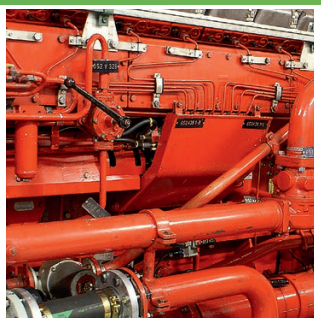
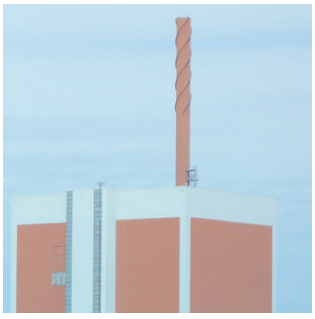
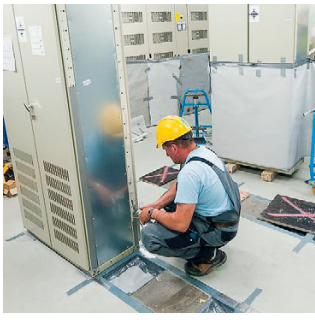
Resources for Plant Life Management in Nuclear Power Plants









IAEA

60 Years

Atoms for Peace and Development

PERSPECTIVES

Plant Life Management in Nuclear Power Plants

We have seen significant changes in the electricity market and electrical power industry in the past few years. These led many Member States to look at nuclear power as a possible source to address energy security, climate change and development issues.

As we look towards the future, we need evolutionary and innovative nuclear power technologies. But at the same time, we need a safe bridge between the current fleet and the future systems. Over 60% of the approximately 450 operational reactors are over 30 years of age. Taking measures to optimize their life cycle will become a growing issue in the coming years. Depending on the market situation, some Member States have given a high priority to extend the designed lifetime of their reactors from 40 years to 60 or 80 years.

The safe, economical and long term operation of nuclear power plants (NPPs) must address both physical and non-physical ageing issues. Well established workforce planning for the planned lifetime of a plant is key to ensuring that experience and knowledge is available and up-to-date. Information transfer to the authorities, equipment manufacturers, suppliers and contractors is also crucial to support long term operation of NPPs.

Recognizing the importance of this issue and in response to requests from Member States, the IAEA has been supporting operating countries. We disseminate operational experience and good practices in technology, management and human resources to help both newcomer and expanding countries. We help share new or advanced models, tools and processes for efficient construction and operation. We have expanded activities to analyse economic challenges and cost drivers, to identify optimized approaches.

The IAEA will continue to support its Member States in the safe, secure and sustainable operation of nuclear power plants.

Mikhail Chudakov
Deputy Director General
Head of the Department of
Nuclear Energy, IAEA

Juan Carlos Lentijo
Deputy Director General
Head of the Department of
Nuclear Safety and Security, IAEA

CURRENT STATUS OF NUCLEAR POWER

As of October 2017, 448 nuclear power reactors were operating worldwide, with a total installed capacity of 391 GW(e). The nuclear industry is still concentrated in Europe, North America and Asia (Figure 1). There is one operational unit in long-term shutdown. Fifty-seven reactors are under construction with a total capacity of 57.9 GW(e), 19 of them being built in China.

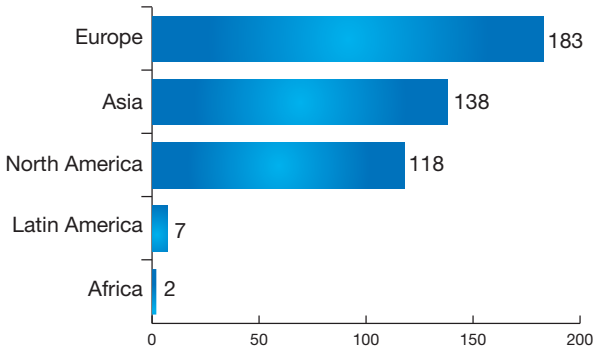


Fig. 1. Number of reactors by region (Source: IAEA PRIS database).

The Energy Availability Factor (EAF) has increased continuously by an average ~1% per annum in the 1990s and early 2000s, reaching 84% in 2002 (Figure 2). It has decreased over the last 14 years, reaching the 1991 levels in 2016.

Figures 3(a) and 3(b) compare the energy availability factors of all reactors and best performers between 2010 and 2015. The majority (90%) of NPPs can improve their energy availability factor in the future to achieve the same levels of best performers (10%). These results can be achieved by improving outage planning, execution and maintenance policy.

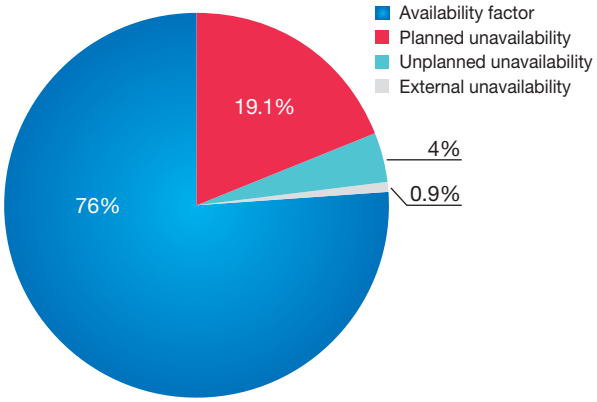


Fig. 3(a). Energy availability factor: all reactors between 2010 and 2015.

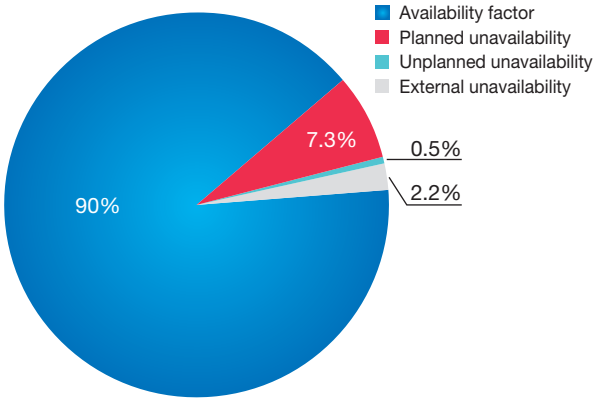


Fig. 3(b). Energy availability factor: best performers between 2010 and 2015.

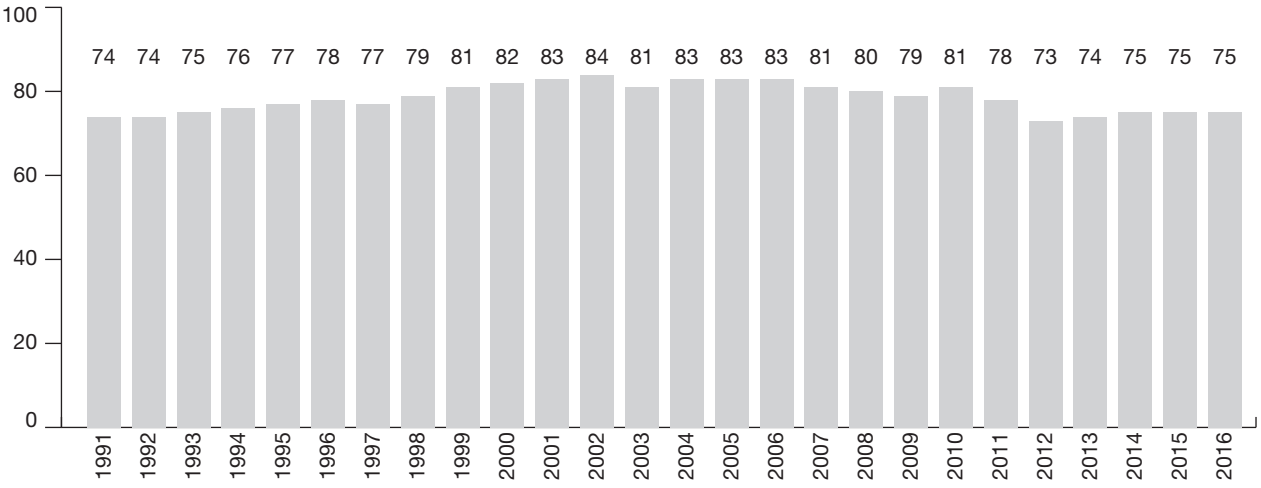


Fig. 2. Energy availability factor: trend.

RESOURCES

The IAEA supports Member States in Plant Life Management, or PLiM, programmes for nuclear power plants through technical publications, coordinated research programmes, peer review missions, the PRIS database, and major conferences and technical meetings. This brochure summarizes IAEA publications that address different technical and safety aspects of PLiM. The publications can be downloaded from the IAEA website at https://www.iaea.org/publications.

Plant Life Management Models for Long Term Operation of Nuclear Power Plants

IAEA Nuclear Energy Series No. NP-T-3.18

Plant life management integrates ageing management and economic planning to optimize NPP investment. The aim is to maintain a high level of safety, commercial profitability and competitiveness, all while providing a reliable supply of electric power.

Long term operation (LTO) of an NPP is defined as operation beyond an established time frame set forth by safety assessment. Consideration is given to life limiting processes and features of systems, structures and components. The report showcases life management models of 10 Member States to help others build the most appropriate model for their needs. This publication:

- describes and discusses the three approaches to PLiM for LTO used by the Member States;
- compares differences, and highlights equivalencies between periodic safety review and licensing renewal approaches;
- highlights pitfalls, and draws conclusions and recommendations based on the long term operation experience from Member States.

Requirements for a successful LTO process are:

- demonstrating a good understanding of the plant condition;
- the capability to operate safely after extended lifetime (after designed lifetime).
- Critical SSCs are effectively managed, so that all required safety functions can be maintained through the LTO period.

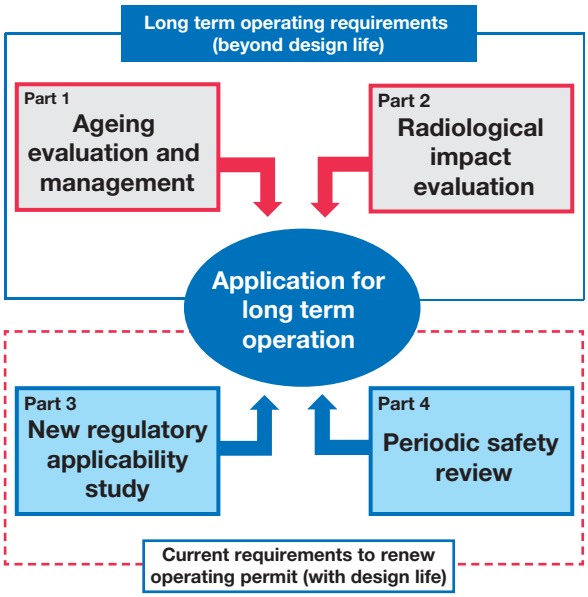


Fig. 4. Authorization requirements for long term operation.

Available at:
http://www-pub.iaea.org/books/IAEABooks/10520/Plant-Life-Management-Models-for-Long-Term-Operation-of-Nuclear-Power-Plants

Periodic Safety Review for Nuclear Power Plants

IAEA Safety Standards Series No. SSG-25

This Safety Guide deals with the periodic safety review (PSR) for an operating NPP. PSR is a comprehensive safety review of all important aspects of safety, carried out at regular intervals, typically every 10 years. A PSR may also be used in support of the decision making process for licence renewal or long term operation, or for restart of a nuclear power plant following a prolonged shutdown.

The Guide recommends 14 safety factors, which are based on international experience and are intended

to cover all aspects important to the safety of operating NPPs:

1. Plant design
2. Actual conditions of structures, systems and components (SSCs) important to safety
3. Equipment qualification
4. Ageing
5. Deterministic safety analysis
6. Probabilistic safety assessment
7. Hazard analysis
8. Safety performance
9. Use of experience from other plants and research findings
10. Organization, the management system and safety culture
11. Procedures
12. Human factors
13. Emergency planning
14. Radiological impact on the environment.

PSR provides an effective way to obtain an overall view of actual plant safety and the quality of the safety documentation, and to determine reasonable and practical modifications to ensure or improve safety.

Based on international experience, it is reasonable to perform PSR about ten years after the start of plant operation, and then every ten years until end of operation. Ten year intervals are considered appropriate for such reviews in the view of likely changes in:

- National and international safety standards;
- Cumulative effects of plant modifications;
- Identification of ageing effects;
- Accumulation of operating experiences;
- Changes in plant operation;
- Changes in natural, industrial or demographic environments;
- Generational changes in staff;
- Changes in management structures and procedures.

IAEA Operational Safety Review Team (OSART) Mission, Smolensk NPP, Russian Federation (Photo: IAEA).

Available at:
http://www-pub.iaea.org/books/IAEABooks/8911/Periodic-Safety-Review-for-Nuclear-Power-Plants

Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL)

Safety Report Series No. 82

In 2009, the IAEA conducted a Technical Meeting where Member States recommended establishing an international platform for discussion between regulators and utilities regarding implementation of acceptable ageing management programmes (AMPs). The recommendations were to:

- develop and maintain a document to serve as a practical guide for implementing, maintaining and improving AMPs, made up of best practices and universal knowledge on proven AMPs for safety related SSCs;
- establish a common basis for discussion between regulators and utilities with regard to implementation of acceptable AMPs.

In response, the IAEA initiated in 2009 the Extra-budgetary Programme (EBP) on International Generic Ageing Lessons Learned (IGALL) for Nuclear Power Plants.

This Safety Report was published as result of the IGALL Programme Phase 1 (2010-2013). The publication provides a technical basis and practical guidance on managing ageing of mechanical, electrical and instrumentation and control (I&C) components and civil structures of NPPs important

to safety to support the application of the Specific Safety Requirements on design, commissioning and operation, the Safety Guides on Ageing Management and LTO and on Periodic Safety Review.

The publication contains for SSCs important to safety:

- A generic sample of ageing management review (AMR) tables;
- A collection of proven AMPs;
- A collection of typical time limited ageing analyses (TLAAs).

Phase 2 (2014-2015) and Phase 3 (2016-2017) of the IGALL Programme were aimed at:

1. Providing a forum for exchanging experiences, while supporting Member States in applying IGALL as a tool to address ageing management and safe LTO;
2. Enhancing the completeness and quality of IGALL;
3. Preparing the IGALL Safety Report, version 2018.

The IGALL Safety Report is supported by the IGALL database which contains 84 AMPs, 28 TLAAs, technological obsolescence programme and more than 2000 consolidated line items in AMR tables. The IGALL database is updated twice per five years.

All IGALL deliverables described above can be found on the IAEA web site: http://gnssn.iaea.org/NSNI/PoS/IGALL/SitePages/Home.aspx

Available at:
http://www-pub.iaea.org/books/IAEABooks/10665/Ageing-Management-for-Nuclear-Power-Plants-International-Generic-Ageing-Lessons-Learned-IGALL

Ling Ao NPP, China (Photo: IAEA).

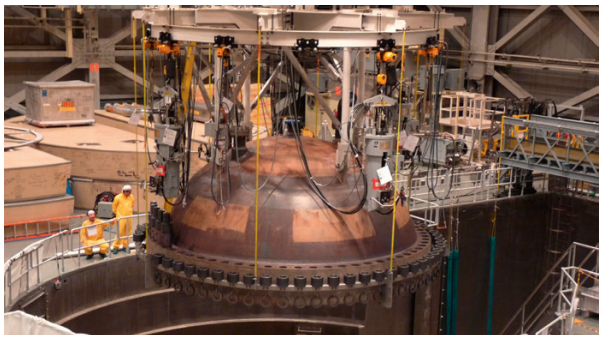
Approaches to Ageing Management for Nuclear Power Plants

International Generic Ageing Lessons Learned (IGALL) Final report

IAEA TECDOC No. 1736

As a result of the IGALL Programme Phase 1, this TECDOC provides an overview of the approaches to ageing management in participating Member States, covering:

- National regulatory requirements for ageing management and LTO;
- Management of physical ageing;
- Management of obsolescence;
- Scoping and screening of structures, systems and components for aging management and LTO (passive and active components, long term and short term components);
- Ageing management review for LTO;
- Review of ageing management programmes for LTO;
- Revalidation of typical time limited ageing analyses for LTO.



Reactor Vessel Head, Laguna Verde Nuclear Power Station, Mexico (Photo: IAEA).

Available at:
http://www-pub.iaea.org/books/IAEABooks/10672/Approaches-to-Ageing-Management-for-Nuclear-Power-Plants

SALTO Peer Review Guidelines: Guidelines for Peer Review of Safety Aspects of Long Term Operation of Nuclear Power Plants

IAEA Services Series No. 26

Recognizing the need to assist Member States in dealing with the unique challenges associated with

LTO, the IAEA developed a Safety Aspects of Long Term Operation (SALTO) peer review service.

The SALTO service is a comprehensive safety review directly addressing strategy and key elements for safe LTO of NPPs, which complements OSART reviews. The evaluation of programmes and performance is made on the basis of IAEA safety standards and other IAEA publications, and of the combined expertise of the international review team. The review is a technical exchange of experiences and practices at the working level aimed at strengthening the programmes, procedures and practices implemented at the plant.

The key objectives of the SALTO peer review are to provide:

- The host organization with an objective assessment of the status of the preparedness for LTO with respect to international nuclear safety standards, and with recommendations and suggestions for improvement in areas where performance falls short of international best practices;
- Key staff at the host organization with an opportunity to discuss their practices with experts who have experience with related practices in the same field;
- Member States with information regarding good practices identified in the course of the review;
- Reviewers and observers from Member States and the IAEA staff with opportunities to broaden their experience and knowledge of their own field.

This document provides a basic structure and common reference across the various areas covered by a SALTO peer review. As such, they are addressed principally to SALTO peer review teams, but they also provide guidance to operating organizations for preparation for a SALTO peer review.

SALTO missions highlights 2005–2015

The SALTO service is available to all Member States with NPPs considering long term operation. By mid-2015, 22 SALTO peer review missions (including eight pilot missions) have been conducted at 13 NPPs in 12 Member States. A further six follow-up missions reviewed the implementation of previous SALTO results. For two plants, the LTO module was included in the OSART mission including the SALTO follow-up missions in this period.

SALTO peer review mission, Qinshan NPP, China (Photo: IAEA).

This report summarizes SALTO mission results so that all the aspects of these missions are gathered in one publication.

Available at:
http://www-pub.iaea.org/books/IAEABooks/10673/SALTO-Peer-Review-Guidelines

Ageing Management of Concrete Structures in Nuclear Power Plants

IAEA Nuclear Energy Series No. NP-T-3.5

Concrete ageing, due to irreplaceable items, is one of the most important issues in plant life management for long term operation.

Experience shows that ageing degradation of a concrete structure, often caused or accelerated by factors such as faulty design, use of unsuitable or poor quality materials, improper construction, exposure to aggressive environments, excessive structural loads and accident conditions, can impair the safety functions of concrete structures and can increase risk to public health and safety.

Effective ageing management of a concrete containment building and other concrete structures is required to ensure their fitness for service throughout operation and during decommissioning.

This publication details the five components of ageing management for concrete structures:

1. Understanding the structure and/or component that is ageing.
2. Development and optimization of activities for ageing management.
3. Operation of the NPP within design limits to minimize age related degradation.

4. Inspection, monitoring and assessment to detect and characterize significant component degradation before fitness for service are compromised.
5. Maintenance to manage ageing effects.

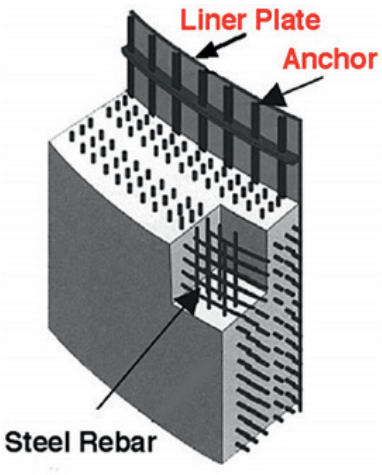


Fig. 5. Metallic liner plate adjacent to reinforced concrete.

Available at:
http://www-pub.iaea.org/books/IAEABooks/10659/Ageing-Management-of-Concrete-Structures-in-Nuclear-Power-Plants

Procurement Engineering and Supply Chain Guidelines in Support of Operation and Maintenance of Nuclear Facilities

IAEA Nuclear Energy Series No. NP-T-3.21

In recent years, nuclear facilities have been impacted by significant procurement related events and concerns. There is an increasing need for nuclear facility procurement organizations to address obsolescence and component ageing issues. This has led to new actions by facility operators and regulators.

Procurement for nuclear facilities plays a key role in nuclear safety. Beyond ensuring that the required parts are available when needed for operation and maintenance activities, the procurement function helps to ensure that the correct equipment and components are installed in the correct locations in the plant, to maintain proper configuration management and safety functions.

This publication provides an overview of nuclear equipment procurement processes and issues of special concern, as well as guidance for good practices to set up and manage a high-quality procurement organization. Lessons learned for organizations considering new nuclear power plant projects are also included.

Available at:
http://www-pub.iaea.org/books/IAEABooks/10865/Procurement-Engineering-and-Supply-Chain-Guidelines-in-Support-of-Operation-and-Maintenance-of-Nuclear-Facilities

IAEA Nuclear Contracting Toolkit

A related nuclear contracting toolkit is intended to support all levels of procurement activities related to a major nuclear power project, and to help manage the expectations of stakeholders, customers and suppliers alike.

The Nuclear Contracting Toolkit is freely available on the IAEA web site: https://www.iaea.org/NuclearPower/Infrastructure/NuclearContractingToolkit/index.html

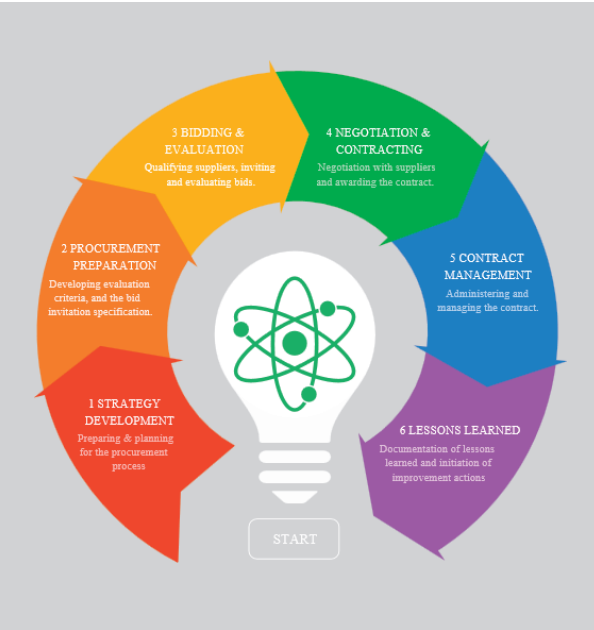


Fig. 6. The IAEA nuclear contracting process

Nuclear Power Plant Outage Optimization Strategy

IAEA TECDOC No. 1806

and

Maintenance Optimization Programme for Nuclear Power Plants

IAEA Nuclear Energy Series No. NP-T-3.8, (forthcoming)

The goal of maintenance at a nuclear power plant is ensure that nuclear operators have the use of all systems necessary for safe and reliable power production and are able to keep these systems available and reliable. Traditionally, most maintenance activities are performed during refuelling and maintenance outages, which already require a great deal of attention and planning as they are the main cause of NPP unavailability and a large portion of the operational and maintenance costs.

In recent years, there have been significant changes in the electricity production industry and the electricity market itself. This has prompted plant managers to manage NPPs more effectively to optimize the operational and maintenance costs and increase availability.

Outage management is a very complex task, involving many aspects of plant policy. These include the coordination of available resources, plant safety, the regulatory body, technical requirements and all activities and work before and during an outage.

The duration and costs of an outage should be optimized to achieve the best possible result, without compromising personal, operational, or environmental safety. The best possible result is in an overall reduction in the cost of electricity generation over the life, or the remaining life, of the plant. This requires balancing the best possible capacity factor against the cost required to achieve an optimal level of performance given the expected payback period for investments. Optimization of outages is a continuous process. It is driven by corporate and plant goals as well as regulatory requirements.

Maintenance and outage optimization are key factors for good, safe and economic power plant performance. Maintenance optimization is vital to asset management.

Both IAEA documents will provide practical suggestions and ideas on how to increase equipment reliability and optimize outage duration, including how to implement these strategies.

Fig.7. Continuous improvement in maintenance and outage optimization process.

IAEA TECDOC No. 1806 is available at: http://www-pub.iaea.org/books/iaeabooks/11099/Nuclear-Power-Plant-Outage-Optimization-Strategy

Preparing and Conducting Review Missions of Instrumentation and Control Systems in Nuclear Power Plants

IAEA TECDOC No. 1662/Rev. 1

The instrumentation and control (I&C) system, together with plant operators, serve as the 'central nervous system' of an NPP. It senses basic physical parameters, monitors performance, integrates information and makes automatic adjustments to plant operations as necessary.

It also responds to failures and abnormal events, ensuring efficient and safe power production. Hence, the design, testing, operation, maintenance, licensing and modernization of I&C systems are crucial for safety and performance. The IAEA offers an Independent Engineering Review of Instrumentation and Control Systems (IERICS) service to assist Member States in improving

the design, implementation and operation of I&C systems.

IERICS is conducted by a team of international experts from complementary technical areas. It is applicable at any stage of the life cycle of an NPP's I&C systems. IERICS consists of peer reviews of I&C design documents, implementation processes, prototype and actual I&C systems already deployed in operating NPPs. Nuclear utilities, regulators, technical support organizations, research laboratories and universities can benefit from the detailed technical assessments of I&C systems and the recommended improvements that IERICS missions provide.

This TECDOC provides the guidelines and common references as well as the various areas that can be covered by such a mission.

IERICS Mission to China, April 2016 (Photo: IAEA).

Available at:
http://www-pub.iaea.org/books/IAEABooks/11071/Preparing-and-Conducting-Review-Missions-of-Instrumentation-and-Control-Systems-in-Nuclear-Power-Plants

Benchmark Analysis for Condition Monitoring Test Techniques of Aged Low Voltage Cables in Nuclear Power Plants

IAEA TECDOC No. 1825

An IAEA Coordinated Research Project (CRP) on benchmark analysis for condition monitoring techniques of aged low voltage cables in nuclear power plants was conducted from 2012 to 2015, with the goal of providing guidelines for monitoring the performance of insulation and jacket materials of existing cables and establishing a programme of cable degradation monitoring. The CRP involved eleven chief scientific investigators and 21 observers, together representing 17 Member States.

For the benchmark analysis, two types of cable samples donated by six manufacturers were aged in an irradiation cell or a thermal chamber, replicating thermal or radiation conditions in a nuclear power plant.

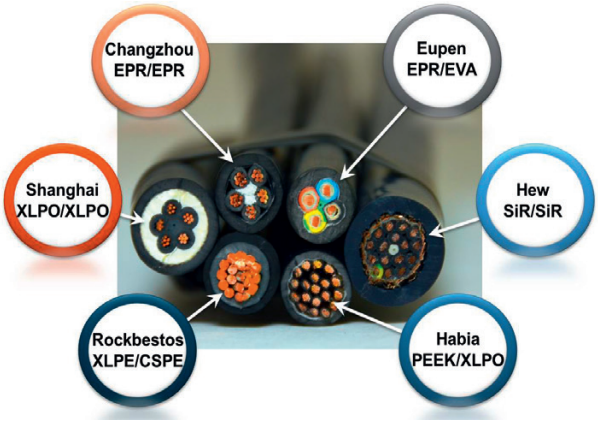


Fig. 8. Cable examples from different manufacturers.

Test results from before and after ageing were compared to identify suitable condition monitoring techniques and provide recommendations for their improvements. In particular, twelve types of cable insulations or jacket materials were tested using 14 different condition monitoring techniques.

As results of the benchmark analysis, the electrical cables in situ tests did not show great promise for cable degradation trending or ageing assessment, although these methods are known to be very effective for finding and locating faults in cable insulation material. Electrical methods such as insulation resistance and reflectometry techniques can be rather effective for locating insulation damage, hot spots or other faults in essentially all cable types. They have also the advantage that they can be used for in situ testing of installed cables while the nuclear power plant is in operation.

Available at:
http://www-pub.iaea.org/books/IAEABooks/11164/Benchmark-Analysis-for-Condition-Monitoring-Test-Techniques-of-Aged-Low-Voltage-Cables-in-Nuclear-Power-Plants

FORTHCOMING PUBLICATIONS

Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants

IAEA Safety Standards Series No. SSG-48

Ageing management is aimed at ensuring that the effects of ageing will not prevent structures, systems and components (SSCs) from being able to accomplish their required safety functions throughout the lifetime of an NPP (including its decommissioning). This requires addressing both the physical ageing effects of SSCs, resulting in degradation of their performance characteristics, and the non-physical ageing of SSCs, i.e. their becoming out of date in comparison with current knowledge, codes, standards and regulations, and technology.

This Safety Guide focuses on managing the physical ageing of SSCs within the scope of ageing management. It also provides recommendations on safety aspects of managing technological obsolescence and on the programme for safe long term operation of NPPs for ageing management related activities.

Providing guidance for operating organizations, the Safety Guide may also be used by regulatory bodies in preparing requirements, codes and standards, and in verifying effective ageing management in NPPs.

It revises and supersedes the Safety Guide on Ageing Management for Nuclear Power Plants (NS-G-2.12), issued in 2009. This revision takes into account developments in the ageing management of NPPs worldwide and expands the scope to include provisions for maintaining the safety of nuclear power plants during long term operation.

Buried and Underground Piping and Tank Ageing Management for Nuclear Power Plants

IAEA Nuclear Energy Series No. NP-T-3.20

Buried and underground piping systems associated with NPPs have a number of safety aspects. Their integrity ensures nuclear safety, equipment reliability and enviromental protection.

High density polyethylene liner being placed into host pipe (Photo: Swagnelining, UK).

A number of NPPs have experienced leakages of materials from underground structures that caused contamination of groundwater, although no risk to the public health and safety were identified.

Ageing degradation, such as corrosion, can lead to failures in plant infrastructure which are usually costly to repair. These are costly in terms of environmental damage and possibly in terms of human or enviromental safety.

The report introduces the generic ageing management programme as it relates to underground piping and tanks, describing underground piping and tank material, while providing an effective ageing management programme to follow:

- Understanding ageing;
- Developing and optimizing the ageing management programme;
- Inspection, monitoring and assessment;
- Maintenance and repair.

Non-Baseload Operations in Nuclear Power Plants

IAEA Nuclear Energy Series No. NP-T-3.23

For commercial, technical and regulatory reasons, most existing NPPs are optimized to operate at steady full power, known as baseload operation. This is generally considered the most efficient use of capital investment.

However, in some Member States, nuclear units are operated flexibly, while in several others, especially in those planning an NPP for the first time, there is an increasing need to operate them flexibly. Primary reasons for this are large nuclear generating capacity relative to total capacity, growth in renewable generation, and deregulation or structural changes of the electricity supply system and the electricity market.

This necessitates not only adopting technical and regulatory changes, but also operational, economic and financial rearrangements to maintain the efficiency of capital investment.

This report highlights that with growing emphasis on reducing global greenhouse gas emissions and on increasing the shares of both renewables and nuclear energy, electricity grids would benefit from increased flexibility.

Improvement of In-Service-Inspection Effectiveness in Nuclear Power Plants

IAEA TECDOC No. 1400/ Rev.1

During the operating life time of the NPP, its components will be exposed to multiple influences whose individual or combined effect cannot be fully predicted with an accuracy level desirable for nuclear safety. The most important affects are stress, temperature, irradiation, hydrogen absorption, corrosive attack, vibration and fretting, all of which depend upon time and operating history.

As part of the In-Service-Inspection (ISI), non-destructive examination (NDE) plays an important role in ensuring component integrity and avoiding failures and thus is a key tool in nuclear power plant safety and productivity over lifetime.

ISI is performed through destructive and non-destructive examinations to detect flaws and other degradations that may exist on the weld and base metal areas of a reactor pressure vessel (RPV), tubes and piping, heat exchangers, and other pressure vessels and components, key bolts and supports, which bear direct and indirect implications on the safety of the NPP. These inspections enable appropriate repair or replacement measures to support the safe and efficient operation and maintenance of NPPs.

The ISI effectiveness has a strong correlation with the structural integrity assessment, mitigation repair and replacement actions. Effective ISI is a substantial part of plant life management, which needs a reliable diagnosis of the condition of the components and a prediction of their future status.

Figure 9 shows the relation of ISI to total operating and maintenance cost. The cost of ISI increases with a broader scope of inspection.

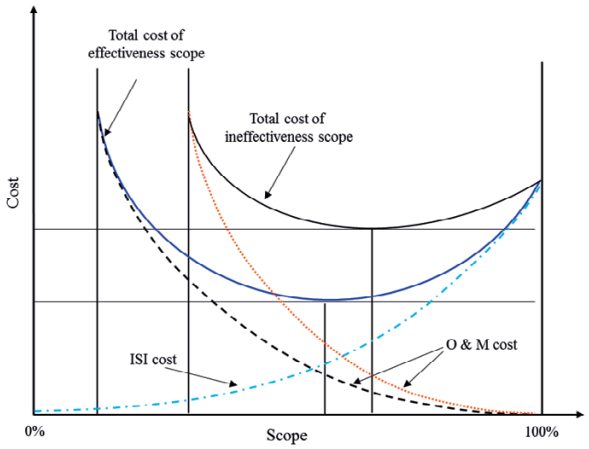


Fig. 9. Qualitative relation of ISI scope with cost.

This TECDOC is aimed at exchanging information to increase harmonization in the areas of ISI effectiveness, practices and codes and standards, for achieving a higher level of safety and reliability in NPPs operation. The publication presents a rationale for ISI, taking into account risk informed assessment methodology.

DATABASE

IAEA Power Reactor Information System (PRIS)

https://www.iaea.org/pris

The Power Reactor Information System (PRIS), developed and maintained by the IAEA for over four decades, is an up-to-date, comprehensive database of NPPs across the world. It contains information, provided to the IAEA via data providers nominated by Member States, on power reactors in operation, under construction, or that were shut down.

The database covers:

- Reactor specification data (status, location, operator, owner, suppliers, milestone dates) and technical design characteristics.
- Performance data including energy production and energy loss data, outage and operational event information.

Monthly production and power loss data have been recorded in PRIS since 1970 and are complemented by information on nuclear-power generated energy provided to non-electrical applications such as district heating, process heat supply or desalination. Information relating to the decommissioning process of shutdown units is also available.

PRIS facts and outputs:

- About 150 000 visits/year
- Global, country and reactor specific overview
- Over 30 types of statistical reports
- PRIS related publications
- PRIS related glossary.

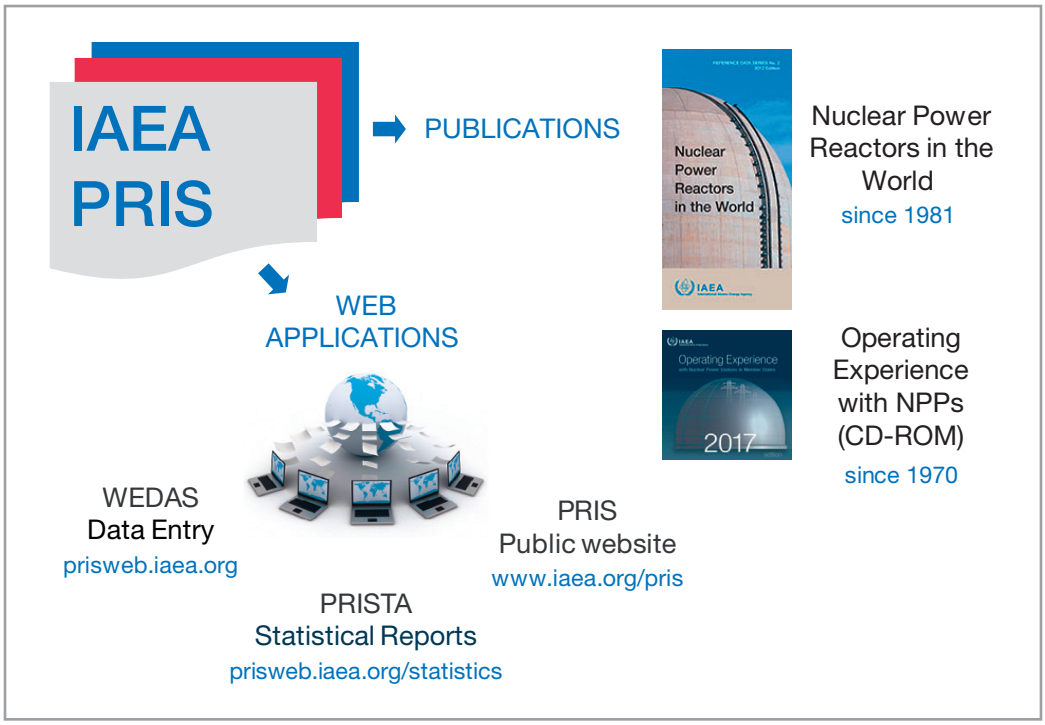
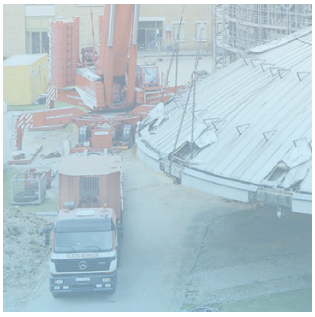


Fig. 10. PRIS Output.









Nuclear Power Engineering Section (NPES)
Department of Nuclear Energy

International Atomic Energy Agency
Vienna Internatioanl Centre, PO Box 100, 1040 Vienna, Austria
Telephone: +43 1 2600-0; Fax: +43 1 2600-7
www.iaea.org/ne
twitter.com/IAEANE

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