OPERATIONAL EXPERIENCE ON AGEING MANAGEMENT AT THE TRIGA RESEARCH REACTOR OF LENA (Laboratory of Applied Nuclear Energy) - University of Pavia (Italy) -

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ABSTRACT

The Laboratory of Applied Nuclear Energy ("LENA") of the University of Pavia operates, since 1965, a 250 kW TRIGA Mark II nuclear research reactor providing training and services to private enterprises and public institutions as well as being involved in several research projects carried out by the University and other research groups. Being an almost fifty years old facility, ageing, together with its potential premature failures, is a key point in the reactor safety. For these reason, in order to mitigate ageing effects, the facility has had to deal with several issues due to the time-dependent degradation of its structures, systems and components (SSCs). After an accurate assessment of SSCs conditions and the identification of ageing mechanisms, during the past years, several activities were successfully carried out. The paper will provide an overview of the above-mentioned topics and the forthcoming plans, together with lessons learned on ageing management in a small-sized reactor facility.

1. Introduction

Up today, about 70% of the operating research reactors are more than 30 years old (see Ref.[1]), with many exceeding their design life, with most of them challenged by the negative impacts of ageing of their Systems Structures and Components (SSCs). The Laboratory of Applied Nuclear Energy ("LENA") of the University of Pavia operates, since 1965, a 250 kW TRIGA Mark II nuclear research reactor providing services to private enterprises, public institutions as well as being involved in several research projects carried out by the University and other research groups. Being an almost fifty years old facility, ageing, together with its potential premature failures, is a key point in the reactor safety; in fact, in order to mitigate ageing effects, during its service life, the facility has had to deal with several issues due to the time-dependent degradation of its structures, systems and components (SSCs), in order to maintain adequate safety and operational conditions. Safety is in fact considered by the management to be the most important issue with respect to employees, public, operation and utilization of the reactor.

2. Major and most recent ageing mitigation activities

Pursuing the main objectives mentioned above, in the past years, many activities were carried out in order to prevent, manage and mitigate aging effects. The most relevant under safety, technical and economical point of view were focused on:

Biological Shield efficiency test (1997): After about 35 years of utilization of the biological shield a new neutron and gamma dose inspection has been performed in order to verify the shielding efficiency. The 1997 campaign of measurements was made with modern and calibrated instruments. Gamma dose and neutron dose have been assessed separately on each wall of the biological shield, with a grid of 1m2 between 2 consecutive points. The tests showed that there were no changes compared to the original situation. Based on the results of the tests, changes and implementation of safety procedures have been introduced, in particular in the field of radiation protection for some mechanical and electrical maintenance procedures.

Electrical power distribution and emergency power supply (2000): the electrical system was completely replaced due to the obsolescence of components, changes in regulations and cable deterioration. Even if this system is not strictly a safety system, the availability, reliability of the system can assure a correct operation of the reactor. Furthermore, the installation of more performing components, together with more efficient surge suppressors, avoids and contains potential damages due to external events such as spikes, transients or indirect lightning. Safety-critical systems are operated as privileged loads, trough an on-line type UPS. The emergency power supply, granted by a diesel generator was also replaced with a more performing one. The new installed components lowered the overall fire-related risk of the electrical power distribution, with an overall safety improvement.

Heating, ventilation and air filtration system (2001): due to the aging of components, repetitive unscheduled maintenance activities and in order to avoid unplanned long reactor shut-down periods, the new system was completely renewed with a new computerized air filtering and ventilation system. The inlet air is filtered by high efficiency (~ 95%) filters while the air extracted from the reactor room is filtered by absolute HEPA filters (total efficiency > 99.95%) before the release in atmosphere. The air extraction is powered by an inverter-driven motor that keeps automatically the reactor building at 50 Pa less than atmospheric pressure, as required by Technical Prescriptions. The new system, is now equipped with a modern computerized supervisory system capable of visualizing and trending data, feature resulted particularly useful for preventive maintenance purpose.

Radiation monitoring system (2006)

The area radiation monitoring system has been renewed after 30 years of operation. The new system, based on proportional counters, a micro-computer (PLC) and an home-made software, completely replaced the former one based on analog components and Geiger type counters. The system collects the data sampled by six β-γ dose-rate proportional counters, a free-air ionization chamber and a weather station through a serial data bus. Collected data are stored and displayed on PC in the reactor control room as well as in the emergency control room. The software allows the operator to access the data, modify parameters and perform tests remotely.

Cooling system (2007): a complete substitution of the tertiary heat exchanger and a partial substitution of the components of the secondary heat exchanger circuit was realized, due to corrosion and degradation phenomena. In particular, the substitution involved the following components: secondary/tertiary circuit heat exchanger (plate type); tertiary circuit water flow control valve, valve drive motor and valve controller (PID type); tertiary circuit water filters and magnetic filter for water macromolecules and carbonates removal. For predictive and improved maintenance purpose, a dedicated PLC-based data acquisition system was implemented in order to collect data thus obtaining on line parameter for evaluating the system behaviour (e.g. heat exchange efficiency, pumps efficiency, pressure/temperature drops across the exchangers).

Reactor console (2008): most of I&C system were in operation since their first installation in 1965. During the years several repairs and had to be carried out, affecting the system availability. Moreover, the original design was based on electromechanical components and vacuum tubes, then the availability of spare parts was becoming a critical issue. In order to grant a safe and continuous reactor operation for the future, improving reliability and extending the system life time, most of the I&C were refurbished with home-made designed system using high quality commercial components. As a result, almost a complete substitution, channel-by-channel, of the I&C system was realized without changing the operating and safety logics. Thanks to the new components, a dedicated acquisition system was implemented for data collection and analysis.

The off-gas radiation monitoring system (2009): it was completely replaced with a new measurement system based on a NaI spectroscopy detector. The gamma-ray spectrum of reactor gaseous effluents is collected on-line using commercial software and data are remotely accessible (i.e. from reactor control room or from reactor emergency control room). Also the environmental airborne particulate monitoring system was completely upgraded and redesigned for a better efficiency and reliability.

Water purification system (2010): After about 20 years of utilization, in the filling-water demineralization system was completely replaced with a new mixed-bed, laboratory-grade demineralizer. In this type of demineralizer, cation and anion resin beds are mixed together, resulting therefore equivalent to a two-step demineralizers in series. In a mixed-bed demineralizer, more impurities are replaced by hydrogen and hydroxyl ions, and the water that is produced is extremely pure. The new system allows a safer and quicker resins replacement avoiding the personnel to deal with resins regenerations and acid/basis solution handling.

Data acquisition system (2012): several efforts have been made recently in order to implement a comprehensive data acquisition system for the most important parameters (e.g. reactor console, radiation monitoring systems, ventilation, cooling systems). The system allows to constantly monitor parameters, early detecting anomalies or drifting instruments in order to prevent potential and unexpected failures. This can be seen as an extensive predictive maintenance activity, resulting useful also for ageing purpose; in fact the trend of performance can be a good indicator of system degradation, and the related data analysis can positively contribute to a more efficient understanding of ageing mechanisms and their counter measures.

3. Ageing management and quality management system interactions

In 2010, in order to continuously improve the quality of reactor management and for the accomplishment of the stakeholder requirements (both under legal and commercial framework), LENA implemented an Integrated Management System in accordance with International Standard ISO 9001:2008. This choice allowed satisfying both national and international compulsory requirements (i.e. safe reactor operation and maintenance) and typical ISO 9001 requirements (as e.g. continuous improvement, users/stakeholders care and satisfaction) as well as complying with the IAEA GSR-3 “The management system for facilities and activities” (see Refs [2,3,4]). The requirements for conformity are therefore set out in an integrated management system (IMS) and are binding on all personnel and levels of management within LENA. Amongst others, effective maintenance, ageing management and in-service inspection are some of the most important activities to achieve safety and maintain the intent of the design objectives during the operation of the facility. The experience in the application of IMS on regards of maintenance and ageing concerns resulted particularly helpful, allowing a general improvement of the reactor operation and maintenance. As far as ageing is concerned, the introduction of an IMS leads to the following main benefits:

- better and more detailed in-service control plans were defined to examine plant components and systems for possible deterioration in their integrity to assess the safety margins and their acceptability for continued operation of the plant and to take corrective measures as necessary. The main systems and equipment important to safety of the plant are identified in the maintenance and equipment control plan, which gives the requirements with respect to frequency of inspection, method of inspection and the acceptance criteria
- more accurate control of equipment: all instruments are under a documented metrological confirmation plan according with well defined standards (e.g. ISO standards) [4,5]
- enhanced surveillance program to verify and ensure that the provisions made in the design to ensure safety margins keep on existing and the safety of the plant does not depend upon untested or unmonitored components, systems or structures
- performance review program aimed to identify and rectify gradual degradation, chronic deficiencies, potential problem areas or causes. This includes review of safety-related non-conformances & failures of SSCs of the plant, determination of their root causes, trend, pattern and evaluation of their safety significance, lessons learnt and corrective measures taken
- control of documents and records ensures that personnel use only up-to-date documentation avoiding the accidental use of obsolete documents, work instructions or diagrams; also adopting appropriate procedures for the management of obsolete documents. Well managed records ensure a proper process traceability as well as providing a database on the status of the individual components and systems
- the audit programme, planned and carried out quarterly, takes into consideration the status and importance of the processes and areas to be audited, as well as the results of previous audits. The audit criteria, scope, frequency and methods are documented and are inputs for the periodic management review
- periodic management review on the status of SSCs: review includes evaluations for improvement opportunities and for changes needed, including quality policy and quality objectives. Records from management reviews are maintained and utilized as input for further management review meetings. The organization applies a specific documented procedure for the conduct of management reviews.
- supply chain: the control of supplies provides an accurate control of purchased products and their suppliers, ensuring compliance with the requirements in terms of safety, quality and reliability. A key point is ensuring adequate availability of spare parts and the implementation of a purchase plan that can compensate for the obsolescence of components, ensuring that changes in technology are compatible with the installed components.

4. Implementation of an ageing management programme

Based on the positive outcomes from the implementation of the above mentioned activities and for a better and more formal consideration of ageing concerns, LENA is currently working on the implementation of a formal ageing management programme (AMP) following the IAEA guideline SSG-10 “Ageing Management for Research Reactors” (see Ref. [6]).
The ageing management program under development is expected to result in a set of organized policies, processes, procedures and activities for managing the aging of SSCs with the main purpose of ensuring reliability and availability of required safety functions throughout the extended life of the plant. In order to implement the ageing management programme, the first task is to compare the IAEA guideline with the IMS in place. The outcome will lead to the drafting of a first a road map for all the activities not already included

or providing adjustments aiming to incorporate ageing in the main management system.
The presence of a well-established and documented management system is in fact a prerequisite for an efficient ageing management programme.

The categorization of structures, systems and components susceptible to ageing plays a central role in the definition of the AMP, and can be realized trough a detailed analysis of said systems, according with the following figure 1:

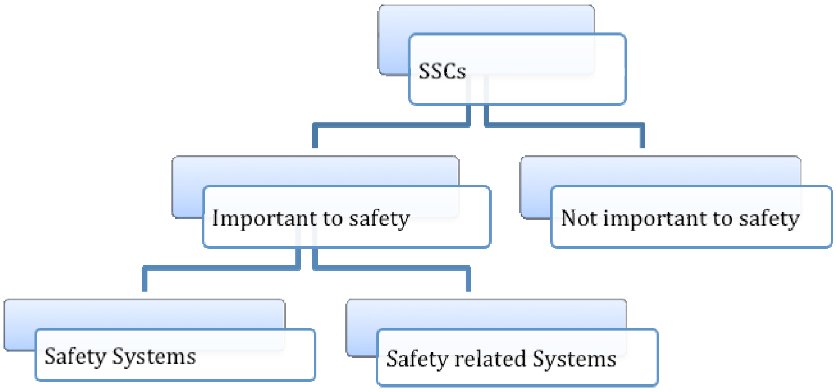

Figure 1: Categorization of structures, systems, components

Based on the screening results, SSCs will be analysed in detail trough a series of screenings aiming to identify the most relevant activity areas not already included in the IMS and in need for the implementation of new or revised procedures for ageing management.
Furthermore, to manage ageing it is necessary to understand how ageing affects the components and materials that are used to achieve overall safety of the reactor, in other words, the ageing mechanisms. Due to the technical nature of the systems and based on specific analysis of the past activities results, LENA identified the following mechanisms as the more relevant to ageing, and they will be the subjects of the initial efforts for the implementation of the AMP:

Ageing mechanism	Code (IAEA SSG 10)
Changes of properties due to neutron irradiation	1
Motion, fatigue or wear (resulting from cycling temp., flow, vibrations, etc.)	4
Corrosion	5
Chemical processes	6
Changes of technology	8
Obsolescence of documentation	10

Based on a preliminary analysis, the following table shows the planned activities regarding the SSCs LENA identified as important to safety, not already included in the periodic maintenance or test&inspection activities, needing to be considered under the AMP and the IMS.

SSC	Planned activities
Pool structure and vessel	Visual inspections with underwater camera, development of procedures and definition of acceptance criteria. Assessment of results
Core Structure	
Reflector	
Shielding	
Beam Tubes	
Liner	
Fuel assemblies and storage in reactor pool	
Primary	Efficiency monitoring by on line data acquisitions and real-time parameters evaluation. Trending of data to assess conditions. Periodic result evaluation.
Biological shield	Efficiency of shielding of gamma and neutron dose to be tested every 5 years
Ventilation: emergency	Improved maintenance and controls on the rotating equipment. Definition of procedures
Control Console (LOG channel, SCRAM loops)	New design for the channel refurbishment. Updating of the documentation, management of spare parts. New calibration procedure
Cabling (control console internals and interconnections)	Step by step cable replacement.
Shielding Beam tube lines	Visual inspections. Definition of test to be carried out on periodic base.

The ageing management programme will therefore include the main following elements:

- screening of Systems, Structures and components identification for reliability and safety Detection, monitoring and trending of ageing degradation
- preventive actions to minimize expected ageing degradation
- continuous improvement of the ageing management program
- management of obsolescence.

The overall graded and systematic approach to the reactor ageing management will be based on the well known Deming Cycle, as shown in the Figure 2, aiming to the continuous improvement of safety efficiency and effectiveness of the AMP.

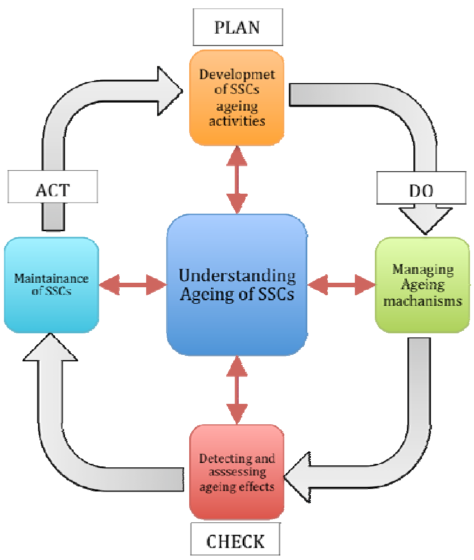

Figure 2: PDCA cycle for ageing management

5. Conclusions

Though the plant undergoes to a well defined and organized maintenance plan, complying with regulatory and several other technical requirements, a more and in depth analysis of the past experiences highlighted how ageing concerns were faced more "based on need" rather than planned on the mid-long period. Due to the potential criticality of ageing effects on safety, a run-to-fail approach is not a proper option, so the organization is going to move toward the implementation of an improved overall maintenance program based more on condition based maintenance concept rather than conventional time-based preventive maintenance. In fact, as ageing concerns arise, the scheduled maintenance approach might not be a sufficiently efficient solution to grant reliability, availability and safety. The experience gained during the years led the organization to the idea of implementing a more formal and documented framework for the aging management (taking also in account economical and long term budget allocation considerations), will bring a more efficient end effective impact on reactor safety extended operation lifetime.

6. References

[1] IAEA Research Reactors Database (RRDB)

[2] Implementation of a management system for operating organizations of research reactors, IAEA Safety Reports Series n. 75, INTERNATIONAL ATOMIC ENERGY AGENCY, Vienna (2013)

[3] The management system for facilities and activities, IAEA Safety Standards Series Gs-r-3, INTERNATIONAL ATOMIC ENERGY AGENCY VIENNA, 2006

[4] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Quality Management Systems - Requirements, ISO 9001:2008, ISO Geneva (2008)

[5] INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, ISO 10012:2003 Measurement management systems - Requirements for measurement processes and measuring equipment ISO Geneva (2003)

[6] Ageing Management for Research Reactors, IAEA Specific Safety Guide n. No. SSG-10, INTERNATIONAL ATOMIC ENERGY AGENCY Vienna (2010)