EXPERIENCE OF AGEING MANAGEMENT AT 14 MW TRIGA RESEARCH REACTOR FROM INR PITESTI, ROMANIA

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Abstract

The 14 MW TRIGA Research Reactor designed in the early '70s is a relative new research reactor with an operational experience of 30 years.The specific design of reactor core objectives, were to manufacture, build and operate a flexible structure which incorporate previous experience of pool type research reactors. Aluminum alloy 6061 and stainless steel are only materials used for core structural components, which are all easily remotely removable and replaceable by simple hand tools. Properties of those categories of materials were well characterized / known for many other reactors predecessors, and no special criteria or preliminary tests were performed. In spite of well known materials properties, the behavior uncertainties of those materials in each reactor case may have special aspects related to design of components, manufacturing technologies, surface finishing and processing, quality control methods, price of specific components, complex conditions in core and vicinity, history of operation, inspection and verification of components, radioactive waste characterization at the end of life of components. Limited assessment of materials properties and suitability for certain application without considering the each individual component load, exposure and life time, may produce limited information on material itself in fact the issue is the selection criteria for a standard material suitable for a certain application and consequent failure of components. The degradation and ageing are specific to components starting from design, manufacturing technology and expected life when the component should be replaced. The paper presents the practical experience on maintenance requirements specific to TRIGA core components and some techniques of material investigations available at Institute for Nuclear Research Pitesti Post Irradiation Laboratory as well as in the Materials Development and Research Department. Some consideration concerning correlation between the reactor safety and materials or component conditions are also presented.

1. RESEARCH REACTOR UTILIZATION FOR POWER PLANT NUCLEAR FUEL AND NUCLEAR MATERIALS TESTING

The 14 MW TRIGA Research Reactor was designed to accommodate several irradiation devices in core positions with significant flux spectrum for nuclear fuel and materials testing with maximum thermal neutrons flux 3.2×10^{14} and fast flux 1.2×10^{14}. The reactor core configuration is flexible and can be arranged in order to allow installation of 1 to 5 irradiation devices in vertical channels. The irradiation devices are natural convection (capsules) and forced convection loop operating with pressurized water at power reactors pressure, temperature and chemistry.

The main irradiation programme for qualification of manufacturing technology for nuclear fuel and zirconium alloys was developed between 1982 till 1996. Starting from 1994 a new irradiation programme was designed and developed for irradiation of zirconium alloys, for studies concerning materials properties under irradiation and analyses of combined effects of factors of degradation. An irradiation capsule for materials testing at high temperature and high fluence in inert atmosphere is also available.

One of challenging irradiation was designed and performed for assessment of individual degradation factors in different conditions, but during the same history of irradiation for standard samples of power reactor pressure tube. Several sets of samples were installed in the irradiation loop, one set in core position under neutron and gamma exposure, and a second set of samples was installed in the same loop in the chemistry and temperature out of core. The third set of similar samples was irradiated in the inert gas capsule at the temperature controlled by loop temperature.

A large and well equipped post irradiation laboratory is built in the same complex with reactor and connected through an underwater transfer channel. These features have several advantages for irradiation, testing and post irradiation examination, allowing an easy transfer of samples, interim examination at different stages of irradiation, samples management shuffling, recovery. The methods, procedures and capability of Post Irradiation Laboratory are presented in the section concerning ageing surveillance. The Post Irradiation Laboratory was also used for TRIGA reactor fuel nondestructive and destructive examination during reactor core conversion. Several other components of TRIGA core were investigated in Post Irradiation Laboratory during their life. The Post Irradiation Laboratory is also used to perform some research and material investigations for samples from Nuclear Power Plant Cernavoda.

Testing of nuclear fuel and materials for CANDU NPP lead to building of the infrastructure of institute and appropriate competences for research reactor ageing management

1.1. Ageing and safety of research reactors—actual perspective

Ageing starts from design of research reactor as well the safety. In order to comply with principles of nuclear safety, a series of requirements are used in the early design stage several decades ago, and these together with other additional measures are applied during the entire life cycle of a research reactor facility. The additional measures are now provided in standards, guides, national law and regulations concerning defense in depth, reliability, safety analysis, operation, maintenance, modification, quality management and regulatory / safety supervision making the design basis obsolete in some extent.

Ageing is a natural phenomenon which applies to all materials being dependent on time and conditions of utilization of side materials. Ageing is also a process in which materials of components, systems and structures (SSC) gradually degraded limiting the ability of components to perform safely in normal and transient conditions.

The designed lifetime of a facility was considered one of the basis of materials knowledge and a simplified model of operation and maintenance. At the end of designed lifetime of a research reactor we found an ageing research facility and we are confronted with a difficult decision to definitive shutdown and decommissioning or to extend the life of facility. Longer term operation versus shutdown and decommissioning decision have to be justified to be done safe and responsible well in advance of designed life expire, and any decision will be costly in terms of certain amount of money which were not anticipated during design.

The Management of Ageing is a complex matter starting with understanding of real conditions of operation of SSC, behavior of materials in those conditions, mechanism of degradation and forecast of consequences. To prevent those consequences, a series of conventional mitigation countermeasures are applied, like maintenance, testing and inspection, data collection and analysis in order to detect and evaluate deficiencies and degradation produced by service conditions. Feedback of evaluation of deficiencies and degradation analysis are countermeasures for prevention and mitigation of consequences, before those may have safety consequences. The ageing management plan is complementary to routine maintenance programme, both being subject of a set of procedures and quality management as essential process which contribute to the safety of research reactor.

The management of ageing due to degradation will produce data and information about materials and components behavior in real time and in real conditions of utilization and maintenance, those data properly collected, processed and understood will reduce the probability of unexpected failure with safety consequences.

Either a limited set of materials with standard properties are used in research reactor construction, subject to almost the same limited set of degradation mechanisms and operation condition, the behavior of materials and ageing of each research reactor are unique in each facility with substantial differences in remaining life of SSC and consequently with substantial differences in safety level. This is the reason of comparison of different Ageing Management practices and results in order to avoid those which are adverse to nuclear safety and availability of facility. The main sources of differences may be related to understanding of ageing of materials due to loads, conditions of operation including improper maintenance and also due to Management of Ageing in the areas of the service inspection, surveillance, monitoring and in the area of mitigation activities.

Attributes of ageing management are understanding of ageing, detection of ageing, consequences and assessment and mitigation.

<table>
<tr><td colspan="2"></td><td colspan="2">Management of Ageing</td><td></td></tr>
<tr><td colspan="3">Understanding of ageing</td><td>Detecting/assessment</td><td>Mitigation</td></tr>
<tr><td colspan="3">Materials, loads, conditions of operation, results of maintenance</td><td rowspan="4">Service inspection, surveillance, monitoring, modeling techniques analysis, PSA, development of NDT
DT
Online monitoring Training
Safety Culture
Quality Culture</td><td rowspan="4">Redesign of components
Development of methods for reparation
Correct or modify condition of operation as chemistry, cycling</td></tr>
<tr><td>Types</td><td>Sites</td><td>Safety concerns due to ageing</td></tr>
<tr><td>Corrosion
Irradiation embrittlement
Fatigue</td><td>Components, Systems</td><td>Loss of safety function
Reduced reliability
Research needs</td></tr>
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Classification of SSC on perspective of ageing:

— Risk of failure following a risk analysis:

  - Very important for safety;
  - Important for safety;
  - Not important for safety;
  - Not analyzed;

— Trends of data failure analysis:

  - Obvious trends of ageing;
  - Not relevant trends of ageing;

— Sensitive to ageing following the qualitative analysis:

  - Very sensitive to ageing;
  - Sensitive to ageing;
  - Not sensitive to ageing/latent ageing;

— Final classification following the combination of above criteria.

Level of vulnerability to ageing	Importance of SSC		
	LOW	MEDIUM	HIGH
LOW	L	L	M
MEDIUM	L	M	H
HIGH	M	H	H

The classification will be used for planning and prioritization activities related to ageing monitoring and mitigation.

In addition to service conditions there are conditions not related to processes which can lead to obsolesce and could affect nuclear safety:

— Technology changes;
— Safety requirements and regulation changes;
— Obsolesce of documentation;
— Inadequacy of design proven during operation and/or maintenance;
— Improper maintenance or testing;
— Lack of safety supervision;
— Lack of feedback and return of experience.

Ageing and obsolesce are challenging nuclear safety special for systems with nuclear safety significance. Monitoring and configuration control of repair is critical and yet many of original components are not longer manufactured and some of original manufacturers are no longer on the market. The life of an standard industrial product and/or manufacturer is shorter than the designed life of a Nuclear Installations. The Nuclear Power Industry and Nuclear Regulators are decided to improve and rise the requirements of safety standards without being sure that industry and manufacturers could follow the requirements in terms of standards, reliability, safety and economy.

1.1.1. Ageing and safety related documentation

Continuous improvement of requirements of radiation protection, standards and recommendations of nuclear safety reflecting trends in accomplishment of safety objective made the design and safety analysis of a research reactor several decades ago obsolete. Updating the safety related documentation of research reactor is the first step to cope with ageing of facility, being a major source of information based analysis to proceed to close the gap between facility performances and standards requirements through specific methods of Ageing Management.

Peer review and INSARR mission at 14 MW TRIGA Research Reactor revealed the necessity of completely update the Safety Analysis Report (SAR)

1.1.2. Ageing and advances in technology and safety requirements

In the last two decades the development of I.T. measuring instruments with high reliability, precision and versatility challenge the initial design of 60 – 80’s. Following this evolution, refurbishment of modernization of instrumentation and control of research reactor which will be used in the next decade is a necessity and a safety requirement.

Continuous monitoring of radioactive releases regulated in Romania lead to a complete redesign and replacement of all radiation protection instruments at 14 MW TRIGA research reactor. The Safety Standard for research reactors recommended the separation and independency between control system and safety system. The recommendation leads to new design of instrumentation and control of 14 MW TRIGA research reactor and modernization of entire Control Room. An internal network of process computers allows the control of continuous operating systems and data acquisition and processing. The overall conditions of operation of 14 MW TRIGA research reactor are recorded, analysed and monitored in order to detect deviations due to ageing.

1.1.3. Monitoring of physical conditions of operation of SSC

The neutron irradiation on metals and aluminum alloys are periodically determined following history of operation. In core pressure tube of irradiation devices are subject of special analysis. Those items are instrumented with neutron detectors and their history of irradiation is considered in order to evaluate exposure and irradiated materials properties. Pressure testing are applied periodically as a part of periodic plan of inspections and verifications. Other System, Components are not subject of neutron irradiation, some electrical cables of instrumentation are subject of moderated gamma irradiation.

Temperature and Pressure are conditions for irradiation devices where thermal parameters of CANDU Power Plant are maintained during fuel and materials testing are subject of irradiation testing.

Vibration is routinely measured in rotating equipments but due to regular quality maintenance this is not a concern for ageing.

Cycling of materials in research reactor was not considered on research reactor design due to values of temperature and pressure close to ambient conditions and being considered as low cycle fatigue.

Corrosion effects are monitored on removable items of Primary Cooling System or/and in Purification System. The quality of water on the lower limits of operation does not lead to corrosion phenomena other than previously analyzed. The water quality is analyzed continuously online and offline by laboratory qualified staff, instruments and methods, and data are recorded and processed in real time.

1.1.4. Inadequacies in design

The control rod absorber claded in square aluminum alloy boxes was provided with a method of periodic inspection of tightness but without any possibility of maintenance and reparation. Due to leaks of cladding by internal corrosion, the control rods become unsafe. The initial design was modified using discrete absorbers claded in zirconium alloy tubes.

1.2. Prevention and mitigation of ageing effects

The design from 1972 considered a standard aluminum alloy 6061 well qualified and used in most of research reactors to date, also stainless steel T.P.304, due to quality of those materials, of technology of manufacturing and testing and operational conditions concerning water chemistry, the selected materials and components behave without obvious degradation.

The plan for periodic testing, verification and inspection sustained by special procedures, reports and records are performed during shutdowns of 14 MW TRIGA research reactor. Periodic analysis of those data trends produces valuable information on material and systems behavior and trends.

Preventive maintenance is a continuous planned, scheduled and inspected process. Preventive maintenance is dedicated to several categories of Structures, Systems and most of the Components important for safety as well to other which are important for reactor availability and performances. Analysis of data allows establishing the trends in ageing, and providing plans for refurbishment and modernization.

1.2.1. Periodic evaluation of operational experience

- This is performed for Annual Report of operation of 14 MW TRIGA research reactor which is submitted to Regulatory Body in first quarter of coming year;
- Operational experience is also evaluated in the assembly of analysis performed by the management of processes supervised through yearly Quality Management Plan;
- The Nuclear Installation Safety Committee of institute is a permanent forum which systematically analyze the safety of operation, events reports, and determine the root causes, being entitled to establish new proposals for ageing effects mitigation

2. MODERNIZATION OF 14 MW TRIGA RESEARCH REACTOR

The large engineering capital project developed by Institute between 2005 and 2009 was engaged after careful analysis of ageing and technical obsolescence of reactor systems and equipments. Accomplishment of this project leads to modernization by redesign and replacement of entire parts of existing systems. This was a strategic approach considering the age and availability of the world research reactors requested to sustain irradiation services within present growing interest for nuclear power energy and new materials for development of future reactor as set for Generation IV.

The 14 MW TRIGA Research Reactor and Post Irradiation Examination Laboratory is a unique, valuable research infrastructure in the region. Now the safety and reliability in direct correlation with availability of reactor, was improved due to the following systems modernization:

- Reactor control and safety systems;
- Primary cooling system instrumentation; Electrical emergency power system;
- Ventilation system instrumentation, control and new type filters;
- Complete new radiation and releases continuous monitoring system;
- New fire detection system;
- Water purification control system;
- Liquid radioactive waste system control and instrumentation;
- Completely refurbished cooling tower with 50% capacity increase to sustain future reactor power increase

The Table 1 presents the causes of ageing and obsolescence mainly concentrated on quality of materials proposed 35 years ago by design and availability for construction. Instrumentation systems and safety functions provided by instrumentation was the most sensitive to ageing and obsolescence.

TABLE 1: AGEING MATRIX

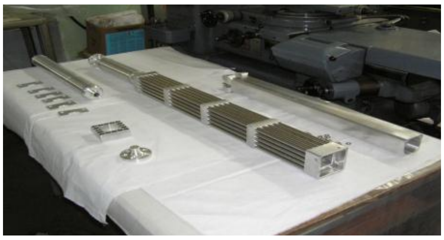
Reactor Systems	Design	Standards	Ageing issues							Environmental requirements	Safety requirements	
			Construction	Technology	Materials	Commissioni	Maintenance	Operation	Procurement		Obsolescence of materials	Instrumentation obsolescence
Reactor core					X				X			
Reactor safety systems	X	X	X	X	X		X		X			X
Reactor control systems	X	X		X					X			X
Radiation protection	X	X					X		X	X		X
Radioactive releases monitoring	X	X		X						X		X
Primary cooling systems									X		X	X
Secondary cooling systems	X	X		X	X	X			X	X	X	X
Confinement / ventilation		X	X		X		X	X	X	X	X	X
Water purification											X	X
Liquid radioactive waste system	X										X	X
Irradiation devices		X					X		X		X	X

The “Modernization Project” was proposed and justified by Feasibility Study as a new investment for 14 MW TRIGA Reactor in Institute for Nuclear Research in Pitesti, Romania, to attain the scope and accomplish the objectives presented earlier. The Feasibility Study contains the requirements for design, procurement, construction, commissioning in main lines with reference to existing standards for materials and equipments, Quality Management, national and international Safety Standards and Regulations to be applied during removal of obsolete parts, reconstruction, installation and commissioning.

2.1. Systems subject of modernization

The list of systems subject of modernization is presented in Table 1 in correlation with the Root Causes. Each affected system was subject of individual analysis, requirements, technical specifications in the extent of modernization works to be provided to meet the objective of the project, being concentrated in a design basis document and technical specifications for each system and subsystem. One system may be subject of 3 or 4 technical specifications concerning categories of work and contractors specialization.

The control rod was manufactured using discrete absorbing neutron rods and high resistant materials to temperature and corrosion.

Reactor control and monitoring system is extensively digital, computer assisted, to provide advanced processes graphic, integration in to control room and to allow combinations of alarms with reactor operation.

Radiation protection System was designed and built with components and technology available in 1975 – 1978. the original supplier are not anymore on the market. The requirements and standards for radiation protection evolved in the last 15 years and existing system become obsolete and inadequate.

Area Monitoring System was designed and built by institute using wide range intelligent ionization chambers connected in a computerized monitoring and alarms system which ensure data acquisition, processing and correlation.

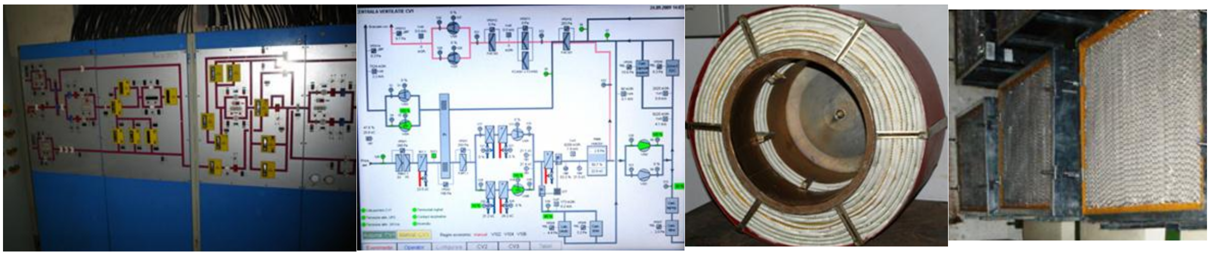
 

Radioactive Releases Monitoring System was redesigned to meet the requirements of continuous monitoring of releases during normal operation and in accident conditions, ensuring sensibility and all range of measurements for expected radioactive species gamma emitters gases and aerosols. This system was designed and built by a provider licensed by Regulatory Authority on contractual basis.

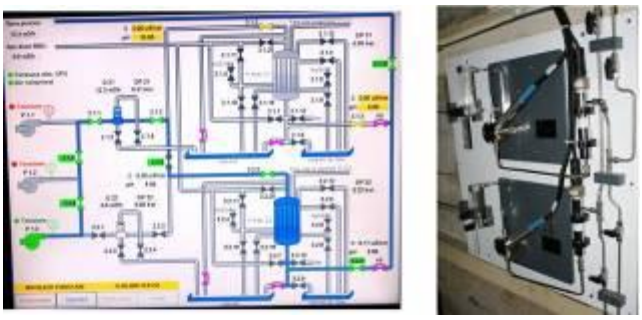
  

The cooling tower for 14 MW TRIGA Research Reactor was designed in 1973 and built in 1976, and operated for more than 25 years as a secondary cooling system. Efficiency of cooling tower and heat transfer capacity increased with 30%, allowing for a future reactor core power increase. A computer assisted system for operation of cooling tower, pumps, fans, etc, is part of the project.

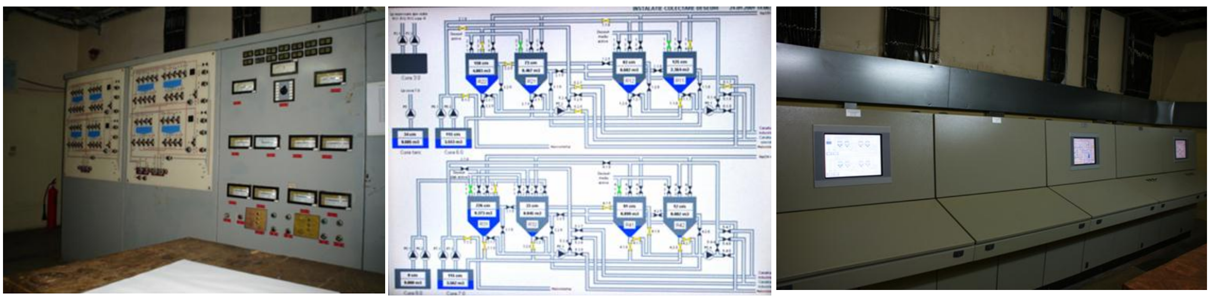
The 14 MW TRIGA confinement and ventilation system design provide normal operation, economic operation and emergency mode operation. The main issue of this system was unavailability of original HEPA filters for inlet and outlet filtering.



The instrumentation and control of water purification system was designed materials, components and electrical equipment from the same generation as for other control and instrumentation of reactor systems, obsolescence of those components and unavailability was a common cause of ageing of instrumentation of reactor.



The same considerations concerning common causes of obsolescence of instrumentation affected also the liquid radioactive waste collecting system. A dedicated computer assisted instrumentation system was designed, built, installed and commissioned.



For nuclear fuel and material testing at 14 MW TRIGA Research Reactor, several irradiation devices are dedicated and permanent installed. Those irradiation devices are Loop A – 100 kW thermal power for fuel irradiation, capsule C2 for instrumented fuel rods irradiation, Capsule C9 for power cycling testing and other for nuclear safety tests. An integrated IT system for reactor, systems and irradiation devices provide, in an intranet, recording of all operational data and configuration of systems.

3. LESSON LEARNED

- Design of new systems and cost control should be implemented since the beginning of the project, many operations are not specialized in this field and following the case those activities should be subcontracted;
- Solid references and experience in nuclear installation contractors / similar project / equipment should be accepted to diminish the risks;
- Will be difficult for an organization without experience in radioactive waste handling, commissioning, and disposal to perform the activity without incident or environmental consequences;
- Financing schedule should be flexible to accommodate delays or modification of project accomplished;
- Training resources for continuous instruction of reactor staff for operation and maintenance of new modernized, modified systems should be provided as well training schedule and manuals.

4. CONCLUSION

TRIGA-14 MW reactor is among youngest research reactors in Europe, after this project of modernization the reactor will remain only few research reactors for materials testing and radioactive production, which satisfy new regulatory requirements.