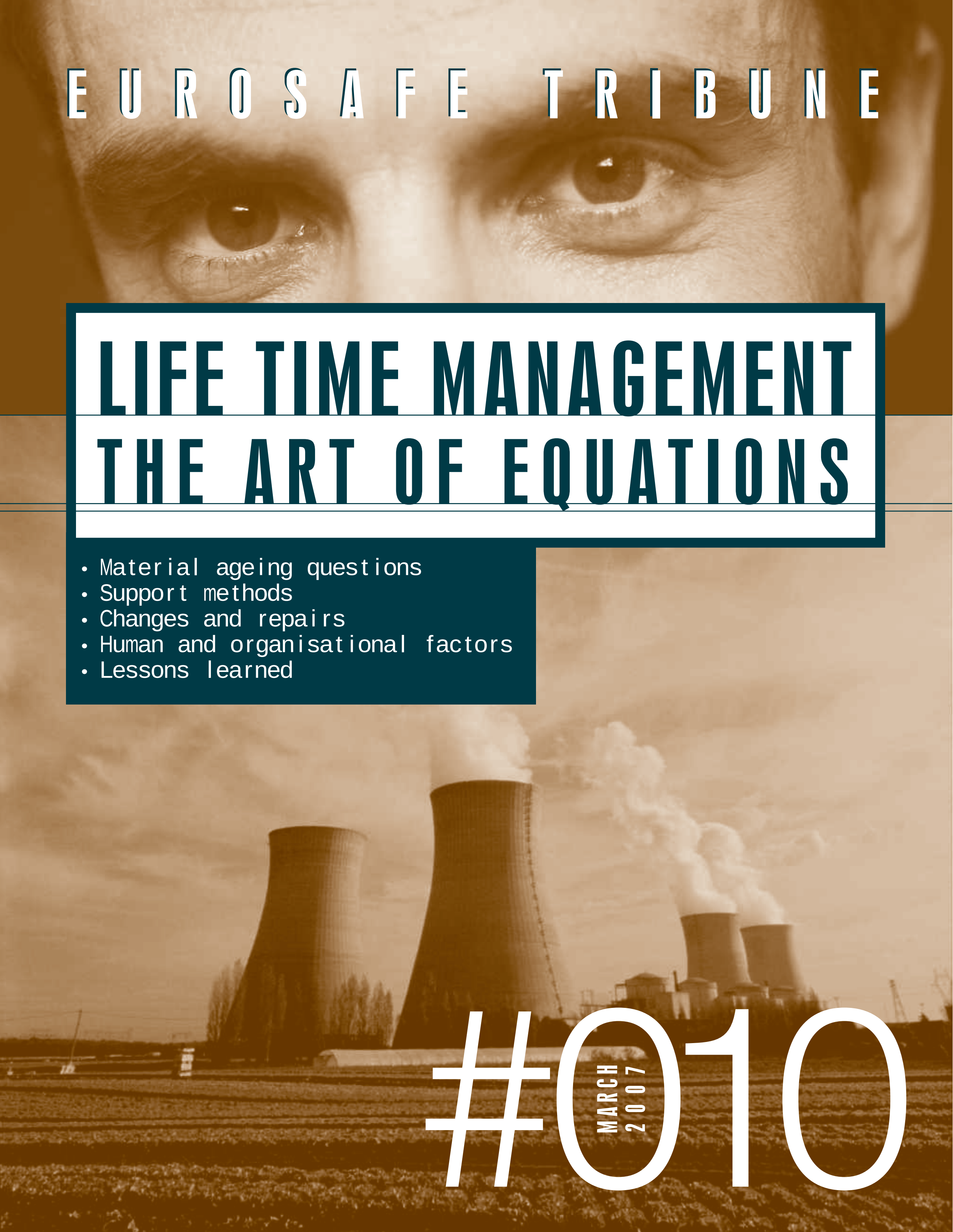


EUROSAFE TRIBUNE

LIFE TIME MANAGEMENT THE ART OF EQUATIONS

- Material ageing questions
- Support methods
- Changes and repairs
- Human and organisational factors
- Lessons learned

MARCH 2007

#010

CONTENTS

INTRODUCTION p.4

Extending the service life of nuclear power plants (NPPs): a challenging shift for safety organisations

MATERIAL AGEING QUESTIONS p.6

Beware of loaded guns! p.6

Application of condition monitoring techniques to electrical cables in Spanish nuclear power plants....... p.9

Containment integrity: findings from studies performed on LWRs in Sweden.......................... p.12

SUPPORT METHODS p.16

Nuclear power plants' life prediction: NULIFE harmonises R&D at EU level p.16

Putting physics to work for nuclear safety p.20

CHANGES AND REPAIRS ... p.22

Ageing management and exceptional maintenance of PWRs: an EDF view p.22

Digital Instrumentation and Control: keeping up with technology disruptions......................... p.25

HUMAN AND ORGANISATIONAL FACTORS p.28

Knowledge management, a key issue to the revival of the nuclear industry

LESSONS LEARNED p.31

Tapping experience to sharpen design

VENUES & WEBSITE p.34

TO OUR READERS

Lothar Hahn and Jacques Repussard

Around 440 nuclear power stations are currently connected to the grid world-wide. Regardless of the licensees' or governments' intention whether or not to extend the operating lifetime of those plants beyond designers' assumptions, maintaining – and improving – operational safety requires important issues to be taken into consideration, such as material ageing, technological developments or knowledge conservation.
At a time when the engineers who designed and built the fleet in operation have retired or are preparing to do so, those who are taking over are faced with a major challenge: caring for plants where end-of-life issues will require growing attention in the future. In some countries, utilities have to prepare simultaneously for the planned construction of new-generation fuel cycle facilities or power reactors.
Subsequently, ensuring safety over the operating lifetimes of facilities requires up-to-date methods, processes and procedures to be implemented to inspect and assess the status of hardware components (e.g. piping, cables, concrete structures) as well as electronic components (shifting from analogue to digital technology) with a view to not only keeping the prescribed safety level but, based on continuous knowledge acquisition, enhancing operational safety.
In this context, the licensees, the regulatory authorities and technical safety organisations should implement a lifetime management policy based on a three-pronged approach: first, decennial safety reviews performed drawing upon deterministic and probabilistic methods; secondly, periodical inspections, and thirdly, the management of ageing as such. In other words, the art of managing the lifetimes of nuclear facilities consists in keeping the right balance between these three aspects, largely reflected in the seminar presentations held at the 2006 EUROSAFE Forum in Paris co-organised by AVN, GRS and IRSN (the respective Belgian, German and French technical safety organisations).
As a Forum aimed at sharing experience feedback from different technologies and operating approaches to support convergence and optimise implementation of technical practices, EUROSAFE can contribute to giving technical safety organisations increased visibility, weight and legitimacy towards governments and populations.
Such recognition will, in turn, help maintain the competence and motivation of all the people tasked with nuclear safety.
We wish you pleasant reading. ●

EXTENDING THE SERVICE LIFE OF NUCLEAR POWER PLANTS (NPPs): A CHALLENGING SHIFT FOR SAFETY ORGANISATIONS

By Francis Vouilloux, Institut de radioprotection et de sûreté nucléaire (IRSN), France

■ Up to the beginning of the 80s, energy independence was the prime objective which drove nuclear power development. Today, economics are clearly the priority in managing the nuclear fleet for the utility. The utility's search for greater returns on investment, often accompanied by extensions of reactor service life, is leading safety organisations such as the IRSN to analyse deeply the safety consequences of NPP ageing.

Francis Vouilloux

The shift from a technical approach to a financial one in nuclear facility operations is a trend seen among operators on every continent. However, on a regulatory level, the situation can be quite different from one country to another. In the United States, for example, a nuclear facility operating licence is given for a specific period of time (40 years and now 60 years), while the regulatory authority of France, which licenses facilities to operate for an indeterminate period of time (safety reviews every 10 years), has the power to shut down any nuclear facility at any time. The French operator must therefore be able to:

• demonstrate that his facility complies with regulatory requirements at any point and any time;

• prove, starting with the third 10-year inspection, that facility ageing has no impact on safety, and produce a report showing the fitness for continued operation of all safety-related components and functions significantly affected by ageing (vessels, containment building, instrumentation and control systems, etc.), to the point that the safety of the reactor could be impaired; and

• account for loading combinations in the primary and secondary circuits, ranging from load variations of a few percent to emergency shut-downs, that could trigger a safety re-examination when the limit value set by design and accepted by the regulatory authority has been reached.

› Facing the safety assessment of ageing. In the context of NPP life extensions, nuclear safety organisations have requested an ageing management programme and safety analysis with the following objectives:

• determine safety criteria appropriate to assess a potential service life extension. Nevertheless, end-of-life criteria have not yet been defined for all equipment or systems;

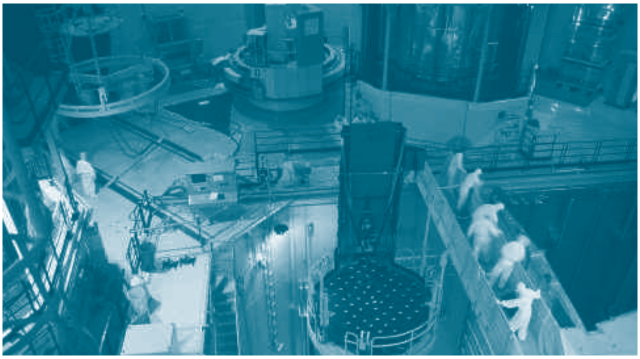
• develop end-of-life evaluation methods for components that cannot be either repaired or replaced, such as reactor pressure vessels (embrittled under neutron irradiation), or electric cables (sensitive to oxidation and therefore hardened), or containment buildings (loss of tension in tendon cables);

• maintain the required level of defence in depth, despite deterioration due to ageing. Strategies and repair or replacement techniques need to be developed. To do so, R&D and inspections are conducted to evaluate the parameters, kinetics and safety consequences of ageing. Both targeted and random in-service inspections are recommended;
• initiate facility safety improvements during periodic reviews by taking into account operating experience, improved knowledge, and changes in safety requirements and rules, such as requirements to re-perform seismic analyses with new rules;
• maintain and improve knowledge, skills, resources and technologies (non-destructive testing, expertise resources such as hot laboratories or qualification loops, etc.) needed to evaluate facility ageing and to determine safety criteria. To assess new technologies, such as the transition to digital instrumentation and control systems, resources are also needed;
• maintain equipment that must continue to operate, even in the event of an accident, and demonstrate that it is qualified for operation in accidental conditions. At the design stage, this demonstration was based on tests simulating accidental conditions with accelerated ageing. Nevertheless, IRSN considers that this initial demonstration must be completed by loop testing of retired equipment to demonstrate that qualification is always valid and could be extended (referred to as "ongoing qualification").

› Research and development, inspection and knowledge management: three requirements for safety performance.

In addition to the huge effort of the utility, IRSN has also invested in R&D, e.g. evaluation techniques for instrumentation and control (I&C) software reliability, thermal ageing of metallic materials, ageing of electric cables, seismic behaviour of I&C cabinets, etc.
The development of such R&D resources is undeniably necessary to evaluate ageing kinetics and their impacts on safety in order to define repair or replacement strategies. However, in-service inspection and "on-going" qualification must have a preponderant role. In-service inspection and "on-going" qualification are the key ways for the early detection of new ageing damage. For instance, among 15 known main types of degradation mechanisms for French NPP materials and structures, only one was identified during the design (neutron-irradiation vessel embrittlement) and one was revealed by laboratory research (thermal ageing of austeno-ferritic steels). The other degradation mechanisms were discovered during inspections, maintenance activities, hydraulic tests, or even in service.
With the coming retirement of designers, builders and operators of existing NPPs [1], preserving knowledge is also a major challenge. The service life of a reactor is longer than a few working generations. ■

(1) This aspect is dealt with in the article by Dr. Gail H. Marcus entitled "Knowledge Management, a Key Issue to the Revival of the Nuclear Industry" (on p.28).



Scheduled shutdown at Lingao NPP (China)

BEWARE OF LOADED GUNS!

By Guy Roussel, Association Vinçotte Nuclear (AVN), Belgium

■ As ageing degradation can decrease the safety margins so as to create a "loaded gun", an accident waiting to happen, ageing is for many observers one of the most important issues facing the nuclear industry world-wide as well as the bodies that provide safety oversight and regulation. The main systems susceptible to suffer such degradations and some design or inspection measures aimed at preventing potential incidents are described below.

Guy Roussel

Every component in a nuclear power plant is potentially subject to some form of ageing. As evidenced by the recent detection at the Davis-Besse Nuclear Power Station (Ohio, USA) of a cavity in the top of the reactor pressure vessel head that may have been caused by corrosion from boric acid deposits, the components of the reactor coolant loop system do not depart from this statement.

› The particular issue of unsuspected degradation mechanisms. Ageing is an important area of concern for the reactor coolant system components since, even if the degradations do not lead to failure, degraded conditions may exist for which the required safety margins are no longer adequate. Not all the ageing mechanisms have been considered during the initial design. Some mechanisms were detected during service or during outages and measures needed to be taken to maintain the safe operation of the plants. However, past experience shows that degradation mechanisms appear that were not suspected to occur. Hence, degradation modes not yet observed in practice may become problems as reactors get older.

› Ageing considered at design stage. The primary objective of designing a mechanical component is to ensure that it will be capable of satisfactorily performing its intended function for the prescribed lifetime. That objective is achieved by recognising and evaluating all potential modes of failure that might govern the design.

As far as possible, ageing is implemented in the design in order to allow the component to cope with the potential ageing mechanisms. Ageing is defined here as *any form of degradation to materials or components that results from exposure to environmental conditions in the nuclear power plant or from the operational conditions.*

The ageing-inducing agents include, inter alia, high temperatures, corrosive chemicals, radiation, thermal and pressure cycling. The ageing phenomena include, inter alia, embrittlement, fatigue, corrosion and cracking.

The main ageing-degradation mechanisms potentially affecting the lifetime of the reactor pressure vessel and the other reactor coolant system are described below.

› Reactor vessel neutron embrittlement. The section of the reactor pressure vessel closest to the core, i.e. the vessel beltline, is subject to neutron (or irradiation) embrittlement. Irradiation embrittlement and low vessel temperature both act to reduce the cleavage fracture toughness of reactor vessel material. Regulatory requirements limit permissible irradiation embrittlement of reactor vessel material such that adequate fracture prevention margins are maintained under both operating and potential accident loading conditions. The requirements for preservation of required fracture prevention margins are expressed in terms of an adjusted reference nil-ductility transition temperature [1] and a minimum acceptable level of upper shelf energy [2]. As a part of the regulatory requirements, reactor pressure-temperature limit curves bound the permitted reactor operating envelope. Those curves are adjusted in response to irradiation embrittlement. Consideration of the pressurised thermal shock (PTS) loading is also taken. PTS can occur under some scenarios where high thermal stresses due to introduction of cold water into the reactor vessel are combined with the stresses due to high internal pressure causing pre-existing cracks to potentially propagate through the reactor pressure vessel wall. A mandatory reactor vessel surveillance programme provides data on the progressive effect of irradiation on the reactor vessel material toughness.

› Metal fatigue. Fatigue is the gradual degradation of a material that is subjected to repeated cyclic loadings. Fatigue failure takes place by the initiation and propagation of a crack until it becomes unstable and propagates suddenly to failure. During the design of the reactor coolant system components and piping, a fatigue analysis is performed

that considers an assumed set of design transients and their anticipated number of occurrences. The measure of the fatigue damage is the *cumulated usage factor (CUF)* that is evaluated on the basis of the fatigue properties of the materials and the expected fatigue service of the component. During plant operation, the validity of the fatigue analyses is ensured by implementing a programme monitoring the plant transients, i.e., the temperature and pressure variations, so as not to exceed the design transients. However, some transients may be identified in service which have not been accounted for in the design. A typical case is the occurrence of thermal stratification transients in the pressuriser surge line. As a consequence, a specific programme needs to be implemented to determine the impact of thermal stratification on surge line integrity.

› Corrosion. Corrosion mechanisms, often interacting with other degradation mechanisms, are well known from the operation of conventional plants. Therefore corrosion-resistant materials have been selected for the components of the reactor coolant system exposed to conditions where stress corrosion and flow-assisted corrosion attack might be expected. However, operational feedback has shown that the corrosion resistance of some materials was less favourable than expected. It is very noticeable that primary water stress corrosion cracking (PWSCC) of nickel-based alloys is today the governing ageing process that limits the life of some of the primary circuit components. PWSCC of Alloy 600 materials was first detected. In terms of number of affected components, the steam generator tube bundles rank above the other components. The extensive PWSCC degradation of steam generator tubes made of mill annealed Alloy 600 material has resulted ➜

➜ in tube leaks and tube ruptures and eventually to the replacement of steam generators. Later, PWSCC was also found to affect the welds made of Alloy 82 and 182 materials. Those materials are often used in the butt welds joining low-alloy steel to austenitic stainless steel, for instance at the reactor vessel nozzle safe-ends. Cracking at those locations is important from two major aspects. First, axial or circumferential cracking, if not detected, may lead to leakage of primary coolant. Secondly, extensive circumferential cracking may ultimately lead to rupture, resulting in accident. The penetrations in the reactor vessel head are a special case since the penetration nozzles are often made of Alloy 600 material with the J-groove weld (3) joining the penetration nozzles to the vessel head made of Alloy 82 material. Boric acid corrosion of the outer surface of the primary circuit components made of low-alloy steel may also occur in connection with a leak of primary coolant. Corrosion may only be detected by visual inspection and/or non-destructive examination. For that reason, occurrence of corrosion also led to inspection issues.

› **Thermal ageing.** Cast duplex stainless steels used in primary components such as pump casings and piping elbows are susceptible to thermal ageing at reactor operating temperatures. Thermal ageing of those steels causes embrittlement, i.e. an increase in tensile strength and a decrease in ductility and fracture toughness. Thermal embrittlement reduces the resistance of the material to crack extension by ductile tearing and unstable propagation. Thermal embrittlement, as an ageing phenomenon, has not been taken into account during the design as the design codes rely on the initial material properties. However, effects of thermal ageing must be accounted for when assessing the structural integrity of cast stainless steel components for existing or postulated flaws. Assessing thermal ageing of cast stainless steel may be performed from correlations estimating the Charpy-impact energy (4) and fracture toughness J-R curves (5) under operating conditions from information available in the material test reports.

Like other industrial facilities, nuclear power plants are facing ageing. Knowing the ageing processes accurately and managing them adequately allows the nuclear power plants to be operated safely throughout their life duration but also to extend their lifetime. ■

Visual inspection of a steam generator

(1) The nil-ductility transition temperature characterises the ductile-brittle transition in ferritic steels and is determined by impact testing. It is adjusted to account for irradiation effects.

(2) The upper shelf energy characterises the toughness of the ferritic steels at temperatures above the upper end of the transition region and is determined by Charpy impact testing.

(3) A J-groove weld is a type of groove weld in which one member (here the vessel head) has a joint edge in the form of the letter "J".

(4) The Charpy test is used to characterise the toughness of ferritic steels by impact testing notched bars.

(5) The J-R format is used to analyse the ductile fracture toughness.

APPLICATION OF CONDITION MONITORING TECHNIQUES TO ELECTRICAL CABLES IN SPANISH NUCLEAR POWER PLANTS

By Javier Alonso, Tecnatom, and Tomás López Vergara, Empresarios Agrupados, Spain

Cables are critical components in nuclear power plants since they supply all electrical and I&C components and they are conducting channels for all monitoring, alarm and control signals. Safety-related cables located in harsh environments have been subjected to qualification tests aimed at providing confidence that aged cables will retain their functionality in accidental conditions. However, given the considerable uncertainties in the qualification process, and the need for monitoring the non-safety-related cables important to the plant's availability, procedures to monitor the real condition of electric cables are being developed.

› Monitoring the ageing of electrical cables in NPPs: motivations and outcomes. Several reasons basically motivate the monitoring of long-term cable behaviour, for instance:

• a high volume of cabling is distributed throughout the plant, including areas which are difficult to access and have harsh environments;

• cables connected to hot process piping or components are likely to be under high temperature and dose conditions in the end portion of their run;

• cable functionality is based on the maintenance of the mechanical and electrical properties of its jacket and insulation, which are normally composed of organic materials subject to ageing degradation;

• at present, NPPs are considering life extension strategies beyond the initial duration for which cables currently in use were designed and qualified.

The results and conclusions of numerous studies being carried out by different international organisations associated with the nuclear industry are now being applied directly to cable monitoring and diagnosis throughout a plant's life, although significant limitations have been encountered, since:

• no generic techniques can be applied equally to all types of cables, as construction and materials have a fundamental effect when it comes to determining the applicability of a condition monitoring technique;

• there are wide ranging results for cables of the same type with similar materials, depending on the manufacturers. Fixed applicable limits or acceptance criteria cannot therefore be generally applied to test results, but have to be established for each cable;

• it is very difficult to perform *in situ* tests on cables in certain cases, given their general inaccessibility. ➜

› Monitoring cables specifically manufactured within and/or for the Spanish market. In Spain, the nuclear power plants have been applying cable monitoring and surveillance activities of different scope and methodologies in order to obtain a better understanding of the condition of their electrical wiring systems. By using common methodologies, less effort would be required for each plant and uniform results would be obtained for all of them. Therefore, it was decided to develop a common methodological basis for the systematic monitoring of installed cables, taking the following into account:

• given the average age of Spanish plants, real ageing data obtained for certain cables can be used as pilot samples, enabling the results to be applied to other similar cables in the plant;

• the current status of plant life also made it appropriate to begin monitoring/data acquisition with a view to obtaining sound results on the evolution of the general condition of the cables in the light of the plant life extension programmes;

• applying systematic methodologies to monitor cable condition would allow the timely detection of faults and their consequent impact on plant availability;

• with the majority of cables installed in Spanish NPPs being specifically manufactured within and/or for the Spanish market, the results of cable condition monitoring studies performed on an international level are not directly applicable.

For these reasons, a specific agreement was drawn up between the Spanish Electricity Industry Association [1] and the Spanish Nuclear Safety Council [2] to execute a R&D programme for the follow-up and monitoring of cable ageing in nuclear power plants in Spain. This programme, awarded to the Spanish engineering companies Empresarios Agrupados and Tecnatom, is aimed at establishing a common basis actuation framework for all the Spanish NPPs, taking into account the international state of the art and criteria as developed by well recognised organisations in the area and the specific characteristics of the cables installed.

Javier Alonso

Tomás López Vergara

› A specific programme to monitor cable safety in Spanish NPPs. The specific goals established for the cable condition monitoring programme under development are as follows:

• assessment of the international state of the art in electric cable condition monitoring;

• definition of applicable actions in the Spanish NPPs by establishing common criteria and methodologies for developing monitoring activities for electric cable life management;

• consolidation of the above in application guidelines usable by the plant teams to establish plant specific monitoring programmes;

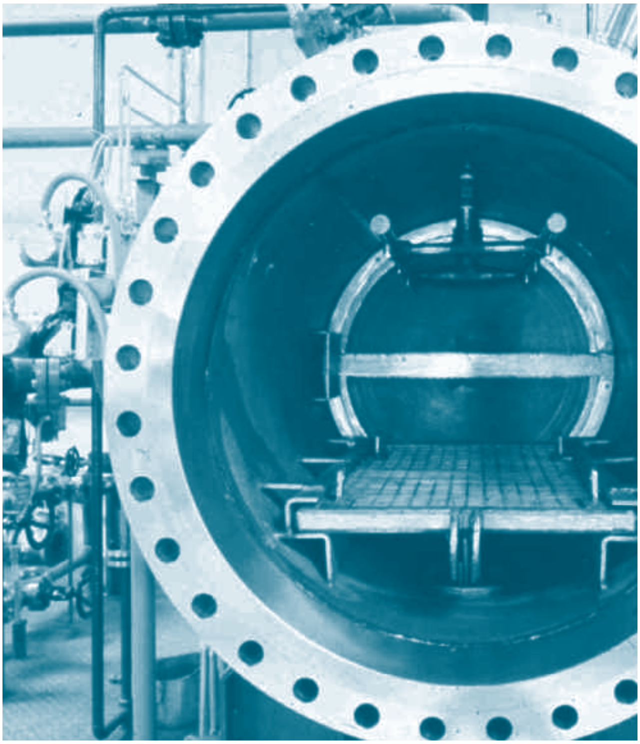
• development of specific technical procedures for carrying out recommended first-level monitoring activities (those based on well established industry practices) as well as for the evaluation of the results obtained;

• development and validation of second-level monitoring techniques (those requiring some R&D before practical implementation in the considered cable materials) and associated ageing models.

To date, the first phase has been successfully completed, and the developed guidelines as well as technical procedures are available and being currently used by the plants. The second scheduled phase of the project corresponding to the 5th estab-

lished goal is now underway [3].
In order to validate the condition monitoring techniques to be applied [4], a representative sample of cables in Spanish NPPs has already been selected, bearing in mind the cable type, material, manufacturer, scope of applicability of each technique, and the possibility of taking samples of new cable and cable that had been in service at the same time (cable naturally aged). The different samples of the new cables will, inter alia, be subjected to thermal ageing and radiation tests to simulate different ageing steps due to their operation in the power plants.
By comparing the results obtained with the application of condition monitoring techniques and the results of the characterisation control tests [5], the existence of correlation factors between the condition monitoring techniques and the real material degradation will be determined. Finally, the results obtained will be further validated and adjusted as necessary with cable which has been in plant service under well established operating conditions.
These condition monitoring techniques and ageing models will serve as a basis for future methodology developments and practical application in electric cable life extension activities in the Spanish NPPs.

› Future prospects: widely usable experience feedback. Results from this programme, which started in October 2002 and is due for completion by March 2008, are believed to provide a consistent approach and practical methodologies and tools for the life management (including life extension) of electrical cables in the Spanish NPPs. The methodology, results and experience gained from this project can also be applied to the cabling systems of other nuclear or conventional facilities. ■



Test facility for the simulation of accident environments in nuclear power plants

(1) Asociación Española de la Industria Eléctrica (UNESA).
(2) Consejo de Seguridad Nuclear (CSN).
(3) Two additional organisations are participating in the 2nd phase of the project: the Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT), in charge of the irradiation tests, and the Consejo Superior de Investigaciones Científicas-Instituto de Ciencias de Materiales de Madrid (CSIC-ICMM), tasked with performing the OIT/OITP and TGA tests.
(4) The condition monitoring techniques considered for programme development are: indenter modulus and thermal analysis of micro-samples using Oxidation Induction Time/Temperature (OIT/OITP) and Thermo-Gravimetric Analysis (TGA) techniques.
(5) The characterisation control tests considered are: Elongation at Break (EAB) and Tensile Strength (TS).

CONTAINMENT INTEGRITY:
FINDINGS FROM STUDIES PERFORMED ON LWRs IN SWEDEN

By Behnaz Aghili, Swedish Nuclear Power Inspectorate (Statens kärnkraftinspektion, SKI), Sweden

■ Ageing management for different parts and components in a nuclear power plant can be carried out in different ways. Some are easy to repair or replace and will be repaired or replaced when defects or degradation are a fact. Others are more difficult to repair, or impossible to replace, such as the reactor's pressure vessel and containment buildings. It is therefore very important to acquire good knowledge of the condition of these structures or components and of the different possible degradation phenomena which can lead to unacceptable changes in their characteristic properties. Results from research projects on ageing containment buildings in Swedish NPPs are reviewed below from the regulatory point of view.

Ageing issues for different constructions and components are of concern, since most power plants in operation the world over – and for instance in Sweden – are expected to be in use for a longer period than anticipated for the original design, i.e. around 40 years. To be able to maintain a high safety level, at least to the same extent as today, some issues need to be considered.


Steam generator replacement

› Watch over the age-related degradation of the containment components.

Two different types of reactors – boiling water reactors (BWR) and pressurised water reactors (PWR) – are operating in Sweden. All the containment buildings in Swedish NPPs are built using pre-stressed concrete. The pre-stressing tendons aimed at supporting the tensile loads that arise in the event of an accident are placed in liners filled either with grease or cement, or ventilated with dry air to protect them from corrosion. The cylindrical walls of the containments were cast in two concentric shells. The containment building is also reinforced with reinforcing steel. A steel liner, embedded into the concrete to provide leak tightness in the event of an accident, lies between the two concentric concrete shells, and is usually made of stainless steel *(see Figure on p. 15)*.

In any event, containments must maintain their leak tightness to protect the public and the environment from radiation. To fulfil this requirement, the design of containment incorporates measures that prevent plastic deformation of reinforcing steel, crack formation in concrete, loss of pre-stressing force, and significant damage such as holes in the embedded liner.

Although certain safety factors have been achieved during the design and construction of containments, the safety of containments can still be affected adversely by age-related degradation of containment materials. In this respect, serious incidents have been reported by Barsebäck 2 (1993), Forsmark 1 (1997) and Ringhals 2 (2004), involving corroded liners and seals, degrading the leak tightness of the containment. All these events were related to installation work which was not in accordance with the design drawings. Corrosion has been the dominant damage mechanism. Therefore attention needs to be paid to the age-related degradation of the different components in containments.

› Research projects focused on five areas of concern. The aforementioned incidents in Sweden and some others abroad, as well as exploratory investigations performed by the Swedish Nuclear Power Inspectorate (SKI) pointed to five main

Behnaz Aghili

areas of concern: the degree of relaxation of the pre-stressed tendons; corrosion of pre-stressed tendons; corrosion of embedded liner due to installation work not in accordance with drawings; the ability to investigate the liner; and the condition of the concrete itself. The research projects performed by SKI and Swedish utilities over the past five years have addressed these issues.

In particular, the condition of pre-stressed cables and the degree of relaxation in them were studied in a PhD thesis, whereas other projects were dedicated to surveying the condition of the concrete and the embedded metallic parts (liner, reinforcing steel) after 30 years in service. The project termed *Material investigation of the containment of Barsebäck 1* was thus carried out on the containment building of Barsebäck 1, and the EU-funded project CONMOD [1] was aimed at finding a system to maintain the safety of the containment over the entire lifetime of the plant. This project was also a screening work to assess the ability of different non-destructive evaluation (NDE) methods to investigate flaws and degradation in thick concrete constructions. The critical areas identified thanks to the finite element analysis (FEA) were thus investigated using different NDE methods to detect if the containment had been constructed in compliance with drawings and if flaws or corrosion could be detected.

› Promising survey results... and some pending questions. The containment building of a BWR, in contrast to the one of a PWR, is located entirely within the plant building. This means that it is unlikely to be damaged by external factors, such as water, moisture or airborne contaminants, leading to carbonisation, frost, abrasion or erosion damages, whereas the contain- ➜

➜ ment building of a PWR is exposed to these elements.

In order to assess the risk for leaching, sulphate, acidic or basic attack, it is necessary to gain knowledge of the quality of the cement and its water content. Recent studies performed on the containment building of Barsebäck 1 show that high quality concrete has been used, and the condition of the concrete is very good after 30 years in service. Thus, no serious deterioration mechanism – or at least no serious damage chargeable to any degradation process – was identified. For instance, the degree of carbonisation and chloride diffusion were found to be very limited, and humidity measurements showed that the concrete still had a high moisture content. This means that shrinkage and creep have not been serious, which also partly explains the low relaxation rates in pre-stressed cables embedded in grease, measured in other projects.

In general, the temperatures in the containments lie at around 60°C, although somewhat higher temperatures can occur locally, such as in the vicinity of certain penetrations. In recent research programmes, some of these areas have been investigated. The concrete has lower moisture content in areas exposed to higher temperature, but even in these areas, the moisture content is still higher than expected.

These results are very promising, but one must bear in mind that the investigations are made on just one single containment, and are very limited, and there are still some unanswered questions about the construction of the containment. Thus, neither the degree of irradiation in some parts of the containment nor the extent to which it would affect the characteristics of the concrete, are clearly understood. This question needs to be addressed in future work.

› Non-compliance with design specifications: a major source of trouble.

Irradiation and corrosion are two possible mechanisms for damage of reinforced steel. The reinforcements are embedded deeply in the concrete, and irradiation should not be a problem. Results of recent research show that neither corrosion due to carbonisation nor diffusion of chlorine ions are of such an extent as to threaten the containment function.

Although corrosion of the embedded liner is a possible scenario, general corrosion of these components is not of concern. Assuming that the designs follow applicable regulations and that the specifications are adhered to, even localised corrosion should be avoided because steel is in a passive condition in the basic environment provided by concrete. Unfortunately it has been proved necessary to investigate localised corrosion in the light of the cases that have occurred both in Swedish reactor plants

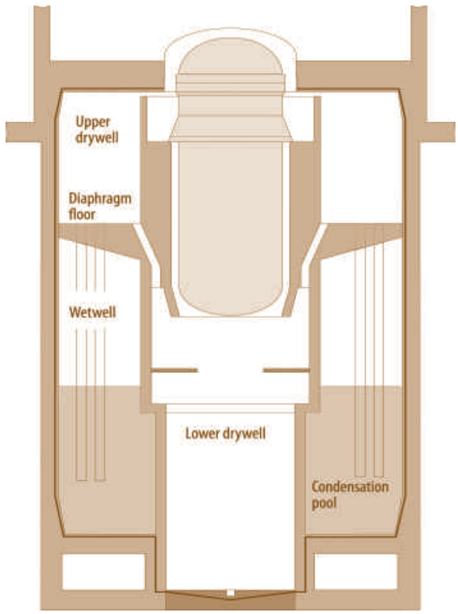
Visual inspection of a steam generator by the manufacturer and in other plants and of the results from the recent research programme. The underlying cause behind these cases is non-compliance with the design specifications. This has led to deviations in the local environment with an increased risk for corrosion, and subsequent degradation of the leak-tightness function of the containment. The conclusion is also valid for pre-stressed liners which are embedded in cement.

Two pipe penetrations were investigated as part of the CONMOD project and both of them showed non-compliance with valid drawings. The conclusion is that if the construction is in agreement with valid drawings, the risk for corrosion of embedded metallic parts, i.e. liner, is minimal.

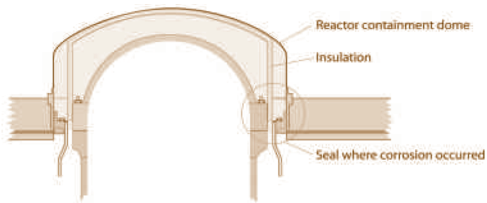
› A plant-specific management programme is necessary. SKI's preliminary conclusion is that to be able to have a valid assessment of the condition of the containments, every plant needs to determine which deviations from drawings might exist in the containment buildings and how these deviations might have affected the integrity of the containment. A management programme is needed for every plant in which the methods to investigate such deviations and to detect and repair possible defects are described. Areas of special interest are pipe penetrations and pre-stressed tendons embedded in cement. ■

(1) The EU-funded CONMOD project is focused on the concrete containment management using the finite element technique combined with *in-situ* non-destructive testing of conformity with respect to design and construction quality. Carried out from 01 Jan. 2002 to 31 Dec. 2004, this 36-month project co-ordinated by Force Institute (Denmark) involved EDF (France), Scanscot Technology AB (Sweden) as well as Barsebäck Kraft AB (Sweden). **For further information,** connect to the Community Research & Development Information Service (Cordis) web site: http://cordis.europa.eu/en/home.html

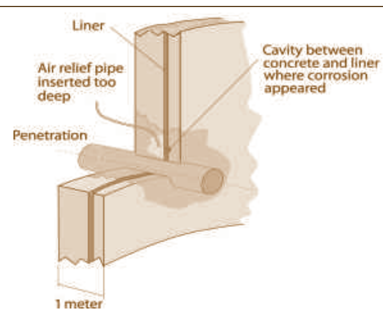
Figure: example of age-related degradation of components in containment



Corrosion attack on liner at the containment penetration. The moulding cavity was not satisfactory filled with concrete, Barsebäck unit 1.



Corrosion attack at the seal connecting liner and the containment cupola, Forsmark unit 1.



Schematic drawing of containment, Forsmark unit 1 and 2.

NUCLEAR POWER PLANTS' LIFE PREDICTION: NULIFE HARMONISES R&D AT EUROPEAN UNION LEVEL

By Professor Rauno Rintamaa, Technical Research Centre of Finland (VTT)

■ The demand for NPP lifetime evaluation methods is driven by the need to maintain safety margins over extended operational lifetimes. As a network aimed at providing harmonised R&D in the area of lifetime evaluation methods for structural components, NULIFE is an innovative approach to co-ordinate fragmented European R&D in a multidisciplinary area which requires a complete understanding of how the safety of nuclear plant systems, structures and components is impacted by the interaction between ageing mechanisms, environmental effects and loadings. Explanations on how the research programmes are determined and conducted are provided below.

Prof. Rauno Rintamaa

A proposed network of excellence funded by the EC's 6th Framework Programme together with contributions of the participants, NULIFE (nuclear plant life prediction) is intended to create a single organisational structure in the form of a virtual institute, capable of providing harmonised R&D to the European nuclear power industry and national safety authorities in the area of lifetime evaluation methods for structural components *(see Box on page 19)*. Its activities are prioritised by an end-user group, comprising representatives of utilities and the manufacturing industry. Together with strong links to safety authorities, this will ensure customer-driven programmes, which can be sustained beyond the 5-year period of EC financial support.

› NULIFE's vision: the creation of a virtual institute. As shown on the Figure on page 18 (*From project integration to permanent R&D entities: the organisational evolution of NULIFE*), the network's ultimate goal is to establish a perennial organisation in the form of a virtual institute providing:

- an integrated RTD platform embracing all European stakeholders within a completely new structure with improved and efficient use of public and private RTD funding;
- a sustainable forum for developing harmonised technical procedures directed at the nuclear energy industry, national regulators and European regulatory working groups;
- services and a sustainable source of qualified expertise for all customers in the nuclear energy field.

Within the framework of customer-driven programmes, detailed planning of the activities is made on an 18-month basis, updated annually. At the beginning of the project, substantial effort will be devoted to putting the organisational, governance and administrative structure in place.

Advanced testing facilities for the evaluation of materials performance in simulated reactor water and loading conditions

› **NULIFE's priorities for the next year and a half.** During the first 18 months of the organisation, its activity will be structured drawing upon four pillars: expert groups, a R&D road mapping group, pilot projects as well as other activities.

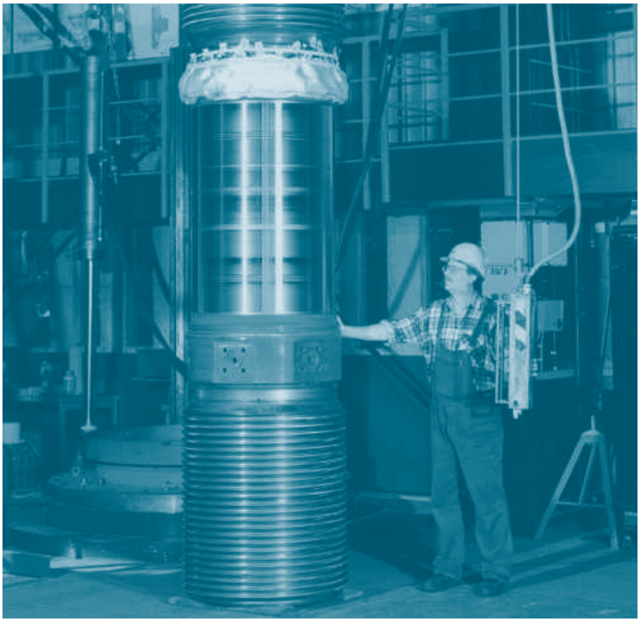
Four groups devoted to providing expertise for R&D projects

• *Expert Group 1* deals with the material property issues, in particular the mechanisms of material degradation (environment assisted cracking, thermal ageing, irradiation embrittlement) and characterisation of the properties of aged materials, i.e. as a function of in-service conditions.

• *Expert Group 2* is concerned with establishing the state of the art in methods for defect and loading assessment. It does not only handle fracture mechanics methods such as those used in the assessment of pressurised thermal shock and leak before break, but also includes a consideration of existing Codes and Procedures, non destructive testing, failure modes, safety factors and selected special topics such as effects of load history, crack arrest, and secondary and residual stresses.

• *Expert Group 3* will take a long-term perspective of component integrity, in particular the safety justification of components over their intended operational lifetime, where the demonstration of safety margins is predominantly driven by considerations of fatigue (including thermal fatigue and corrosion fatigue), irradiation embrittlement and other ageing processes (including creep and creep-fatigue).

• *Expert Group 4* will support the network by providing advice on the identification, characterisation and management of uncertainties in lifetime evaluation. By modelling structural reliability and performing risk assessments, this group will provide additional insights into the assessment of safety margins.



Emergency cooling testing - Simulation of extreme conditions in a feedwater line

R&D planning

The content of the R&D programme for the network is driven in the first instance by the End-User Group who already met in the proposal preparation phase to determine the research topics of preliminary interest. Consultation with regulators and safety authorities will be addressed separately. The technical content and resources will be planned by the *R&D Road Mapping Group*.

R&D pilot projects

The pilot studies are intended to demonstrate the network's capacity to work in an integrated way with a view to delivering consensual best-practices based on R&D work. Two studies will be launched at inception of the project:

• *stress corrosion cracking* aims at bringing together data from past and on-going national and transnational projects on stress corrosion cracking and environmental assisted cracking on a European level, with the compilation of the data into a common database. Best practice guidelines will be based on this and round-robin testing on reference material;

• *thermal fatigue* will take advantage of work from earlier projects and groups and from the best-practice procedure being devel-

Figure: From project integration to permanent R&D entities: the organisational evolution of NULIFE

Integration plan	Preparation of business plan	Consolidation of integration plan	Creation of Virtual Institute	Transition plan for permanent entity
- Viable expert groups - Coherent structure - Communication methods	- Business plan - Links with national programmes - Updated structure - Approaches to training, knowledge and communication	- Launching of new RTD projects - Development and application of procedures and best practices	- Structure with permanent entity features - Joint use of facilities - Investment policy	- Permanent mangement structure - Long term business plan - Acknowledged solution provider

Box: NULIFE, the network of excellence aimed at providing harmonised R&D in the area of lifetime evaluation for NPP structural components

NULIFE (nuclear plant life prediction) is a proposed network of excellence (1) funded under the auspices of the European Commission (6th Framework Programme) together with contributions of the participants. The NULIFE network itself is made up of 10 WP (2) leader organisations (contractors) and 27 associate member organisations.

Co-ordinator	Technical Research Centre (VTT)	Finland
Contractors	European Commission Directorate General Joint Research Centre (JRC)	EU
	Studiecentrum voor Kernenergie/Centre d'Etude de l'Energie Nucléaire (SCK/CEN)	Belgium
	Ústav jaderného výzkumu Řež a.s./Nuclear Research Institute Řež plc (NRI)	Czech Republic
	Commissariat à l'Energie Atomique (CEA)	France
	Electricité de France (EDF)	France
	AREVA NP GmbH	Germany
	British Energy Generation Ltd	UK
	Serco Ltd	UK
	Forsmark Kraftgrupp AB	Sweden

The projected costs for the 5-year duration of NULIFE amount to €8.4 million. This includes approx. 500 person.months of work. The requested grant from the European Commission is €5 million.

(1) Network of excellence refers to a specific type of projects funded under the EC's R&D Framework Programme. Networks of excellence are intended to strengthen scientific and technological excellence on a particular research topic by integrating at European level the critical mass of resources and expertise. This expertise should be networked around a joint programme of activities (JPA) aimed principally at creating a progressive and durable integration of the research capacities of the network partners while at the same time advancing knowledge on the topic.

(2) work package.

oped to complete the *European Thermal Fatigue Procedure (ETFP)*, including consensus on applicable fatigue damage curves.

Other Activities

Besides planning its R&D programme and launching two pilot projects, NULIFE will carry out other significant activities over the next 18 months:

- mapping the expertise available to the network, with a gap analysis and recommendations for future integrated work planning;
- collecting Knowledge Management case studies;
- listing the technical documents selected for their potential to develop as best practices;
- drafting a position paper on the long-term business plan;
- commissioning the internal document database;
- implementing the Ph.D. programme (incl. reports on inter-site exchanges);
- planning the 1st NULIFE training course;
- selecting partner projects/networks and developing the Memorandum of Understanding template;
- defining the generic framework for the advancement of a harmonised regulatory approach to plant life management at European level.

› The focus: the organisation's long-term viability. NULIFE's planning over the next 18 months is focused on making the network a reliable and attractive source of life assessment technology and related applications for its stakeholders.

Its participants recognise that the long-term viability of the intended virtual institute will depend on its ability to achieve this goal. ■

PUTTING PHYSICS TO WORK
FOR NUCLEAR SAFETY

By Professor Dr. Anton Erhard, Federal Institute for Materials Research and Testing (Bundesanstalt für Materialforschung und -prüfung, BAM), Germany

■ Non-destructive testing methods are used to test for a wide variety of defects ranging from planar flaws like cracks to such volume defects as lack of fusion or slag inclusion generated in the liquid phase at very high temperatures e.g. during the welding process. Cracks are an important inspection area, as their formation during operation can mean that mechanical loading or stress corrosion resulting from pressure or vibrations is higher than anticipated by design [1]. An overview of the various proposed techniques and improvements is given below.

› **Non-destructive testing: field-proven, yet innovative techniques.** A wide array of physical processes can be used as non-destructive techniques to detect material flaws or ageing phenomena by means of surface or volume inspections.

Surface inspection techniques

• *Visual testing* makes it possible to detect various types of surface damage, either directly with the human eyes or instruments such as endoscopes, or indirectly with radio systems. In the former case, information is immediately available; in the latter, it is stored on a data carrier (DVD, tape, etc.) and processed.

• *Liquid penetration* is used to inspect open defects when dealing with uncoated surfaces: the liquid penetrates into the defect; then a developer is put on the surface to reveal the trace once the surface is cleaned.

• *Magnetic particle testing* techniques are appropriate for the inspection of ferritic material such as carbon steels or nickel alloys.

• *Eddy current* techniques use the conductivity of materials such as metals to detect surface or near-surface (8 to 10 mm) flaws, depending on conductivity, permeability and frequency of the technique used.

Volume inspection techniques

• *Radiography:* traditionally used for medical diagnoses, X-ray or gamma radiography also find industrial applications such as the inspection of welded areas (e.g. welded piping). In the past 6 to 7 years, the develop-

Maintenance work performed using testing equipment

ment of digital technology allowed signals to be obtained from X-ray tubes by film digitization and the application of cameras.
A variant of radiography, *computer tomography* is a mobile technique used in nuclear power plants for both surface and volume inspections. This new technique called "TomoCar" is qualified for NPP piping with a maximum thickness of 25 mm. The acquired signal is reconstructed by computer processing.
• *Ultrasonic techniques* used for inspections of defects/failures inside components in the range 0.5 mm to 5 mm (0.5 MHz and 10 MHz) draw upon the difference in acoustic impedance between the base material and the defect (e.g. cracks, lack of fusion, etc.). Cosines and tangents are calculated to provide the exact location of the defect; then sizing techniques such as echo-tomography allow additional information on the defect to be gained by means of image reconstruction.

Further techniques are based on the ultrasonic principle
• *The Synthetic Aperture Focusing Technique (SAFT)* is a scanning procedure based on wave lengths, derived from techniques implemented in astronomy, where the resolution is a function of aperture size (i.e. from antennas spread all over the Earth's surface). SAFT is a major sizing technique even more widely used than echo-tomography for heavy steel components like turbine shafts with a diameter of approximately 2 metres. *The Time Of Flight Diffraction (TOFD)* technique is similarly used for the detection and sizing of defects.
• *Phased Array* techniques, used for inspections of, for example, an entire nuclear vessel, draw upon the inclination of sounds in the material to reveal such defects as cracks.


Prof. Anton Erhard

The equipment is computer-steered and the signal digitised, allowing defect reconstruction by reconstruction of the sound field e.g. using the SAFT approach.
Many other non-destructive testing methods such as infrared thermography or acoustic emission exist but are rarely applied to the inspection of nuclear power plants.

› **Significant improvements for more accurate, reliable and comparable test results.** Over time, non-destructive testing methods have benefited from significant improvements that do not translate into cost reduction, but into higher accuracy and reliability consequently leading to enhanced safety. Thus, if a crack is found (e.g. on the main cooling system of a reactor) and characterised accurately, an appropriate decision can be reached as to whether it is advisable to wait for the next outage before commencing repairs, or whether they should be made immediately.

The three major benefits linked to the aforementioned improvements are:
• the possibility, thanks to evolved mobile tomography, ultrasound or Eddy currents, to detect very small defects and to obtain details such as the position, extension and sometimes also the precise nature of the defect (lack of fusion, slag inclusion, etc.);
• time savings resulting from the implementation of mechanised techniques, which also reduce the human factor and therefore improve the reliability of the results;
• the possibility of accurately and reliably comparing results obtained presently and in the future, this benefit being particularly meaningful for periodic in-service inspections. ■

(1) This was the case with the Davis-Besse nuclear power station (Ohio, USA).

AGEING MANAGEMENT AND EXCEPTIONAL MAINTENANCE OF PWRs: AN EDF VIEW

By Christian Pichon and René Boudot, Electricité de France (EDF), France

■ The ageing management of EDF's reactor fleet – 58 pressurised water reactors (PWR) with an average age of about 22 years – depends firstly on the quality of its design and construction, and secondly on the quality of its operation and maintenance. Deciding the relevant preventive measures and implementing them advisedly and timely requires a prospective vision of the possible deteriorations. For EDF, this anticipation is all the more necessary in that the standardisation of its fleet is not only a lever for productivity but also a potential source of vulnerability with regard to generic deteriorations.
Three examples of the utility's policy on ageing management and maintenance are provided below.

Christian Pichon

René Boudot

Drawing upon its prospective approach to reactor ageing, EDF focuses on a three-pronged policy to ensure the safety, reliability and performance of its 61 GWe strong fleet:

• the obsolescence management of instrumentation and control systems;

• technical maintenance based on such routine operations as wear parts or repair of malfunctions;

• the 'judicious replacement' of major components such as reactor vessel closure heads or steam generators.

› Fighting oblivion. Faced with the risk of disappearance of electronic and electrical components as well as of some mechanical parts or rare skills, EDF prospectively monitors the conservation of sensitive industrial competencies in order to define its industrial policy regarding design studies, maintenance, prime contractor skills, etc. These provisions are supplemented by a process aimed at detecting risks of breaks in the supply of components and spare parts with a view to adopting the best possible countermeasures: e.g. constitution of preventive stocks, search for substitution products, and modification of facilities, etc.

› From routine to exceptional maintenance operations: a convergent approach.

Maintaining the equipment's functional capabilities on a daily basis and thereby ensuring the plants' availability and productivity in compliance with nuclear safety requirements is the aim of EDF's technical maintenance policy based firstly on routine operations. In this framework, EDF developed *on-condition preventive maintenance* based on:

• stepped-up diagnostics and prognostics;

• a sample of pilot equipment, taking advantage of the high level of standardisation of its fleet.

Optimising this preventive routine maintenance calls for knowledge of the functional consequences of failures as well as experience feedback supported, inter alia, by the examination of removed components and non-destructive inspection methods.

Exceptional preventive maintenance is aimed at coping with ageing phenomena that irreversibly impact such major components as reactor vessels, steam and turbine generators, condensers, instrumentation & control systems, as well as buildings and civil works. Theoretically performed only once in a facility's lifetime, consequent operations are planned for EDF's entire NPP fleet based on identified or anticipated deterioration, taking account of significant industrial stakes in terms of radiological exposure, costs, plant outages, required resources, etc.

Regardless of the repair, rehabilitation or replacement involved, exceptional maintenance requires the ability to:

• look 20 to 30 years ahead in terms of reparability and replaceability;

• make economically sound decisions and scheduling in compliance with nuclear safety requirements, the facilities' expected technical lifetime, and possible performance increase.

Three examples given below epitomise EDF's 'judicious replacement' policy.

› Reactor vessels' closure heads. In September 1991, a leak detected in an alloy 600 vessel head penetration at Bugey-3 NPP after 10 years' operation triggered an initiative intended to inspect the reactors' operation under perfectly safe conditions and preparing for the future. After the trouble was characterised in 1993, EDF decided to replace the closure heads of its 54 units in operation at this time, taking into consideration:

• the generic and, in the long run, inescapable nature of the cracking of several adaptors per closure head, combined with an extensive repair plan spanning over several decades;

• the fact that all alternative options such as the adaptors' repair or replacement were more penalising from financial, radiation protection and plant outage aspects;

• the robustness of the replacement of the old closure heads by new heads with vessel head penetrations in 690 alloy, with respect to the facilities' lifetime.

Today, 47 closure heads have been replaced, and the remaining 7 will be replaced between now and 2010. The work has been scheduled according to:

• the results of the in-service inspections, in compliance with the safety criterion (remaining ligament preventing in-service leakage on the closure head until the next shutdown);

• the industrial streamlining of the operations.

On some plant units, closure heads replacements were combined with those of control rod drive mechanisms, thus displaying a high number of operating steps.

Bearing witness to its relevance regarding nuclear safety and competitiveness, this exceptional preventive maintenance approach has been adopted by an increasing number of nuclear operators internationally.

› Steam generators. Steam generators benefit from operating procedures and routine maintenance aimed at guaranteeing safety and limiting the risk of unscheduled shutdowns. This draws upon:

• operation with low primary/sec- ➜

Professional training at Cattenom NPP (France)

Maintenance work on steam generator tubes

ondary leakage based on continuous monitoring;

- periodic inspection of the steam generator tubes using qualified methods;
- preventive maintenance governed by plugging criteria, chemistry optimisation of the primary and secondary environments, choice of condenser materials, cleanness policy, lancing, etc.

The steam generators with mill-annealed alloy 600 tube bundles have proved to be particularly sensitive to primary water stress corrosion. Estimation of their service life's termination is derived from a probabilistic assessment of the plugging rates based on experience feedback and a prediction of such degradation phenomena as primary and secondary stress corrosion cracking.

Optimised scheduling is required by the significant investment associated with the replacement of a steam generator (about €100 million per unit). Although industrially mastered, such operations are costly in terms of radiological exposure (in spite of the ALARA procedure), therefore justifying implementation of routine operating and maintenance actions intended to delay replacement, i.e. control of the chemistry, heat treatment of small U-bends, chemical cleaning, tube sleeving, overplugging with a reduction in power, etc.

Since 1990, the year of the first steam generator replacement, 15 out of the 25 EDF power plants initially equipped with mill-annealed alloy 600 tube bundles have performed similar changeovers. The technical service life forecasts for the remaining steam generators require replacement operations to be continued at a rate of one unit per year over the next 10 years, with several cases of early replacement with respect to the end of technical service life for reasons of industrial streamlining or caution regarding the integration of experience feedback, should it turn out to be less favourable than expected.

› Instrumentation and control (I&C) systems. Besides major upgrades specifically needed to achieve targeted performance increases, EDF's strategy for I&C is aimed at carrying out judicious partial and gradual renovation work. Managing component as well as software obsolescence and maintaining skills are decisive factors, given the investments at stake (I&C system rejuvenation amounts to approx. €60 million).

EDF's approach for these systems is as follows:

- observe, plan for and anticipate the ageing of I&C components;
- keep a strategic stock of spare parts to cover routine maintenance requirements for several decades;
- safeguard win-win partnerships with the manufacturers by striking long-term deals aimed at getting experience feedback to be taken into account in an appropriate manner and maintaining skills and logistic resources.

› Plea for a long-term strategy. The lasting safety and competitiveness of EDF's PWR fleet are part of one and the same operational objective. Exceptional maintenance operations are consistent with this objective, provided that creation of value is evidenced. In this respect, a forward-looking strategy based on knowledge improvement, monitoring and analysis of experience feedback and of the industrial means and skills is pivotal today to gain visibility over the next 20 to 30 years – i.e. the residual lifetime of major equipment – with regard to the options pertaining to investments and industrial strategies. ■

DIGITAL INSTRUMENTATION AND CONTROL: KEEPING UP WITH TECHNOLOGY DISRUPTIONS

By Deryk Pavey, British Energy, United Kingdom

■ The first programmable full reactor protection system in the UK has now been operating for more than a decade at Sizewell B. The novel challenges represented by this system led to a licensing approach that set an important precedent for further programmable systems required for modernisation of the existing plant, at all levels of integrity. The key elements derived from the safety justification for the Sizewell B Primary Protection System (PPS) software are reviewed below.

Deryk Pavey

In its safety case for the operation of a nuclear reactor in the UK, a licensee must demonstrate, firstly to itself and then the regulator, that the overall risk – i.e. the combination of risks from all sources, attenuated by any relevant safety measures – is no greater than the 'tolerable' level required by its design safety guidelines, which align with those published by the regulator. As part of this case, the reliability of the programmable Primary Protection System (PPS) is judged in terms of *failures per demand* (fpd). Recognising the difficulty of demonstrating such a numerical reliability for programmable systems, and the requirements of relevant nuclear sector standards, the regulator expects claims lower than 10^{-4} fpd to be treated with caution.

› A 'three-legged stool' to justify PPS software reliability. Since there is no accepted scientific method of assessing a reliability figure for software (all faults being unknown design faults), the safety justification for the Sizewell B PPS software rests on the 'three-legged stool' summarised in the Table on page 26. The quality of the production process includes consideration of the qualification and experience of the developers as well as confidence in the reliability and correctness of the development tools used. Analysis of the product is performed by an independent organisation after formal release by the developers, and includes mathematically based formal analysis techniques as well as structured technical review. Testing includes use of a simulated environment to subject the system to statistically large numbers of variants of potential scenarios that place a demand on the system.

Following the Sizewell PPS experience, a 'philosophy' has developed that seeks two major elements of safety case evidence. This is like reducing the three 'legs' described above by incorporating testing activities into the other 'legs' according to whether they are part of the development process or the independent technical assessment.

The two major elements of this 'philosophy' are *Production Excellence* and *Confidence Building*. A high level of independence is expected between them. The Production 'leg' is expected to develop and verify the product to the highest stand- ➜

➜ ards commensurate with the required integrity target before formal release as a fully configured and validated product. Then the assessors, ideally reporting to independent management at a senior level, apply confidence building measures to confirm the quality of the product using tools and techniques that are (as far as reasonably practicable) diverse. Communication between developers and assessors and resolution of 'findings' are formally managed and recorded.

This 'philosophy' can be illustrated by the infrastructure that has been set up for maintenance of the PPS 'application' software. Responsibility for maintaining 'application' software modules has been transferred from the original designers (Westinghouse) to a UK team, drawing on specialists from British Energy and other companies with experience in the appropriate technologies. Software modules that provide 'common functions' shared with other Westinghouse products (such as input/output modules and protocols for communication between and within processors) are still maintained by Westinghouse.

Smart Flow Meter for a Resin Transfer System

› Maintaining skills and infrastructure over the long run. Twenty years is a long time in the world of programming methods and tools. The software technologies for the PPS were chosen in the mid 1980s when the initial design process started, so the challenge of maintaining an infrastructure to make changes today is not trivial. Maintenance of a skilled base of engineers familiar with the technology thus has been addressed with a programme of training to pass on skills built up during the original development process. The other main challenge is the obsolescence of the development tools and infrastructure. However, re-hosting solutions have proved feasible.

Much of the experience gained during the PPS software safety justification was distilled and documented in a set of company guidelines for Programmable Electronic Systems (PES). The experience was extended 'downwards' to provide graded guidance for systems of several levels of integrity. A major revision was made in 1998 following an extended trial period, incorporating the results of wide consultation, feedback and review. A further revision in 2002 incorporated a new major appendix addressing 'Commercial Off The Shelf' (COTS) systems and a relatively 'slim' companion set of guidelines for safety systems of 'modest integrity' (up to 10^{-1} failures per demand). Future PES guidelines issued by British Energy will concentrate on interpretation of international standards in the British Energy context, and guidance on how to meet them.

Table: Diversity of Safety Case Evidence

Diversity of evidence	Process Quality	Product Analysis	Product Testing
evidence	indirect	direct on model	direct
fault prevention	yes	possible	no
fault detection	not usually	yes	yes
fault absence	no	yes	no
maintainability	essential	valuable	mixed

› Specific programmes to address Instrumentation & Control safety. In order to inform and underpin safety Instrumentation & Control (I&C) practice and guidance, British Energy has been sponsoring nuclear related I&C safety research programmes covering various fields such as:

• research into Software Diversity developing a scientific diversity quantification method based on fault injection;

• research on Formal/Static Analysis of Legacy Code continues a series of projects aimed at improving the effectiveness and efficiency of software Static Analysis techniques;
• statistical Software Testing (SST) research has the overall aim of developing a new, practical technique for software reliability assurance.

› Coping with the surge of COTS. The increasing use of COTS systems poses a difficulty in assessing their suitability for use in nuclear applications. Research in this area addressed the static analysis of 'Commercial Off The Shelf Software of Uncertain Pedigree' (SOUP/COTS) systems and the feasibility of extending the approach to Smart sensors. The study examines techniques for integrity checking that can be applied to systems for which the source code is available, but for which little prior knowledge of the system is available.
Collaboration towards European Harmonisation is seen as an effective way to develop and propagate best practice in I&C modernisation. British Energy coordinated the recent Cost Effective Modernisation of Systems Important to Safety (CEMSIS) project [1], which brought together representatives of plant operators, equipment suppliers and regulators from Belgium, France, Germany and Sweden as well as the UK. The main deliverables were a Safety Justification Framework, a Requirements Best Practice Guide, Guidelines for Off-The-Shelf Product-based Safety Systems and a Public Domain Case Study.
New technology instrumentation is not generally qualified for nuclear use, and specifically, the new 'Smart' technology contains 'Software of Uncertain Pedigree' (SOUP), which must be assessed in accordance with relevant safety standards before it may be used in a safety application. This assessment process is not a trivial task. A project known as EMPHASIS (Evaluation of Mission imPerative, High-integrity Applications of Smart Instruments for Safety) is intended to be a key part of the future British Energy approach to Smart instrument justification.

View of Control Room Training Simulator

› Improving techniques and guidance with increased international collaboration. The challenge of providing a convincing case for the integrity of programmable safety systems has been met over the last decade with a comprehensive and graded application of diverse techniques and tools. British Energy are actively involved in seeking improvements in the techniques and guidance, and the understanding of the nature of a safety argument, including improving international collaboration and consensus. ■

(1) The Final Public Synthesis Report (April 2004) is accessible on www.cemsis.org

KNOWLEDGE MANAGEMENT,
A KEY ISSUE TO THE REVIVAL OF THE NUCLEAR INDUSTRY

by Gail H. Marcus, Deputy Director-General,
OECD Nuclear Energy Agency

■ In an area where safety is paramount, a long period of stagnation coupled with a dramatic renewal of interest may lead to circumstances where the needs for tapping past and existing knowledge are particularly acute. In the nuclear community, it sometimes seems that knowledge management (KM) has become the new 'magic bullet' for doing everything from preserving research data to dealing with the ageing workforce. Significant challenges and new approaches to the collection, selection, conservation and mining of data and knowledge are reviewed below.

The recent recognition of the urgency to capture information that can aid in the redevelopment of the nuclear industry has promoted a structured approach to KM *(see definition on page 30)*, both to reap the maximum value from work already done, and to help assure that the problems of the past, which have made the KM needs so acute, are not repeated again.

In the area of organisational operations (including both corporations and government entities), the major issue in KM is the knowledge that resides largely in the minds of existing, or even retired, employees. This problem exists in every industry, but is particularly acute in the nuclear industry. The stagnation of the industry relatively shortly after its inception led to a lengthy period in which the normal replacements of a workforce did not occur. Thus, the industry has just recently begun to face the retirements of large numbers of the employees who actually designed and built the current infrastructure. These retirements are occurring at exactly the same time as the industry is beginning to grow, thus compounding the human resource problem. The new employees being hired do not know the 'lore' that tends to grow around complex facilities – that is, the implicit knowledge, usually undocumented, that comes from having built a facility and operated it for many years.

In the area of research, the cancellation of many research programmes during the hiatus in nuclear activity and the closure of many research facilities resulted in research efforts that did not culminate in the usual analysis and publication of research results. Not only is there much data that, if analysed, might be useful today. Some of this data has been preserved on media that are decaying (such as magnetic tapes) or using computer programs that are obsolete. Thus, in addition to the normal KM activities associated with ongoing research, there is a large body of research data that must be evaluated to see what is potentially useful and useable, transferred to stable media, and indexed.

› Managing past knowledge: identifying data relevant to current needs. While it sounds desirable to cull all possible value from past work, attempting to do so can quickly become very expensive and can sometimes yield marginal results. For example, research data may be too incomplete or in too poor a condition to be of value, may involve materials or environmental conditions (temperature, pressure and chemical) no longer of interest today, or may be missing critical information about the conditions under which the data was generated. Older workers may have forgotten the basis for some of their tacit knowledge or may recall the past incorrectly. Much time and money can be spent to little effect archiving data that is no longer useful, or collecting anecdotes from older workers that, while of human or historical interest, are not important to an organisation from an operational standpoint.
The 'trick' is to be selective in KM efforts to preserve old research data or to transmit tacit knowledge. This, of course, is easier said than done. It may prove helpful to integrate efforts to preserve data or knowledge of the past with efforts to integrate and systematise the current knowledge base. This will help ensure that the areas of focus are areas that are of interest today.
Of course, older information and data relevant to current needs must still be identified. In the research area, that calls for some effort to inventory, at a very general level, what materials exist and where they are located. In the area of tacit knowledge, this calls for identifying individuals most likely to have the best corporate history and being sure that the interviews and questionnaires really elicit the information needed for operations. In particular, the interviewer must make a concerted effort to drill down into the stories and assure that what is documented includes exactly what was done and why it was done. This may seem obvious, but the current inventory of taped interviews contains examples that are high in human interest but have limited technical value. For example, the story of a local machinist who proved smarter than the one from the home office and figured out how to fix an important component may be of interest to a historian. However, it is not of use to current personnel at the facility unless it identifies exactly what the local machinist did that was different and why.

› Managing present knowledge: maintaining integrated resource systems. One thing that characterises current knowledge is the interrelationship ➜

Gail H. Marcus

➜ of widely divergent sources relating to a particular technical issue. The U.S. Nuclear Regulatory Commission (NRC), for example, has developed a knowledge portal that allows staff to identify, for a given issue, all research reports, regulations, technical specifications, information notices, enforcement actions, internal experts, and other resources relevant to that issue. Thus, someone needing information on a particular problem can go to one place to find the needed technical information, past experience, requirements, and available assistance that he or she may need. While the NRC system is built around the regulatory context, similar systems can clearly be used in a corporate context. Computer-based portals today can help integrate information stored in different places, and can include everything from raw data, to reports, to videos.

The value of such a system is that it provides for "one-stop shopping" for the user and therefore gives everyone higher assurance that anyone needing information has access to everything that might be useful. Further, it can be used at a variety of levels and by a wide range of users, including for the critical role of training new workers, or training workers in new assignments. It also allows for the integration of old research data and tacit knowledge and assures that such information is accessible, and allows for the continued incorporation of new information as it is developed.

Clearly, the development of such a system requires a long-term commitment to keep it up-to-date as new knowledge is developed and as changes occur. As in any area where things change over time, if such systems are not kept up-to-date (including by replacing, or at least flagging, information that has become dated or obsolete), they quickly become useless, or worse, they mislead users who may assume they have a complete, current and reliable data base. Organisations that are struggling with the current problem of assuring that tacit knowledge is recovered and passed on before it is too late should be well motivated to make both the initial and continuing investments required.

› **Appropriately inform the activities of tomorrow.** While it might be a bit melodramatic to say that the future of the nuclear industry depends on KM, it is certainly true that the long hiatus between the initial surge of nuclear development and the pending second surge have created some acute needs to assure that needed knowledge from the past is retained and transmitted to a new generation of users. A deliberative approach to selecting the key information from the past and to integrating it into a "living" framework can help assure that the knowledge of yesterday and today appropriately informs the activities of tomorrow. ■

Maintenance work performed on a steam generator

Knowledge management (KM) encompasses all activities related to the creation, preservation and transmission of data and information. For different groups of users, different subsets of these elements are important.
For the corporate community, KM generally focuses on the training of new employees and the communication of experience, often termed 'tacit knowledge', from older workers to younger ones. For the research community, KM is usually taken to encompass the generation of data from experiments, the synthesis of the data into meaningful results, and the publication of reports on the work.

TAPPING EXPERIENCE TO SHARPEN DESIGN

By Catherine Ensel and Pascal Quinot, Areva NP, France

■ Areva's experience in designing and building a hundred PWR and BWR units around the globe is being used to support operator approaches to demonstrating reactor safety and improving the determination of their service life and, in some cases, extending that service life. This article will illustrate that expertise and our contribution as a designer-manufacturer. Our review will be limited to mechanical engineering of the primary and secondary cooling system components.

Catherine Ensel

Pascal Quinot

Plant operators are responsible for knowing and optimising the service life of operating reactors. This involves the following aspects:

- knowing the design documentation, which identifies in particular areas most subject to stress and the nature of the stress;
- updating the design documentation as technical knowledge evolves and based on lessons learned from operations, including international experience;
- developing a suitable monitoring program for operations;
- defining additional steps to be taken to optimise the capital invested in the reactor's service life, e.g. preventive maintenance, additional operating guidelines, R&D, etc.

In all these areas, the component designer can contribute to the reactor operator's analyses.

In the case of new plant design or for replacement components, lifecycle optimisation is taken into account very early in the design phase. This process is based on:

- lessons learned from previous designs;
- the most recent regulatory requirements;
- the operator's requirements for streamlining plant operations or improving performance.

› Knowledge of design documentation Initial design data concerning the Nuclear Steam Supply System (NSSS), and more specifically the primary cooling system components, are summarized in the documentation provided by the reactor designer:

- manufacturing data, particularly equipment drawings and specifications, as-built dimensions and measured mechanical characteristics, and handling of non-conformities;
- the loads and conditions report encompassing normal operations and accidental conditions taken into account during the design phase, as well as site-specific characteristics such as seismicity;
- the component stress analysis report;
- the safety analysis report indicating the unit's safety requirements and demonstrating compliance with those requirements. ➜

› Updating the documentation. Design documentation must be periodically updated in several respects:

• changes in the various codes, standards and regulations must be taken into account. For example, for reactors in service in France, the Operating Order of November 10, 1999, requires the operator to establish Regulatory Reference Files to improve knowledge on sensitive areas in the main primary and secondary cooling systems with respect to various kinds of damage (risk of cracking due to metal fatigue, fast fracture, etc.). The main change from previous practices is greater and systematic consideration of the fast fracture risk. Areva provided support to EDF during the preparation of this documentation by performing an assessment of all initial design studies to identify areas requiring more in-depth analysis;

• increased knowledge of component degradation modes, based on major R&D programmes to which Areva was a significant contributor (e.g. thermal ageing of austeno-ferritic steels and radiation-induced ageing of the steel in the reactor vessel) and on lessons learned (stress corrosion of nickel-based alloys);

• lessons learned from reactor operations are under the complete control of the plant operator. However, Areva provides support for updating condition reports and offers special instrumentation concepts to improve the detection and understanding of local thermo-hydraulic events or conditions (e.g. thermal stratification or vortices in auxiliary and secondary systems). Areva also helps interpret them.

This document is used to define and rank areas prone to deterioration and contributing factors.

› Developing an in-operations monitoring programme. The in-operations monitoring programme is a major component of the reactor life expectancy management strategy. In France, these programmes fall squarely within the responsibility of EDF as operator. The operator relies on data contained in the Reference File to establish a monitoring programme that defines areas to be monitored, the specifications for certifying non-destructive testing methods, and the schedule of inspections. However, the monitoring programme goes well beyond the mechanical field to include aspects such as dosimetry optimisation, the duration of maintenance, etc. In many instances, Areva is able to propose and implement suitable monitoring and inspection resources.

› Optimising reactor service life expectancy: regular preventive maintenance, exceptional maintenance, additional operating recommendations.

Knowledge of components' sensitive areas and of the related ageing cycle is instrumental in evaluating the 'safe' service life of components in accordance with regulations. Armed with this data, the operator defines appropriate maintenance strategies and acts proactively to ensure that these components achieve their full service life:

• targeted sample collection to confirm the damage mode and/or kinetics (e.g. sampling of cast austeno-ferritic steel products to check ageing kinetics);

• component repair, plugging steam generator tubes, targeted replacement of RPV internals baffle bolts, etc.);

• exceptional maintenance may include full or partial component replacements (replacement of pressuriser at St. Lucie and Millstone, of steam generators, of vessel heads,

Reactor vessel bolting machine at Penly NPP (France)

of control rod drive mechanism pins). The replaced component benefits from the latest advances in terms of design, operating flexibility and maintenance optimisation (e.g. advanced performance steam generators, vessel heads forged in one ingot, etc.);

• Areva has developed an array of replacement components meeting the requirements of operators around the globe. Operating conditions are adapted to limit occurrence of penalizing transients, such as controlling low flow in the common section of steam generators' Auxiliary Feedwater and Feedwater flow control Systems to reduce thermal fatigue caused by thermal stratification, or reducing pressure vessel fluence when designing new fuel management methods.

› New reactor design. To meet the objective of a demonstrably long service life (60 years), the new generation EPR incorporated a number of factors very early in the design process:

• lessons learned from previous designs;

• the most recent regulatory requirements, such as the French regulation regarding nuclear equipments in a pressurized environment and the YVL guides in Finland; and

• operator requirements to streamline reactor operations.

In fact, manufacturing specifications are adjusted for each of the sensitive areas identified, based on the Reference Files and lessons learned from previous units. Examples include:

• Lessons learned:

- optimisation of materials: selection of a low residue material (phosphorus, sulphur, etc.) for ferritic steels used in primary cooling system components to limit the effects of ageing;
- improved local design (e.g. reduction of geometric discontinuities to limit stress levels) and global design (e.g. modification of the layout of certain lines to limit harmful local thermo-hydraulic phenomena);
- significant improvements in the design of habitually sensitive components, e.g. replacement of screwed vessel internals baffle assembly with a heavy one, with no bolts and no weld;
- optimisation of vessel and vessel internal geometry to achieve a very low neutron fluence after 60 years of service life, i.e. about 2×10^{19} to 2.5×10^{19} n/cm^2 ($E < 1$ MeV), or even significantly less, depending on the method of fuel management selected.

• Regulatory requirements:

- limitation of the number of welds by using single cast forgings;
- limitation of the use of cobalt, in accordance with radiation protection requirements, which has been incorporated in all materials specifications.

• Operational streamlining:

- maintenance optimisation (e.g. simplified adjustment of the gap between components and their end stops);
- optimisation of in-service-inspections (e.g. limitation of the number of welds and improved access to the remaining welds for inspection);
- easier replacement of components (e.g. flanged connections for Control Rod Drive Mechanisms and for pressuriser heaters).

A detailed body of knowledge regarding the potential service life of operating reactor components was developed in full compliance with safety regulations by pooling our reactor design expertise with the experience accumulated by operators. This body of knowledge was used extensively to design the EPR reactor. ■

VENUES & WEBSITE

UPCOMING EVENTS

➤ *23-27 April 2007, Aix-en-Provence, France*
The Challenges faced by Technical and Scientific Support Organizations in Enhancing Nuclear Safety
International Conference organised by the IAEA

➤ *28 May-1 June 2007, St. Petersburg, Russia*
Nuclear Criticality Safety (ICNC 2007)
International Conference co-sponsored by the American Nuclear Society

➤ *18-21 June 2007, Vienna, Austria*
Knowledge Management in Nuclear Facilities
International Conference organised by the IAEA

➤ *30-31 October 2007, Daejon, Republic of Korea*
Advanced Safety Assessment Methods for Nuclear Reactors
Co-sponsored by the American Nuclear Society

EXPERIENCE FEEDBACK ON THE WEB

➤ The Safety Knowledge-base for Ageing and Long Term Operation of Nuclear Power Plants (SKALTO)
The IAEA has established an international working group on lifetime management of NPPs named SKALTO and conducted a series of IAEA-co-ordinated research projects as well as created a worldwide database to store the results from reactor pressure vessel surveillance programmes.
The Safety Knowledge-base for Ageing and Long Term Operation of Nuclear Power Plants (SKALTO) aims to develop a framework for sharing information on ageing management and long term operation of nuclear power plants. It provides important published documents and information related to these thematic areas created by the IAEA and other national or international organisations.
http://www-ns.iaea.org/tech-areas/engineering-safety/skalto/pubs-rpv.htm

The EUROSAFE Tribune #11
will contain reports about the lectures and discussions of the 2006 Paris EUROSAFE Forum

The EUROSAFE Forum 2007
will take place in Berlin on 5 & 6 November at Maritim proArte Hotel Berlin

The corresponding debates and seminars will be reported in the EUROSAFE Tribune #13

EUROSAFE Tribune is a periodical from the EUROSAFE Forum. Editorial Committee: Jean-Bernard Chérié, IRSN – Benoît De Boeck, AVN – Ulrich Erven, GRS – Seppo Vuori, VTT – Peter Storey, HSE – Gustaf Löwenhielm, SKI – Antonio Munuera Bassols, CSN. Coordination: Horst May, GRS – Emmanuelle Mur, IRSN. Credits: Thomas Gogny/IRSN, Corbis, Médiathèque EDF, MPA, DR. Writer: Jean-Christophe Hédouin. Production: Euro Rscg C&O. ISSN: 1634-7676. Legal deposit: March 2007.

The EUROSAFE Tribune will be available on the website www.eurosafe-forum.org

INSTITUT DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE (IRSN)
B.P.17
F-92262 FONTENAY-AUX-ROSES
CEDEX

GESELLSCHAFT FÜR ANLAGEN-
UND REAKTORSICHERHEIT (GRS) mbH,
SCHWERTNERGASSE 1
D-50667 KÖLN

FOR FURTHER INFORMATION:
www.eurosafe-forum.org

E U R O S A F E

GRS IRSN

Towards Convergence of
Technical Nuclear Safety Practices in Europe