrical, irradiation device, human failure);
- scram cause;
- scram mode.

Relative large number of scrams was recorded in 1982 and 1983 due to irradiation devices and operational experience (see Table 1). The irradiation devices are high pressure, high temperature water capsules and a loop for irradiation of fuel samples having their own control and safety systems. Several factors (training and corrective actions) lead to reducing the number of unscheduled shutdowns (see Table 1).

Processing the data the availability of research reactor was defined for each year of operation between 1980 and 2005 (see Figure 2).

Table 1. Data collected from the reactor operation log books

YEAR	Scrams Number	Operating Time(hours)	Outage Time (hours)	Average Outage Time (hours)	Reactor Availability
1980	8	144	12.1	1.51	0.9224
1981	7	216	8.4	0.91	0.9712
1982	206	2940.2	471.55	2.27	0.6817
1983	100	2187.8	245.0	2.45	0.899
1984	58	3014.0	462.5	7.97	0.8669
1985	43	5980.0	435.7	10.13	0.932
1986	46	4401.0	663.5	14.42	0.8689
1987	49	5149.0	767.0	15.85	0.8703
1988	76	6720.0	893.25	9.12	0.9064
1989	47	1807	524.25	11.15	0.7751
1992	40	3923	97.0	2.425	0.9758
1993	21	3208	196.25	9.3	0.9423

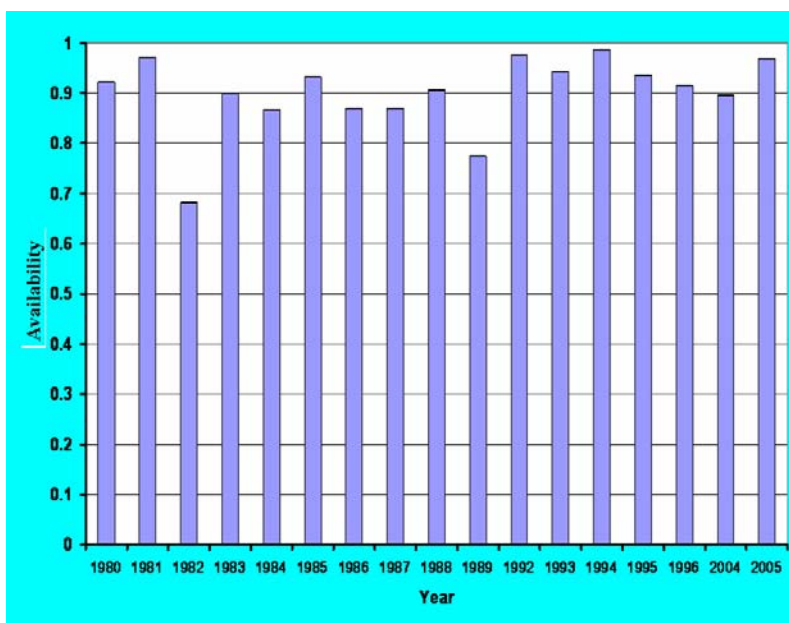


FIG. 2. The 14 MW TRIGA Research Reactor availability

The classification of events which impaired the reactor availability is shown in Table 2. The main reason of reduced availability in 1982 was the simultaneous operation of 3 irradiation capsules within narrow OLC's, each one acting on reactor scram. In 1984 an internal contamination of one irradiation loop occurred due to an operation error. The large internal decontamination of loop work and experiment recovery prevents the reactor operation. In 1989 the reactor availability was limited due to the lack of refuelling with HEU fuel and delayed decision for core conversion. Since beginning of 1990, the reactor core conversion becomes the most important objective to ensure future reactor availability.

Table 2. The classification of events which impaired the reactor availability

Scram Cause	Scrams number	Total outage time (hours)	Average outage time (hours)
electrical	344	949.0	2.76
mechanical	19	158.0	8.36
irradiation devices	273	3168.25	11.61
human error	7	5.0	0.76
<b>Total</b>	<b>643</b>	<b>4282.25</b>	<b>6.84</b>

Main causes of unavailability of reactor over 25 years of operation are (see Figure 3):

- cooling system – 46%, due to unreliable submerged emergency pump and cooling towers capacity;
- irradiation devices – 43%, due to their own protection systems and too conservative OLC's
- control rods drive mechanism and high voltage power supply – 11%

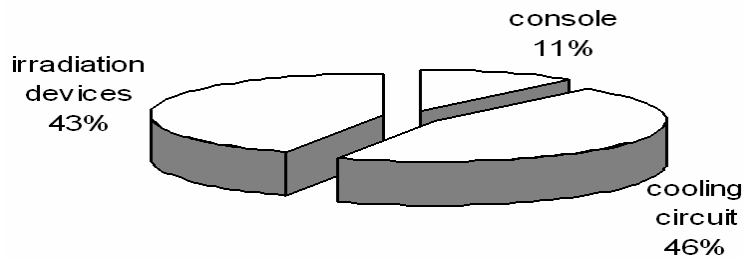


FIG. 3. Main causes of unavailability of reactor

Main causes of reactor outages as resulted from the operational data reported through yearly reports submitted to the Regulatory Authority, are (see Figure 4)

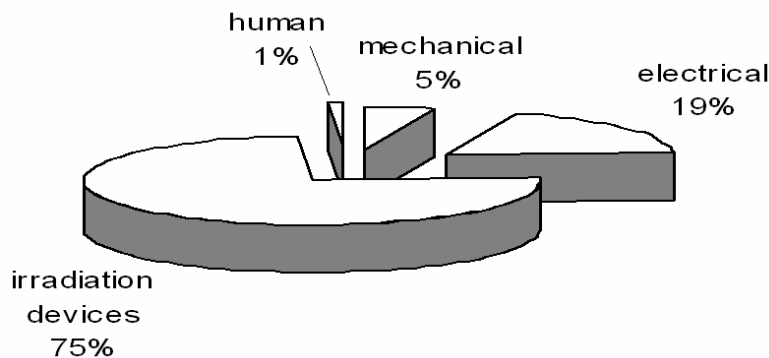


FIG. 4. Main causes of reactor outages

- irradiation devices 75%, due to high load of reactor core;
- electrical failures 19%, due to electrical motors of emergency pump failure and DC batteries from uninterruptible power supply failures;

- mechanical 5%, due to some leak tightness and valves which were not properly selected by designers;
- human errors – 1%

### DATA COLLECTION COMPUTERIZED SYSTEM FOR TRIGA RESEARCH REACTOR

The necessity to develop a raw data collection and processing computerized system arose due to the need to:

- Store all the information regarding the events produced in the operation of TRIGA SSR reactor, whether these are systems or components failures, events due to test or maintenance or information about reactor power, time intervals, number of scrams, etc.
- Identify, retrieve, select and group information from raw data sources in a time interval period
- Calculate reliability data, failure data and confidence interval limits, which are used as input data in the Probabilistic Safety Analysis for TRIGA Research Reactor.

The computerized system [4] includes operation events for TRIGA SSR 14 MW reactor during 1979 – 2000, covering three data sources: Shift Supervisor Reports, Reactor Logbooks, Work Authorizations.

For the development of the computerized system called “PSARelData”, the Visual Basic 6.0 programming environment was chosen. The interfaces of Visual Basic 6.0 with Windows Access and Windows Excel allowed to develop the database and to calculate the failure rates and confidence interval limits (95%, 5%) using statistical functions.

The logical diagram used for the computerized data system is presented in the Figure 5. Information regarding the failure data, test and maintenance data, number of scrams, etc, is collected from the three above mentioned raw data sources of TRIGA research reactor and is available for processing. By the processing action one obtains a visualization of all the failure records ordered in time, or just a selection of these. In addition, the processing of data may go on with the calculation of failures rates and confidence intervals limits. The visualization is possible on the screen but paper reports can be produced, too.

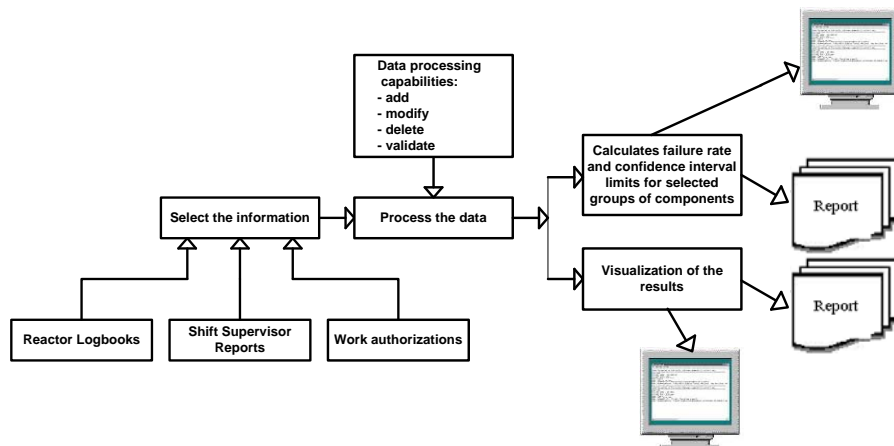


FIG. 5. Logic diagram for data computerized system

The computerized application contains five screens (forms). The main form of the application (Figure 6) gives the view of the whole database and offers the possibility to navigate inside it. By means of the main form it is possible to introduce new data and to edit the already existing records using the corresponding buttons. Also, from the main form one can switch to the queries form (enlarged main

form), which allows one to impose different simultaneous criteria for data grouping and selection. The selection criteria are:

- the name of the component
- the starting and ending dates of the failure
- the component type
- the system to which component belongs
- the failure mode
- the operation mode (run or stand-by).

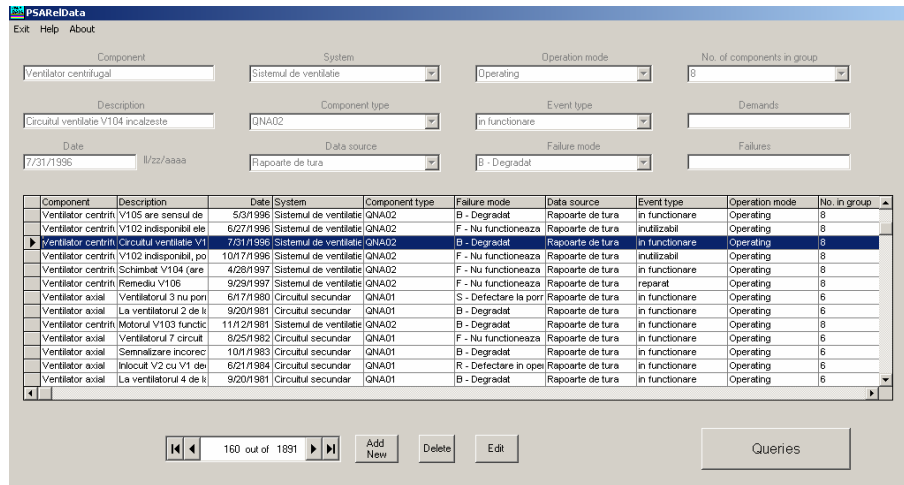


FIG. 6. Main form of the application

From the enlarged main form is also possible to write a report containing the result of selection process and to calculate the failure rate or failure probability (depending on the operation mode: run or stand-by) according to statistical formula. This calculation is accompanied by the calculation of confidence interval limits and the results are displayed in a new view of the data grid in the enlarged main form. The Figures 7 - 9 show the results of the selection process and calculation of failure rates for two components (centrifugal cooling fan and control rod drive).

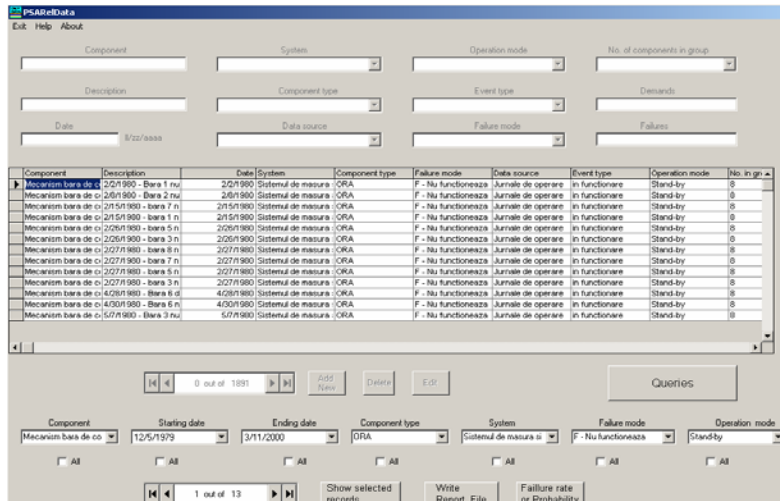


FIG. 7. Selection process results for a component in stand-by (control rod drive) in scope of failure rate calculation



The operation mode is different for the two examples: centrifugal fan – run mode and control rod drive – stand-by mode, for the selected failure modes.

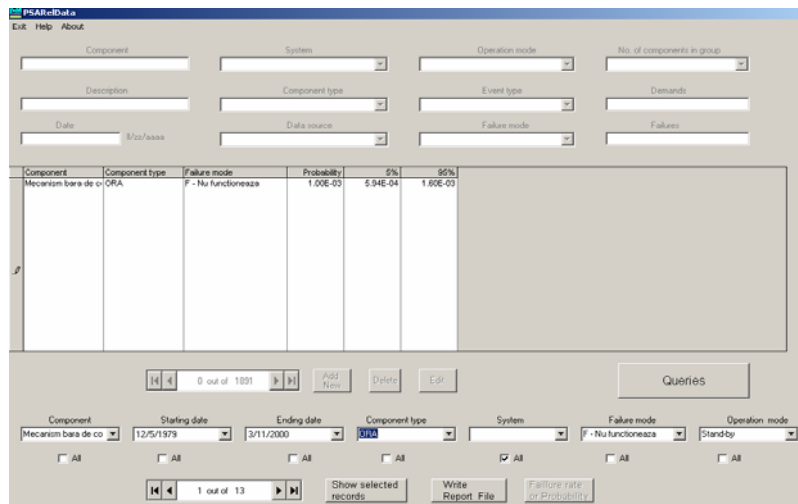


FIG. 8. Results of calculation of failure rate and confidence interval limits for control rod drive

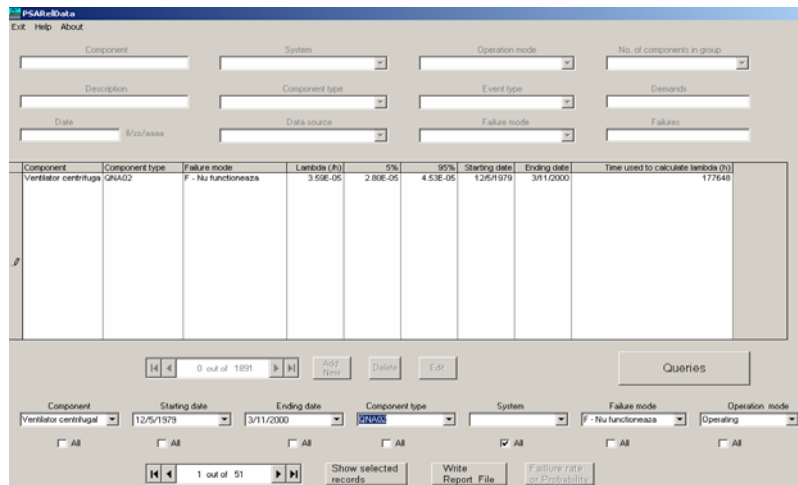


FIG. 9. Calculation results of failure rate and confidence interval limits for the centrifugal fan

### THE HUMAN FACTOR ANALYSIS FOR 14 MW TRIGA R.R.

The computerized data collection described above allows the peculiar study of contribution of the human factor to safe operation of research reactor, human reliability analysis (HRA) is used.

The types of human errors are:

- errors of omissions (omits entire task or omits a step in a task) in the casis when operators uses the procedures;
- errors of commission;
- selection errors on the equipments as keyboards, switches (manual control) and readings of information.

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Effect of Performance Shaping Factors are relative low and are determined from a list of activities concerning performance of written procedures, administrative control, communication, training, characteristics of personnel and stress. Failure probabilities of activities by operating staff of TRIGA reactor range between 0.033 for reactor start-up and 0.027 for normal reactor shutdown. Probabilistic human errors data [5] will be used within Probabilistic Safety Assessment of TRIGA safety in order to provide a complete description of the human contribution to risk and to identify ways to reduce that risk and to perform corrective actions such as:

- reduce the number of manual actions;
- reduce the dependence between manual control and display;
- reduce oral instructions;
- verification of human actions by Senior Reactor Operator

### **SAFETY CULTURE OF OPERATING ORGANIZATION**

Safety Culture of Operating Organization is appreciated in regards of actions oriented to foster responsible behaviour and the manner in which conditions and resources for safety are allotted. In correlation with IAEA Research Reactor Incident Reporting System proposal, a set of performance indicators was selected. The Annual Operation Report contains the synthesis of performance indicators and trends derived from multi annual analysis based on self-evaluation of safety issues and concerns, diverse challenges need diverse approach.

The main challenges identified in TRIGA Research Reactor operated in Institute for Nuclear Research in Pitesti, Romania, are in fact similar with challenges of many other research reactors in the world, those are:

- Ageing of work forces and knowledge management;
- Maintaining an enhanced technical and scientific competences;
- Ensuring adequate financial and human resources;
- Enhancing excellence in management;
- Ensuring confidence of stakeholders and public;
- Ageing of equipments and systems.

### **MODERNIZATION PROGRAMME**

To ensure safety AND availability of TRIGA Research Reactor in INR Pitesti, the financial resources were secured and a large refurbishment programme and modernization was undertaken by management of institute. This programme concern modernization of reactor control and safety systems, primary cooling system instrumentation, radiation protection and releases monitoring with new spectrometric computerized abilities, ventilation filtering system and cooling towers.

Results of these analysis and availability lead to a large refurbishment/modernization programme with forecasted consequences on reliability of reactor systems and availability. First step of this programme was to achieve the complete conversion of core for utilization of LEU fuel trough an international cooperative effort [6]. The second step concern the equipment and systems of reactor to reduce the consequences of ageing, obsolescence and technological development. The reactor control and safety system will be replaced with a new computer assisted system. The original control rods of reactor will be completely replaced with new more reliable designed ones, considering the root causes of failure of the old ones.

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The radiation protection monitoring system will be replaced with modern integrated computer system using online gamma spectrometry for potential releases or for exposure of staff and contamination of environment.

The heating and ventilation system and emergency ventilation will be equipped with new more efficient and available HEPA and charcoal filters.

The secondary cooling system was pre-constructed with modern equipments allowing the increase of reactor power with a factor of 1.5 – 2.0.

Some of irradiation devices will be also refurbished through new control system.

The expected life extension of 14MW TRIGA Research Reactor will be about 15 years.

## **CONCLUSIONS**

The operational safety experience for 14MW TRIGA Research Reactor is relative new. The systematic approach of requirements, methods and objectives of nuclear safety, is a continuous activity developed by the management and other entities or organizations. The role of operating organization is to predict, detect and manage all the situations challenging the safety and availability of facility.

Learning from the past events analysis and from the other events communications, the predictive function is accomplished.

The long term trends of performance indicators associated with analysis methods will contribute to the prevention of recurrences.

The international cooperation fostered by International Atomic Energy Agency in the field of nuclear safety is very usefull, ensuring the exchange of experience in the framework of technical cooperation oriented to continuous safety of nuclear instalations improvement.

## **ACKNOWLEDGEMENTS**

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