Ageing management

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Ageing management is generally defined in a broad sense covering not only ageing management of "hardware" (structures, systems and components), but also management issues such as keeping up with developments in state-of-the-art technology and the latest management practices. The importance assigned to "traditional" ageing management, in terms of issues related to hardware degradation problems, is clearly very high. The other aspects, for example developments in engineering or management, are considered important as well, but are less emphasized.

Plant ageing management is composed of the following necessary elements, which are all linked together:

- understanding and knowledge of ageing-related damage mechanisms, including benchmarking of the consequences of damage mechanisms into macroscopic behaviour of materials and structures under applicable conditions;
- predictive models to extrapolate behaviour of systems, structures or components up to a defined time;
- qualified methods for detection and surveillance of ageing degradation;
- qualified mitigation, repair and replacements measures;
- reliable plant documentation, including optimisation of the ageing management programme based on current understanding and knowledge and periodic self-assessment;
- availability of a technical service and knowledge base.

The subject of plant ageing management has gained increasing attention over the past years, notably as more nuclear power plants across the world are being considered for lifetime extension. In this context, the NEA has conducted numerous technical studies to assess the impact of ageing mechanisms on safe and reliable plant operation. International research activities have also been initiated or are under way to provide the technical basis for decision making.

This article provides an overview of some of the activities and accomplishments of the NEA Committee on the Safety of Nuclear Installations (CSNI) Working Group on the Integrity and Ageing of Components and Structures (IAGE), the OECD/NEA Piping Failure Data Exchange (OPDE) Project and the OECD/NEA Stress Corrosion Cracking and Cable Ageing Project (SCAP).

NEA regular activities on ageing mechanisms

The focus of the IAGE activities has been on improving knowledge and understanding of ageing mechanisms, assessing material properties, operating conditions and environmental effects, potential degradation locations and the consequence of degradations and failures. Activities have also been devoted to the inspection, monitoring and assessment portion of ageing management programmes as well as assessing mitigation, repair and replacement measures.

Due to the expertise required for addressing integrity and ageing issues of different components, the IAGE is supported by three subgroups dealing with the integrity and ageing of metallic

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components, the integrity and ageing of concrete structures and the seismic behaviour of components and structures.

Thermal cycling is a widespread and recurring problem in nuclear power plants worldwide. Several incidents with leakage of primary coolant water inside the containment has challenged the integrity of nuclear power plants, although no release outside the containment has occurred. Thermal cycling is a complex phenomenon that involves thermal-hydraulics, fracture mechanics, materials and plant operation. The IAGE undertook a programme of work on thermal cycling to provide information to NEA member countries on operating experience, regulatory policies, countermeasures in place, and the current status of research and development, as well as to identify areas where research is needed both at the national and international levels.

The programme included:

- A review of operating experience, regulatory frameworks, countermeasures and current research; the results were documented in NEA/CSNI/R(2005)8.
- A benchmark to assess calculation capabilities in NEA member countries for crack initiation and propagation under a cyclic thermal loading, and ultimately to develop screening criteria to identify susceptible components; the results of the benchmark were issued in NEA/CSNI/R(2005)2.
- The organisation of a series of international conferences on fatigue of reactor components, which review progress in the area and provide a forum for discussion and exchange of information between high-level experts; the conferences are held every two years to monitor progress and to focus research on key aspects.

In addition, the IAGE is about to start a new activity intended to assess fatigue data transferability from standard specimens to structures and components, including environmental effects. Objectives are to confirm code practices for analysing fatigue of components, to propose a synthesis of existing fatigue tests performed on components and structures and to select a set of reference tests to verify proposed regulations in different countries.

There have been several instances of primary water stress corrosion cracking in nickel-based alloys and weldments. Recent examples include cracking at safe ends of primary loop piping and in reactor vessel head penetrations. While considerable research has been ongoing for steam generator tubing, there is an incomplete understanding of susceptibility of the thick sections. This is needed for alloys used in the existing components as well as alloys used for the replacements. The NEA has generated considerable information on events related to stress corrosion cracking, including comparisons between operating experience, inspection practices and acceptance criteria applied in different countries [NEA/CSNI/R(2006)8], as well as piping failures through the OPDE Project, and SCC component failures through the SCAP Project, which is consolidating the acquired knowledge and experience into commendable practices.

The effect of radiation on the reactor pressure vessel material resulting in embrittlement has been the subject of various CSNI activities, due to its potential to reduce the safety margins in the event of pressurised thermal shock. Pressurised thermal shock is still a relevant issue for lifetime extension, and its analysis requires a large amount of data as well as consideration of their uncertainties (transients, material properties and flaw distribution). As the deterministic approach is too conservative, probabilistic methodologies are used or under development in many countries.

NEA project on piping failure

Structural integrity of piping systems is important for plant safety and operability. In recognition of this, regulatory authorities of 11 countries decided to collect information on degradation and failure of piping components and systems. The OECD/NEA Piping Failure Data Exchange (OPDE) Project, established in 2002, provides systematic feedback in such areas as reactor regulation and research and development programmes associated with non-destructive examination (NDE) technology, in-service inspection (ISI) programmes, leak-before-break evaluations, risk-informed ISI and probabilistic safety assessment (PSA) applications involving passive component reliability.

The OPDE project addresses typical metallic piping components of the primary coolant system, main process and standby safety systems, as well as support systems (i.e., ASME Code Classes 1, 2 and 3, or equivalent). It also covers non-safety-related (non-Code) piping, which if leaking could lead to common-cause initiating events such as flooding of vital plant areas. The types of degradation or failure include service-induced, inside-diameter pipe wall thinning and non-through-wall cracking as well as pressure boundary breaches such as pinhole leaks, leaks, severance and major structural failures (pipe breaks or ruptures). In other words, the OPDE database covers degradation and failure

Overview of the OPDE database content

Degradation/damage mechanism	Number of database records by failure type		
	Non-through-wall crack/wall thinning	Active leakage	Structural failure
Corrosion (including crevice corrosion, pitting, galvanic corrosion, microbiologically-induced corrosion)	45	272	5
Design, construction and fabrication errors	79	239	9
Erosion-corrosion and flow-accelerated corrosion	190	327	50
Stress corrosion cracking (including ECSCC, IGSCC, PWSCC, TGSCC)	837	273	0
Thermal fatigue (including thermal stratification, cycling and striping)	62	63	3
Vibration fatigue	60	810	48
Other [including erosion-cavitation, fretting, severe overloading/water hammer, strain-induced corrosion cracking (SICC), classification pending]	48	147	44
Total	**1 321**	**2 131**	**159**

of high-energy and moderate-energy piping as well as safety-related and non-safety-related piping.

As of June 2009, the OPDE database included approximately 3 600 records on pipe failure data from 321 nuclear power plants representing 8 300 reactor-years of commercial operation. Roughly half of the records relate to PWRs, 44% to BWRs and 4% to PHWRs. The table above presents an overview of the OPDE database content.

NEA project on stress corrosion cracking and cable ageing

The OECD/NEA SCAP project began in 2006 and is being financed by a Japanese voluntary contribution. The project, to be completed in 2010, will establish a complete database and a knowledge base for stress corrosion cracking (SCC) and cable ageing, and to perform an assessment of the data to identify the basis for commendable practices which would help regulators and operators enhance ageing management.

The SCAP SCC database addresses degradation or failure of passive components attributed to SCC, occurring at nuclear power plants in participating countries. The scope of the database includes ASME Class 1 and Class 2 pressure boundary components, reactor pressure vessel internals and other components with significant operational impact, excluding steam generator tubing. The following mechanisms are considered: inter-granular SCC in austenitic stainless steel and nickel-based material, irradiated-assisted SCC, primary water SCC, external chloride SCC and transgranular SCC.

The SCAP cable database covers safety-related cables (including those supporting emergency core cooling), cables important to safety (cables that are needed to prevent and mitigate design basis events) and cables important to plant operation (cables whose failure could cause a plant trip or reduction in plant power). The scope of the database includes cables with voltage levels up to 15 kV AC and 500 V DC, including instrumentation and control (I&C) cables. The cable database will assist regulatory authorities, plant owners, operators and designers in their decisions on suitable cable choices for mild and harsh environments and in their assessments of existing cable performance.

The SCAP project has established the database performance requirements, data format and coding guidelines and is currently focusing on populating the database and assessing the data collected. The database, together with the knowledge base and the commendable practices to be developed, will provide a tool for assisting member countries in developing suitable ageing management programmes. The final project report will be issued in 2010 and will describe the technical basis for commendable practices in support of regulatory activities in the fields of SCC and cable insulation. A final workshop will be held in May 2010 to present and to discuss the results of the project.

Additional aspects of ageing management

Over the past few decades, the nuclear industry has experienced service degradation of many components, both in the primary and secondary coolant systems. This degradation and the related inspections, together with economic and political factors, have consequently created pressure for more efficient and cost-effective, in-service inspection programmes to ensure that there are adequate safety margins so that anticipated degradation of components does not lead to failures that result in accidents or even unplanned shutdowns with adverse effects on power production reliability. In this context, nuclear regulators and utilities in many countries have developed and implemented risk-informed inspection approaches together with more stringent requirements for demonstrating the performance of the non-destructive testing (NDT) systems that are being used for inspecting safety-related components which are susceptible to different kinds of degradation mechanisms.

The IAGE collected and compiled risk-informed ISI practices and status in NEA member countries through a questionnaire, and the results were documented in NEA/CSNI/R(2005)3. To complete the technical information, a CSNI workshop was held in Stockholm, Sweden. Papers presented at the workshop were issued in the proceedings under reference NEA/CSNI/R(2004)9. Based on the information collected, a Status Report on Developments and Co-operation on Risk-Informed In-Service Inspection and Non-destructive Testing (NDT) Qualification in OECD/NEA Member Countries was issued under reference NEA/CSNI/R(2005)9.

In order to guarantee structural integrity, ageing management is also important for all concrete structures fulfilling a nuclear safety function. Consequently, various national and international programmes have investigated ageing effects and potential failure mechanisms in order to improve understanding of the mechanisms involved.

A programme of workshops run under CSNI auspices has directly addressed the concerns of designers, operators and regulatory bodies with regard to the performance of nuclear facilities' concrete structures. The workshops have allowed the exchange of information and good practice among individual plants, and national and international programmes, and have informed decision making in other international bodies such as the IAEA and the EC. The workshop topics included pre-stress loss [NEA/CSNI/R(97)9], non-destructive examination in concrete [NEA/CSNI/R(97)28], finite element analysis of degraded concrete structures [NEA/CSNI/R(99)1], instrumentation [NEA/CSNI/R(2000)15] and monitoring and repair [NEA/CSNI/R(2002)7].

In 2008, the IAGE sponsored a Workshop on Ageing Management of Thick-walled Concrete Structures, including ISI, Maintenance and Repair, Instrumentation Methods and Safety Assessment in View of Long-term Operation. The objective of this workshop was to present and to discuss state-of-the-art techniques for the integrity assessment of concrete structures, and to recommend areas in which further research was warranted. Special emphasis was given to performance-based in-service inspection based on non-destructive examination methods (such as impact echo, ultrasound and high frequency radar) and instrumentation. Limits of applicability were extensively discussed. Ageing management programmes based on suitable structural monitoring was also addressed in the framework of safety assessments of the installations for long-term operation. Probabilistic methods used for reliability structural assessments were also discussed in terms of consistently managing integrity assessments of civil structures.

Finally, the IAGE seismic sub-group has been involved in many activities aimed at assessing the seismic safety of nuclear power plants. In 2008, the seismic sub-group published a report summarising the conclusions and recommendations of the workshops on engineering characterisation of seismic input, the relation between seismological data and seismic engineering, and on seismic input motions incorporating recent geological studies. The IAGE seismic sub-group also conducted a specialist meeting on seismic hazard assessment and is currently addressing assessments of seismic impact on degraded metal components. In this context, it is discussing the worldwide implications for nuclear facilities of the 16 July 2007 Niigata-ken Chuestu-oki earthquake and its effects on the Kashiwazaki-Kariwa nuclear power station. ■