AGEING MANAGEMENT EXPERIENCE AT NUR REACTOR

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Abstract

NUR is a 1 MW, open pool reactor moderated and cooled by light water. It was commissioned in 1989. NUR is used for education and training in Nuclear Engineering and related topics for COMENA and National Scientific Community. It is also used to perform R&D works and services at national and regional levels. In this presentation, we describe the methodology and the main development activities related to the ageing management at NUR reactor. These activities include inspection actions and development actions to introduce modifications, to solve obsolescence issues in view to implement the required preventive and curative maintenance programs and to improve the performances of the installation. These actions involved mainly the Operation Assistance System of the Reactor (OAS), the secondary cooling loop, the cooling tower. A new OAS using a new technology and having more possibilities than the older one was introduced in the control system of the reactor. The OAS hardware structure, software structure and the main functions performed are presented. The second loop is entirely refurbished. Two new cooling towers are installed and connected to the main heat exchanger with new piping and valves. The architecture of this new installation is described and the performance assessed. Other actions which involve auxiliary systems like emergency electrical system, air pneumatic system and automatic fire extinguishing are presented.

1. INTRODUCTION

The NUR reactor (“light” in Arabic) is an open pool 1 MW research and training reactor. Designed and built by INVAP (Argentina), NUR was inaugurated in April, 1989 in Draria, Algiers (Fig.1). It is mainly used for training of operators and nuclear engineering students and in the development and utilization of nuclear analytical techniques and applications that support socio-economic development. The main activities performed at NUR reactor are:

- Studies and experiments in physics and reactor technology.
- Neutron activation analysis.
- Neutron reflectometry.
- Neutron radiography.
- Small angle neutron scattering (SANS).
- Production of radioisotopes and radiopharmaceuticals (at laboratory scale).

FIG.1. View of the reactor building

2. REACTOR DESCRIPTION

The main characteristics of NUR reactor are:

- Pool type, 1 MW research reactor.
- Fuelled with MTR plate-type fuel enriched to 19.75%.
- Cooled and moderated by light water.
- Graphite reflector.
- Neutron flux of 10^{13} cm^{-2} s^{-1}.
- Four radial and one tangential beam tubes.
- Two vertical irradiation positions and two fast pneumatic transport systems.
- One hot cell and one transfer cell.

The design of the reactor core and its associated control and safety systems is based on the following criteria:

- Natural convection cooling in case of loss of pumping power.
- Access to the reactor core from the top of the tank even with the reactor operating at full power.
- Mechanisms associated with control and safety rods are located on top of the reactor tank, in order to facilitate staff training and implementation of experiments.
- The core is cooled by water that flows downwards to the decay tank beyond the pool.
- Reactivity is controlled by the reactor safety and control rods.

Reactor safety is complemented with a network of radiation detectors located in contamination-risk areas, plus a smoke detection and manual and automatic fire extinguishing systems. There is an auxiliary pool to store spent fuel elements.

Auxiliary services such as demineralized water supply, compressed air, electrical systems, emergency power generators, communications systems, workshops, physical security system and labs are also available.

3. AGEING MANAGEMENT METHODOLOGY ADOPTED IN NUR REACTOR

The ageing management methodology adopted in NUR reactor consists of the identification and implementation of effective and appropriate ageing management actions and practices that provide for timely detection and mitigation of ageing effects in structures, systems and components (SSCs). It came out that this objective could only be achieved by performing these three following hierarchical actions: preventive, assessment and corrective actions.

Preventive actions are taken in order to limit the effects of ageing degradation. These actions relate primarily to the appropriate operating conditions and limits as well as the strict and rigorous implementation of the NUR preventive maintenance program. It is also to undertake periodic reviews at appropriate intervals to determine the effectiveness of actions and practices for preventing ageing degradation of SSCs. Thus reparation and restoration procedures have been established and a program of suitable monitoring, calibrations and tests implemented. Preventive actions in NUR reactor are continuously improved, taking into account relevant operating experience and research results.

Assessment actions are essential to understand the ageing degradation of a structure or component by identifying and analyzing ageing mechanisms and effects. This approach is the basis for an effective monitoring and mitigation of ageing effects. Thus a continuous effort is made to assess interactions between materials, and service conditions in order to identify degradation mechanisms. It is also to assess the consequences that may result from the effects of ageing and to study their impact on reactor safety, availability and performance.

Corrective actions aim to mitigate or stop the evolution of the ageing effects. As degradation may result in a reduction or loss of the ability of SSCs to function within their acceptance criteria, timely appropriate corrective actions are necessary to maintain the necessary levels of safety, availability and performances. Corrective actions are also taken when obsolescence of SSCs is identified in order to prevent the occurrence of any decline in reliability or availability of the NUR reactor.

4. PLANNED AND ACCOMPLISHED UPGRADE AND/OR REFURBISHMENT ACTIVITIES

4.1. The instrumentation and control (I&C) system of the NUR reactor

The former Operation Assistance System (OAS) provided by the reactor manufacturer (INVAP, Argentina) is a system designed according to an architecture based on a data acquisition system using obsolete components and a microcomputer of the 80’s. The signal acquisition system "ELAPALMS" was installed and started operating since 1989 at the NUR reactor. This system consists of two “Z80” microprocessor based CPUs, supporting a user software and "CDP 1802" ensuring management of IO (Fig.2). The obsolescence of such components and associated circuitry combined with the lack of access to the source code (unable to introduce or change other settings, DOS 3.1 environment), reduces the uptime of the system, very essential for the reactor safety parameters monitoring. Also, its performance was very limited and inadequate with the originally planned subsystems (fast storage of data in various formats, automatic reactor control, etc.) (Fig.3). The OAS could not be maintained longer and was decommissioned at the end of 2010.

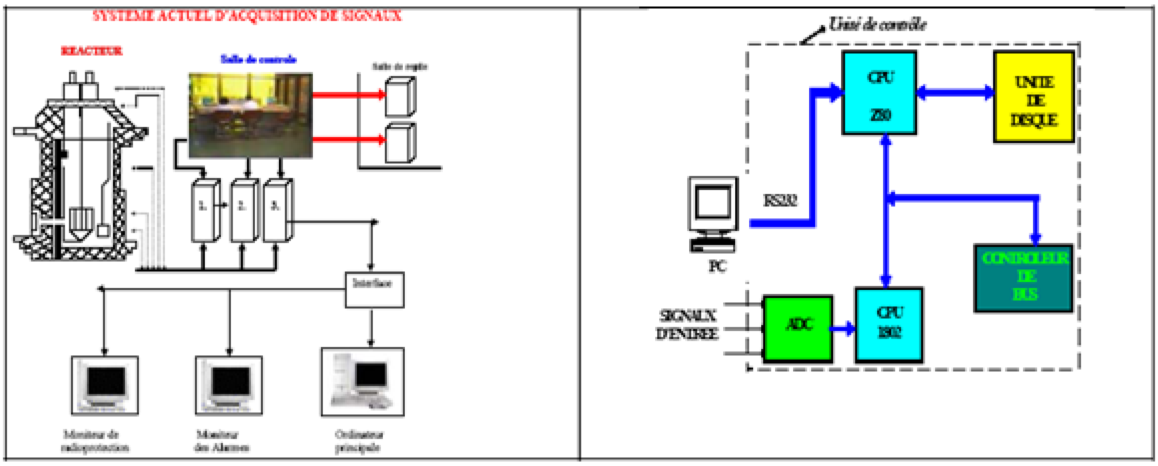

FIG.2. The former OAS architecture

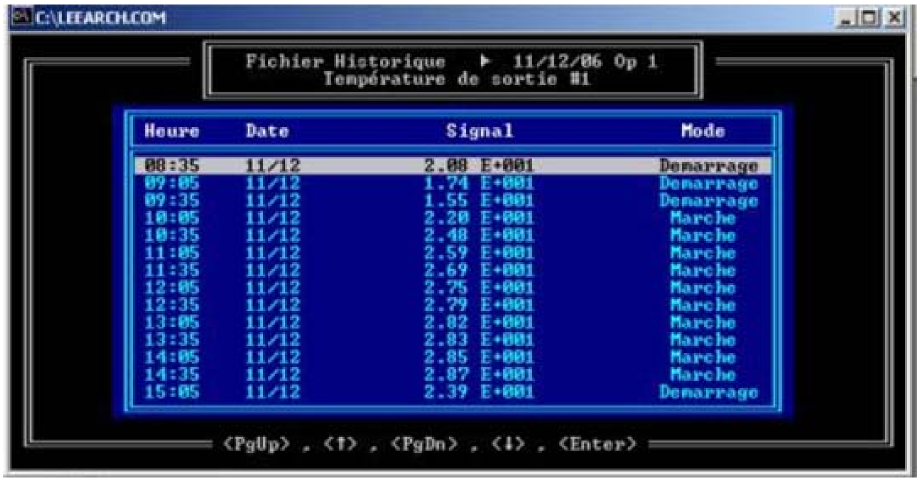

FIG.3. Data storage with the former OAS every 30 min

A new OAS was designed, developed and gradually implemented in the instrumentation and control system of NUR reactor. This OAS produced around an acquisition system and a network of modern computers, was operationally integrated into the systems of the reactor under the supervision of an ad hoc committee set up for this purpose.

The " Operation Assistance System of NUR reactor" (NURSAO) has the main function to perform monitoring of various systems of the reactor (nuclear and conventional), to provide assistance to the control room staff, so that it can determine at any moment the state of the reactor, and so it can determine whether there are abnormal conditions to be corrected. The NURSAO is based on the use of intelligent data acquisition system FLUKE, and personal computers for the communication with operators. It performs the following basic objectives:

- Collecting signals from the process reactor.
- Providing an alarm system, performing analysis and selection of existing alarms and displaying the results of this analysis to the operator.
- Providing a visualization of the reactor state through a friendly and ergonomic interactive interface using chart, graph, mimicry, alphanumeric, etc.
- Providing a chronological record of events.
- Indicating the status of the "hard" logic of security in a parallel, redundant and independent way.
- Redundancy with nuclear and conventional instrumentation in the presentation of values.
- Detecting and displaying on screen signals off prescribed limits.
- Checking the presence of licensed personnel in required number for the reactor operation.
- Generating permanent files with the values of some parameters of interest on hard disk and printing them on paper for archiving.
- Controlling some operations performed by the operator.
- Transmitting the acquisition of nuclear and conventional real-time data for different users through the network connection system.
- Providing the system with a speech engine that allows the operator to quickly locate alarms, according to a programmable safety priority.

In addition, NURSAO automatically provides alarm signals when an abnormal situation occurs. NURSAO is designed so that the quantities shown on the screen can be quickly understood and interpreted by operators in the control room. It is an interactive program that allows the operator to change the appearance at his convenience.

NURSAO is structured so that it can be modified when changes are made in the plant systems or in the operating processes. To do this, NURSAO has a modular structure that allows it to update without major changes. This is why if changes are made in the installation (improvements or new systems), they can be easily implemented in the program. The NURSAO software works in conjunction with SAQD dataloggers to form the main datalogger. These devices were chosen for their high performance (20 to 120 inputs expandable up to 2000 channels, sampling rate of 1000 channels/sec, input isolation voltage up to 50V, 16-bit resolution, measuring of different types of signals: voltage, current, thermocouple, thermistor, RTDs, etc.) (Fig.4). Each SAQD device can contain from 1 to 6 analog modules: the precision analog module (PAI), the fast analog module (ISP), the totalizer module and the IO digital relay (DIO). Systems explore 20 to 120 channels. The NURSAO software configures and controls up to 05 SAQD devices through an Ethernet connection. The software provides the means to view the analyzed data and save them as files.

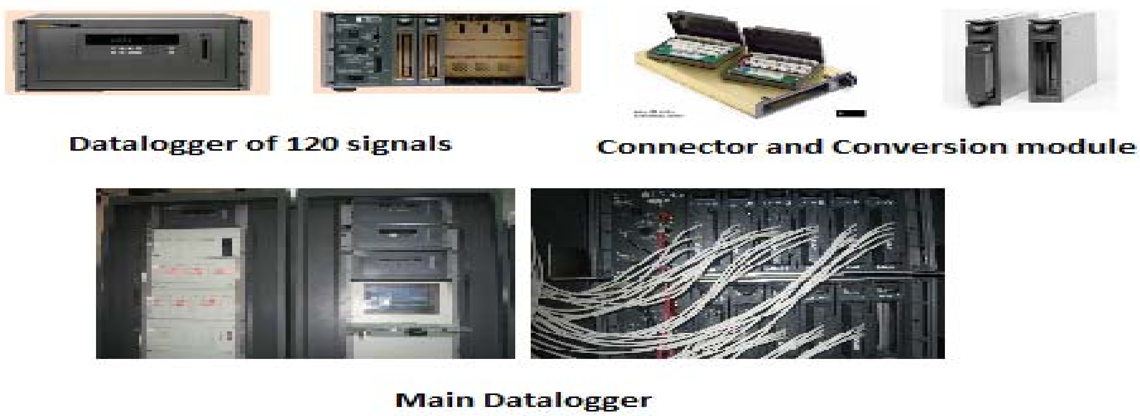

FIG.4. Hardware installation

NURSAO is based on the use of an intelligent data acquisition system, which takes the data from the various sensors placed in the installation (analog and digital signals), and when NURSAO requests it, the SAQD sends signals to the NURSAO associated computer (Fig.5).

NURSAO uses five totally independent channels of data acquisition:

- Channel 1: acquires analog nuclear-type signals (neutron flux, rate of change of flux, etc.), analog radiation-type signals (area monitors) and conventional flow of the primary system signals (outlet and inlet temperatures, etc.).
- Channels 2 & 3: acquires digital nuclear-type signals (neutron flux, rate of change of flux, etc.), digital radiation-type signals (area monitors) and conventional flow of the primary system signals (outlet and inlet temperatures, etc.).
- Channel 4: acquires digital nuclear type and the reactor ventilation system signals.
- Channel 5: acquires fire and electrical systems analog and digital signals.

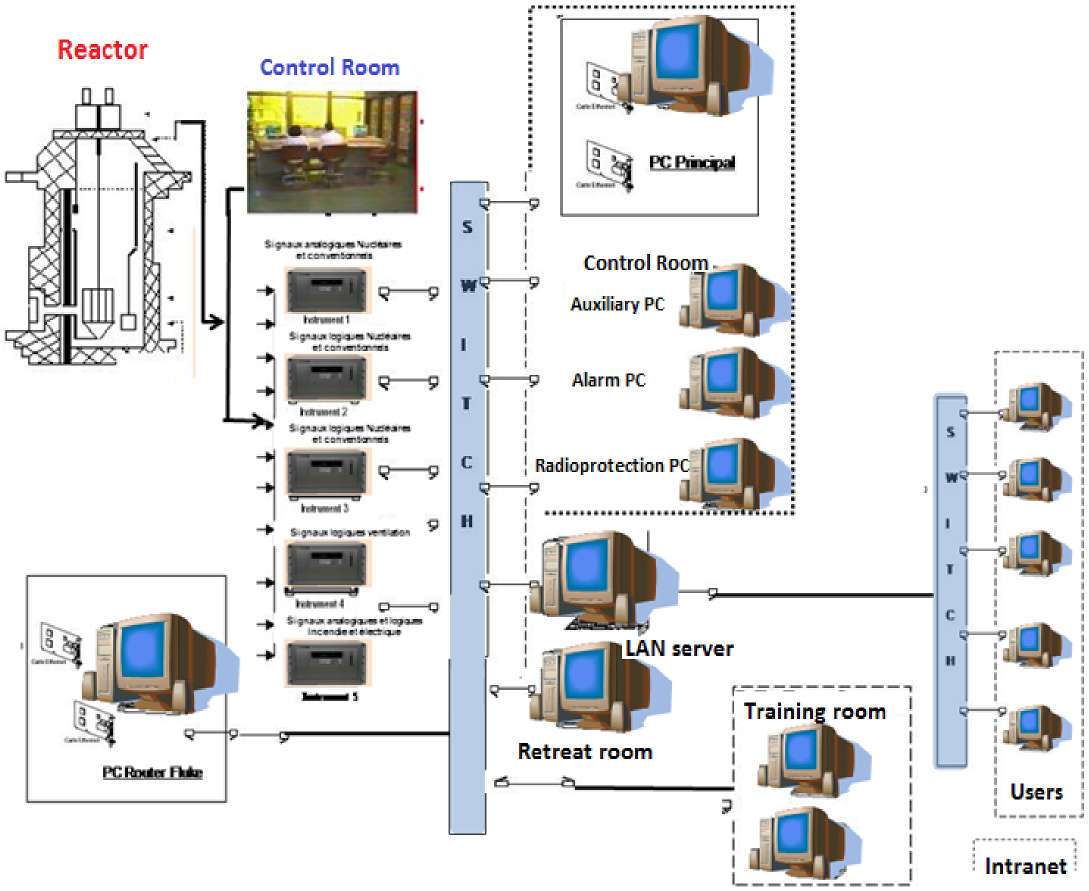

FIG.5. NURSAO configuration

NURSAO software is structured in modules and each module performs a particular task. There are modules for:

- The start of operations (which includes checking the valid authorization of the operation staff, selection of rods, configuration of the reactor core, etc.).
- Diagrams of the reactor (block, irradiation facilities, primary and secondary cooling systems, etc.).
- The ventilation system showing the general scheme and diagrams of the extraction, injection and recirculation systems, indicating the status of valves, filters, etc.
- Fire protection system showing plans of the unit and indicating the location and status of the respective sensors.
- Radiation monitoring system showing plans of the unit and indicating the location and the indication of the respective detectors.
- The Logic of Security (detailed mimicry).
- The Power System (detailed mimicry).
- Etc.

Each Module is divided into subpage, and each page is dedicated to a specific and determined task. For example, NURSAO has a module dedicated to the reactor security logic (L-Module). This module consists of several pages, each of which performs a specific task (Fig.6). The program has pages that show the operator mimics of the SCRAM logic, the start logic, the operating logic, etc.

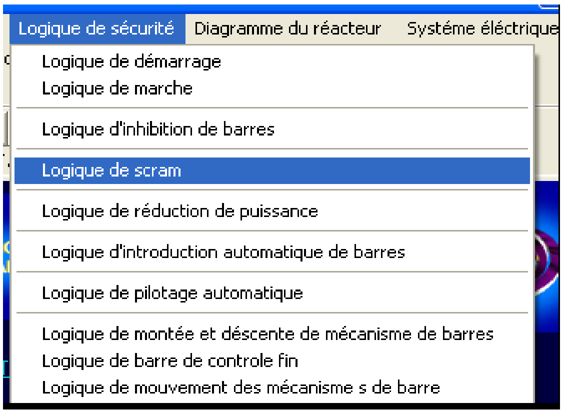

FIG.6. L-Module with subpages

In each page, NURSAO performs a reading of analog and digital signals from the data acquisition channels, carries out the automatic scale conversion for graphical evolution analog signals, analyzes anomalies and storing the values of some parameters at prefixed intervals in the hard disk. There is a special page of alarms, which allows the operator to know the value or status of the most important signals for the safe operation of the reactor, among which are identified signals with abnormal values. NURSAO has a special module, in which are included graphical interfaces of operation assistance, such as control rods calibration interface, sub-critical approach, temperature effect, power balance, etc. (Fig.7).

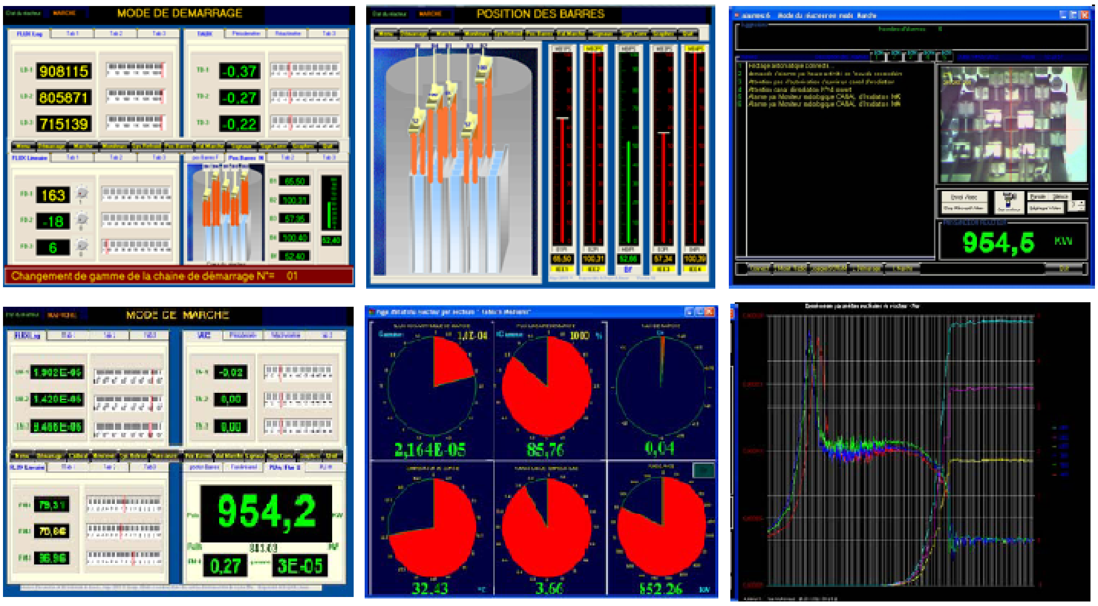

FIG.7. Examples of graphical interfaces of operation assistance

The Main Control Room is equipped with 5 PCs: a mainframe computer, a computer for alarms which is also used to store log files, a computer for radiation protection, an auxiliary computer and an intranet server computer.

The introduction of this new human-machine interface, and the modernization performed at the control room were also aimed to improve ergonomic and aesthetic properties of the operator’s desk and the control room, to enhance the operator’s comfort and thus to improve the conditions for utilization of the reactor, and the nuclear safety.

The performance analysis of the new Operation Assistance System NURSAO performed by the ad hoc committee noted that it is satisfying the following points:

- Structured data management as laid down in the former OAS.
- Fast data processing and displaying.
- Rapid access to different data display pages.
- Accuracy of data conversion.
- Accurate representation of the measurements sensitivity.
- Graphical representation of the data temporal evolution through trend lines.
- Easy Integration of measures to graphical representations of the reactor systems.
- Fast processing of threshold violations and alarm displaying.
- Good frequency, capacity and information storage management.
- Dynamic restitution of archive files and a quick access to failure points.
- Intuitive and ergonomic conditions for the graphical user interface operation.

4.2. Secondary cooling loop refurbishment

The design of the reactor main cooling circuits consists of a primary light water circuit and a secondary light water circuit. The two circuits are separated by a plate-type heat exchanger. The water in the secondary circuit is circulated by a centrifugal pump through the main heat exchanger and is cooled in an air/water cooling tower. The secondary circuit is then open to the environment via the cooling tower.

The secondary cooling system of the NUR reactor was designed to ensure a safe and continuous cooling of the reactor core by venting of the heat accumulated by the coolant via the heat exchanger to the atmosphere, to remove the waste heat generated after a normal or accidental shutdown and to minimize the probability of radioactivity release from the primary cooling system to the environment.

Erosion originating from the coolant flow inside the standard pipes of the secondary circuit was observed during inspection of parts of secondary coolant loop related with preventive maintenance (Fig.8). This phenomenon is due to the bad quality of the material and to the chemical degradation of water, too. The erosion which has undergone the internal walls of the pipes caused corroded matter detachments in the form of remains accumulating between the plates of the heat exchanger. This phenomenon acted negatively on the heat transfer effectiveness. Thus, a substantial aggravation of the erosion of the pipes could lead to their rupture.

FIG.8. Corrosion/erosion of standard pipes of secondary loop

Corrosion and erosion of inner elements of the cooling tower were also observed and are due to their permanent exposure to rainwater, wind and the normal conditions of use (Fig.9). This degradation of the internal elements of the cooling tower caused a partial loss of the core cooling capacity, which could lead to the use of reactor at reduced powers.

FIG.9. Cooling Tower degradation

It was decided after assessment and analysis to:

- Maintain the current secondary pump.
- Maintain the current heat exchanger.
- Acquire two cooling towers with better performances and enhanced cooling capacity, and place them in a new location in line with the design and installation of new pipelines.
- Perform the new lines of secondary cooling circuit using pipes manufactured in an improved corrosion-resistant material.

Prior to the selection and acquisition of equipment and civil works and making pipes, it was assessed load losses caused by changes to ensure that:

- The secondary side pressure still remains higher than the primary side pressure.
- The NPHS (Net Positive Suction Head) is much higher than the available NPSH required for the pump.
- The water pressure at the spray pump of the cooling towers is between 0.2 and 0.9 bar (pressure required for proper spray).

These requirements were taken into account with minimal change in the secondary system and with very minor interventions on existing civil engineering infrastructure. In addition, the system configuration was performed according to the specific requirements related to the primary coolant circuit structure.

The new secondary cooling circuit consists then of two redundant circuits, each linked to a different cooling tower but supplied from the same pump (Fig.10). Redundancy is ensured by a set of bypass valves in order to reduce the workload of cooling towers and therefore slow down the ageing process. Redundancy also provides an opportunity to intervene for the maintenance of one of the towers without forcing the reactor shutdown, and to counter the possible failure of one of the towers to evacuate the residual heat in case of accident.

The selection and choice of organs and other accessories constitution materials were performed according to the following criteria:

- Physicochemical compatibility with the coolant.
- Thermal and electrochemical compatibility between the various materials.
- Very good resistance to corrosion and erosion.

The new cooling towers acquired are made with synthetic resins which have the advantage of a high cooling capacity in a very small space (Fig.11). The main characteristics of the elements that make up these towers are:

- The frame is made of polyester reinforced with glass fiber, which is very stable to the influence of the salts and other components contained in the water and the effects of weather variations.
- The filling forms the surface heat exchange and is made of polypropylene.
- The cooling water supply is done by means of nozzles made from synthetic resins. Large openings which they are provided ensure proper operation and prevent virtually any possible obstruction.
- The fans fitted to the towers are very low noise, and very easy to maintain. They are statically and dynamically balanced at the factory.
- The motors used to drive fans are two speed and three-phased. They are protected against splashing water.

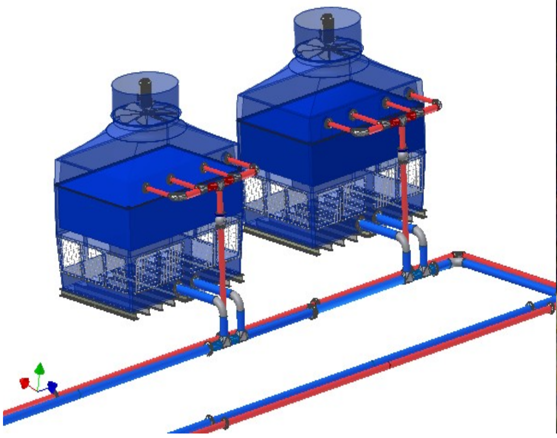

FIG.10. Secondary loop redundancy

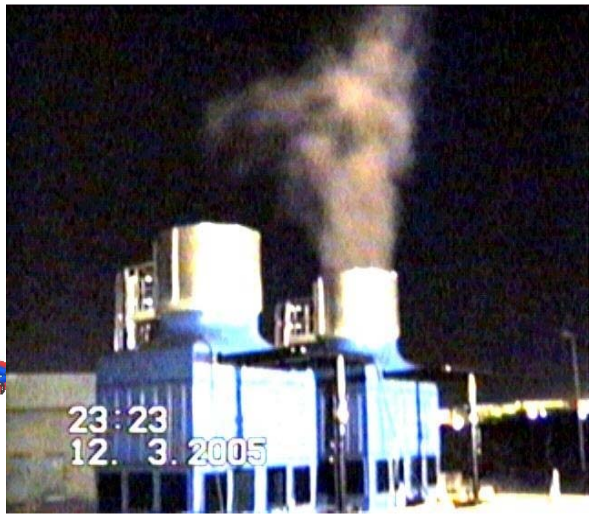

FIG.11. New cooling towers operating

In addition, it was decided to acquire in the near future, a microprocessor-based chemical controller and corrosion inhibitor that can allow us to preserve the condition of the secondary loop pipes providing good quality water, and avoid the occurrence of corrosion problems already met. Primary and secondary pumps will also be replaced by better-ones to improve quality and capacity of the cooling systems. A new heat exchanger of better quality has been acquired to replace the old one when necessary. Moreover, and in order to ensure availability of these equipment, we have implemented a new approach of predictive maintenance using the techniques of vibrations analysis, such as FFT, HFRT, Wavelets, etc.

4.3. Air compressor replacement

The former oil-injected air compressor was replaced by a new oil-free one because of frequent breakdowns and unavailability of spare parts. In addition, and with the advent of new international standards, especially the ISO 8573-1 CLASS 0 (2010), the choice of such an air compressor has been confirmed for its ability to eliminate the risk of oil contamination that could alter the analysis results on the samples irradiated through the pneumatic system and prevent the accumulation of oily residues in the irradiation site. The high quality air also prevents the small ports on instruments, controls, and air operated valves from becoming clogged with debris, moisture or oil, which could prevent the proper operation of the equipment.

4.4. Modification of fire protection system

The former fire protection system operates with halon-1301 gas. The use of this gas, although widespread a few years ago, began to be phased out because of its adverse effects on the environment (gas containing CFCs). Also, most system manufacturers have discontinued the support of these systems so that finding spare parts to properly maintain the system became more and more difficult. The migration to a new system has therefore become recommended according to environmental standards and the choice fell on a system using the FM200 ® gas.

FM200® contains no bromine or chlorine and therefore has zero Ozone Depleting Potential (ODP). The atmospheric lifetime of FM200® is between 31 and 42 years which along with its zero ODP presents a long-term solution to fire protection requirements. It has a low toxicity level and is super-pressurized with Nitrogen to 24.8bar. It rapidly extinguishes most commonly found fires through a combination of chemical and physical mechanisms.

Due to the similarities in the equipment, the system retrofit concerned only the change of container valves and nozzles, and the changing from halon to FM200® has been accomplished with minimal disruption and little system downtime.

4.5. Acquiring of new electrical generators

The use of the former electrical generator was definitively abandoned because of its frequent breakdowns and insufficient power to operate some equipment. Two new electrical generators were acquired; one was dedicated to the auxiliary building and the other for the reactor building, especially for the operation of safety equipment in the event of prolonged power failure.

5. CONCLUSION

NUR reactor was operated for more than twenty years without any damage on its safety. This result comes from the appropriate specific measures applied in the design, with regard to the standards of realization and the good practices in the reactor exploitation. It also results from the continuous efforts made to maintain the reactor utilization index as high as possible and proves that the reactor staff is fully capable of planning and accomplishing important modernization and refurbishment projects with a high sense of collective responsibility. However, the application of the principles and concepts of safety in the various phases of the reactor life constitutes undoubtedly, an essential factor which made possible the guarantee of this end result.

Among these principles and concepts, the adoption of the in-depth defense approach, the redundancy in the control parameters, the equipment reliability, the performing of quality assurance programs and the continuous improvement are the key words in the ageing management strategy.

Finally, degradations having occurred in the installation have led to the adoption of additional measures such as:

- Revision of some maintenance and operation procedures.
- Ensuring compliance with the new standards.
- Use of improved materials (corrosion-resistant, weather variations resistant, etc.).
- Design and implementation of new systems and installation of modern equipment promising to solve obsolescence problems.

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