IAEA-TECDOC-1957

IAEA TECDOC SERIES

IAEA-TECDOC-1957

Ageing Management of Nuclear Power Plants during Delayed Construction Periods, Extended Shutdown and Permanent Shutdown Prior to Decommissioning

IAEA
International Atomic Energy Agency

IAEA SAFETY STANDARDS AND RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish or adopt standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards.

The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety. The publication categories in the series are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides**.

Information on the IAEA's safety standards programme is available on the IAEA Internet site

http://www-ns.iaea.org/standards/

The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at: Vienna International Centre, PO Box 100, 1400 Vienna, Austria.

All users of IAEA safety standards are invited to inform the IAEA of experience in their use (e.g. as a basis for national regulations, for safety reviews and for training courses) for the purpose of ensuring that they continue to meet users' needs. Information may be provided via the IAEA Internet site or by post, as above, or by email to Official.Mail@iaea.org.

RELATED PUBLICATIONS

The IAEA provides for the application of the standards and, under the terms of Articles III and VIII.C of its Statute, makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its Member States for this purpose.

Reports on safety in nuclear activities are issued as **Safety Reports**, which provide practical examples and detailed methods that can be used in support of the safety standards.

Other safety related IAEA publications are issued as **Emergency Preparedness and Response** publications, **Radiological Assessment Reports**, the International Nuclear Safety Group's **INSAG Reports**, **Technical Reports** and **TECDOCs**. The IAEA also issues reports on radiological accidents, training manuals and practical manuals, and other special safety related publications.

Security related publications are issued in the **IAEA Nuclear Security Series**.

The **IAEA Nuclear Energy Series** comprises informational publications to encourage and assist research on, and the development and practical application of, nuclear energy for peaceful purposes. It includes reports and guides on the status of and advances in technology, and on experience, good practices and practical examples in the areas of nuclear power, the nuclear fuel cycle, radioactive waste management and decommissioning.

AGEING MANAGEMENT OF NUCLEAR POWER PLANTS DURING DELAYED CONSTRUCTION PERIODS, EXTENDED SHUTDOWN AND PERMANENT SHUTDOWN PRIOR TO DECOMMISSIONING

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ANTIGUA AND BARBUDA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHAMAS
BAHRAIN
BANGLADESH
BARBADOS
BELARUS
BELGIUM
BELIZE
BENIN
BOLIVIA, PLURINATIONAL STATE OF
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BRUNEI DARUSSALAM
BULGARIA
BURKINA FASO
BURUNDI
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHAD
CHILE
CHINA
COLOMBIA
COMOROS
CONGO
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DJIBOUTI
DOMINICA
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ERITREA
ESTONIA
ESWATINI
ETHIOPIA
FIJI
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GRENADA
GUATEMALA
GUYANA
HAITI
HOLY SEE
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
KYRGYZSTAN
LAO PEOPLE'S DEMOCRATIC REPUBLIC
LATVIA
LEBANON
LESOTHO
LIBERIA
LIBYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITANIA
MAURITIUS
MEXICO
MONACO
MONGOLIA
MONTENEGRO
MOROCCO
MOZAMBIQUE
MYANMAR
NAMIBIA
NEPAL
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORTH MACEDONIA
NORWAY
OMAN
PAKISTAN
PALAU
PANAMA
PAPUA NEW GUINEA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
RWANDA
SAINT LUCIA
SAINT VINCENT AND THE GRENADINES
SAN MARINO
SAUDI ARABIA
SENEGAL
SERBIA
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
TOGO
TRINIDAD AND TOBAGO
TUNISIA
TURKEY
TURKMENISTAN
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VANUATU
VENEZUELA, BOLIVARIAN REPUBLIC OF
VIET NAM
YEMEN
ZAMBIA
ZIMBABWE

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA-TECDOC-1957

AGEING MANAGEMENT OF NUCLEAR POWER PLANTS DURING DELAYED CONSTRUCTION PERIODS, EXTENDED SHUTDOWN AND PERMANENT SHUTDOWN PRIOR TO DECOMMISSIONING

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2021

For further information on this publication, please contact:

Operational Safety Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
Email: Official.Mail@iaea.org

Printed by the IAEA in Austria
May 2021

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: Ageing management of nuclear power plants during delayed construction periods, extended shutdown and permanent shutdown prior to decommissioning / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2021. | Series: IAEA TECDOC series, ISSN 1011–4289 ; no. 1957 | Includes bibliographical references.
Identifiers: IAEAL 21-01409 | ISBN 978-92-0-107921-3 (paperback : alk. paper) |
ISBN 978-92-0-107821-6 (pdf)
Subjects: LCSH: Nuclear power plants — Aging. | Nuclear power plants — Maintenance and repair. | Nuclear reactors — Shutdown. | Nuclear power plants — Decommissioning.

FOREWORD

At present, several nuclear power plants under construction have experienced some delay in or suspension of the construction process, in some cases lasting several years. There is also experience available from Member States that, after long delays during construction, have successfully commissioned nuclear power plants, following evaluation of ageing effects during the long term safekeeping of components. Currently, there are also several nuclear power plants that, for different reasons, have been shut down for extended periods with the intention of ultimately restarting operation. During this period, the operating conditions of the structures, systems and components differ from those expected during normal operation and new ageing effects can adversely affect safety functions.

Ageing management during delayed construction, extended shutdown and permanent shutdown (prior to decommissioning) of nuclear power plants needs to be considered in order to preserve the safety functions of structures, systems and components. To assist its Member States in managing ageing effectively, in 2009 the IAEA initiated the extrabudgetary programme on International Generic Ageing Lessons Learned (IGALL). IGALL is a collection of proven best practices for implementation of ageing management, based on examples provided by Member States.

In Phase 3 of the IGALL programme (2016–2017), it was recognized by Member States that, in addition to the operating experience and practice of plants during the period of normal operation (including long term operation, if applicable), ageing management during specific periods different from normal operation — periods of delayed construction, extended shutdown and permanent shutdown — is an important area where relevant national practices can be collected and shared. In response, the IGALL Steering Committee, consisting of representatives of 30 IAEA Member States operating nuclear power plants, established a working group dealing with ageing management during these specific periods. The working group, which began in Phase 4 (2018–2019), was tasked with developing a publication collecting proven practices and the experience of Member States.

The present publication describes Member States' experience in ageing management during these specific periods as well as proven practices and examples on meeting the recommendations for ageing management. It takes into account the nine attributes for description of ageing management for the particular circumstances in the three specific periods set out in IAEA Safety Standards Series No. SSG-48, Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants.

The contributions of all those who were involved in the drafting and review of this publication are greatly appreciated. The IAEA officer responsible for this publication was M. Marchena of the Division of Nuclear Installation Safety.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

Nuclear power plants implement ageing management to provide reasonable assurance that structures, systems and components (SSCs) important to safety are able to accomplish their intended safety functions throughout the entire plant lifetime. This necessitates addressing both the physical effects of ageing, which could result in degradation of performance characteristics, and non-physical ageing (obsolescence) of SSCs.

Ageing management is most effective when it is implemented throughout all stages of the lifetime of a nuclear power plant. This includes design, construction, commissioning, operation and decommissioning. Throughout the lifetime, the plant environment and the SSCs' operational modes will be changing. For this reason, it is important to review, and as needed, modify the ageing management practices at each stage of the plant's lifetime.

To assist its Member States in managing ageing effectively, the IAEA developed a programme on International Generic Ageing Lessons Learned (IGALL). The IGALL is a collection of proven practices for implementation of ageing management based on input provided by Member States. The ageing management programmes (AMPs) in the IGALL programme are typically implemented during the plant operational phase. The IGALL programme started in 2010 and is currently structured in biannual phases.

During Phase 3 (2016–2017) of the IGALL programme, the IGALL Steering Committee requested the IAEA to collect operating experience and proven practices for ageing management and lessons learned during periods of delayed construction, extended plant shutdown with the intent to restart the plant, and permanent shutdown prior to decommissioning of the plant. This publication was developed by a working group of 12 Member States during Phase 4 (2018–2019) of the IGALL programme.

The proven practices and lessons learned described in this TECDOC consider the nine attributes of an effective AMP based on IAEA Safety Standards Series No. SSG-48, Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants [1], and IAEA Safety Standards Series No. SSR-2/2 (Rev. 1), Safety of Nuclear Power Plants: Commissioning and Operation [2]. In accordance with para 3.6 of SSG-48 [1], ageing management activities need to be overseen by the regulatory body throughout the lifetime of the plant.

This publication complements IAEA-TECDOC-1736, Approaches to Ageing Management for Nuclear Power Plants [3], IAEA-TECDOC-1110, Management of Delayed Nuclear Power Plant Projects [4], and IAEA Nuclear Energy Series No. NP-T-3.4, Restarting Delayed Nuclear Power Plant Projects [5]. In particular this publication updates technical information contained in chapter 4 and some aspects of chapters 5 and 6 of IAEA-TECDOC 1110.

1.2. OBJECTIVE

The objective of this publication is to provide a summary description of international practices and examples of national approaches applied by Member States to the ageing management for nuclear power plants during three specific periods: delayed construction, extended shutdown, and permanent shutdown prior to decommissioning.

This TECDOC is intended for use by regulatory bodies, operating organizations, manufacturers, designers and technical support organizations.

1.3. SCOPE

The scope of the TECDOC focuses mainly on SSCs included in the scope of ageing management in accordance with SSG-48 [1]. During the special periods considered in this publication, the safety functions of these SSCs may be different than in normal operation, or not be of primary importance. For these reasons, the TECDOC also addresses ageing management of other SSCs not important to safety (e.g. generation assets that carry high business risks or are non-replaceable). The number of Member States with available operating experience sources for these specific periods is limited. This publication summarizes the information collected from 12 Member States that indicated their willingness to share their experience. This information was collected during Phase 4 of the IGALL programme between 2018 and 2019.

1.4. STRUCTURE

The publication is structured in three main sections: Section 2: Ageing management during delayed construction periods; Section 3: Ageing management during extended shutdown; and Section 4: Ageing management during permanent shutdown prior to decommissioning. These sections provide the proven practices considering the nine attributes for an effective AMP based on SSG-48 [1] and SSR-2/2 (Rev. 1) [2]. The last subsection in each of these sections describes the experience and considerations taken for the specific period. The Annexes I to III present additional experiences of Member States in ageing management during the three specific periods addressed in this publication.

2. AGEING MANAGEMENT DURING DELAYED CONSTRUCTION

There have been, and there are, several nuclear power plant projects worldwide that began their manufacturing and/or construction activities but subsequently suspended them for indefinite durations. For these projects, it is important to preserve the SSCs in a condition that will allow a later resumption of activities and adequately complete the construction.

The construction stage is considered to include manufacturing and assembling the components of a facility, carrying out of civil works, the installation of components and equipment, and the performance of associated tests. For the purpose of this publication, the period considered in this section lasts from the beginning of the construction of the plant until the start of commissioning, even when some construction works are continuing once commissioning has started. For the purpose of this publication, ‘delayed construction’ is any suspension of work occurring during the construction stage due to any reasons (e.g. political or economic reason) with the intention of later completion.

A delayed construction period presents several ageing management challenges that need to be overcome. Availability of financial resources for the preservation tasks is crucial, since a significant number of working hours and material are necessary to preserve the SSCs in accordance with the technical requirements. The suspension may also need changed or revised maintenance inspection, walkdown, and periodic surveillance programmes and schedules that necessitate adjustment and coordination. This implies that personnel involved in these tasks need is trained and qualified to know exactly how to perform their changed responsibilities.

Ageing effects may degrade some critical safety related SSCs (e.g. concrete structures, transition zone of steel containment, cables, empty pipelines or pipelines with stagnating medium) which could jeopardize the restart of construction or later operation. The preservation activity is implemented during the entire delayed construction period. The environmental parameters are also to be kept in mind during planning of the preservation of the SSCs. In these conditions, some additional ageing management activities, such as special preservation practices, need to be implemented to maintain the SSCs in an appropriate condition, in order to keep the quality and safety function of SSCs as originally designed.

The most common scenarios for preservation during delayed construction are as follows:

— Components are stored in a warehouse or storage place;
— SSCs are already installed at their determined locations in the plant.

The objective of this section is to summarize the proven practices of ageing management being applied by Member States during delayed construction of nuclear power plants to ensure that the SSCs are in an appropriate condition when the plant starts its commissioning and operation at a later time. The experience from Brazil, Japan, India, Iran, Romania and Slovakia was used to develop this section.

The design of SSCs usually does not explicitly consider a delayed construction period, during which specific, unexpected ageing effects may occur. Also, the ageing effects may evolve over time differently under changed (environmental) conditions compared to what was expected. This implies that the originally designed ageing management activities including maintenance, surveillance, inspections, testing, qualification, walkdown or any other planned activities need to be modified to cope with the changed circumstances. For this reason, some Member States have introduced specific ageing management specifically for delayed construction periods (see Annex I).

Documentation of all relevant information is critical for the success of all future ageing management activities.

An important aspect for ageing management during the delayed construction period is that the responsibility for the condition of the SSCs rests with the licensee (owners) although most activities are performed by, and the site is under the control of, a vendor or principal contractor.

In the case that responsibilities to perform ageing management activities are not assigned to the vendor or principal contractor, because of contractual constraints, the licensee is responsible to address ageing related issues as described in IAEA-TECDOC-1110 [4]. The annexes of Ref. [4] provide a brief description of Member States' experience in planning protection and preservation measures in short and long term, maintenance, cleaning and repair activities, including consideration of necessary resources in terms of materials, tools and staff.

2.1. SCOPE OF SSCS COVERED IN AGEING MANAGEMENT

Since consideration of the aspects of ageing management starts from the design phase, it is assumed that all SSCs already installed or stored at the site are addressed by ageing management in accordance with their design requirements and specifications.

This section follows the concept for implementation of ageing management in accordance with SSG-48 [1] and applies to the following SSCs subject to delayed construction, including those that have already been installed, constructed or stored:

— Mechanical components (e.g. pumps, valves, tanks, vessels, heat exchangers, overhead cranes, locks, penetrations, supports, embedded parts);
— Mechanical parts (e.g. plates, bolts, nuts, forgings, welding material, piping, fittings);
— Electrical components (e.g. cables, motors, switchgear, transformers, electrical actuators, diesel generators);
— Instrumentation components (e.g. cabinets, sensors, monitors, hardware);
— Civil structures (e.g. rebar, reinforced concrete, steel structures, intake channels, steel containment, roofing, bulkheads, special coatings).

For delayed construction projects, the scope of SSCs is usually impacted by the following environmental stressors and degradations, as indicated in the EPRI Aging Assessment Field Guide [6]:

— Environmental stressors: temperature, humidity, dust, sea breeze, freezing, rain;
— Degradation mechanisms and ageing effects: uniform corrosion, pitting, concrete cracking, seizure, coating degradation (e.g. cracking, blistering, discoloration, delamination).

A complete list of degradation mechanisms, ageing effects and the condition that can lead to their occurrence can be found in Safety Report Series No. 82 [7]. A list of degradation mechanisms and ageing effect experience during delayed construction in some Member States are given in IAEA-TECDOC-1110 [4] and could be taken as reference.

Spares and polymers which have short shelf life are not covered in the scope of a delayed construction period. The applicable publication during resumption of construction and start of commissioning is IAEA Nuclear Energy Series No. NP-T-3.21, Procurement Engineering and Supply Chain Guidelines in Support of Operation and Maintenance of Nuclear Facilities [8].

2.2. PREVENTIVE ACTIONS TO MINIMIZE AND CONTROL AGEING EFFECTS

To minimize and control ageing effects, it is necessary to apply preventive actions.

2.2.1. Storage of SSCs

This section applies to SSCs (except for civil structures) that were manufactured and received at the site and placed in a warehouse, under tents, at a manufacturer facility, outdoor or other storage place.

According to the experience of Brazil, Japan, India, Iran, Romania and Slovakia, the following activities may be undertaken (more details can be found in Annex I):

— Follow the manufacturer’s instructions, procedures and specification requirements for long term storage. Request additional instructions and/or certificates from manufacturers, if needed;
— Maintain an appropriate environment in the storage place (where applicable) by controlling temperature, humidity, dust, aerosol, aggressive agents within the acceptable limits for the SSCs;
— Collect and retain environmental data for the stored SSCs;
— Wrap up the SSCs and apply the following means: plastic foil, desiccant, humidity indicator;
— Preserve the SSCs’ surface by protective material such as wax layer, grease, and coating;
— Apply a gas corrosion protection system (e.g. nitrogen, CO_2) for some specific SSCs (e.g. vessels, heat exchangers);

— Use heaters to control humidity in motor windings;
— Perform periodic visual inspections of SSCs stored in accordance with manufacturer's instruction, to check condition of the package and component;
— Rotate machine shafts periodically;
— Perform sampling of oil to confirm parameter properties remain within specified limits;
— Stock qualified equipment (including subassemblies, spare parts and materials) in the warehouse and mark it as qualified;
— Control qualified equipment subjected to shelf life considerations to ensure that, upon installation, the qualified status of the equipment is maintained;
— Establish a reliable means to ensure that shelf life expiration dates of qualified equipment are not being exceeded.

The SSCs are stored in accordance with specifications provided by the manufacturer for the storage period, considering their requirements for environmental conditions. Appendix 6 of Ref. [4] presents a classification of storage categories and its application to storage of specific materials. Additional information regarding preventive actions for stored SSCs is described in Appendix 8 Ref [4].

2.2.2. SSCs installed and constructed

This section applies to SSCs that were manufactured and received at the site and installed at the buildings or structures that were already constructed.

According to the experience of Brazil, Japan, India, Iran, Romania and Slovakia, most of the activities described for stored components in Section 2.2.1 are applicable to the SSCs already installed, and the following additional actions are implemented, more detailed and other specific processes can be found in Annex I:

— Protect the SSCs using for example temporary roofs and walls, tents, or plastic devices to avoid exposure of the SSCs to aggressive conditions, fill with inert medium, and avoid contamination;
— Develop or modify the foreign material exclusion (FME) programme for the delayed construction period with ageing aspects;
— Perform visual inspection of the SSCs periodically;
— Implement a housekeeping plan (cleaning and keeping the SSCs in order) in the buildings.

In addition, the following are applicable to preserve the SSCs' condition:

— Mechanical components (carbon steel):
  - o A primer coating or a special protective layer on the SSCs' surface;
  - o A gas corrosion protection system (e.g. nitrogen, CO_2);
  - o Closure of SSCs' openings with temporary covers to minimize control and prevent ingress of foreign materials;
  - o Connection of SSCs to a heating device to keep inside humidity at a low level.
— Mechanical components (other materials):
  - o Cleaning of SSCs' surfaces and wrapping them up by a resistant plastic to protect against dirt, sulphates, fluorites, sea breeze or other aggressive agents. For cleaning of SSCs' surfaces, Appendix 7 of Ref. [4] contains additional information;
  - o Closure of SSCs' openings with temporary covers to avoid ingress of aggressive aerosols;

  - Control of SSCs' area to avoid dust, heat, grease and other products that may contaminate the SSCs;
  - Separation of stainless-steel equipment from carbon steel materials in workshops in order to avoid contamination.
- Electrical, instrumentation and control components:
  - Sample oil to confirm parameter properties remain within specified limits;
  - Perform routine tests of the auxiliary components (e.g. performance test of the transformer fans) in accordance with manufacturer's instructions.
- Civil structures:
  - Preservation of embedded parts and metallic structures;
  - Installation of pumping systems to avoid water accumulation;
  - Installation of additional drainage systems inside and outside of buildings, if needed;
  - Coating of rebars with concrete slurry or paint;
  - Periodical inspection of active anti-corrosion protection systems.

2.3. DETECTION OF AGEING EFFECTS

The concept of detection of ageing effects is the same for both SSCs in storage and SSCs already installed or constructed.

For most mechanical components and civil structures, the detection of ageing effects or preservation problems is verified by a periodic visual inspection programme. In addition, a special inspection or test, if necessary (e.g. concrete strength test), is performed.

For electrical and instrumentation components, special inspections or tests may be performed (e.g. measurement of insulation resistance of the motor, routine test, inspections for to detect corrosion points).

2.4. MONITORING AND TRENDING OF AGEING EFFECTS

In order not only to monitor and trend the ageing effects, but also to monitor the preservation condition of the SSCs, the following monitoring and trending actions are established:

- Periodical inspection of SSCs stored to verify, as a minimum:
  - Package conditions;
  - Surface conditions;
  - Protective layer or coating;
  - Humidity level;
  - Gas corrosion protection system operation (e.g. pressure, manometer operation, calibration);
  - Operation of the electric resistance heating system;
  - Conditions of motors and pump shafts.
- Periodical inspection of SSCs installed or constructed to verify, as minimum:
  - General condition at the storage;
  - Protection against weather conditions;
  - The surface conditions of SSCs and packing;
  - Surface and opening protections;
  - Protective layer or coating;
  - Oil leakage and level;
  - Functional and control characteristics (e.g. fans, thermometers, valves, pumps, switchgear, oil indicator);

  - Motors and pumps shafts conditions;
  - The operation of the electric resistance heating system.
- Performing of special tests or inspections (e.g. performance test, check insulation properties and NDT) to complement the monitoring actions, if necessary.

2.5. MITIGATING AGEING EFFECTS

In the case that any ageing effect or preservation problem is detected, the preventive measures described in Section 2.2 need to be improved, supplemented or modified. Examples of mitigation measures could include the following: application of protective coating, replacement of protective package, cleaning of surface and implementation of inert atmosphere, or other repairs and replacement actions to mitigate detected ageing effects of SSCs.

2.6. ACCEPTANCE CRITERIA

The ageing management acceptance criteria for SSCs are derived from standards, specifications, instructions, technical requirements of design, and requirements established by the regulatory body. Current regulatory requirements, codes and standards are reassessed for the determination of acceptance criteria.

The following are some examples of acceptance criteria established for the SSCs' ageing management and preservation conditions:

- Relative humidity of packages and storage place (where applicable) are within specified values;
- No visual surface corrosion indications;
- No defects in coatings or protective layers;
- No deformed or failed shafts;
- Successful test results, e.g. functional tests, leakage tests, performance tests, condition specifications;
- No trash and dirt in the buildings;
- No flooded buildings or submerged components;
- No concrete cracking larger than specified;
- No foreign materials;
- Environmental conditions within acceptable limits, including specified parameters of protective gas, if applicable;
- No contact with any unpermitted medium.

Corrective actions are taken if any criteria are not achieved.

2.7. CORRECTIVE ACTIONS

Corrective actions are performed if an ageing effect or preservation problem is identified during monitoring of the SSCs and if the acceptance criteria for ageing management are not met. According to the experience of Brazil, Japan, India, Iran, Romania and Slovakia, the following activities may be undertaken (more details can be found in Annex I):

- Package or storage place (where applicable) with relative humidity beyond the specified values:
  - Correction of humidity within the package or warehouse;
  - Replacement of desiccants (if used);
- Surface corrosion:

    - Remove the uniform corrosion and cleaning the SSCs' surface, in case of stainless steel. For cleaning of SSCs' surfaces, Appendix 7 of IAEA-TECDOC-1110 [4] provides additional information;
    - Improvement of the protected area around the SSC or package;
    - Cleaning of concrete rebar surfaces until the surfaces are free of rust and recoating with concrete slurry or paint;
- Defects with coatings or protective layers: remove of old protective layers or coating and application of new protective layers or new coatings;
- Deformed or failed shafts: repair or replacement of shafts;
- Unsuccessful test results: repair or replacement of SSCs or parts of SSCs with performance failures;
- Trash and dirt in the buildings: implementation or modification of housekeeping plans;
- Flooded structures:
    - Isolation of flooded area (e.g. pumping the water from a sump or specific room);
    - Installation of additional pumping systems to avoid water accumulation;
    - Installation of additional drainage systems inside and outside of buildings;
- Concrete cracking larger than specified:
    - Characterization (quantity and quality) of cracking;
    - Definition of an appropriate treatment in accordance with the characterization of the cracking;
- Foreign materials identified:
    - Remove foreign material and check for damage;
    - Revision of the FME programme, if necessary;
- Environmental conditions outside design values:
    - Modification of environmental parameters, if possible (e.g. heating, cooling, air conditioning);
    - Relocation of components to alternate location;
- Contact with unpermitted medium:
    - Elimination of the contact;
    - Decontamination of the component or surface;
    - Isolation of the component;
    - Maintain and monitor pressure of inert gas.

The corrective actions are implemented in accordance with standards, specifications, instructions, and technical requirements of the project.

Depending of the regulatory requirements and/or plant contractual arrangement in the State, if the corrective action in accordance with the specification necessitates a non-conformance report, the design authority is involved in the issuance of the corrective actions. In this case, the root causes are investigated to avoid new issues. The regulatory body is informed of the occurrence of non-conformances depending on the severity of the issues.

If the corrective action does not restore the original design condition of the SSCs and it impacts on the fitness for service or life time of the equipment, root cause analysis is performed to provide a statement (e.g. technical report, calculations check and electrical test qualification) for the applicability of the SSCs before the resumption of the construction or during the construction time.

2.8. OPERATING EXPERIENCE FEEDBACK

All the ageing related experience during delayed construction, including the problems detected, corrective actions taken, and effectiveness of the actions, are documented and feed back to the ageing management processes of the plant.

Since any ageing effects and preservation problems experienced during delayed construction phase have an impact on the safety of SSCs during the operating phase, all collected ageing related experience information needs to be carefully analyzed and documented.

As an example, one State experienced degradation caused by water ingress due to inadequate protection in the transition zone (interface) between the concrete and metallic spherical containment during the delayed construction period. The issue was treated and resolved during the construction period; however, periodic inspections are necessary during scheduled plant outages to confirm acceptable condition.

In another case, an inspection performed during completion of a plant revealed that insulation resistance of the winding of the feedwater pumps motors, which were procured approximately 20 years before, did not meet the specification. It was assumed that this happened due to the humidity of the environment in the warehouse. Therefore, two solutions were worked out: either procurement of new motors or rewinding of the existent motors. The second solution was chosen, and the motors were rewound. Their performance is satisfactory till development of this publication.

2.9. QUALITY MANAGEMENT

Implementation of the quality processes of the management system in the delayed construction phase is an essential element.

The quality management system of the project is either modified as necessary and the process and responsibilities are defined for that phase or a separate plan is developed. Specifications and procedures for preservation are defined and in place to be used.

It is important that the preservation instructions of the manufacturer cover the delayed construction period. If such preservation instructions do not exist, they need to be developed. It is effective for the licensee (owner) to cooperate and share issues related to quality management with the supplier.

The quality management system contains appropriate documentation provisions, and the protocols, checklists, data sheets and reports are established to record the preservation activities. Appropriate data control provisions are implemented to control inspections and records. These provisions describe the role and use of the databases for recording and tracking the condition of SSCs, including data transmission and access between the separate databases.

The qualification or certification requirements to perform tasks or application of material during the delayed construction phase follow the construction or manufacturer requirements.

2.10. EXPERIENCE AND INFORMATION FOR CONSTRUCTION, COMMISSIONING AND OPERATION

Delayed construction is an unanticipated change to the project plan. It is important to modify the planned ageing management activities to address the new challenges presented by the delays. IAEA Nuclear Energy Series No. NP-T-3.4 [5] provides general information and practical examples concerning necessary management actions to preserve and develop the capability to restart and complete these projects.

An appropriate ageing management ensures all SSCs are ready for continued construction, commissioning and operation without any ageing related problems resulting from delayed construction. In order to minimize problems, the SSCs are checked completely for functional capability, including checking for possible problems and/or necessary replacement of those parts. The respective experience of Member States is summarized below.

Prior to commissioning, a specific inspection is typically conducted by the owner, manufacturers and contractors to check the completeness of the SSCs, damage, or performance failures and to exclude possible ageing effects before the resumption of construction. The SSCs in Section 2.1 were included in the specific inspection, as applicable.

A list of SSCs is developed to describe all criteria for inspections, including the respective construction, operating and maintenance instructions. This list is prepared in accordance with the safety significance of the SSCs and risk factors (e.g. environmental conditions, degradation found during delayed construction) identified during storage. The inspections are completed in coordination with the foreseen schedule for construction and commissioning.

It is important to ensure that ageing management activities are continuing through the commissioning period until commercial operation. The integrated management system ensures that the documentation and information from the delayed construction period is kept, as well as clear roles, responsibilities and procedures for ageing management and maintenance for the commissioning stage.

Further in this section, the general experience of Brazil, Japan, India, Iran, Romania and Slovakia is compiled. Additional details can be found in Annex I.

2.10.1. Mechanical, electrical and I&C components

Specific inspections may include the following tasks for resumption to construction:

— Removal of the preservation, packing, external and internal preservation;
— Disassembling and reassembling of the components in accordance with the operating and maintenance instructions, if necessary;
— Checking of the important functional parts in accordance with the approved documents;
— Checking the seals and sealing surfaces for damage and general surface and internal corrosion in accordance with the test procedures;
— Checking for surface damage of SSCs and corrosion points (if any);
— Checking the coating, in accordance with the test procedure;
— Checking the remaining life of consumable elements (e.g. lubricants and grease), when applicable;
— Checking the tight fit of all threaded connections;
— Carrying out functional and performance tests, if necessary and possible;
— Checking if there are open ageing management issues from the preservation during the delay construction;
— Completion of the inspection records in accordance with Section 2.10.3;
— Statement to release to construction, commissioning and operation.

If the inspection identifies adverse conditions, corrective actions are taken (e.g. repair, replacement, including retesting).

2.10.2. Civil structures

Specific inspections may include the following tasks for resumption to construction:

- Removal of the external preservation as far as necessary for inspections;
- Removal of concrete slurry or coating of the rebar preservation;
- Checking the concrete strength;
- Checking the mass loss of the rebar;
- Checking the wall coating in accordance with the test procedures;
- Checking the concrete cracking;
- Completion of the inspection records in accordance with Section 2.10.3;
- Statement to release to construction, commissioning and operation.

If the inspection identifies adverse conditions, corrective actions are taken (e.g. repair, replacement of SSC parts or the entire SSC, including retesting).

2.10.3. Documentation of inspections

Inspection activities are documented using a checklist and protocol describing inspection steps, responsibilities, findings and disposition.

2.10.4. Obsolescence

In addition to the inspections performed during the delayed construction period, a review of obsolescence status is performed for all SSCs in Section 2.1, where applicable. This review is conducted before the resumption of construction.

As an example, one State cited obsolescence issues that required the replacement of circuit cards in the electrical panels that had been designed as part of the original project. The panel was redesigned using a new technology.

In another example, analogous protection relay of metal–clad and power center was replaced with digital type because it was not available commercially. It was replaced after resuming construction and before inspection of installation status.

In one more case, in the conventional (non-nuclear) side of a nuclear power plant, the equipment control was provided using relay logic cabinets. Due to obsolescence of this type of equipment, the entire control of the conventional side of the plant was replaced by a digital control system.

Another State reported that a large number of SSCs became obsolete during the construction of a nuclear power plant, and a new qualification process to replace the SSCs was needed. During the delayed construction period, which lasted more than 30 years, about 70% of SSCs were replaced due to obsolescence.

If original equipment is replaced by new one due to end of shelf life or obsolescence, the original assumptions in the safety analysis are re-evaluated.

3. AGEING MANAGEMENT DURING EXTENDED SHUTDOWN

An extended shutdown is considered to last from several months to several years but, in any case, with the intention of ultimately restarting the nuclear power plant unit. There can be several reasons for units entering into extended shutdowns. The most common factors are the following ones:

— Planned shutdowns for major refurbishments;
— Natural hazards or other major events;
— Major equipment failures;
— New or modified regulatory requirements.

During extended shutdown, many of the SSCs may experience operating and environmental conditions different from their normal operating state that may challenge residual equipment life. Examples are the reduced or stagnant flow conditions in process piping, changed ventilation, temperatures and ambient air qualities or SSCs with increased duty cycles such as the irradiated fuel storage pool. A proactive approach is needed to manage and preserve the SSCs conditions as soon as the decision for an extended shutdown is made.

The planning and activity levels of ageing management related work for these conditions are different. Owing to the circumstances of how the shutdown of the unit took place, the conditions for restart vary. If the reasons for shutdown were natural disasters or other major events, or major equipment failures, most probably there are actual damages to SSCs that would not have been experienced in a systemic or normal shutdown process.

An extended shutdown also provides an opportunity to implement ageing management and life extension measures requiring long term outage duration of the unit. Development of a comprehensive preservation plan for SSCs ensures implementation of an effective ageing management during the extended shutdown period.

Management's attention during the extended shutdown period is important to ensure healthiness of the following SSCs:

— SSCs important to safety, so they are capable of fulfilling their intended safety functions during the extended shutdown and when the unit is returned to operations;
— Other SSCs whose failure may prevent SSCs important to safety from fulfilling their intended functions;
— Generation assets that carry high business risks or are non-replaceable, so they are fully functional and minimize the potential of expensive replacements or refurbishments, prior to return of the unit to operations.

The following list provides the key aspects of the planning process to specify the ageing management activities as compared to the total scope of extended shutdown activities:

— Development of new procedures or modification of existing procedures to ensure a proactive ageing management strategy to preserve the SSCs during the extended shutdown period and unit restart;
— Defining and documenting the scope along with a basis for inclusion of the SSCs in the preservation plan;
— Identification and documentation of the degradation mechanisms and effects during the extended shutdown and restart, paying attention to parameters, which could change a known

degradation mechanism, or could potentially cause creation of a new degradation mechanism;
- Identification of additional regulatory and/or internal upgrade requirements to ensure reliability for the SSCs;
- Identification of modifications necessary to address ageing concerns during extended shutdowns;
- Assign the risk, document financial evaluation, and reach a decision for the extent of activities, to ensure higher risk SSCs receive the ageing mitigation with higher priority;
- Preparation of the critical path network detailing the process involved during the extended shutdown to examine the windows of opportunities for carrying out additional activates for life management;
- Assessment of additional facilities and services to support the extended shutdown activities for safe storage of dismantled SSCs to prevent accelerated ageing, for storage of nuclear fuel removed from the reactor core, and for increased storage capacity for solid and liquid radioactive waste;
- Preparation of special surveillance, inspection, preservation and maintenance plans; as an example, India follows practices in accordance with Ref. [9];
- During extended shutdown of the unit(s), some SSCs necessitate placement into temporary lay-up or safe storage states that necessitate supplementary measures and controls to prevent or minimize ageing effects.

The experience from Armenia, Japan India and Pakistan was used to develop this section. Detailed information about State specific practices are documented in Annex II.

3.1. SCOPE OF SSC COVERED IN AGEING MANAGEMENT

Preparation of scope necessitates an extensive planning, including risk and reliability, as well as value added analysis to address the path forward for returning the unit back to operation. This section provides information and good practices for setting the scope for ageing management during extended shutdown. Tt follows the concept to implementation of ageing management provided in SSG-48 [1]. Some Member States follow specific guidance, such as Ref. [10] in the case of India.

Activities performed by the plant provides an understanding of ageing phenomena such as significant degradation mechanisms, service conditions, stressors, ageing effects, SSCs condition indicators and acceptance criteria, in particular those that are significant during the lay-up or safe storage period. The scope of SSCs is impacted by the environmental stressors and degradations, as indicated in the EPRI Aging Assessment Field Guide [6].

Member States having experience with extended shutdown have defined a scope of ageing management on SSCs placed in lay-up or safe storage states in the following manner:

- Identification of SSCs subjected to ageing placed in lay-up or safe storage states during extended shutdown. For example: reactor components, major civil structures, steam generators, turbine generator system, process water systems piping and equipment, feed water system piping and equipment, secondary cycle heat exchangers, condensers;
- Identification of environmental stressors of the unit, storage facilities where the SSCs have been kept. For example: temperature, humidity, dust, and external environmental factors, like rain;
- Identification of SSCs condition indicators. For example: general corrosion, pitting, crevice corrosion, wear and tear, insulation embrittlement and degradation, mechanical wearing.

In terms of extended shutdown, actions on the spare parts, like polymers and consumable elements, are consistent with the information provided in Ref. [8].

3.2. PREVENTIVE ACTIONS TO CONTROL AND MINIMIZE AGEING EFFECTS

Examples of preventive actions taken by Member States to minimize and control ageing effects on SSCs during extended shutdown include the following:

- Preparation of preservation documents outlining SSCs' specific lay-up steps;
- Documentation of specific maintenance plans for the SSCs in lay-up state, and those with changed duty cycle;
- Drying of the equipment and systems drained for long time, with instrument air;
- Blowing of dry instrument air, whenever possible, for example on a monthly basis, to maintain the desired humidity level and dew point;
- Filling the system with inert or non-corrosive fluid, e.g. with nitrogen or appropriate liquids;
- Maintaining the necessary water flow in reactor systems related to core cooling, along with maintaining chemistry parameters and the necessary flow in purification circuits in service;
- Circulate suppression pool water, such as running suppression pool pumps, as deemed necessary;
- Maintaining helium purge in the primary heat transport system, reactor coolant pumps seals and surge tanks;
- Steam blanketing in heat exchangers;
- If the components are in a dry lay-up state (either with dry air or nitrogen), periodic dew points and oxygen contents measurements are performed. In case the dew points are on positive sides, flushing and fresh filling of dry air is performed;
- Using dry hot air circulation in generator stator winding to maintain it in dry condition;
- Maintaining lubricant oil flow through all bearings of turbine generator set;
- Using space heaters for standby and non-operating motors, to prevent insulation degradation, by moisture ingress;
- Periodic inspections and functional tests of SSCs to ensure that they perform their intended function; for example, electrical motors, reactor system instruments;
- FME plays an important role during the activities of shutdown outages. The generic example of FME impact on the units being fuel failure, heat exchanger tube leaks, clogging of pipes and damage to rotating equipment. An enhanced FME programme is implemented to address FME during extended shutdowns and unit restart;
- Preserve SSCs in accordance with manufacturer's instructions, if available, to control degradation of SSCs within acceptable limits during lay-up state. This is necessary as the flows and pressures in process circuits are not the same as in normal operating conditions. Examples are the increase in equipment's change over frequencies, and feed and bleed to achieve desirable chemistry of the systems;
- If temporary modification and configuration changes are undertaken to support the maintenance and storage process, they are monitored for impacts of ageing on SSCs.

The SSCs are stored in accordance with their design specification that takes into account criteria to protect them against the environmental conditions. For storage categories purpose, Appendix 6 of Ref. [4] presents a classification of storage categories.

3.3. DETECTION OF AGEING EFFECTS

The timely detection and characterization of ageing effects on SSCs is important to prevent SSCs degradation. The following methods of detection of ageing effects on SSCs are used by Member States during extended shutdown:

- Modified preventive maintenance programme for detecting ageing effects;
- In-service inspections (ISI) for operating or in modified operating state SSCs;
- Specific inspections for detecting flow accelerated corrosion (FAC) and microbial influenced corrosion of the stagnant-leg SSCs and piping not drained;
- Modified routine surveillance, functional testing for components that remain out of service, and routine process for the components that are in service;
- Analysis of deviation from chemistry programme specification may be a sign or result in of enchanted corrosion of construction materials. However, water chemistry is a mitigation programme;
- Condition monitoring of SSCs in lay-up, shutdown or modified operating state;
- Special lube oil analysis for lubricants covering metal particle analysis, in addition to monitoring for total solid contents and moisture (this provides additional information on the specific components undergoing wear);
- Vibration measurement and signature analysis on rotating equipment;
- Thermography;
- Dissolved gas and Furan analysis of transformer oil;
- Diagnostic testing on power transformers and generators;
- Insulation resistance and polarization index on cables;
- Current signature of motorized valves;
- SSCs' degradations are monitored and non-conformities of structures or components are corrected through repair, replacement or refurbishment;
- Re-evaluation of AMP based on the results from the assessment of the above processes.

3.4. MONITORING AND TRENDING OF AGEING EFFECTS

The timely detection and characterization of ageing effects through inspection and monitoring of in-scope structures or components is crucial to prevent failures. These are some of the practices followed by Member States during extended shutdown:

- Provisions for online monitoring are in place, particularly where this provides signs of degradation leading to failure of SSCs and where the consequences of failure could affect safety;
- Thickness gauging programme for piping systems is used to predict the residual life of the piping components;
- Enhanced creep measurement and ISI programme for coolant channels and steam generators of pressurized heavy water reactors (PHWRs). This includes scrapping of additional channels for hydrogen ingress and tube eddy current testing to determine long term ageing. Water lancing of tube sheet areas to inhibit corrosion is performed;
- Established trending analysis specific to ageing mechanisms. Monitoring ageing effects, based on trends of data, and analysis for SSCs in lay-up, SSCs in shutdown, and those with changed duty cycle;
- Analysis of equipment data based on comparative methods for similar SSCs at the station and other stations;
- Testing of standby and switched OFF loads at predetermined frequency;
- Measurement of current in motor space heaters;

— Functional testing on circuit breakers;
— Water chemistry parameters are recorded, evaluated and trended in accordance with the different water chemistry guidelines to obtain early warning of potential material degradation.

3.5. MITIGATING AGEING EFFECTS

Mitigation of ageing effects in extended shutdown can be done as follows:

— Upgrading of SSCs, specifically those requiring longer unit outages for replacement or repair, for example, changing the electrical or control cables with higher or modified ratings. Reblading of the turbine rotors with energy efficient blades and shot peening of blade roots for longer life;
— Change and material upgrade for example replacing piping having stress corrosion cracking (SCC) with low carbon stainless steel, replacing secondary side piping with chrome–molybdenum, seawater piping with epoxy, glass, tar or biological resistant coated piping;
— Replacement or repair of equipment with history of repeated failures and low reliability;
— Replacement of obsolete SSCs where possible;
— Consider analysis and suitable modification to address single point vulnerability;
— Oil condition improvement by filtering and hot circulation of oil in the system;
— Modifying duty cycle of the SSCs that has standby equipment, such as condensate extraction pumps, containment exhaust fans;
— Replacement with better quality components, and subcomponents like glass coated ion exchange columns;
— Improving the lubrication, and cooling of equipment. Consider additional cooling for equipment showing higher bearing or winding temperatures;
— Enhanced surveillance for timely detection of incipient failures;
— Improving the environmental conditions surrounding the equipment, for example additional ventilation for equipment that have higher thermal duties, flow balancing in equipment areas, improving air changes;
— Enhanced FME strategy using industry best practices. Examples: Filtration strategy (through bleed filters to remove corrosion products), control total suspended solids prior to hot conditioning automatic temperature control, and installation of boiler inlet strainers.

3.6. ACCEPTANCE CRITERIA

The adequacy of the SSCs is determined by estimating balance residual life either by design calculations or non-destructive examinations. The acceptance criteria of SSCs for further continued operation are specified below:

— Safety goals, as in original design or higher due to various improvements implemented;
— Adequacy of residual life of SSCs important to safety;
— Identification of systems requiring upgrading.

The functional integrity evaluation of each system is checked before restarting the unit. A graded approach is used which is based on its importance for reactor safety. For further continued operation, the following measures are considered:

— Residual life assessment. The assessment methodology includes a pre-service inspection, detailed walk down, thickness measurement on critical components and other non-destructive examinations, and further analysis according applicable codes and standards if necessary;

— Confirmation of availability of the SSCs;
— Confirmation of completion of the SSCs permanent modifications;
— Ensuring availability of spare parts;
— Condition assessment and integrity checks of the civil structures;
— Plant status control tag out, and configuration management issues are taken care, as part of declaring systems and components available for service;
— Evaluation of systems' functional integrity to confirm effectiveness.

The acceptance criteria for various process systems are verified before final start-up of the plant after extended shutdown. The following checks ensure satisfactory system performance:

— Performance check of all the rotating equipment, such as pumps, compressors, diesel generators for their design basis operability values;
— Electrical and air operated valves for their design basis operability values;
— Instrumentation and control logic and functionality checks.

3.7. CORRECTIVE ACTIONS

The acceptance criteria for various process systems is verified before final start-up of the plant after extended shutdown. The following checks ensure satisfactory system performance during further operations:

— Performance check of all the rotating equipment, such as pumps, compressors, diesel generators for their design basis operability values;
— Electrical and air operated valves for their design basis operability values;
— Instrumentation and control logic and functionality checks;
— Condition assessment and integrity checks of the civil structures;
— Address the plant status control tag out, and configuration management, as part of declaring systems and components available for service;
— Evaluation of systems' functional integrity to confirm effectiveness.

Suitable corrective actions are taken if acceptance criteria are not met. The corrective actions depend on the severity of ageing degradation observed, the degradation causing mechanism, and the safety significance of the affected SSC. The corrective actions are categorized as immediate, short term and long term, depending on the case. Examples of possible corrective actions in extended shutdown are the following:

— Enhanced maintenance programme on deficit equipment;
— Enhanced condition monitoring to estimate rate of degradation;
— Repair or modification as applicable;
— Replacement with existing design or improved design;
— Chemical cleaning and system decontamination if the corrosion rates are found on higher side during extended outage before restart;
— Enhanced administrative measures;
— Removal and replacement;
— Root cause analysis is conducted in case of any failure of critical equipment.

3.8. OPERATING EXPERIENCE FEEDBACK

Operating experience feedback during extended shutdown is compiled by Member States in the following manner:

— Collection and consideration of operating experience from units in similar conditions and from the vendor;
— Documentation and analysis of the lessons learned from the shutdown activities in support of the continuous operation and return to service activities, as well as future evolution of refurbishment or upgrade outages;
— Comparison of the experienced ageing phenomenon, 'as found' conditions gathered through inspection, monitoring and observations with acceptance criteria;
— Conducting periodical evaluation of the AMP to confirm the adequacy of the extended shutdown activities;
— Utilizing the operating experience in further improvement in appropriate attributes of AMP;
— Benchmarking with practices and performance with similar unit design and taking corrective action to meet the performance, where feasible.

3.9. QUALITY MANAGEMENT

Implementation of the quality management programme is based on documented procedures, software programmes and databases. Administrative controls are implemented for AMP during the extended shutdown outage such as appropriate procedures, instructions and record keeping. Modification of the project quality management plan or preparation of a separate or supplementary plan is necessary, in order to define the process and responsibilities for each phase of the outage.

Quality management for extended shutdown includes the processes and activities relating to the configuration management programme and the modification management programme, a well-defined SSCs preservation plan, including procedures and specifications for SSCs preservation. The preservation activities follow the manufacturers specifications, procedures and instructions. The plan contains appropriate documentation provisions, protocols with well-established checklists, data sheets, and report templates to document the preservation activities.

The effectiveness of the quality management programme can be examined through internal and external audits. For extended shutdown, appropriate data control provisions are implemented to control inspection records. Training requirements to ensure qualification or certification to perform tasks or application of material during the extended shutdown period follow the requirements for the construction or manufacturing stage. The appropriate documentation, such as operating, maintenance, design, and training documents with the modified ageing related information (including upgrades), are updated in support of returning to service and continuous operation.

As an example, India follows practices in accordance with AERB Safety Guide No. AERB/SG/QA–5, Quality Assurance during Commissioning and Operation of Nuclear Power Plants [11]. Although this guide was not developed specifically for extended shutdowns, the general principles established therein are applicable.

3.10. RESTART ACTIVITIES AFTER EXTENDED SHUTDOWN

For a safe and reliable transition from shutdown to the unit start-up phase, a systematically planned and well-executed process needs to be in place for restart of the SSCs from wet lay-up preserved state. IAEA Nuclear Energy Series No. NP-T-3.4 [5] provides general information and practical examples concerning necessary management actions to preserve and develop the capability to restart these projects. The following important activities are considered by Member States before restart of the plant after extended shutdown:

— Inspection of important systems in accordance with prevailing ISI documents through visual inspection of all SSCs including supports (e.g. pressure vessel, pressure tubes, steam generator tubing);
— Air retention, hydro tests, helium tests of the systems in accordance with first start up procedures;
— Flushing of all the process systems and bringing those to normal operating conditions;
— Winding healthiness and insulation resistance check of all the motors. Insulation resistance value checking of electrical systems;
— Commissioning procedures are prepared for all refurbished equipment. Refurbished equipment is commissioned and brought into service when plant system conditions permit;
— Logic checks on the process systems and equipment;
— Residual life assessment of important systems, equipment and structures (e.g. secondary piping thickness measurement);
— Test run and commissioning of important rotating equipment;
— Containment leak rate test at loss of coolant accident pressure to qualify it for further continued operation;
— Special start-up surveillance programme is made for start-up activities, having seen any critical job(s) to monitor leakages, performance and identity issues with the equipment overhauled;
— Secondary short circuit and open short circuit test on generator;
— Unit synchronization and auto transfer tests.

4. AGEING MANAGEMENT DURING PERMANENT SHUTDOWN PRIOR TO DECOMMISSIONING

According to the definition in the IAEA Safety Glossary [1], the term 'permanent shutdown' means the cessation of operation of a nuclear power plant with no intention to recommence operation in the future. Between the permanent shutdown of the facility and the approval of the decommissioning plan, there may be a period of transition. During such a transition period, the authorization for operation of the facility remains in place unless the regulatory body has approved modifications to the authorization on the basis of a reduction in the hazards associated with the facility. During the transition period, some preparatory actions for decommissioning can be performed in accordance with the authorization for operation of the facility or a modified authorization.

The transition from operation to decommissioning starts after permanent shutdown of the facility. The end of the transition period is defined by the date on which the authorization for decommissioning is granted or by the date of approval of the final decommissioning plan. During the transition period, (a) the authorization for operation of the facility remains in place unless the regulatory body has approved modifications to the authorization on the basis of a reduction in the hazards associated with the facility; and (b) some preparatory actions for decommissioning can be performed, in accordance with the authorization for operation of the facility or a modified authorization. This may include, for example, management of waste from operation and management of residual materials (including drainage of systems and removal of combustible materials to reduce the fire loads), radiological characterization of the facility, removal of spent fuel, modification of the facility and preparation of systems to support decommissioning, and preliminary decontamination of the facility's systems as part of the post-operational clean-up (see IAEA Safety Standards Series No. SSG-47, Decommissioning of Nuclear Power Plants, Research Reactors and Other Nuclear Fuel Cycle Facilities [2]).

During the transition period, appropriate ageing management arrangements are evaluated to ensure that SSCs important to safety are well maintained so that they are capable of fulfilling their intended safety functions. This may necessitate the implementation of relatively long term ageing management provisions for certain SSCs (e.g. containment and spent fuel pool (SFP) systems, fire protection systems, lifting equipment and monitoring equipment), consistent with national regulations. Furthermore, the ageing management requirements of the SSCs change with time as the dismantling and decontamination processes are progressing.

Some Member States have experienced an unplanned permanent shutdown of nuclear power plants. Appropriate planning regarding ageing management of critical SSCs is necessary for planned as well as unplanned permanent shutdown of a plant. The major difference of responding to an unplanned permanent shutdown, in comparison to a planned one, is the additional time necessary for proper documentation, training of staff and financial resources.

Three Member States (Germany, India and Switzerland) having experience with permanent shutdown of nuclear power plants have given relevant input to address challenges during the transition period from operation to decommissioning. Specific experience and practices of the contributing States are detailed in Annex III. General experiences of Member States and recommendations are summarized in Section 4.10.Typical challenges can be summarized as follows:

- Due to change of operation conditions of the SFP cooling system, additional wear of cooling pumps can occur;
- In case of parallel dismantling while spent fuel is still in the SFP the dismantling activities affect the SSC within scope;The continuation of SFP cleaning is necessary to prevent increasing activity, therefore ion exchangers are necessary not only to meet the abovementioned acceptance criteria but also to keep the activity as low as possible;
- Shutdown induced changes in water chemistry can cause ageing related issues.

4.1. SCOPE OF SSCs COVERED IN AGEING MANAGEMENT

The scope of an effective ageing management programme in the transition period from operation to decommissioning includes SSCs subject to ageing management, considering the plant specific major changes after cessation of normal operation.

The scope setting is mainly based on the safety classification of SSCs, so the scope is re-evaluated for the transition period provided that the classification is subject to change. In this case, the scoping process is in principle the same as described in paras 5.14–5.21 of SSG-48 [1]. In the case that the safety classification for the transition period has not been changed, a review of scope setting regarding the SSCs which are still relevant to safety is performed. Specific aspects, such as the radiological impact of equipment for radioactive waste management and contaminated SSCs, are considered. The revision of scope setting considers possible new stressors and degradation mechanisms.

Examples of the scope of ageing management during permanent shutdown can be found in Section 4.10.

4.2. PREVENTIVE ACTIONS TO MINIMIZE AND CONTROL AGEING EFFECTS

There is no difference in the general approach of preventive actions between the operational phase of a plant and the transition period. Ageing management review is performed several times during the transition period and, therefore, the preventive actions are revised periodically. Specific examples are presented in Section 4.10.

4.3. DETECTION OF AGEING EFFECTS

One of the key objectives of ageing and plant life management is the early identification of possible degradation mechanisms, which could compromise the safety the plant. During permanent shutdown, some of the ageing effects could not be relevant anymore and, therefore, the activities for their detection can be reduced. However, some unexpected ageing effects could occur that were not identified for normal operation. A revalidation of possible ageing effects is conducted in particular due to changing operating conditions.

Helpful publications for this process are for example the Appendix (IGALL master table) to Safety Reports Series No. 82 [7], the EPRI Report 1010639 [3], and the ENSI Guidelines ENSI–B01 [4].

4.4. MONITORING AND TRENDING OF AGEING EFFECTS

The relevant documents, records, operating parameters and trends are analyzed to verify that all the parameters, including water chemistry, remain within their specified limits.

Therefore, inspection plans, ISI and functional tests on SSCs are continued, taking into account the scope changes for permanent shutdown. The reduction of scope depends on the plant and national regulatory requirements. Examples of monitoring for a reduced scope during permanent shutdown are documented in Annex III.

4.5. MITIGATING AGEING EFFECTS

There is no difference in the general approach of mitigating ageing effects between the operational stage of a plant and during permanent shutdown. For specific examples, see Section 4.10.

4.6. ACCEPTANCE CRITERIA

There is no difference in the general approach of acceptance criteria between the operational stage of a plant and during permanent shutdown.

4.7. CORRECTIVE ACTIONS

There is no difference in the general approach of corrective actions between the operational stage of a plant and during permanent shutdown the PFS (Paragraph 4.52 in SSG–48 [2]).

4.8. OPERATING EXPERIENCE FEEDBACK

There is no difference in the general approach of operating experience feedback between the operational stage of a plant and during permanent shutdown. In several Member States, licensees cancelled their membership in nuclear associations (e.g. WANO, INPO, VGB, COG) when entering into permanent shutdown. This resulted in reduced feedback of relevant experience during this period. IAEA Safety Standards Series No. SSG-50, Operating Experience Feedback for Nuclear Installations [5], recommends continuing reporting experience feedback, including past corrective actions (if any), to established nuclear reporting systems, such as the International Reporting System for Operating Experience (IRS), even if the aforementioned memberships have been cancelled.

4.9. QUALITY MANAGEMENT

There is no difference in the general quality management between the operational stage of a plant and during permanent shutdown.

4.10. EXPERIENCE AND INFORMATION REGARDING PERMANENT SHUTDOWN PRIOR TO DECOMMISSIONING

This section summarizes the experience in Member States with significant impact on effective ageing management of SSCs during permanent shutdown prior to decommissioning.

Member States recognized that proper planning is essential for the transition period from operation to decommissioning. This includes documentation, scope setting, AMPs' review, maintaining records, development of databases, and procedures. In one State, due to unplanned permanent shutdown, many issues arose concerning planning.

By analyzing the experience of Member States with the transition period from operation to decommissioning, three main aspects with an impact on ageing were identified: scope setting for the transition period, time delay prior to getting approval for decommissioning, and change of conditions during the transition period. These aspects are addressed further in this section.

4.10.1. Scope setting for permanent shutdown

Scope setting for the permanent shutdown period leads to a simplification regarding ageing management of the SSCs. One State redefined the scope to the following SSCs due to the update of their safety classifications for permanent shutdown:

- Buildings with radioactive protection zones, especially buildings containing the spent fuel;
- Buildings important for control of SFP cooling and emergency power supply;
- SFP cooling;
- Emergency power supply;
- Safety related and safety support systems for above mentioned SSCs (e.g. fire protection systems, lifting equipment and monitoring equipment);
- Electrical and I&C equipment for above mentioned SSCs.

In plants in the United States of America, the scope setting is part of the so-called 'system evaluation recategorization and transition process' [6]. This process includes an evaluation of each SSC against the following criteria:

- Is the SSC used to prevent or mitigate the design basis accident for the permanently defueled condition?
- Is the SSC needed for the safe storage of radioactive wastes or spent fuel?
- Is the SSC needed to satisfy the plant design, licensing basis or technical specifications for the permanently defueled condition?
- Is the SSC needed to monitor effluents; or
- Is the SSC needed for day-to-day plant operations during decommissioning?

Systems for which ageing management needs to be addressed, prior to moving spent nuclear fuel to dry storage, include the following:

- SFP inventory control;
- SFP cooling;
- SFP make-up;
- Fuel building ventilation and effluent monitoring;
- Electrical supply system;
- SSC for liquid radioactive waste management;
- Fire protection system;
- Support systems of abovementioned SSCs.

4.10.2. Time delay prior to getting approval for decommissioning

In order to minimize ageing effects, the duration of the permanent shutdown period is reduced, to the extent possible, before entering the decommissioning stage. This is also considered in the planning for permanent shutdown. Some Member States experienced significant time delays of several years due to the following circumstances:

- Preparation of the final decommissioning plan and getting approval for decommission licensing by the regulatory body;
- Procurement process for spent fuel storage casks;
- Provision of an additional storage facility for radioactive waste arising from decommissioning;
- Special treatment of damaged spent fuel rods;
- Financing gaps or unclear financial competences.

Due to the abovementioned experiences, additional AMPs were developed to mitigate time dependent ageing degradation mechanisms and their effects.

4.10.3. Change of conditions during the transition period

In the transition period from operation to decommissioning, many physical and organizational conditions at the plant which have a significant impact on the ageing management of SSCs are subject to change. According to Member States' experience, special attention is given to changes in the following conditions:

- Chemical properties of systems within the scope lead to new or increased degradation effects;
- Operational mode (e.g. reduced flow or increased flow, different transients, temperature range);
- Operating hours of systems (e.g. increased or permanent use of former standby safety systems, examples are described in Annex III–1);
- Obsolescence issues for SSCs within the scope;
- Human resources management and knowledge sharing (e.g. increased fluctuation of staff shortens plant specific knowledge).

In the transition period from operation to decommissioning, the following challenges were experienced by Member States:

- Cancelled memberships in nuclear associations (e.g. EPRI, WANO) led to limited experience feedback in both directions;

— Some specific guidelines of the operational stage do not cover the transition period;
— Dismantling activities already during the transition period could affect SSC within scope (e.g. pollution of the SFP due to cutting and grinding in the vicinity).

Concerning the changed conditions, some Member States have implemented good practices such as:

— Continued maintenance on SSCs within the scope as preventive action;
— Continued (if needed modified) testing and inspection plans;
— Continued operation of the SFP cleaning system in order to maintain a good SFP water chemistry (water chemistry still has to meet the criteria of the fuel supplier in order to stay within its guarantee);
— Installation of additional monitoring equipment (e.g. vibration monitoring at pumps with modified operation conditions);
— Conduct of ageing management reviews during the transition period, in order to identify the possible impact on all attributes of the AMP.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants, IAEA Safety Standards Series No. SSG-48, IAEA, Vienna (2018).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Commissioning and Operation, IAEA Safety Standards Series No. SSR-2/2 (Rev. 1), IAEA, Vienna (2016).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Approaches to Ageing Management for Nuclear Power Plants, IAEA-TECDOC-1736, IAEA, Vienna (2014).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Management of delayed nuclear power plant projects, IAEA-TECDOC-1110, IAEA, Vienna (1999).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Restarting Delayed Nuclear Power Plant Projects, IAEA Nuclear Energy Series No. NP-T-3.4, IAEA, Vienna (2008).

[6] ELECTRIC POWER RESEARCH INSTITUTE, Aging Assessment Field Guide, EPRI Report 1007933, EPRI, Palo Alto, CA (2003).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL), Safety Reports Series No. 82, IAEA, Vienna (2015).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Procurement Engineering and Supply Chain Guidelines in Support of Operation and Maintenance of Nuclear Facilities, IAEA Nuclear Energy Series No. NP-T-3.21, IAEA, Vienna (2016).

[9] AERB Safety Guide No. AERB/NPP/SG/O–7: Maintenance in NPPs, AERB, Mumbai, India (2005).

[10] AERB Safety Guide No. AERB/NPP/SG/O–14: Life management of nuclear power plants, AERB, Mumbai, India (2005).

[11] AERB Safety Guide No. AERB/SG/QA–5: Quality Assurance during commissioning and operation of Nuclear Power Plants, AERB, Mumbai, India (2005).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Safety Glossary:, Terminology Used in Nuclear Safety and Radiation Protection, 2018 Edition, IAEA, Vienna (2019).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Decommissioning of Nuclear Power Plants, Research Reactors and Other Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. SSG-47, IAEA, Vienna (2018).

[14] ELECTRIC POWER RESEARCH INSTITUTE, Non-Class 1 Mechanical Implementation Guideline and Mechanical Tools, EPRI Report 1010639, EPRI, Palo Alto, CA (2006).

[15] EIDGENÖSSISCHES NUKLEARSICHERHEITSINSPEKTORAT, Alterungsüberwachung, ENSI–B01, ENSI, Brugg, Switzerland (2011).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Operating Experience Feedback for Nuclear Installations, IAEA Safety Standards Series No. SSG-50, IAEA, Vienna (2018).

[17] ELECTRIC POWER RESEARCH INSTITUTE, Decommissioning Planning: Experiences from U.S. Utilities, EPRI Report 1013510, EPRI, Palo Alto, CA (2006).

ANNEX I.

EXPERIENCES OF MEMBER STATES WITH AGEING MANAGEMENT DURING DELAYED CONSTRUCTION

I-1. BRAZIL

I-1.1. Description of the plant(s)

The main technical details of the plant are presented in Table I–1.

TABLE I–1. SUMMARY OF INFORMATION OF THE PLANT

Plant name	Angra 3
Member State	Brazil
Reactor Type	PWR
Model	Siemens–KWU – 4 loops
Power	1405 MW_e (net)
Construction Start Date	1984
Construction First Suspension Date	1986
Construction Restart Date	2010
Construction Second Suspension Date	2015
Standby time	First time: 24 years (reduced scope–primary equipment) Second time: 4 years
First Criticality Date	To be defined
Current status	Construction suspended

I-1.2. Historical Aspects

The current status and the main facts of the Angra 3 project are as follows:

- 1975: Contract agreement Brazil – Germany (Angra 2 and 3), PWR from Siemens–KWU (currently Framatome) and reference plants Biblis and then Grafenrheinfeld;
- The construction of Angra 3 has started in 1984 and the first suspension occurred in 1985; The construction has restarted in 2010 and the project was stopped in 2015 again;
- For the first phase for the Angra 3 project, several items were manufactured and delivered, for example reactor vessel; steam generators; pressurizer; main cooling pump; main cooling piping;

- For the second phase, the project continued, with deliverables, and made a civil construction progress around 67% and erection progress of around 10%.

I-1.3. Environmental stressors of plant site and/or storage facilities where the SSCs have been kept

The plant site is placed between sea and mountain, resulting in aggressive climate conditions such as high number of hours of sunshine, frequent rain, high relative humidity values and presence of sea breeze. Main environmental parameters are as follows:

- Annual average temperature: 22.5°C;
- High relative humidity: 82% (annual average);
- High rain intensity: 2178.4 mm (average annual precipitation);
- Weather favorable to condensation.

I-1.4. Ageing during delayed construction

I-1.4.1. Scope of SSCs covered in ageing management

The scope of SSCs covered in ageing management includes the following:

- Material and mechanical components (e.g. plates, bolts, nuts, forgings, pumps, tanks, vessel, cranes, locks, penetrations, supports, embedded parts);
- Electrical and instrumentation components (e.g. motors, switchgear, cabinets, sensors, transformers);
- Civil structures (including rebars).

I-1.4.2. Preventive actions to minimize and control ageing effects

The Angra 3 NPP project have worked in three preservation situations as described in the following paragraphs.

The first preservation condition is considered when the SSCs are wrapped up and storage in duly warehouse or provisory tents and the SSCs are placed at Site (inside of the buildings) and also in the civil structures. The preservation in Angra 3 follows the manufacturer's instructions, procedures and specification requirements for long term preservation. Important points to consider are:

- SSCs are wrapped up in accordance with the Eletronuclear procedures for 24 months storage.
- The Eletronuclear 24-month packages procedure specifies plastic foil, desiccant and humidity indicator.

In order to prevent ageing effects, the project checks the following:

- The SSCs wrapped up are located in a structured warehouse at site, and they are inspected to verify:
  - The package conditions;
  - The humidity indicator and replace the desiccants, if necessary;
  - The protective layer (wax or primer coating);
  - Turn the motors and pumps shafts (where applicable);

- o Check the inert gas corrosion protection system operation (e.g. pressure, manometer operation, calibration) (where applicable);
- o Check the operation of the electric resistance heating system (where applicable);
- o Check the oil level (where applicable).

— Purpose built tents were additionally installed for storage the SSCs at site.

The second preservation condition came from the erection and construction real progress phase of Angra 3 project, where components were erected, and the civil structures were placed on. Tents were positioned on the reactor building to avoid inlet water and contact with the SSCs. The SSCs installed in the buildings are being preserved in accordance with the manufacturer's preservation instructions, such as:

(a) Carbon steel components:

— A primer coating or a special protective layer is applied on the SSC's surfaces;
— The SSC's are protected by tents and the nozzles are closed to minimize humid;
— Provide physical protection (cap) for nozzles and plates;
— Condensers and feedwater tank are connected to a dehumidify machine in order to keep inside lower than 30% of humid.

(b) Stainless steel components:

— The SSC's surfaces are decontaminated and wrapped up by a resistant plastic in order to protect against dirties, pollutes, sulphates, fluorites and sea breeze;
— The SSC's area is controlled to avoid dust, heat, grease and other products that could contaminate the SSCs.

(c) Electrical and instrumentation components:

— Check the surface protection;
— Check the oil level;
— Check the oil condition (once a year);
— Check the oil leakage (valves, tank, radiators and filters);
— Check the heating resistance performance;
— Check for cracks in the surface;
— Check the fan motors performance.

(d) Civil structures:

— A housekeeping plan was implemented;
— A pumping system to avoid water accumulation was implemented;
— The rebars are coated by a concrete slurry.

The third preservation condition is implemented on manufacturer's facilities in which there are some components or parts already manufactured. In this case, the requirements are the same as applicable for the first and the second preservation condition, respectively.

General provisions about preservation measures are described in Ref. [I–1].

I-1.4.3. Detection of ageing effects

For the electrical and mechanical components, checklists were established in accordance with the manufacturer's preservation instructions, in order to check the necessary preservation status of the components. The components are inspected monthly.

The checklist for mechanical components verifies:

- Storage place conditions;
- Protection against weather conditions;
- Control of component access;
- Surface and nozzles protections;
- Stainless steel parts protection;
- Bevel protection;
- The holes and threads holes preservations;
- General visual inspection to verify corrosion;
- General visual inspection to verify mechanical damage;
- The machined surfaces are coated by wax layer or primer.

The checklist for electrical components verifies:

- Storage place conditions;
- Protection against weather conditions;
- Control of component access;
- General visual inspection to verify corrosion;
- General visual inspection to verify mechanical damage;
- Oil leakage and level;
- Functional and control characteristics (fans, thermometers, valves, pumps, switchgear, oil indicators).

Additional information about inspection procedures applied for each component type is detailed in Refs [I–2, I–3].

I-1.4.4. Monitoring and trending of ageing effects

Some actions are been performed by Eletronuclear in order to guaranty the preservation of the components, as described:

- The SSCs wrapped up and placed on warehouse are inspected monthly to verify the humid indication, package damage and ageing effects;
- The SSCs already placed on the building and the civil structures are being inspected monthly in order to detect and prevent ageing effects;
- Biannual inspection, which parts of the SSC's packages are completely open to perform a full visual inspection to ensure that the SSCs are in a good condition of preservation;
- Special tests on the SSCs, if necessary.

I-1.4.5. Mitigating ageing effects

If any ageing effect or preservation problem is detected, the preventive actions are improved.

I-1.4.6. Acceptance criteria

The following acceptance criteria are used in Angra 3 in order to provide mitigating actions:

Material and mechanical components

- Package with relative humid higher than 30%;
- Visual surface corrosion points;
- Mechanical damage;
- Problems against coating or protective wax layer (blistering and delamination).

Electrical and instrumentation components

- Package with relative humid higher than 30%;
- Visual surface corrosion points;
- Mechanical damage;
- Problems against coating or protective wax layer;
- Performance fail.

Civil Structures

- Trash and dirt in buildings;
- Flooded structure;
- Visual surface corrosion points.

I-1.4.7. Corrective actions

The following actions are conducted by Eletronuclear for mitigating ageing effects for carbon steel components:

- Removal of the physical protection (cap), where applicable, cleaning with cotton cloth soaked in solvent to remove the old protective layer, the corrosion points are removed with fine abrasive sponge or a rotating brush (carbon steel wire) and then application of the protective wax layer (Tectyl) or surface preparation and then application of epoxy zinc coating;
- Cleaning and application of grease to the threaded holes;
- Placement of physical protection (cap).

Example No. 1: Mechanical and electrical connections (steel containment)

Ageing mechanism identified: uniform corrosion.

Treatment:

- Removal of the physical protection (cap), where applicable, the corrosion points are removed with fine abrasive sponge or fine rotating brush (steel wire) and then application of the protective wax layer (Tectyl);
- Cleaning and application of grease to the threaded holes;
- Placement of physical protection (cap) under the penetration.

Example No. 2: Special embedded plates (primary support components)

Ageing mechanism identified: uniform corrosion.

Treatment:

- Cleaning with cotton cloth soaked in solvent to remove the old protective layer, the corrosion points are removed by a fine rotating brush (steel wire) and then application of the protective wax layer (Tectyl);
- Cleaning and application of grease to the threaded holes;
- Placement of physical protection (cap) under the threaded holes.

Stainless steel components:

- Corrosion points are removed with fine abrasive sponge and cleaned with isopropyl alcohol;
- The whole stainless steel structure is cleaned up with isopropyl alcohol;
- The nozzles were sealed to keep the corrected humid;
- The area is improved in order to avoid any contaminant.

Electrical and instrumentation components:

- Surface preparation with use of steel brush and grinding and then application of epoxy zinc coating;
- Replacement of parts or components with cracking or performance failure.

Civil Structures:

- A housekeeping plan was implemented;
- A pumping system to avoid water accumulation was installed;
- All unnecessary material between the rebar are removed;
- The rebar surface is cleaned by steel brush process until the surface is free of crusts;
- The rebars are coated with concrete slurry.

Example No. 3: Rebar (civil structures)

Ageing mechanism identified: uniform corrosion;

Treatment:

- All unnecessary material between the rebar is removed;
- The rebar surface is cleaned by steel brush process until the surface is free of crusts;
- The rebars are coated with concrete slurry.

Additional information about cleaning of component prior to testing and inspection is provided in Ref. [I–3].

I-1.4.8. Quality management

The preservation of Angra 3 follows the manufacturer’s instructions procedures and specification requirements for long term preservation, the standard from the Brazilian nuclear regulatory body [I–4], and the guidelines for others documents in that phase [I–1].

During the delayed construction, the Eletronuclear departments are arranged to support the preservation tasks and avoid ageing effects on SSCs as described in Fig. I–1. More detail about the responsibilities can be found in Ref. [I–5].

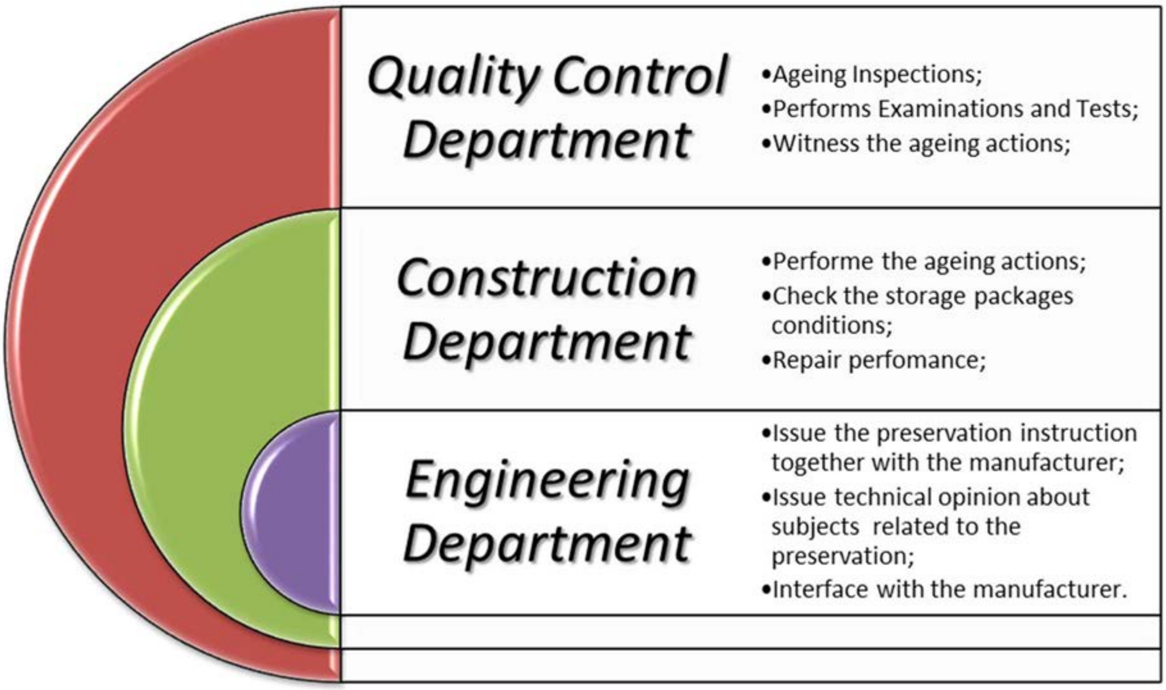

FIG. I–1. Organizational structure of the Eletronuclear departments for preservation tasks.

I-1.4.9. Administrative controls that document the implementation of the ageing management programme and actions taken

As a result of the Angra 3 delayed construction and from the point of view of administrative controls, two different situations are set up:

(1) The SSCs are wrapped up and storage in duly warehouse or provisory tents:

— The SSCs are inspected monthly to verify the humid indication and ageing effects;
— For packages inspected by month, a monthly storage protocol is issued;
— If any problem was verified during the inspection and a preventive or mitigation action was performed, an individual inspection protocol is issued that describes which kind of action was performed;
— There is a database to control the parameters related to these inspections.

(2) The SSCs are placed on site (inside the buildings) and also the civil structures:

— The SSCs are being inspected monthly in order to detect and prevent ageing effects;
— A checklist for electrical and mechanical components is implemented in accordance with manufacturer's instructions;
— During the inspection, the ageing effects identified are recorded in a preservation inspection protocol;
— A monthly preservation report is issued, which contains all the information related to the preservation inspection protocols and additional information of the preservation activities. The report is issued for electrical, mechanical and civil disciplines;
— If any actions are performed to prevent or mitigate ageing effects, the preservation inspection protocol is also issued to control these actions;

— There is an excel file to control all the preservation inspection protocols opened and the actions that were performed;
— All the preservation inspection protocols and monthly preservation reports are available in an electronic document management system.

Specific practices identified for delayed construction include the following:

— Work meeting with all departments involved in the preservation, including a regulatory body's representative, to follow up on the preservation actions every week;
— Effective participation of an independent quality control department to perform inspections and check the preservation actions;
— Strong record system for all the processes and tasks;
— The requirements for qualification or certification to perform tasks or application of material during the preservation phase are the same as during the construction or manufacturing stage;
— A preservation team is dedicated for civil structures, mechanical and electrical components preservation;
— Based on the ageing effects identified, the necessary preventive or mitigatory actions are scheduled on a monthly basis;
— The engineering department is consulted and directly involved in ageing management action that it is not specified in the preservation instructions.

I-1.4.10. Experience to bring the unit back after the delayed construction

For Angra 2, a so-called 'general inspection' was performed for some mechanical equipment, for example valves (and drives), pumps, and tanks.

The general inspection is performed by the owner and the manufacturers of the components. It is performed by visual inspection and includes a completeness check, verification of damage or performance failure, and verification of possible ageing effects before the erection or resumption of construction.

The components are ready to the erection time without damages due the interruption of the erection or construction. In order to minimize problems, the components are checked completely for functional capability; this includes a check of possible damages and/or necessary replacement of those parts which jeopardize normal operation as their lifetime is exceeded due to natural ageing. General provisions about these issues are described in Refs [I–6 to I–9].

Description of the inspection:

— Removal the preservation, packing, external and internal preservation as far as necessary for inspections;
— Disassembly the components in accordance with the operating and maintenance instruction;
— Check if the rotary parts can be moved freely and smoothly;
— Check the important functional parts in accordance with the test procedures;
— Removal of minor damage and corrosion points;
— Check the seals in accordance with the test procedures;
— Check the coating in accordance with the test procedure;
— Repair the coating, if necessary, in accordance with the test procedures;
— Renew the lubricants and grease, when applicable;
— Reassembly the component;
— Check the tight fit of all threaded connection;

- Functional test, if necessary and possible;
- Replace parts of components, if necessary;
- Check if there are open points from the preservation time;
- Close the inspection documentation;
- Release to erection.

Criteria for the inspection: A list of components is established that will be inspected including their respective instructions for erection, operation and maintenance. This list is prepared in accordance with the foreseen time schedule for erection or commissioning. The inspection activities were documented through the inspections plans and protocols describing inspection steps, responsibilities, findings and disposition.

I-2. INDIA

I-2.1. Description of the plant(s)

The main technical details of the plant are presented in Table I–2.

TABLE I–2. SUMMARY OF INFORMATION OF THE PLANT

Plant name	Rajasthan 5&6 / Rajasthan 7&8
Member State	India
Reactor Type	PHWR
Model	CANDU
Power	220 MW_e / 700 MW_e (net)
Construction Start Date	Rajasthan 7&8: July 2011
Standby time	Rajasthan 7&8: 3 years
First Criticality Date	Rajasthan 7&8: Planned 2021
Current status	Rajasthan 5&6: Operating
	Rajasthan 7&8: Construction in advance stage

I-2.2. Historical Aspects

Construction at site began in the year 2011. It is the first 700 MW_e domestically designed reactor. The construction was delayed by 3 years due to contractual problems, delay in freezing designs and late delivery of critical equipment. The plant is expected to go critical by 2021.

I-2.3. Environmental stressors of plant site and/or storage facilities where the SSCs have been kept

Main environmental parameters are as follows:

— Riverside site with mild weather (no sea fog, no freezing cycles, annual average temperature variations from 5°C in winter to 47°C in summer);
— Average humidity: 32% (annual average);
— Maximum humidity: 70% (during rainy season);
— Average annual rainfall: 761 mm.

I-2.4. Ageing during delayed construction

I-2.4.1. Scope of SSCs covered in ageing management

Structures (including structural elements) and components subject to ageing management were categorized as following:

— Pump spares;
— Main equipment spares. i.e. storage tanks, heat exchanger, vessel;
— Electrical and instrumentation spares;
— Pipes and pipe fittings;
— Structural items, small tanks, air receivers;
— Elastomers and rubber items;
— Rotating machines;
— Coolant channels;
— End shield calandria assembly;
— Stainless steel liner.

For each structure or component group, a set of condition indicators to be managed was defined, as indicated in Table I–3.

TABLE I–3. CONDITION INDICATORS FOR AGEING

Condition Indicators	Susceptible Materials and SSCs
General corrosion, pitting, crevice corrosion	Crevice and hide out region, low and no flow components, service water systems, service water heat exchangers, anchor bolts
Fatigue (low and high temperature)	Rotating equipment supports and piping attached to large components
Weld related cracking: (lack of fusion, ferrite depletion, crevice formation; low and high temperature)	Weld, wrought materials to casting, seam weld
Sensitization	Stainless steel and cast components
Wear and tear	Components within pumps and valves
Insulation embrittlement and degradation	Cables, motor windings, transformers
Temperature effects	Cables, elastomers
Corrosion of reinforcement, Carbonation, Spalling, cracking of concrete, loss of pre-stressing force due to long term losses	All civil structures

I-2.4.2. Preventive actions to minimize and control ageing effects

Proper storage of equipment to prevent deterioration of quality due to such effects as corrosions, contamination, and physical damage including the following measures:

— Proper access to storage area;
— Cleanliness and housekeeping practices;
— Secured and safe storage;
— Protective cover and seals;
— Special environmental condition like temperature and humidity control, inert gas blanketing as per requirement;

— Large size fittings and valves, stainless steel pipes and small diameter carbon steel pipe, and other equipment, are stored in covered storage area;
— Gas cylinders, paints, oils, chemicals, and other hazardous materials are stored separately in ventilated or semi closed area and away from main store;
— Instruments, other electronics and instrumentation items are stored in closed and dry store area;
— Equipment which cannot be stored in the covered storage are stored outside at elevated place, 400 mm above the ground level and covered to avoid any seepage of water;
— All openings of SCs are capped properly to avoid ingress of foreign material;
— Procedures, for preservation of equipment and components, are prepared at the project;
— Separate procedure checklist was prepared for every activity of preservation;
— Repacking of equipment after inspection.

Preservation of stainless steel (alloys containing more than 10% chromium) equipment, components and materials are externally protected as follows:

— Austenitic stainless steel components are not be exposed to saltwater, salt spray or salty atmosphere;
— Columns and pressure vessels are internally preserved by making use of vapor phase corrosion inhibitors if required;
— Installed gaskets and blind flanges remain unremoved until installation of piping;
— Damaged temporary or non-suitable covers of nozzles or openings are removed, machined flange faces are cleaned and reprotected with suitable rust preventive and covers are repaired or replaced, where necessary;
— All exposed bolts and flanges are coated with heavy grease if required;
— All opening of non-installed instruments is plugged or blanked off;
— The suitable primer or paint is applied on external surface, if paint is in damaged condition;
— All SCs are preserved in accordance with manufacturer’s recommendations;
— Electrical equipment and motors are stored in the warehouse where 240 V electrical supply is available to enable anti-condensation heaters in ON condition;
— Motor shafts are rotated manually, at regular intervals;
— Coolant channel: After the installation activity is completed, all the E faces and grey locks nozzles are covered with rust guard paper and plastic caps to prevent dust and ingress of foreign material;
— Fuelling machine, bridge and columns: After the installation, fuelling machine columns are covered with metallic sheet to prevent ingress of foreign material, dirt, dust and damage.

I-2.4.3. Detection of ageing effects

— Specification of parameters to be monitored or inspected: parameters and expectations for detection of ageing effects are defined in individual SCs procedures, which are used, to detect ageing effects in various systems;
— All openings and cappings are inspected regularly, if damaged, they are repaired or replaced;
— Regular inspection of painted surface is done and if damage is noticed, repainting and repairing done;
— Monitoring of nitrogen gas filled in vessels and transformers;
— Monitoring of seal between tanks bottom and foundation, to avoid water ingress under the tank bottom;
— Regular monitoring and replacement of moisture absorbents;
— Periodic shaft rotation of rotating equipment;

- Monitoring of healthiness of anti-condensation heaters;
- Measurement of insulation resistance of motors;
- Inspection of elastomers, rubber components and storage condition on regular basis;
- Programmes used for detection of ageing effects are as follows:
- Preventive maintenance of equipment in service;
- Condition monitoring of installed equipment;
- Regular inspection;
- Component specific programme;
- Functional testing of equipment in service.

Inspection, surveillance and maintenance activities are generally based on guidelines provided in Refs [I–10 to I–12] and adapted to specific actions mentioned above.

I-2.4.4. Monitoring and trending of ageing effects

Ageing effects are monitored through indicators and parameters, such as:

- High temperatures in electrical systems which are in charged condition;
- Corrosion;
- Physical damage;
- Humidity;
- Insulation degradation in electrical systems;
- Oil parameters;
- Elastomers conditions.

Data collected and assessment methods for monitoring ageing as follows:

- Observations are recorded, in procedures, for items in storage areas as well as items installed in field;
- Ageing is assessed based on comparison of specified parameters mentioned in procedures and observation taken in field;
- Recorded observations gathered are further analyzed and trended.

I-2.4.5. Mitigating ageing effects

Based on the observations through monitoring methodologies, mitigating measures are taken, such as:

- Storage and ambient condition are reviewed and improved;
- Segregation between carbon steel and stainless steel storage material;
- Replacement of elastomers, rubber items and sealing and packing materials, wherever applicable;
- Component overhauling;
- Oil condition improvement by filtering and hot circulation of oil in the system;
- Replacement or repair of component;
- Enhanced surveillance for timely detection of incipient failures;
- Change of material storage location.

I-2.4.6. Acceptance criteria

Acceptance criteria are defined in individual SSCs procedures Monitoring of SCs is done subsequent to mitigating measures. Parameters obtained are within acceptance criteria. No major corrective actions were needed.

I-2.4.7. Corrective actions

Suitable corrective actions are taken if component fails to meet the acceptance criteria.

I-2.4.8. Quality management

The implementation of ageing management programme on different SCs is done at the project, by respective sections. Section heads have administrative controls that documents the implementation of ageing management program. The implementation is done through documented procedures and software programmes. General information is provided in Ref. [I–14].

To facilitate evolution and improvement of the ageing management programme, various indicators are monitored and trended. Examples of such indicators are as follows:

— Trends of data relating to failure and degradation;
— Status of compliance with inspection programmes;
— Quality management ensures that preventive actions are adequate and appropriate. Following inspection, an audit process is in place, to verify that a corrective actions are being taken ;
— Self-assessment programme;
— Regulatory inspection;
— The activities, evaluations, assessments and results related to ageing management related are documented in various equipment preservation manuals, procedures and checklists.

I-2.4.9. Specific practices identified for delayed construction

The following specific practices were identified as relevant for delayed construction:

— Long term preservation of the supplied items with periodic inspection;
— Field walk down to observe the material condition of the system, structure and components independently by operation and maintenance groups;
— Filling critical components waiting for erection with dry instrument air or nitrogen;
— Charging all electrical systems and keeping them in operational state;
— Internal protection by keeping silica gel for reactor coolant pump casings;
— External protection with peel off coatings or wax coating or organic paints;
— Preservation and packing carried out at manufacturers shop is taking care of all preservation aspects for transportation from manufacturers works to site stores.

I-2.4.10. Experience to bring the unit back after the delayed construction

An equipment preservation and surveillance programme was established and implemented on site, and qualification of equipment was performed before installation.

For dry preservation, complete draining and drying of the system and isolation of the components were conducted from external atmosphere. Wet preservation was achieved by fully charging the system with liquid media with chemistry control. Chemistry control parameters are controlled on a regular basis and corrective actions taken as necessary.

Detailed pre-service inspection of all SSCs important to safety is conducted, such as eddy current testing of nuclear heat exchangers, feeder thickness gauging, and thickness gauging of secondary cycle piping components, to ensure the SSCs are able to perform its function during the design life .

I-3. IRAN

I-3.1. Description of the plant(s)

The main technical details of the plant are presented in Table I–4.

TABLE I–4. SUMMARY OF INFORMATION OF THE PLANT

Plant Name	Bushehr
Member State	Iran
Reactor Type	PWR
Model	WWER–1000/446
Power	1000 MW_e
Construction history (including relevant major milestones)	1972: KWU contract May 1975: Construction began March 1979: Construction suspended (completed 80%) November 1981: Bombarded during Iran–Iraq war 1994: Redesign (WWER) contract 1998: Construction resumed
Operational history (including prolonged outages and/or extended shutdowns)	From September 2012 up to now
Current status	Under operation

I-3.2. Historical Aspects

The construction history is shown in a timeline in Fig. I–2.

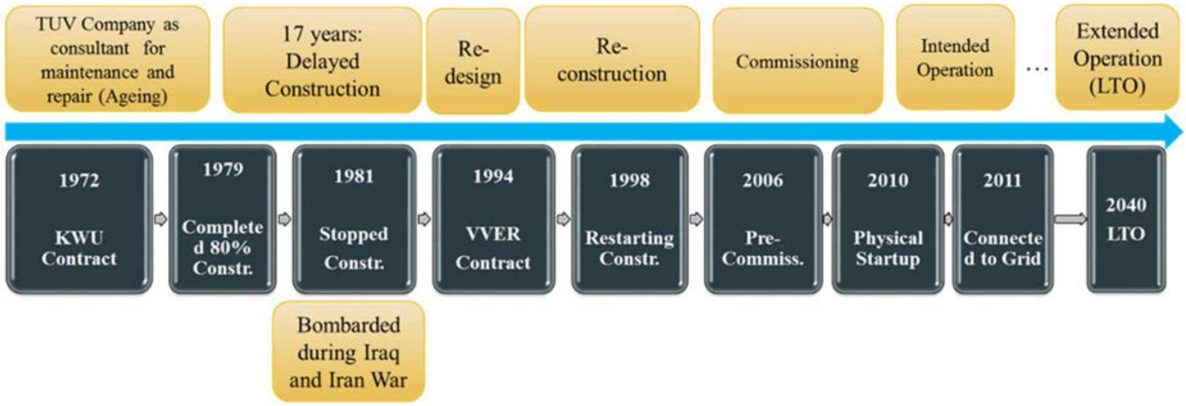

FIG. I–2. Timeline of construction of the Bushehr NPP.

The main difficulties faced during delayed construction were:

- Integration of German KWU SSCs ('integration' means the process of providing those technical requirements which makes it possible to use KWU SSCs and unify the two different designs), the plant has approximately 19% Iranian equipment, 23% German equipment and 58% Russian equipment;
- Missile attacks to the plant leading to the damage of unit 1 steel containment;
- Ageing issues due to a long delay in construction (about 17 years);
- Additional difficulties in procurement of SSCs caused by political issues.

I-3.3. Environmental stressors of plant site and/or storage facilities where the SSCs have been kept

Bushehr NPP site is located at the northern east coast of Persian Gulf. Environment and weather at the site are as follows: maximum air temperature in summer ranges within 40–46°C. Observed absolute maximum and minimum air temperatures are 50°C and –1°C, as displayed by dry bulb thermometer, with relative humidities of 18% and 62%, respectively. Due to the specific characteristics of the region and vast flat areas, significant differences are observed between day and night temperatures in summer.

I-3.4. Ageing during delayed construction

I-3.4.1. Scope of SSCs covered in ageing management

The delayed construction of the Bushehr NPP could be divided into two stages:

- Stage 1: Stopped construction (long term);
- Stage 2: Reconstruction before commissioning (short term).

In stage 1, SSCs focused mainly on civil structures, while in stage 2 whole installed and uninstalled components were involved in ageing management programmes before commissioning. Main components including in Stage 1 are:

— Steel containment;
— Steel made structures located in coastal regions;
— Unpacked equipment preserved in a roof warehouse;
— Material and mechanical components (e.g. plates, bolts, nuts, forgings, pumps, tanks, vessel, cranes);
— Electrical and instrumentation components (e.g. motors, switchgear, cabinets, sensors, transformers);
— Embedded pipelines.

The steel containment of the Bushehr NPP was constructed by the German company Krupp Industrie Stahlwerke in 1976–1978. Installation was completed in 1978. Strength and tightness acceptance tests were performed under a full programme. The SC was not in service because the plant construction was interrupted, and the SC was exposed to the open air and atmospheric effects because the concrete containment was not completed. Due to these effects the protective coating was impaired somewhat. As a result of bombing, there were several defects. For restoring SC in the specified zones, a repair plan was developed. Upon completion of repair work, for validating SC strength with the new geometry that was exceeding KWU design parameters the strength analysis was made for operational parameters. As SC analysis results satisfied strength conditions, the technical decision was made to allow for SC operation with actual geometry.

I-3.4.2. Preventive actions to minimize and control ageing effects

Ageing management activities on Bushehr NPP unit 1 during delayed construction phase:

— Preservation of vessels by injection of N_2 and Argon or keeping them under anti-corrosive solutions in the long maintenance period;
— Packing of components by applying protective layers including aluminum foils and plastic covers;
— Using silica gel packets extensively to absorb moisture and keep equipment dry;
— Improving ventilation systems;
— Applying ejecting pumps;
— Implementing of special heaters for injection of dry air into the components (extracting of wet and moisture);
— For installed SSCs: lubricating, painting, shaft rotating;
— Keeping tubes of steam generators under N_2 pressure;
— Applying impressed current cathodic protection system for embedded seawater pipelines;
— Installation of sacrificial anodes for the structures exposed to seawater at coastal regions;
— Removing moisture of power and I&C panels by putting specific local heaters;
— Considering corrosion test coupons for the steel containment;
— Implementation of manual procedures and manufacture's recommendations;
— Preventing ingress of dust into the power and I&C panels by sealing the cable penetrations;
— Assessment of local meteorological conditions.

Local meteorological conditions routinely monitored in this stage. This section presents the air qualitative characteristics based on the data of studies performed at the Bushehr NPP site. During the delayed construction period, there were observations and measurements of atmospheric air pollution impurities, concentrations of chlorides, sulphates and dust in the air(including their deposition extent), and of the deposition of chemical components. The extent of corrosion of metal samples developing in the Bushehr NPP construction site area was also observed. One of the objectives of these investigations was to acquire the following data:

— Concentrations of dust, chlorides and sulphates in the atmosphere;
— Extent of deposition of dust, chlorides and sulphates;
— Corrosion effects in the atmosphere;
— Distribution of aerosol size particles in the atmosphere;
— Chemical composition of precipitation;
— Concentrations of corrosion active gaseous impurities in the atmosphere.

The data on concentration of corrosion active gas impurities in the atmosphere are necessary for designing of the NPP ventilation system, as well as for the protection measures, which are undertaken against corrosion of equipment, metal parts and concrete constructions. Monitoring of the atmosphere was performed as follows:

— In line with the requirements of the normative documents, it was necessary to determine a concentration of atmospheric gas impurities such as SO_2, NO, NO_2, H_2S, NH_3, HCl, HF, Cl_2 within the Bushehr NPP site area;
— The atmospheric gas impurity concentrations were studied. The investigations on pollution and corrosion activity of the atmosphere at Bushehr NPP have been performed in five points where special observations were made;
— Measurements of sulphate, chloride and dust concentration in the near earth layer of atmosphere have been performed in the fourth point;
— The systematic observations for the near earth concentration of corrosion active impurities have been performed in accordance with the methodical regulations for observation for chloride and sulphate concentration at the coastal meteorological stations. Sampling was made not less than 20 times per month to make it representative. The samples were taken, and chemical analyses were performed in accordance with the normative documents;
— Concentration of chlorides, sulphates and dust in the atmosphere was determined using analogues of the samples taken from a strainer at two different heights (1.5 m and 10 m);
— Sulphate, chloride and dust precipitation from the atmosphere;
— Dust precipitation may cause electric isolation damage and together with the air humidity lead to sharp increase of the corrosion rate of metal structures;
— Precipitation rates of sulphates, chlorides and dust in the atmosphere were determined at five observation points. The observation points were filter stand expositions. An exposition period for each installation took 5 days.

The chemical composition of precipitation is an indirect characteristic of the air pollution. A rate of wet salts precipitation on the ground surface probably may be calculated, if the data on the chemical composition of precipitation and their total amount are available. Precipitation sampling was organized at five observation points. SO_4^{2-}, Cl^-, HCO_3^-, NO_3^-, NH^{4+}, Ca^{2+}, Mg^{2+} ion concentrations were evaluated. Na^+ and K^+ ion concentrations were calculated in milligram equivalents. pH values and electric conductivities of precipitations were also measured.

I-3.4.3. Detection of ageing effects

The results of the visual inspection of all SC segments and penetration nozzles were described and systematized. The scope of the defects selected for the inspection was determined, and the defects were divided into four categories (see below).

During the instrumental inspection, the following measurements and non-destructive testing were performed:

— Category 1 defects (dints and areas of the wall visible thinning):

- Measuring a defect's depth with a depth gauge or indicator;
- Grinding smooth and further penetrant liquids test of the zone around the defect.

— Category 2 defects (base metal and welds corrosion):
  - Dye penetrant testing of the ground surface and ultrasonic testing at the points where metal is mostly ground.

— Category 3 defects (visible deformation):
  - Grinding the surface smooth;
  - Penetration test and ultrasonic test (as far as possible) at the points of maximum deformation;
  - Hardness testing of the SC material (the base metal or weld) at the points of maximum deformation as well as at the points with no deformation on the same SC element.

— Category 4 defects (the SC sections inside the reinforced concrete calotte):
  - Grinding the surfaces smooth to a complete removal of corrosion;
  - Penetration test of the surfaces ground and ultrasonic test of the nozzle. Protective pipe and shell at the points of maximum grinding (at least at three points of each element) specifying the minimum thickness value;
  - Styropor degradation.

The programme also had involved measuring a degree of residual deformation at the points of category 3 defects, allowing for which it had been planned to classify them as those to be heat treated and not to be heat treated during the repair. However, radii of curvature of the deformed sections appeared to be considerably less than the limit values, i.e. all the defects detected during the visual inspection fell into the category of those to be heat treated. Therefore, a decision was made not to perform the above measurements.

To determine variation of the shell geometry at the points of maximum visible deformation, reference points (centre popped points) marked on metal plates and a variety of measurements were taken into practice.

Under the influence of environmental factors such as heat, light or chemicals, material properties (e.g. tensile strength, color, shape) of the Styropor will change. These changes, such as cracking and chemical disintegration, are usually undesirable.

In Table I–5 is the list of degradation mechanisms identified as relevant for lifetime of SC parts.

TABLE I–5. LIST OF DEGRADATION MECHANISMS

Area	Degradation	Critical Location / Part	Severity of consequences
Styropor media	Physical degradation	Styropor	Failure of Styropor causes the SC to experience stress concentration in the region of embedding into concrete
Anti-corrosive coating	Impact due to mechanical effects and coating decomposition	SC internal surface	Material degradation due to corrosion

I-3.4.4. Monitoring and trending of ageing effects

For determining the Styropor degradation, four types of mechanical test are utilized as follows:

- Compression properties;
- Tensile properties;
- Density;
- Damping capacity.

Compression tests are used to investigate the compression behavior of test specimens and for determining compressive strength, compressive modulus and other aspects of the compressive stress–strain relationship under defined conditions. This test is performed in accordance with ISO 1856 [I–15].

For tensile properties, test specimens are extended along the major longitudinal axis at a constant speed until failure or until some predetermined stress or strain value is reached. The properties that can be determined are tensile strength and elongation at break, stress and elongation at yield, elongation at a given stress and Young's Modulus. This test is performed in accordance with ISO 1798 [I–16].

Density is generally measured within polymeric materials to understand the variation in structure and overall composition. This test is performed in accordance with ISO 845 [I–17].

Damping capacity or internal friction of a material is its ability to damp vibrational energy. Standard ASTM E756 [I–18] is utilized to evaluate the damping capacity of Styropor.

Other monitoring and trending actions implemented are:

- Monitoring the pressure gages used for contouring inserted inert gas to primary side of steam generators;
- Checking the recorded data on protected pipelines (including currents and voltages);
- Controlling electrical and physical condition of sacrificial anodes;
- Setting programmes to withdrawal and control of the SC corrosion test coupons;

- Periodical checks are implemented to confirm that appropriate storage measures are being taken at the site and the vendors' factories;
- Periodic walk downs for visual inspection, checks on the atmosphere (temperature, humidity, salinity) in the storage area and insulation resistance measurement;
- Periodic maintenance activities (replacement of desiccants and rust preventing agent, cleaning, replacement of curing);
- If any sign of degradation has been detected on the exterior, maintenance actions (derusting, recoating) are taken as appropriate.

I-3.4.5. Mitigating ageing effects

If any ageing effect or preservation problem is detected, the preventive actions are improved. In particular, actions were taken in management of anticorrosive coating in the part of steel containment over concrete. As the SC protective coating made by KWU, did not match the input technical requirements of the reconstruction project it was removed after repair and reconstruction work.

I-3.4.6. Acceptance criteria

The following acceptance criteria have been used in Bushehr NPP unit 1 to provide mitigating actions.

Assessment of the SC damage caused by the hostilities:

- The instrumental inspection showed that the SC metal features sufficiently high toughness therefore, no injuries (cracks, delamination) were detected outside visible boundaries of the above injuries. Thus, when getting ready for the repair it is possible to assume that the difference between the dimensions of a section repaired and those of the defect itself will be negligible;
- Assessment of the extent of general and pitting corrosion on the base metal and welds.

The instrumental inspection showed that the depth of corrosion on the SC (not enclosed with reinforced concrete) is negligible and that the grinding done to remove corrosion with a view of restoring the protective coating does not result in decrease in the shell thickness beyond the values allowed by the strength analysis.

Assessment of the results of the strength and leak tests obtained by KWU: After the erection of the SC was completed it was strength tested at a test pressure of 6.21 kg/cm^2 and leak tested at a test pressure of 5.3 kg/cm^2. The test results are acceptable and meet the KWU design requirements.

I-3.4.7. Corrective actions

Activities on Bushehr NPP unit 1 ageing management (during redesign and completion phases): correction and replacement of some steel containment segments.

Corrective actions were proposed on the basis of assessment of individual ageing indicators by the ageing management unit in the following cases:

- If high trend of damage of the SC material is found out from NDT, technical inspections, corrosion control samples and follow-up maintenance actions or expert analyses;

— If in output results of displacement measurement system is shown values somewhat more than permitted values.

For preparing a certain corrective action, it is necessary to identify the source reason of an excessive ageing of the monitored SC place, and to propose actions to eliminate found–out degradation reasons.

Ageing management of SC (based on assessment results of condition monitoring) is evaluated using indicators. Main indicators are as following:

— Data changing trend about ageing, degradation and maintenance;
— A comparison between preventive and modifying maintenance activities;
— The number of similar failures and their corresponding degradation;
— Compliance with current inspection programmes.

For category 1 defects (dints): The SC metal features high toughness which became evident from the absence of cracks around the defects (over an area of at least 50 mm wide from the defect edge) when carrying out non-destructive testing. Therefore, when getting ready for the repair the difference between the dimensions of the repaired section and those of the defect itself could be negligible.

For category 2 defects (corrosion of the base metal and welds): Grinding of the base metal sections does not make its thickness less than the values allowed by the strength analysis. A more careful approach is taken during grinding welds, especially vertical ones, damaged by corrosion. In accordance with the strength analysis, minimum shell thickness in welds areas exceed that of the base metal. Taking into account the fact that corrosion of welds is present both on the internal and on the external side of the SC, ultrasonic thickness measurements of the well in this area are performed and sufficiency of its thickness is confirmed before the corrosion-resistant coating is applied.

For category 3 defects (visible residual deformations): No discontinuities of metal were detected during penetration test and ultrasonic test. Examination of shell zones was comprised of an area of deformation and the adjacent space around it. On the basis of the above, in the process of preparation for the repair it can be assumed that the dimensions of the repaired area will not significantly differ from those of the defect itself (deformed steel containment area). Hardness measurement performed in these places shows a slight increase in metal hardness with an increase in deformation degree. The steel containment flange for the equipment lock is straightened during the steel containment repair;

The bottom pole portion (reverse dome) of the steel containment lies in reinforced concrete bed. From inside it is pressed to the bed by confinement reinforced concrete structures and equipment of the reactor plant. To reduce stresses occurring in the steel containment during accident and pneumatic pressure tests an elastic restraint is provided in the area of outcome from concrete, it is a wedge-shaped gap filled with elastic material. The elastic restraint filling the wedge-shaped gap is chosen to meet steel containment structural strength requirements. There is thermal insulation for reducing temperature effects on steel containment in emergency conditions from inner side of steel containment in restraint area. During steel containment repair, the upper belt of elastic restraint material (Styropor) was replaced by the similar material.

For restoring steel containment in the specified zones, a repair plan was developed. Upon completion of repair work, for validating steel containment strength with the new geometry that was exceeding KWU design parameters, the strength analysis was made for operational parameters. As the results of the steel containment analysis satisfied strength conditions, the technical decision was made to allow for steel containment operation with actual geometry.

I-3.4.8. Quality management

Quality assurance of operations aimed at the KWU equipment integration is provided in several stages as illustrated in Fig. I–3.

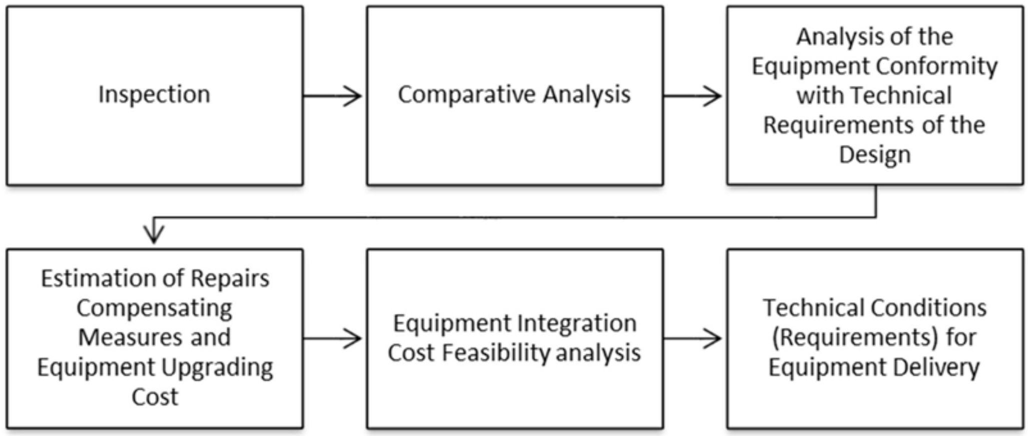

FIG. I–3. Stages for equipment integration.

The programmes aimed at KWU equipment integration into the completion project for Bushehr NPP unit 1 by types of equipment:

— Safety class 4 air ducts integration programme;
— Installed cable steel structures integration programme;
— Cable products integration programme;
— Safety class 4 pipelines integration programme;
— Integration of cable steel structures being stored in the principal warehouses;
— Integration of supports and hangers of safety class 4 pipelines;
— Integration of external firefighting pipeline;
— Additional steel containment non-destructive testing;
— Integration of vessel equipment;
— Integration of KWU evaporation equipment;
— Integration of rotating mechanisms;
— Polar crane integration;
— Hoisting mechanisms integration;
— Steel containment equipment integration;
— Integration of power transformers;
— Equipment of power transformers with auxiliary protection and control panels;
— Integration of waterworks mechanical equipment;
— Integration of refrigerating units;
— Integration of turbine condensers;
— Integration of heat engineering equipment of the low pressure regeneration system;
— Deaerator integration;

— Integration of KWU lining and embedded parts of the reactor pit, spent fuel pool, internals pool and inspection pool.

Quality assurance during operations aimed at integration of the buildings and structures erected by KWU is provided in the following stages as illustrated in Fig. I–4.

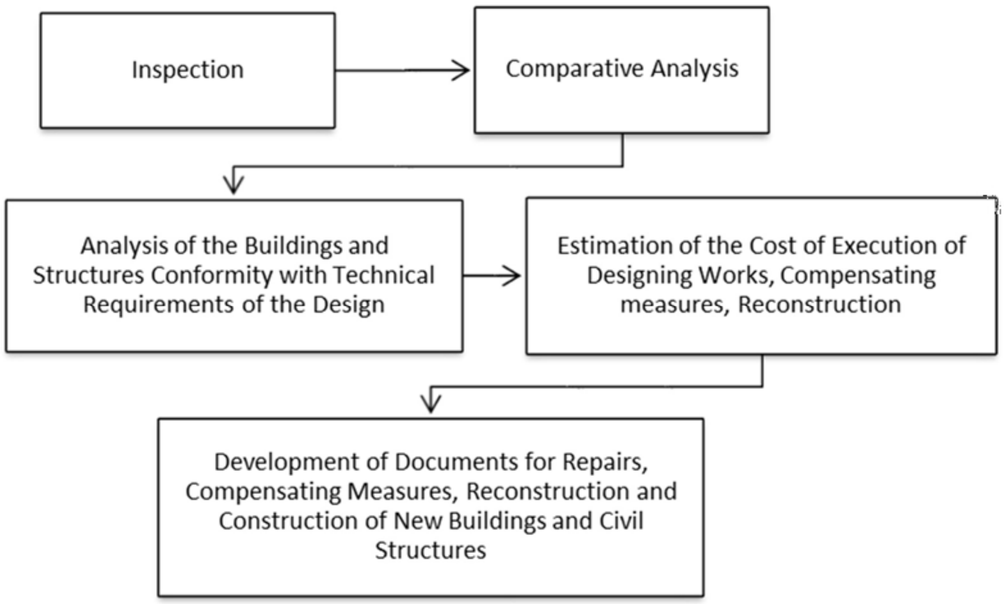

FIG. I–4. Quality assurance process.

— The programmes aimed at KWU buildings and structures integration into Bushehr NPP unit 1 completion project by types of equipment: Programme of documentation development and work performance on the initial data acquisition for preparation of the built-in documentation for buildings and structures of the Bushehr NPP unit 1, made by KWU company;
— Work performance on integration of outer and inner metal, fireproof and special doors, hatches and gates of KWU supply into the Bushehr NPP unit 1 completion design;
— Integration of KWU vibroisolators for feed pumps and startup–stop pumps into the Bushehr NPP unit 1 completion design;
— Integration of spring–damping supports of floor slabs in the rooms of ZX building (Emergency bunkered building);
— Work performance on integration of heat insulating supports for steel cold water pipelines;
— Documentation development and work performance on integration of heat insulating for outer surfaces of equipment at Bushehr NPP unit 1;
— Documentation development and work performance on integration of protective color coatings for outer surfaces of pipelines and supports for the pipelines of safety class 4 at Bushehr NPP unit 1;
— Documentation development and work performance on integration of civil structures erected by KWU;
— Integration programme for protective coating for surfaces of concrete reinforcing structures;
— Integration programme for protective coating based on ‘Kerabutyl’ material;
— Integration programme for anchor bolts for equipment;
— Integration programme for roads, footpaths and asphalt sites;

— Monitoring programmes for settlement of buildings and structures of Bushehr NPP unit 1.

The results of the instrumental inspection are described in the protocols of non-destructive testing.

Analysis of the as-built documentation completeness:

- The manufacturer's reporting and as-built documentation for the performed erection work was reviewed. The review aimed at determining the completeness of the above documentation in the Bushehr NPP Documentation Centre;
- The list of the steel containment elements for which the as-built documents are unavailable (or are incomplete) was compiled;
- Deviations from the requirements of the norms and standards and detail design which had occurred during the fabrication, erection and testing.

Assessment of the containment elements construction completion before the hostilities:

- The analysis of the KWU reporting and as-built documents enables to reach the conclusion that before the hostilities the steel containment had been completely erected. Strength and leak tested and had been ready to perform its functions;
- The results of the instrumental inspection are specified in the protocols of non-destructive testing (ultrasonic test and penetration test) and in the summary table of the visual inspection results.

I-3.4.9. Specific practices identified for delayed construction

The whole specific practices were included in the main related sections.

I-3.4.10. experience to bring the unit back after the delayed construction

The available information has been included the main related sections and unit returning back to normal activities is being done in accordance with approved procedures.

I-4. JAPAN

I-4.1. Description of the plant(s)

The main technical details of the plant are presented in Table I–6. General information about design codes and rules applied, including during delayed construction, are provided in Ref. [I–19].

TABLE I–6. SUMMARY OF INFORMATION OF THE PLANT

Plant Name	Ohma
Member State	Japan
Reactor Type	BWR
Model	ABWR
Power	1383 MW_e
Construction history (including relevant major milestones)	May 2008: Construction started March 2011: Construction suspended due to the Great East Japan Earthquake October 2012: Construction resumed within the limited scope (currently in the long term preservation status)
Current status	Under construction (construction progress: civil engineering work 65%, building construction work 39%, mechanical and electrical equipment installation work 36% as of July 2019). Licensing process under new regulatory standards in progress

I-4.2. Historical Aspects

The construction history and current facility status of the plant is as follows:

— Construction work was started in May 2008;
— Construction work was suspended because of the Great East Japan Earthquake of March 2011.

At that time, the ceiling of the second basement level of the reactor building was under construction, and it was just after equipment and piping were delivered to the site. At the on-site yard, module assembly work was underway.

In addition, at the vendors factories, a significant number of components had been or were being manufactured.

Construction work was resumed in October 2012. At that time, however, the institution of new regulations, which could require equipment modifications, was under discussion. For this reason, the construction work performed was limited in scope, and construction efforts were made within the limited scope that would not be affected by new regulations.

As a result, the construction work involving the reactor building and the turbine building was limited to work associated with the structures up to the first floor level above ground.

After the new regulatory standards became effective in July 2013, the progress of work has been practically restricted by factors such as the inability to have regulatory inspection (pre-service inspection).

At present, it was forced to preserve the equipment for a long period of time at the construction site and the vendors factories.

Since 2014, preservation measures have been implemented with consideration of long term preservation.

I-4.3. Environmental stressors of plant site and/or storage facilities where the SSCs have been kept

Main environmental parameters are as follows:

— The site is in north part of Japan and sea side, low temperature and high wind is experienced in winter;
— Because the NPP is located in a coastal area, it has salt containing atmosphere and high humidity.

I-4.4. Ageing during delayed construction

I-4.4.1. Scope of SSCs covered in ageing management

Because construction is still underway, it is recognized that basically all SSCs are covered by the AMP (including not only system components, but also building reinforcing bars and steel frames).

I-4.4.2. Preventive actions to minimize and control ageing effects

During the construction suspension period (March 2011 to September 2012), preventive actions were mainly taken to enhance humidity control and protective curing.

After resumption of work (October 2012 through 2014): In order to prevent continuous inflow of rainwater, moisture and salt, the following environmental improvement actions were taken in view of the progress of work associated with each area and each component:

— To improve the equipment preservation environment, priority was given to the construction of the ceiling structure in the preservation area;
— The reactor building and the turbine building were constructed up to the floor of the first level above ground;
— In the area where building frame construction was already completed, construction work up to the interior finishing was carried out;
— A large temporary roof was installed over the building;
— Outdoor assembled modules were protected either by installing dedicated storage warehouses or by enhancement of curing.

Based on the following concept, a long term preservation scheme (since 2014) has been established to address ageing management.

Main actions for mechanical and electrical equipment are:

— Dividing the construction area according to the progress degree of the construction. Environmental improvement measures based on the area condition have been considered and implemented. Preservation improvement measures are summarized in Table I–7.
— Equipment covered by ageing management is classified, and degradation factors (environmental stressors) expected in the construction stage are analyzed for each equipment element. Then, individual actions to eliminate the stressors are developed and implemented according to the condition of the area (the progress of work) where the equipment is preserved and stored.

Because humidity and dust deposition are main factors contributing to equipment degradation, the following (and other) environmental improvement measures are implemented in the area to eliminate such stressors:

— Dividing the construction area into smaller areas by temporary wall installation;
— Dehumidification measures (installing dehumidifiers, enclosing desiccants, energizing space heaters);
— Dust removal (installing air cleaners);
— Equipment specific curing.

The preservation, storage and management approach taken for items kept on site is applied to items stored at factories, too (see Fig. I–5).

The reactor pressure vessel (RPV) and the steam turbine rotor are protected with dedicated curing and kept inside under nitrogen gas atmosphere (see Fig. I–6).

FIG. I–5. Hydraulic control unit of a control rod driving mechanism.

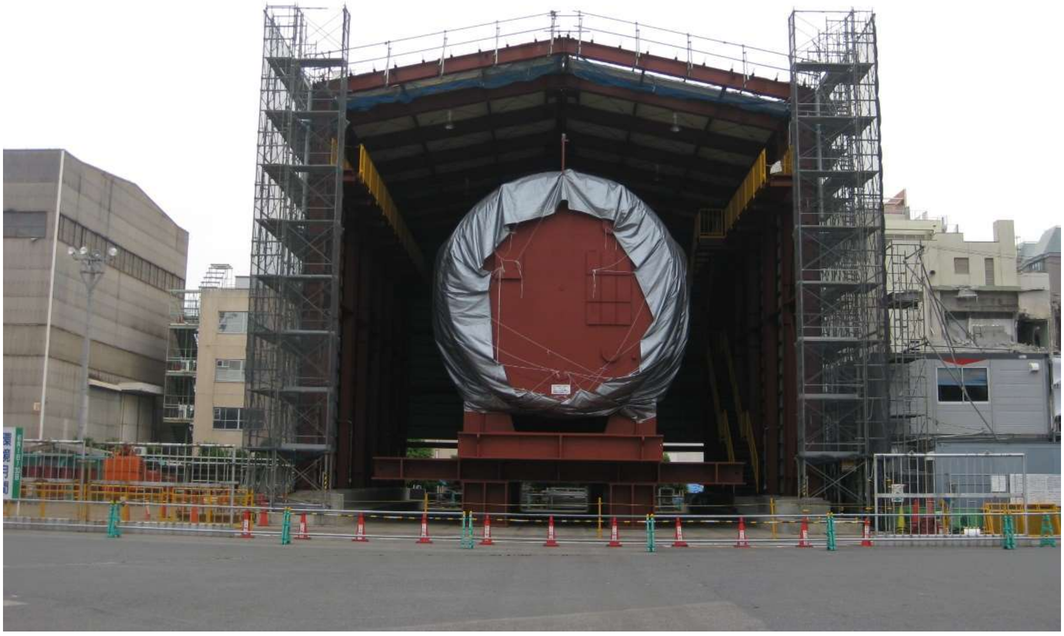

FIG. I–6. Protection of the Reactor pressure vessel (RPV).

TABLE I–7. MEASURES FOR IMPROVING THE PRESERVATION ENVIRONMENT BASED ON PROGRESS STAGE AND AREA CONDITION

Progress Stage	Area condition	Preservation environment improvement measures
1	Outdoor preservation	Items kept outdoors were moved into warehouses for storage.
2	Assembly at the yard (Outdoor assembly; curing with windshield net)	Enhancement of protective curing. Dust removal by placing concrete on the floor surface. Installation of temporary external walls and enhancement of protective curing of openings to prevent outdoor air intrusion.
3	Before building frame construction (ceiling not yet constructed; exposed to the weather)	Roof installation and curing overall building and enhanced protection by curing of individual openings to prevent rainwater intrusion. Installation of blower fans and dehumidifiers. in the area to reduce humidity.
4	After ceiling construction (without humidity control)	Proceeding with finishing of the area to improve environmental conditions. Installation of blower fans, dehumidifiers, in the area to reduce humidity.
5	Mechanical and electrical work stage (areas where dust reduction is difficult)	Enhancing the cleanliness of the area as much as possible through clean-up activities. Installation of blower fans and dehumidifiers in the area to reduce humidity.
6	Stage where mechanical and electrical work completed (good environment in conjunction with coating finish of floors and walls)	Enhancement of cleanliness by removing temporary materials, cleaning the area. Installation of temporary walls to divide into smaller area, and remove and keep out moisture, salt and dust.

Main actions for civil buildings are:

- Steel reinforcing bars
  - Exposed joint bars are derusted and cured with a bag-like cover. Further protection with plywood covering around the bars is provided to prevent the damage of joint bar covers;
  - The covers are checked periodically for damage and are replaced if necessary;
- Steel frames: some of the steel frames used for erection are checked for quality, derusted and coated with rust preventing coating.

I-4.4.3. Detection of ageing effects

- Periodical checks are implemented to confirm that appropriate preservation measures are being taken at the site and the vendors factories (see Section 2);
- Periodic walkdown for visual inspection, checks on the atmosphere (temperature, humidity, salinity) in the preservation area and insulation resistance measurement;
- Periodic maintenance activities (replacement of desiccants and rust preventing agent, cleaning, replacement of curing);
- If any sign of degradation has been detected on the exterior, maintenance actions (derusting, recoating) are taken as appropriate.

I-4.4.4. Monitoring and trending of ageing effects

Monitoring is conducted with periodical check described in above section. Overhaul for sample equipment was also conducted to confirm if preservation and storage measure was appropriate.

In view of possible consequences of long term preservation and storage, representative equipment selected according to the following concepts was overhauled for verification to determine if the preservation and storage measures taken thus far were appropriate.

Concepts for selection:

- Equipment already showing signs of failure;
- Equipment that was brought to the site four or more years ago;
- Uniform selection from pumps, electric motors, valves, containers, special containers, piping and pipe supports.

A total of 27 components were inspected.

Overhaul results:

- Some of the equipment inspected showed minor rusting on the exterior surface, but it was not significant to affect their shapes;
- Internal parts such as slide bearings, roller bearings and heat transfer tubes were found to maintain a glossy metal surface and be in a good condition;
- No degradation such as corrosion attributable to long term preservation was found. Protective curing at shipping or rust preventing coating of some of the equipment inspected, however, showed signs of ageing degradation;
- Overall, it is concluded that current preservation and storage measures are appropriate to maintain the quality of each components and structures.

Currently, the licensee is in evaluation phase whether the developed equipment preservation and storage measure is appropriate, and the evaluation of component integrity is future task. The acceptance criteria would be determined before integrity evaluation is conducted.

I-4.4.5. Mitigating ageing effects

If any ageing effect or preservation problem is detected, improve, supplement or modify the preventive measures described above. For example, it is considered to advance construction progress stage to improve preservation environment if practical.

I-4.4.6. Acceptance criteria

Generally, acceptance criteria are no deformation and no degradation for SSCs and preservation measures due to ageing effects.

Certain extent of degradation is acceptable for SSCs, which is restored by replacement of consumable parts or simple refurbishment or maintenance.

I-4.4.7. Corrective actions

If an ageing effect or preservation problem is identified during the monitoring of the SSCs and it does not comply with the acceptance criteria, a corrective action is performed. If there is significant deviation from acceptance criteria, large scale repair or replacement would be considered (future work).

I-4.4.8. Quality management

Internal manuals on preservation and storage measures have been developed to address long term preservation and storage since 2014.

Management procedures and management records are documented and managed as a part of quality documentation.

Cooperation with supplier to maintain quality:

— With the understanding that the licensee (NPP owner) has the primary responsibility for ensuring the safety of the plant in the future, the licensee has developed a policy to maintain product quality during the period of delayed construction;
— Activities to maintain the quality of each product are planned and performed under the responsibility of the supplier in accordance with the agreement between the licensee and the manufacturer;
— The licensee reviews the quality maintenance measures implemented by the supplier to ensure its consistency with the licensee's policy to maintain product quality; as needed, provides instructions concerning the measures; coordinates quality maintenance activities to ensure that there is no difference between suppliers; and seek that the measures are reasonable and effective to ensure the integrity of the plant as a whole;
— Specifically, the licensee requires all contractors to propose an annual plan for implementing the quality preservation measures and assess them before ordering a contract;
— In order to contribute to maintaining the quality of the plant, the licensee encourages contractors to share knowledge gained in the process of implementing the measures and to develop common understanding;
— The licensee has in place an internal quality manual used for product quality maintenance during the period of delayed construction and takes the following steps to maintain product quality:
    - In accordance with a contract agreement on the implementation of quality maintenance measures, the licensee requires contractors to submit a plan for product preservation and storage measures and ensure that the plan is adequate;
    - The licensee performs witness inspection on a regular basis to ensure that the preservation and storage measures are implemented as planned and preserved products are in good condition. If corrective action is considered necessary, the licensee requires the contractor to make improvements as needed;

- If signs of product degradation are detected, the licensee requires the contractor to report it, take corrective action and improve the plan for storage measures;
- For inspection procedure and record, the licensee specifies development and approval procedures, record form, and retention of inspection records (see Figs I–7 and I–8).

FIG. I–7. Witness inspection.

FIG. I–8. Record of witness inspection.

I-4.4.9. Specific practices identified for delayed construction

During the delayed construction period, obsolescence issues might occur. For example, analogous protection relay of metal clad and power centre is considered to be replaced with digital type because it is not available commercially. It would be replaced after resuming construction and before inspection of the installation status. Another specific practice during delayed construction is the cooperation with the supplier to maintain the SSCs' qualification.

I-4.4.10. Experience to bring the unit back after the delayed construction

Steps to prepare for resumption of construction:

— The licensee has improved the product preservation environments and developed preservation measures appropriate for each preservation environment. Now, the product quality maintenance measures are in place;
— From 2016 to 2017, some typical equipment was disassembled and inspected. The improvements to the storage environments and the storage measures for each environment was reviewed to ensure that they are appropriate. no product degradation involving deformation was found and determined that the current preservation measures is appropriate and product quality would be properly maintained by continuing the current preservation measures;
— When construction is fully resumed, measures for environmental improvement is removed. Temporarily, some areas return to an outdoor environment and are protected only by individually curing products. The cure is replaced as needed in areas with a degrading cure.

Steps to ensure integrity:

— Before construction is fully resumed, products are visually inspected to ensure that they have no structural flaws on the surface. If harmful degradation is detected in product shape, the product is replaced with a new one;
— During construction, structural inspections (installation inspection, visual inspection, pressure testing) are performed to ensure the structural integrity of preserved products;
— During construction, functional inspections (individual systems as well as the plant as a whole) are performed to ensure the integrity of the entire plant.

I-5. ROMANIA

I-5.1. Description of the plant(s)

The main technical details of the plant are presented in Table I–8.

TABLE I–8. SUMMARY OF INFORMATION OF THE PLANT

Member State	Romania
Reactor Type	PHWR
Model	CANDU 6
Power	660 MW_e (net)
Construction Start Date	1983
Construction Suspension Date	1990
Construction Restart Date	2001
Standby time	11 years
First Criticality Date	2007
Current status	Operational

I-5.2. Historical Aspects

Romania has only one NPP, Cernavoda NPP, with two units in operation. Cernavoda NPP Units 1 and 2 cover up to 19% of Romania's total energy production. The operating license is held by Societatea Nationala Nuclear Electrica (SNN).

Cernavoda NPP is located in Constanta county, latitude 44.3°N and longitude 28.01°E in the Dobrogea region. The nuclear site lies about 2 km southeast of the Cernavoda town boundary, at 4 km southeast of Danube river, and at about 1.5 km northeast from the first lock on the Danube–Black Sea Channel.

Cernavoda NPP is based on the CANDU (CANada Deuterium Uranium) technology.

The design of Cernavoda NPP was performed by Atomic Energy of Canada Ltd. (AECL) for the nuclear steam plant and Ansaldo Nucleare for the balance of the plant. The turbine generator was provided by General Electric. The contract for construction of Cernavoda NPP covered only Units 1 and 2. The extension of the plant with other units (Units 3 and 4) is done in the framework of another contract. The construction of Cernavoda Unit 2 started in 1983 and, as per contract provisions, around 67% of the equipment was provided by the main contractors (AECL, Ansaldo, General Electric) by 1990 when the construction was stopped. At the time of suspension, the main activities were developed proportionally as follows:

- Procurement = 67%;
- Civil Construction = 75%;
- Mechanical/ Piping/ HVAC Construction = 25%;
- Electrical and I&C = 10%.

I-5.3. Environmental stressors of plant site and/or storage facilities where the SSCs have been kept

Main environmental parameters are as follows:

- Riverside site with continental mild weather: no sea fog, no freezing/thaw cycles, 10.5°C multiannual average temperature in the area (approx. –2°C in January and 24.5°C in July);
- Relative humidity considered: 72% (annual average), with > 80% in the cold season and < 70% in the hot season;
- Maximum temperature in the hot summer days (40°C) and minimum temperature in the winter (–2°C, sometimes even –30°C in January);
- Average annual precipitation of 400–500 mm.

I-5.4. Ageing during delayed construction

I-5.4.1. Scope of SSCs covered in ageing management

(a) Reactor Building

The reactor building containment is a prestressed concrete structure consisting of the base slab, the perimeter wall, and the dome.

A bonded pre-stressing system is used as principal reinforcement for concrete containment structure. Permanent protection of tendons against corrosion is provided by cement grout.

The main ageing related degradation mechanisms (ARDM) affecting the reactor building are:

- Pre-stressing force losses;
- Creep and shrinkage;
- Corrosion of the carbon steel embedded parts due to air humidity;
- Corrosion of the carbon steel embedded parts due to fluctuant underground water level.

(b) Nuclear Services Building

The nuclear services building is multi storey metallic structure (carbon steel) assembled by bolting material. The basement is made of concrete. Protection of metallic structure against corrosion is provided by a multilayer of acrylic paint.

The main ARDM affecting the nuclear services building superstructure is corrosion of the carbon steel embedded parts due to air humidity

(c) Turbine Building

The turbine building is multi-storey metallic structure (carbon steel) assembled by bolting material. The basement is made of concrete. Protection of metallic structure against corrosion is provided by a multilayer of acrylic paint.

The main ARDM affecting the turbine building superstructure: corrosion of the carbon steel embedded parts due to air humidity.

(d) Equipment

The equipment for Cernavoda Unit 2 was procured together with Equipment for Unit 1. However, the contract with AECL, Ansaldo and General Electric includes only a part of the equipment, the balance of equipment was ordered in Romania. When the construction stops in 1990 most of the contracts with Romanian manufacturers were suspended. Therefore, the preservation programme includes the equipment delivered on the external contracts basis and some equipment already delivered from Romanian manufacturers (i.e. main output transformers).

Mechanical equipment:

- Reactor vessel (calandria) – stainless steel;
- Steam generators – carbon steel;
- Nuclear vessels (i.e. carbon steel pressurizer, carbon steel degasser–condense);
- Turbine rotors;
- Fuelling machines heads;
- Main nuclear pumps (PHT, moderator, feed, ECC);
- Main conventional pumps (condensate, feedwater, raw service water, core cooling water);
- Main balance of the plant heat exchangers;
- Valves.

The main ARDM affecting the carbon steel vessels and heat exchangers is general corrosion due to the rust. Because the absence of mechanical loading, only uniform deterioration on the material surface could occur. Its progression rate depends on several factors including oxygen content, temperature and flow rate of the medium, among others. These vessels were installed inside the reactor building and turbine building which did not have a controlled atmosphere (no operational HVAC).

The main ARDMs affecting the turbine may be permanent deformation of the shaft due to the self-weight of the rotors.

The main ARDMs affecting the valves operability are related to the degradation of organic materials made of rubber, elastomers, and oil and grease.

Electrical equipment:

- Electric generator;
- Main output transformers;
- Service transformers;
- Unit transformers;
- Busbars and breaker 24 kV.

I&C equipment:

Most of the I&C equipment were not procured. However, the already procured equipment (20 years old) became obsolete and was not used.

I-5.4.2. Preventive actions to minimize and control ageing effects

Buildings:

- For the metallic structure the condition of the painting was monitored during entire period of suspension of the construction;
- The underground water level was maintained constant and at low level. All openings were closed to ensure a constant temperature and humidity inside.

Equipment:

- The steam generators, pressurizer, heat exchangers and other large vessels were filled with nitrogen in order to prevent corrosion at inside. Outside surface was protected with the corrosion preventive protection;
- The turbine rotors were paint with a protective film and there were provided devices for monthly shaft rotation;
- The core cooling water and raw service water pumps and motors were delivered between 1992 and 2002 and installed in 2001 / 2002. The preservation included motor heaters, insulation resistance checks, and monthly shaft rotation;
- The fuelling machines which are used for online fuelling in all CANDU stations were shipped to Romania in 1989 under strict preservation requirements, including 24 hour coverage for logging of environmental conditions and monitoring cover gas pressure. In 1994, they were unpacked for full inspection, and a deoxygenation unit was attached to each fuelling machine periodically to take samples and remove oxygen;
- The valves, already procured before the construction was stopped, were stored in warehouse and a specific preservation programme, recommended by manufacturer, was applied;
- The electric equipment was preserved following the requirements provided by manufacturers (i.e. Alstom for 24 kV breaker, Electroputere SA for transformers). Also, measures were taken for reduction of humidity by heating or use of hygroscopic materials.

I-5.4.3. Detection of ageing effects

Detection of ageing effects was done generally by visual inspection. All equipment was dismounted and inspected during completion of construction. Organic materials like rubber, elastomers used for gaskets, membrane and packing, were considered aged after more than 20 years stored on shelf and they were not used.

I-5.4.4. Monitoring and trending of ageing effects

The main parameters relevant for Ageing management identified, monitored and trended are:

- The nitrogen pressure, purity (99.5%) and humidity (less than 0.01%) in the vessels were monitored and maintained in accordance with preservation procedure;
- Monitoring of the parameters in the warehouses (temperature, humidity) was performed also as it was provided in the procedure;
- Visual inspection of the protective films of grease (e.g. RUST BAN 337) or other preservations products (e.g. Tectyl 506) for carbon steel parts.

I-5.4.5. Mitigating ageing effects

There is no activity of mitigating ageing effects during the period of suspension of construction.

I-5.4.6. Acceptance criteria

Acceptance of the preservation effectiveness was performed by verification of requirements in the preservation procedure.

I-5.4.7. Corrective actions

Maintain the pressure of the nitrogen in the vessels. Maintain the temperature and humidity in the warehouse.

I-5.4.8. Quality management

It was prepared a procedure for preservation of SSC for the period of suspension of construction for Cernavoda Unit 2. This procedure contains general and specific requirements for preservation, cleanliness and maintenance of buildings, equipment and installations. These requirements were established based on the recommendations of the manufacturers and designers of the equipment;

There were prepared preservation sheets for all equipment and installations in the preservation programme, both for equipment already installed in the plant and equipment stored in warehouse. These sheets contain the records of the verification activities and corrective actions if required.

I-5.4.9. Specific practices identified for delayed construction

The whole specific practices were included in the main related sections.

I-5.4.10. Experience to bring the unit back after the delayed construction

The PHT pump motors have undergone extensive refurbishment including dismantling to verify the upper thrust bearings, restoring electrical isolation of upper brackets, pressure testing oil and air coolers, confirmation of winding resistances and insulation values and testing of resistance temperature detectors.

In 2002 a clean room was established at Research Center Pitesti where the fuelling machine heads were stored, to start the refurbishment work. This involved draining the fuelling machine heads and removing and dismantling the rams. All elastomers were replaced in the ram assemblies. Each ram assembly was then subjected to 300 ram cycles on the test facility. In 2003, the fuelling machine heads underwent pre-acceptance and acceptance testing under cold and hot loop conditions. In 2005, the equipment has been delivered to site and has undergone some minor design changes and is in pristine condition.

There are more than 20 000 valves, including small instrument valves, in the station. The approximately 2500 old valves, which were stored in the warehouse, were routed to a clean room and all elastomers and rubber elements were replaced, visually inspected, pressure tested and packing changed if required. A small percentage of non-nuclear valves were previously installed in the field and will likely require additional maintenance. For older nuclear valves, the refurbishment strategy varies and depends on the type of valve. For large nuclear valves, like the motor operated valves and containment isolation valves, a rigorous refurbishment programme is in place. The air-operated valves also have had extensive refurbishment.

Important safety components which were found in degraded condition (e.g. the PHT feed pump motor was sent to the manufacturer for complete refurbishment – it was found rust on the motor shaft) were sent for refurbishing to the manufacturer.

Enhanced ageing management practices during operation to follow effects of ageing of components in long term storage:

— There are AMPs in place for main equipment (i.e. steam generators, nuclear heat exchangers and vessels, turbo generator). These programmes are included in the ‘plant life management programme’;
— For the reactor building, the effects of ageing, due to the identified ARDM, may lead to a higher leak rate during an accident like PHT pipe rupture. Reactor building leak test is performed periodically, and corrective actions are taken to repair the detected unconformities. Also, there is a programme of testing the ‘test beams’, which were poured in the same time with the reactor building, in order to verify the rate of pre-stressing force loss.

Other specific experiences: the design report for the reactor building containment was updated taking into consideration the suspension of the construction. The design assumption related to shrinkage of the concrete and the increase of the modulus of elasticity of the concrete for 21 years was taken into consideration in the calculations. Only a part of the pre-stressing cables was installed before stopping the construction. The balance was installed after the construction was resumed.

I-6. SLOVAKIA

I-6.1. Description of the plant(s)

The main technical details of the plant are presented in Table I–9.

TABLE I–9. SUMMARY OF INFORMATION OF THE PLANT

Member State	Slovakia
Reactor Type	WWER 440
Model	V–213
Power	2 x 471 MW_e (net)
Construction Start Date	1987
Construction Suspension Date	1992
Project restart	2004
Construction Restart Date	2007
Standby time	15 years
Construction time	16 years
First Criticality Date (expected)	2020
Current status	Under construction

I-6.2. Historical Aspects

The construction of this facility in Mochovce area started in 1981 by preparation of land for construction of four units. Construction work was divided into several parts as follows:

- Construction: gross earthworks;
- Construction: 1st stage – preparation works, 2nd stage – construction EMO12, 2 x 440 MW;
- Construction: construction MO34, 2 x 440 MW.

The total planned power capacity of the NPP was 1760 MW. Construction work on NPP Mochovce units 3 and 4 was suspended in 1992 due to lack of funds. In 2006, the whole project was re-evaluated, and the construction work restarted. The activities realized during the construction period are summarized in Fig. I–9.

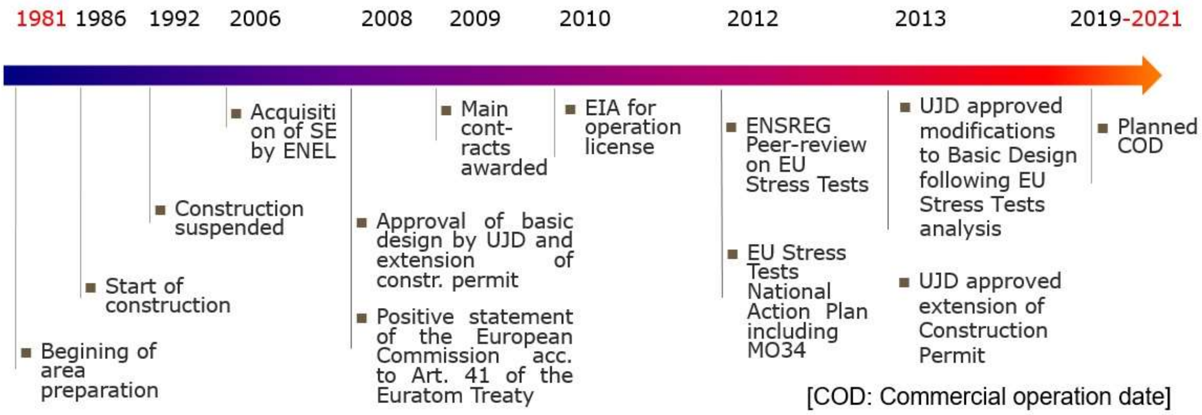

FIG. I–9. Timeline for construction of Mochovce units 3 and 4.

I-6.3. Environmental stressors of plant site and/or storage facilities where the SSCs have been kept

Main environmental parameters are as follows:

— 5 km far from river, altitude of the terrain about 200–250 m, upland;
— Continental mild weather: 9.5°C multiannual average temperature in the area (approx. –1.6°C in January and 19.9°C in July);
— Relative humidity considered: 75% (annual average), maximum humidity 100% during fog and sometimes during night in the cold season, recorded minimum humidity 14% in the hot season;
— Maximum temperature in the hot summer days 36.4°C and minimum temperature in the winter –30.8°C;
— Average annual precipitation of 575 mm.

I-6.4. Ageing during delayed construction

I-6.4.1. Scope of SSCs covered in ageing management

The basic step in the ageing management process is to determine the extent of the monitored SSCs. AMPs generally are oriented on SSCs. Each programme consists of all degradation mechanism impact on SSCs. Structure of ageing management documentation is defined in basic methodological guideline based on SSG-48 [I–20]. Ageing management process and basic requirements on this process is defined in safety guide approved and edited by nuclear regulatory authority [I–21].

The main criterion for the scoping of SSCs in this process is its safety function. Basically, the SSCs are divided to the safety classes I to IV in accordance with the graded approach. Safety class I includes selected SSCs with highest demand on reliability, qualification, quality assurance, number and scope of inspections, and related documentation. Precisely identification of individual selected facilities and their auxiliary systems and subsystems, given their safety function and safety classification pursuant is given by the regulation of nuclear regulatory authority [I–22].

The selection of SSCs for ageing management is also based on the following criteria:

- Requirements of Slovak Republic NRA;
- Requirements of the Western European Nuclear Regulators Association (WENRA);
- Equipment qualifications;
- NPP operating experience;
- Relationship of SSCs to LTO;
- The results of research and development activities;
- Outputs of the IGALL international project.

I-6.4.2. Preventive actions to minimize and control ageing effects

Preventive actions implemented to minimize, and control ageing effect are:

- For construction, there was a long term suspension time, during which construction was stopped (1992–2004);
- Main components (built-in components) were installed inside reactor building and auxiliary building in a controlled environment in accordance with the Complex Preservation Programme (duration 1992–2001) implicated after interruption of construction;
- Strategic plan for preservation, maintenance and protection of SSCs of NPP Mochovce units 3 and 4 (2001–2004) based on IAEA documents was applied during later period. Restart of project in 2004, reassess the status of stored and on-site placed SSCs;
- After decision for restart the project (2004), more than 17 700 components deposited in onsite warehouse were considered. Approximately about 4000 components (22.5%) were classified as ‘not applicable’ or ‘useless’ and consequently were scrapped. Main damaged was due to uniform corrosion by air humidity during long term storage in insufficient conditions;
- Revision of the strategic plan for preservation, maintenance and protection of SSCs of unit 3 and 4 (2005–2007);
- On main SSCs was applied guidelines to manage the component and equipment preservation activities (heat exchangers, condensers, essential system water and non–essential system water, pumps, valves, diesel generators, steam generators, reactor pressure vessel, pressure tanks, storage tanks, pipelines, electric motors and equipment, I&C, civil structures.

I-6.4.3. Detection of ageing effects

The state of the built-in and stored equipment was evaluated in accordance with the internal instructions and guidelines of Slovak NPPs and the recommendations (technical conditions) of the suppliers of the main components, constructions and systems.

Main ways of conservation of built-in SSC:

- Ensure reliable climate conditions – temperature, air humidity;
- Desiccant conservation programme – type of desiccant, time schedule of control and replacement;
- Preservation by protective coatings, respectively paintings – type, thickness, technical conditions;
- Visual inspection and control programmes.

Each of the main contractors or producers of main and large built-in components has its own preservation programme, approved by Slovenske Elektrárne company.

Inspections are performed by the following methods:

— Visual inspection, normal and endoscopic;
— Ultrasonic control;
— Capillary test;
— Surface wiping test;
— Temperature and humidity measurement;
— Pressure tests.

For any of the built-in components, inspections did not identify serious damage affecting their lifetime.

I&C components were mounted during the earlier period of construction. All components are new and were not stored for a longer time in warehouses.

Any electrical components (cables, switchgears, motors) were not mounted during the earlier period of construction. All components are new and were not stored for a longer time in warehouses.

List of documentation for care a preservation of built-in SSCs [I–23 to I–29]:

— Operating instruction for Steam Generators and Pressurizers care and storage, ID: MO34–VIT–8–P–00123, issued 2015, Vitkovice Power Engineering [I–23];
— Operating instruction for care of Main Coolant Pumps, ID: MO34–SIG–3–M01080, issued 2015, Sigma DIZ [I–24];
— Operating instruction for Main Circulation Loop Maintenance, ID: MO34–SJS–8–P–09312, issued 2015, SKODA JS [I–25];
— Operative instructions for Main Stop Valve maintenance, ID: MO34–JSJ–8–P–09313, issued 2015, SKODA JS [I–26];
— Programme: Principle of Care for Equipment during Extension of Completion, ID: PNM34376823, issued 2015, VUJE [I–27];
— Programme of Care for Equipment During the Extension of the Project of NPP Mochovce Units 3&4 completion, ID: PNM34396019, issued 2015, ENSECO [I–28];
— Procedure: Principles of Equipment care in the Period of NPP Mochovce Unit 3&4 Completion Extension, ID: PMN34638795, issued 2018, Profi Steel Holding [I–29].

I-6.4.4. Monitoring and trending of ageing effects

For long term storing of SSCs, each of main contractors prepared procedures with preservation programme, those had been approved by the operator (Slovenske Elektrárne).

Programmes include the following basic principles:

— Transparent warehouse rules (traceability);
— Keeping storage conditions (temperature, humidity);
— Preservation for SSCs;
— Packaging programme;
— Separate storing (stainless steel, carbon steel, chemical, oils);
— Periodical Inspection, ageing effect on consumable parts;

— Periodically cleaning (dust).

Each control or inspection are documented as inspection record and added to the common database. Detail of equipment in preservation packages is shown in Fig. I–10.

FIG. I–10. Preservation of large component by plastic foil – Tanks and filters in auxiliary building.

I-6.4.5. Mitigating ageing effects

Mitigation of ageing effects is achieved through:

- Ensuring suitable climate condition in accordance with the requirements in quality plan and manufacturer technical documentation. For that, humidity and temperature need to be kept in an appropriate range;
- Storing SSCs in origin, intact package (wooden box, plastic foil) without visible damage of them;
- Using preservation by desiccants in accordance with approved programmes specifying the type of desiccant, time schedule for humidity control and time schedule for changing;
- Preserving of SSCs by protective coatings in accordance with approved programmes, selected types, with controlling of thickness and with technical conditions for application;
- Ensuring periodical controls by qualified staff in accordance with inspections programmes. Time periods depend on safety classification of SSCs (usually 6 or 12 months).

I-6.4.6. Acceptance criteria

Acceptance criteria are established in quality plans, which are written and approved for all SSCs. The second important document containing defined acceptance criteria for each damage mechanism is the manufacturer's technical documentation for SSCs. In the case that, for a specific damage mechanism, acceptance criteria do not exist, adequate calculations, depending on the ageing degradation mechanism, are performed.

I-6.4.7. Corrective actions

For solving any events during the construction period, the so-called ‘Construction Failure Committee’ was established. Any defects, damages and incomplete items are added to the so-called ‘punch list’, along with an event description, date, time, room, building, who found this event, who is responsible for this SSCs (supplier or manufacturer). Following event recording, the committee proposes corrective and preventive actions, respectively. Corrective actions are proposed for immediate solution, and preventive actions are recommended for the future.

I-6.4.8. Quality management

Main activities of quality control are oriented to:

— Documentation: control completeness, commenting documentation, supervising of technological procedures, inspection and test plans, quality programmes and welding documentations;
— Inspection: on-site inspections, inspection of refurbishment and reconstruction of existing SSCs, incoming inspection in warehouses, installation inspections, individual tests (fabrication acceptance tests, site acceptance tests), pre-service inspections, on-site random control and inspections;
— For on-site inspection, only qualified inspection methods are used, e.g. mean visual inspection, ultrasonic control, capillary test, magnetic powder method, eddy current test, X ray test surface, wiping tests for contaminations (stainless steel by carbon steel);
— The inspection records are summarized in a common database which is part of the existing database of operating NPPs. These records are the basement for future operation and AMPs’ evaluation.

I-6.4.9. Specific practices identified for delayed construction

AMPs approved for operational plants are being applied to SSCs under construction. Since 2018, 13 AMPs are being applied for the units under construction. Based on this, the initial values of parameters for ageing management have been measured and recorded in a database.

I-6.4.10. Experience to bring the unit back after the delayed construction

The existing ageing management process has been also implemented on the NPP Mochovce unit 3 and 4 under construction.

In 2016, the procedure which identifies the list of in-scope SSCs for the AMP for the NPP Mochovce [I–30] was issued. That procedure defines the scope for ageing management for the mechanical, electrical and building SSCs.

The AMP for cables is implemented is performed in accordance with the respective guide – Cable AMP. This guide is valid for all nuclear units in Slovakia, and also for NPP Mochovce units 3 and 4 under construction. This AMP includes the main degradation mechanisms identified on the basis of operational experience and international recommendations, and also the monitoring of ambient parameters (temperature, radiation dose, relative humidity).

The AMPs for the pipes of essential service water system were implemented for NPP Mochovce units 3 and 4 in the construction phase; the AMP will become effective before their commissioning. The scope of activities within the AMP for the essential service water system (corrosion monitoring, concrete monolith monitoring, wall thickness measurement, visual inspections) covers the monitoring of all relevant degradation mechanisms identified on the basis of operational experience, international recommendations and results of the AMP.

The AMP of the RPV is in accordance with the respective guide – "AMP for the Reactor Pressure Vessel". This guide is valid also for NPP Mochovce units 3 and 4 under construction. The scope of the AMPs for the RPV activities (surveillance specimen programme, fluency monitoring, fatigue assessment, ISI) covers monitoring of all relevant degradation mechanisms identified based on operational experience, international recommendations and results of the AMP. The surveillance specimen programme has been extended with new materials located in the reactor core. The programme covers operating conditions for increased power of nuclear units and for the use of new type of nuclear fuel.

The AMP for the NPP containment for NPP Mochovce units 3 and 4 under construction will become effective before their commissioning.

A programme to monitor the corrosion status of secondary circuit materials was also implemented before commissioning of NPP Mochovce units 3 and 4. More than 80 components were measured (thickness) in the pre-operational phase and added to the existing database of measured components on NPP EMO12.

Next to others, the existing AMPs valid for NPP EBO V2 and NPP Mochovce units 1 and 2 will become effective as of the date of physical start-up of NPP Mochovce units 3 and 4.

In the completion of NPP Mochovce units 3 and 4, in all stages of design, the requirements relating to ageing management of SSCs were taken into account. This was done already within the revision of the basic design in the document "Principles of Development and Implementation of AMPs" for NPP Mochovce units 3 and 4 and also by development of safety concepts for the most frequent degradation mechanisms. These concepts included the specifics of the NPP Mochovce units 3 and 4 project and experiences from implementation of AMPs on units of NPPs EBO V2 and NPP Mochovce units 1 and 2 in operation. At the stage of the implementation project, specific projects of those supplies were elaborated that are necessary in implementation of individual AMPs (RPV surveillance programme, monitoring of the thermal ageing of primary circuit materials, corrosion loop for monitoring corrosion processes in primary circuit materials, erosion corrosion monitoring on the components of secondary circuit, surveillance programme for monitoring cable life).

Within pre-operational inspections of SSCs of NPP Mochovce units 3 and 4, not only the results of NDT inspections already conducted were collected, but also zero measurements of all steam generator heat-exchange tubes, secondary circuit piping components included in the monitoring within AMPs for piping of secondary circuit, samples were taken from the secondary circuit components to verify the chemical composition, prepared surveillance cable specimens for laying in real operating conditions. Data from these measurements are registered in the database on ageing management and will be used for the assessment of SSCs lifetime at NPP Mochovce units 3 and 4.

REFERENCES TO ANNEX I

[I–1] COMISSÃO NACIONAL DE ENERGIA NUCLEAR – CNEN: Conservação Preventiva em Usinas Nucleoelétricas, CNEN NE 1.18, CNEN, Brazil (1985).

[I–2] ELETROBRAS ELETRONUCLEAR, Techinical Instruction – No. ES–3–0237–4600–N90055: Instruções Para Armazenamento e Inspeções, Brazil (2016).

[I–3] ELETROBRAS ELETRONUCLEAR, Process specification – No. DD–3–0232–0623–36010C: Requirements Related to the Cleaning, Pressure Testing and Preservation of Components and Systems of Nuclear Power Plants Testing and Preservation at the Manufacturer’s Shop, Brazil (1995).

[I–4] COMISSÃO NACIONAL DE ENERGIA NUCLEAR – CNEN: Garantia da Qualidade para a Segurança de Usinas Nucleoelétricas e Outras Instalações, CNEN NN 1.16, CNEN, Brazil (1999).

[I–5] ELETROBRAS ELETRONUCLEAR, Executive Procedure – No. PE–A3–IE–009: Atividades e Responsabilidades relacionadas à preservação de itens, Brazil (2016).

[I–6] ELETROBRAS ELETRONUCLEAR, Technical Instruction – No. ES–0237–4600–N90135: Instruction for general inspection of: Rubberized tanks and heat exchangers, Brazil (1997).

[I–7] ELETROBRAS ELETRONUCLEAR, Technical Instruction – No. ES–0237–4600–N90133: Instruction for general inspection of: Pumps, compressors and their accessories, Brazil (1997).

[I–8] ELETROBRAS ELETRONUCLEAR, Technical Instruction – No. ES–0237–4600–N90135: Instruction for general inspection of: Rubberized tanks and heat exchangers, Brazil (1997).

[I–9] ELETROBRAS ELETRONUCLEAR, Techinical Instruction – No. ES–3–0237–0087–N00100: Tratamento de Desvios ou Pendências Durante a Fase de Preservação, Brazil (2016).

[I–10] ATOMIC ENERGY REGULATORY BOARD, AERB Safety Guide No. AERB/NPP/SG/O–2: In-service Inspection of Nuclear Power Plants, AERB, Mumbai, India (2004).

[I–11] ATOMIC ENERGY REGULATORY BOARD, AERB Safety Guide No. AERB/SG/O–8: Surveillance of Items Important to Safety in Nuclear Power Plants, AERB, Mumbai, India (1999).

[I–12] ATOMIC ENERGY REGULATORY BOARD, AERB Safety Guide No. AERB/NPP/SG/O–7: Maintenance in Nuclear Power Plants, AERB, Mumbai, India (2005).

[I–14] ATOMIC ENERGY REGULATORY BOARD, AERB Safety Guide No. AERB/SG/QA–5: Quality Assurance during Commissioning and Operation of Nuclear Power Plants, AERB, Mumbai, India (1993).

[I–15] INTERNATIONAL ORGANIZATION FOR STANDARIZATION, ISO 1856:2018 Flexible cellular polymeric materials — Determination of compression set, Geneva, Switzerland (2018).

[I–16] INTERNATIONAL ORGANIZATION FOR STANDARIZATION, ISO 1798:2008 Flexible cellular polymeric materials — Determination of tensile strength and elongation at break, Geneva, Switzerland (2008).

[I–17] INTERNATIONAL ORGANIZATION FOR STANDARIZATION, ISO 845:2006 Cellular plastics and rubbers — Determination of apparent density, Geneva, Switzerland (2006).

[I–18] AMERICAN SOCIETY FOR TESTING OF MATERIALS, ASTM E756–05: Standard Test Method for Measuring Vibration–Damping Properties of Materials. ASTM International, West Conshohocken, PA (2010).

[I–19] JAPAN SOCIETY OF MECHANICAL ENGINEERS, JSME Codes for Nuclear Power Generation Facilities – Rules on Design and Construction for Nuclear Power Plants, JSME S NA1 (2005/2007, 2012).
[I–20] INTERNATIONAL ATOMIC ENERGY AGENCY, Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants, IAEA Safety Standards Series No. SSG-48, IAEA, Vienna (2018).
[I–21] NUCLEAR REGULATORY AUTHORITY OF SLOVAK REPUBLIC, Safety Guide BNS I.9.2/2014 – The Management of Ageing Nuclear Power Plants – Requirements (2014).
[I–22] NUCLEAR REGULATORY AUTHORITY OF SLOVAK REPUBLIC, Act No. 430/2011 on nuclear safety requirements (2011).
[I–23] Operating instruction for Steam Generators and Pressurizers care and storage, ID: MO34–VIT–8–P–00123, Vitkovice Power Engineering (2015).
[I–24] Operating instruction for care of Main Coolant Pumps, ID: MO34–SIG–3–M01080, Sigma DIZ (2015).
[I–25] Operating instruction for Main Circulation Loop Maintenance, ID: MO34–SJS–8–P–09312, SKODA JS (2015).
[I–26] Operative instructions for Main Stop Valve maintenance, ID: MO34–JSJ–8–P–09313, SKODA JS (2015).
[I–27] Programme: Principle of Care for Equipment during Extension of Completion, ID: PNM34376823, VUJE (2015).
[I–28] Programme of Care for Equipment During the Extension of the Project of NPP Mochovce Units 3&4 completion, ID: PNM34396019, ENSECO (2015).
[I–29] Procedure: Principles of Equipment care in the Period of NPP Mochovce Unit 3&4 Completion Extension, ID: PMN34638795, Profi Steel Holding (2018).
[I–30] Special procedure – The list of SSCs for Ageing Programme for Nuclear Power Plant Mochovce 3&4, ID: 8–SP/0032 (2016).

ANNEX II.

EXPERIENCES OF MEMBER STATES WITH AGEING MANAGEMENT DURING EXTENDED SHUTDOWN

II-1. ARMENIA

II-1.1. Description of the plant(s)

The main technical details of the plant are presented in Table II–1.

TABLE II–1. SUMMARY OF INFORMATION OF THE PLANT

Plant name	Armenia 2
Member State	Republic of Armenia
Reactor Type	WWER
Model	W–270
Power	407.5 MW_e
Start of Operation	1980
Start of the extended shutdown mode	1989
End of the extended shutdown mode	1995
Standby time	6 years
Current status	In operation

II-1.2. Ageing during extended shutdown

II-1.2.1. Scope of SSCs covered in ageing management

This programme provides components, those guarantee operability during the extended shutdown period, AMPs are being developed, within which additional requirements are provided for monitoring the determination of the technical condition and the presence of a residual resources. General requirement of the programme are provided in Refs [II–1 to II–3]. As part of identifying the deterioration of the technical condition in accordance with the results of seismic impact, work was carried out within the framework of one time survey programmes. The selection criteria are listed below:

— SSCs retain their functional and natural characteristics during postulated initiating events, in order to maintain energy stability, the possibility of emergency shutdown and its restoration in a safe stopped state, the ability to prevent or mitigate the consequences of emergencies;
— SSCs do not affect safety, which ensure the performance of functions during the service life in the event of a failure of an emergency shutdown and with complete loss of power supply;

— SSCs do not affect safety, which ensure the fulfilment of functions during the operation period in accordance with the requirements of fire safety and environmental protection;
— Station-wide SSCs necessary for stable power generation.

Groups and subgroups of the equipment of Armenian NPP unit 2, for the organization and performance of the inspection of equipment and facilities, are presented in Table II–2.

TABLE II–2. GROUPS AND SUBGROUPS OF COMPONENTS

No.	Surveyed equipment's groups and subgroups
1	Thermomechanical equipment of Armenian NPP unit 2
1.1	Equipment and pipelines of the reactor installation within the design limits specified by organization: JSC OKB 'GIDROPRESS' including reactor vessel, the upper unit (including covers and drive ARK), internals, pressure compensator, steam generators, main circulation pipelines of the first circuit (main circulation pipeline) and bubbler
1.2	Turbine units
1.3	Main circulation pipeline
1.4	Heat exchange equipment (vessels, heat exchangers, pipelines)
1.5	Ventilation and air conditioning equipment
1.6	Transport and technological equipment and lifting mechanisms
1.7	Pump equipment
1.8	Diesel generator system (mechanical part)
1.9	Valves, including safety and control valves
2	Electrical equipment and equipment of control and management systems (I&C) of unit 2
2.1	0.4 kW Electric motors
2.2	Electrical equipment
2.3	Generator equipment
2.4	Cable management in the composition of electrical equipment and equipment of the SS SIS in the reactor compartment and the turbine hall
2.5	Equipment SIS (safety important systems) CS (control systems)
3	Civil structures
4	Radioactive waste management complex
5	Spent fuel storage pool

II-1.2.2. Preventive actions to minimize and control ageing effects

During extended shutdowns, resource management mechanisms are used to minimize the deterioration of equipment, such as developing checklists for conducting targeted walk downs, indicating the frequency of their conduct aimed at identifying deviations associated with the events that caused the long outage and, accordingly, prevent further deterioration of the components. Control of environmental parameters (temperature, humidity, pressure and, if necessary, activity) are included in the checklist of the targeted walk downs.

II-1.2.3. Detection of ageing effects

Ageing effects are detected by testing.

Reactor vessel, upper unit, internal components, steam generators, main circulation pipeline pressurizer, pressurizer pipeline, bubbler, identified as irreplaceable and non-recoverable components were examined in accordance with the technical control programmes, which include:

- Verification of compliance of the current technical condition with the requirements of the design and operational documentation;
- Identification of restrictions on the parameters and operating conditions, of the components of the reactor;
- Determination of characteristic failures and defects identified during maintenance, based on the results of metal and welded joints inspection, as well as determination of their causes;
- Establishment of metal ageing mechanisms;
- Establish the determining parameters;
- Monitoring the state of the metal by determining parameters;
- The comprehensive survey of materials.

Additional details about inspection methodology is provided in Ref. [II–4].

II-1.2.4. Monitoring and trending of ageing effects

Environmental monitoring (temperature and humidity) to identify the mechanism of ageing is performed by periodic measurements.

II-1.2.5. Mitigating ageing effects

Ageing effects are mitigated by reconstruction and replacement by means of an ageing management work plan.

This is a general approach. SSCs are replaced, resulting in disassembly SSCs overhaul detected achievement of the final state. This is applicable until a decision is made that there is no need for replacement due to decommissioning.

II-1.2.6. Acceptance criteria

Acceptance criteria are described in the relevant documents (programmes, procedures, technical manuals, evaluation reports).

II-1.2.7. Corrective actions

The proposal or recommendation of ageing management reports and other reports are implemented through the AMP work plan.

II-1.2.8. Operating experience feedback

Internal and external events are collected by the department of operational experience and are provided to the units in a planned manner or at the request of interested structures to prepare effective AMPs.

II-1.2.9. Quality management

The quality assurance department is responsible for quality management in accordance with the quality assurance programme. The scope of this programme includes verification of compliance of the provisions postulated in the operational and administrative documentation with the actual condition.

II-1.2.10. Specific practices identified for extended shutdown

In accordance with approved documents and procedures.

II-1.2.11. Experience to bring the unit back after the extended shutdown

The following items summarize actions to bring back the plant after extended shutdown:

— Special procedures on activities during the shutdown period, including long shutdowns due to initiating events that caused the shutdown, are determined based on the situation and are followed by units for the entire period of shutdown;
— A timeline for actions to be followed is also developed accordingly;
— Management meetings provide detailed reviews of current critical work. At these meetings, issues are discussed, especially those requiring management decisions, corporate support and assistance. Both internal and external operating experience associated with shutdown events are presented for analysis and assessment of embedded risks for the plant's current activities;
— A detailed discussion is held with the coordinator regarding plans, priorities, teamwork, requirements, responsibilities, problems, and jobs that need to be addressed;
— A special launch monitoring programme is designed for actions at launch and includes a full range of systems to check the readiness of systems to perform design functions. All items important to safety are subject to inspection, regardless of whether they have been subjected to any maintenance or not;
— Commissioning procedures are prepared for all equipment, considering the revision of operating instructions, which indicate possible restrictions on the operating conditions (mitigation of operating conditions), determined according to the results of the identified ageing mechanisms to ensure long term operation;
— Equipment overhaul is performed according to long term schedules or, if necessary, based on the technical condition of the equipment;
— A review of workplaces is conducted by all interested parties for work that is critical, and for work that is performed after a long break in work;
— All special procedures for monitoring the performance of safety systems are reviewed by all departments concerned;

— To prevent degradation during the extended shutdown period, a system or equipment monitoring programme is developed for the entire period of inactivity.

II-2. INDIA

II-2.1. Description of the plant(s)

The main technical details of the plant are presented in Table II–3.

TABLE II–3. SUMMARY OF INFORMATION OF THE PLANT

Plant name	Kakrapar Atomic Power Station (KAPS) 1&2
Member State	India
Reactor Type	PHWR
Model	Indian Standard PHWR (2 Loop)
Power	220 MW_e
Start of Operation	1993 (KAPS–1) and 1995 (KAPS–2)
Start of the extended shutdown mode	KAPS–1: 2008 and 2016
	KAPS–2: 2015
End of the extended shutdown mode	KAPS–1: 2010 and 2018
	KAPS–2: June 2019
Standby time	KAPS–1: 2 + 2 years
	KAPS–2: 4 years
Current status	KAPS –1 operating and KAPS–2 operating

II-2.2. Historical Aspects

Both units were in extended shutdown stage for en-masse coolant channel replacement for above mentioned period. KAPS–1 restarted after an outage period of 3 years. The replaced coolant channels have shown degradation in outer diameter and failure due to formation of nodules. En-masse coolant channel replacement was again taken up for the same unit. KAPS–1 has restarted in 2018 and KAPS –2 restarted in June 2019. The ageing management practices followed are the same in both units. General details of plant life management procedures can be found in Ref. [II–5].

II-2.3. Environmental stressors of plant site and/or storage facilities where the SSCs have been kept

Main environmental parameters are as follows:

— Riverside site with mild weather (no sea fog, no freezing cycles, annual average temperature variations from 5°C in winter to 45°C in summer);
— Average humidity: 40% (annual average), maximum humidity: 80% (during rainy season);
— Average annual rainfall: 1705 mm.

II-2.4. Ageing during extended shutdown

II-2.4.1. Scope of SSCs covered in ageing management

Structures (including structural elements) and components subject to ageing management were categorized under the following broad categories:

Category 1 — Major critical SSCs limiting plant life and not replaceable

The major critical components are those for which integrity and functional capabilities have to be ensured since they have the highest safety significance, are non-replaceable, and control the plant life. Examples are: calandria, end shield components, calandria tubes, in-core components for reactivity mechanisms, moderator system piping (inside calandria vault). All major civil structures also fall under this category.

Category 2 — Critical SSCs

These components also have high safety significance. Usually they are difficult to replace due to radiation exposure, long shutdown period and high cost, for example: PHT system piping and equipment, pressure tubes, steam generators, primary coolant pumps, PHT feeders, ECC system piping and equipment, shutdown cooling, moderator cooling heat exchangers and pumps

Category 3 — Important SSCs

For these components, preventive maintenance and condition monitoring or assessment is carried to mitigate ageing, for example: end shield cooling system equipment, Calandria vault cooling system components, PHT feed pumps, turbine generator system, process water systems piping and equipment, feed water system piping and equipment, secondary cycle heat exchangers, condensers, diesel generators, uninterruptible power supplies and batteries.

Category 4 — Other SSCs

These are miscellaneous items not covered under above three categories and managed by planned preventive maintenance and condition monitoring and are routinely replaceable. For these items, for example: filters, the degradation mechanism is identfied.

A set of condition indicators was defined as shown in Table II–4.

TABLE II–4. CONDITION INDICATORS

Condition Indicators	Susceptible Materials and Components/SSCs
General corrosion, pitting, Crevice corrosion	Crevice and hide out region, low and no flow components, service water systems, Service water heat exchangers, anchor bolts
SCC on internal surface (low and high temperature)	Weld vicinity in components (outside normal chemistry conditions)
SCC on external surface (chloride related; low and high temperature)	Steam generators, outdoor equipment in coastal area, weld heat effected zone
Microbial influenced corrosion	Water systems
Radiation embrittlement	Components subjected to high flux
Corrosion fatigue (low and high temperature)	Thermal mixing regions, special carbon and alloy steels
Erosion, FAC	High fluid velocity, temperature components
Weld related cracking (lack of fusion, ferrite depletion, crevice formation; (low and high temperature)	Weld, wrought materials to casting, seam weld
Sensitization	Stainless steel and cast components
Mechanical wearing, fretting (low and high temperature)	Rotating equipment, relative motion
Wear and tear	Components within pumps and valves
Insulation embrittlement and degradation	Cables, motor windings, transformers
Temperature effects and irradiation effects	Cables, elastomers
Vibration	Rotating equipment, high velocity piping
Corrosion of reinforcement, carbonation, spalling, cracking of concrete, loss of pre-stressing force due to long term losses	All civil structures

II-2.4.2. Preventive actions to minimize and control ageing effects

Guidelines for preservation of systems during extended shutdown were issued at the plant.

Separate checklist was prepared for every activities of preservation.

Few examples of the preventive actions, specified in preservation procedures, are as follows:

- Drying of the SSCs drained for long time, with instrument air;
- Blowing of dry instrument air, whenever possible, on monthly basis, to maintain the desired dew point;
- Maintaining required water flow in reactor systems, related to core cooling, along with maintaining chemistry parameters and required flow in purification circuits;
- Suppression pool water circulation, once in week by running suppression pool pump;
- Generator casing pressure to be maintained in the range 0.8 to 1.0 kg/cm^2 with instrument air;
- Dry hot air circulation continuously in generator stator winding to maintain it in dry condition;
- Maintaining oil flow through all bearings of the turbine generator set. Turbine generator hand barring is done periodically;
- Space heaters of standby and non-operating motors, to be ensured in ON condition to prevent insulation degradation, due to moisture ingress;
- SSCs' preservation in accordance with manufacturer's instructions;
- Periodic inspections on SSCs to ensure their healthiness;
- Periodically functional tests on equipment, wherever possible, to detect ageing effects;
- Silica gel and moisture desiccants replacement, at increased frequency, in oil filled transformers and in isolated phase bus ducts;
- Use of operating procedures to control degradation of SSCs within acceptable limits that contribute to the ageing;
- Service condition of various SSCs is determined, and operating practices are aimed at precluding degradation of SSCs by following preservation procedures.

II-2.4.3. Detection of ageing effects

Specifications of parameters along with expected values are defined in individual SSCs procedures, which are used, to detect ageing effects in various systems.

Programmes used for detection of ageing effects are as follows:

- Preventive maintenance programme;
- ISI programme;
- FAC programme;
- Surveillance and Functional testing and monitoring programme for the components which are in service and for components which remains out of service;
- Chemistry programme aims to reduce corrosion;
- Condition monitoring of SSCs which includes following:
  - Ferrography;
  - Vibration measurement;
  - Thermography;
  - Physical and chemical analysis of oil;
  - Dissolved gas and Furan analysis of transformer oil;
  - Diagnostic testing such as partial discharge measurement, capacitance and Tan delta test for insulation, dielectric power loss measurement, recovery voltage measurement tests and frequency response analysis on power transformers for monitoring paper insulation condition;
  - Insulation resistance, hardness and polarization index on cables;
  - Current signature of motorized valves;

- o Capacity test and high rate discharge test on station batteries;
- o Diagnostic testing on turbo generator like electromagnetic core imperfection detection test, wedge mapping, capacitance and Tan delta test for insulation, partial discharge test for insulation, winding resistance and polarization index are conducted. Ultrasonic and dye penetration test are conducted for rotor retaining ring.

Specific information about procedures for maintenance, inspections and related programmes is provided in Refs [II–6 to II–8].

II-2.4.4. Monitoring and trending of ageing effects

Ageing effects are monitored through indicators and parameters, such as:

- — High temperatures in electrical and process systems;
- — Oil condition indicators such as dissolved gas analyzes, physical and chemical properties in transformer oil, presence of moisture and other contaminants in turbine side systems, grease parameters in large rotating equipment;
- — Vibrations, during functional testing of equipment, indicating problems in bearings or shafts;
- — Insulation parameters of electrical equipment;
- — Chemistry parameters in process systems to indicate various contaminants;
- — Thickness gauging of system piping;
- — Corrosion;
- — Erosion;
- — Irradiation effects;
- — Creep;
- — Fatigue;
- — Mechanical wear and fretting;
- — Hydride embrittlement;
- — Humidity;
- — Insulation degradation in electrical systems;
- — Degradation of civil structures, ion exchange columns, strainers, circuit breakers, relays, control and power cables.

Data were gathered from various systems using different monitoring technologies, as mentioned above. The ‘as found’ values of data were compared with expected values defined is equipment procedures, manufacturers instruction manuals or Indian standards, to detect ageing effects. Data gathered were analysed and trended to identify ageing effects. Data of some of the equipment were analysed, based on comparative methods for similar equipment condition at the plant and other plant similar equipment condition.

II-2.4.5. Mitigating ageing effects

Based on the observations through monitoring methodologies, mitigatory measures were taken, such as:

- — Upgrades of SSCs;
- — Replacement of elastomers, wherever applicable;
- — SSCs overhauling;
- — Oil condition improvement by filtering and hot circulation of oil in the system;
- — Replacement with better quality components;
- — Improving the lubrication of equipment;

— Replacement or repair of equipment;
— Enhanced surveillance for timely detection of incipient failures;
— Improving the environmental conditions surrounding the equipment;
— Change of material.

II-2.4.6. Acceptance criteria

The following are some examples of acceptance criteria established for the SSCs ageing management

— Upgraded systems are being requalified and tested as per design intent. Acceptance criteria were defined in procedures;
— Diagnostic and functional testing of components or systems is conducted before putting them in service;
— Acceptance criteria are defined in individual SSCs procedures;
— Monitoring of SSCs were done subsequent to mitigatory measures. Data obtained were within acceptance criteria. No major corrective actions were necessary.

II-2.4.7. Corrective actions

Suitable corrective actions are taken if component fails to meet the acceptance criteria.

II-2.4.8. Operating experience feedback

As per approved documents and procedures.

II-2.4.9. Quality management

The implementation of the AMP on different SSCs is done at the station, by respective sections. Section heads have administrative controls, that documents the implementation of the AMP. The implementation is done through documented procedures and software programmes.

To facilitate the evolution and improvement of the AMP, various indicators are monitored and trended. Example of such indicators are as follows:

— Number of low level events reported related to ageing of SSC;
— Trends of data relating to failure and degradation;
— Status of compliance with inspection programmes.

Quality management also includes a verification process to ensure that preventive actions are adequate and appropriate. Following inspection, an audit processes is in place to verify that a corrective actions are being taken in accordance with the following programmes:

— Self-assessment programme;
— Senior Technical Audit Engineer audit;
— Internal audit of the integrated management system;
— External audit of the integrated management system by the Bureau of Indian Standards;
— Regulatory inspection.

The activities, evaluations, assessments and results related to ageing management are documented; this includes:

— Ageing management study reports;
— Procedures and checklists;
— Data monitoring and trend analysis reports;
— Review of effects of ageing and systems performance in periodic safety review reports;
— Ageing related issues in station business plans.

An additional description of quality assurance actions is provided in Ref. [II–9].

II-2.4.10. Specific practices identified for extended shutdown

Guidelines for the preservation of systems during the extended shutdown was issued. All the SSCs which were maintained in operating state for preservation were brought back to operation if isolated for maintenance work as soon as permits were surrendered on these SSCs.

Separate procedure checklists were prepared for ensuring proper preservation and monitoring of individual systems. The procedures include operating requirements for moderator, PHT, end shield cooling, calandria vault cooling, suppression pool circulation, boiler steam and water, condensate and feed water systems, steam extraction, generator, process water and core cooling water. Specific procedures were prepared for PHT system preservation and condensate, feed water and steam generator preservation by periodically blowing instrument air. Separate guidelines were also issued for preservation of generator transformers, unit auxiliary transformer and isolated phase bus data which included periodic monitoring of insulation resistance, polarization index, oil break down voltage and moisture in oil.

These checklists were reviewed and concurred by the engineering group. The status was reviewed on monthly basis. Separate periodic review reports for system chemistry were prepared and reviewed for ensuring healthiness of preserved systems.

The opportunity of extended shutdown was availed to perform following life extension activities:

— The secondary cycle piping components were replaced with high–alloy–chrome–molybdenum piping having excellent erosion resistance;
— The computer based and electronics systems having potential of obsolesce were replaced with latest generation systems, for example upgrade of the programmable logic controller, dual processor based reactor control systems;
— Introduction of additional systems as safety upgraded for example introduction of seismic trip, installation of passive recombiners for post incidents hydrogen management.

II-2.4.11. Experience to bring the unit back after the extended shutdown

Problem of tritium increase was faced during air flushing of PHT circuit especially in the fuelling machine vaults after removal of feeders. As maximum work during En Mass Coolant Channel Replacement was being done in fuelling machine vaults, air flushing had to be suspended on several occasions.

Initially, preservation of the condenser cooling water circuit was planned by maintaining a reverse flow through the condenser water boxes from the non-active low pressure process water system, however this method was not very effective. This was resolved by periodically operating the main core cooling water pumps for short periods for proper circulation.

Detailed pre-service inspection of all critical system structures and components, like eddy current tests and thickness gauging, are performed to ensure fitness for service.

II-3. JAPAN

II-3.1. Description of the plant(s)

The main technical details of the Kashiwazaki–Kariwa units 1 and 7 are presented in Table II–5.

TABLE II–5. SUMMARY OF INFORMATION OF THE PLANT

Plant name	Kashiwazaki–Kariwa unit 1 (TEPCO)
Member State	Japan
Reactor Type	BWR
Model	BWR-5/Mark-II
Power	1100 MW_e
Start of Operation	1985
Start of the extended shutdown mode	2007
End of the extended shutdown mode	2010
Standby time	3 years
Current status	Preservation measures appropriate to each equipment condition are being taken. Modification works to comply with the new regulatory standards instituted after the Fukushima-Daiichi accident are currently underway.
Plant name	Kashiwazaki–Kariwa unit 7 (TEPCO)
Member State	Japan
Reactor Type	BWR
Model	ABWR/Reinforced concrete containment vessel
Power	1356 MW_e / 3926 MW_t
Start of Operation	1997
Start of the extended shutdown mode	2007
End of the extended shutdown mode	2009
Standby time	2 years
Current status	Same as unit 1

II-3.2. Historical Aspects

The situation involving extended shutdown of Kashiwazaki–Kariwa unit 1 and unit 7 is as follows:

— Following the Niigata–prefecture Chuetsu–oki Earthquake of July 2007, the plant was shut down for about three years;
— When the Niigata–prefecture Chuetsu–oki Earthquake struck, unit 1 was undergoing periodic inspection during refuelling outage. The reactor, therefore, was open, and all fuel was stored in the fuel pool. Hence, the equipment at the plant, such as the equipment undergoing open inspection and the equipment whose pipe supports had been removed for piping inspection, experienced the earthquake in a condition different from the condition during normal operation;
— After the earthquake, inspection was conducted to check on the impact of the earthquake and the integrity of the equipment, which took about three years. During this period, equipment preservation managements were taken according to the condition of each equipment. No major trouble occurred after operation was resumed, and periodic inspection (during refuelling outage) was conducted after about one year of commercial operation;
— Since August 2011, when periodic inspection started, the plant has been shut down for about seven years;
— Commercial operation was resumed after the Chuetsu–oki Earthquake, but the Great East Japan Earthquake occurred in March 2011, after about six months of commercial operation. The epicenter was far from the plant, and the plant was not affected by the disaster. Commercial operation, therefore, was continued, and the 16th periodic inspection began as planned in August 2011;
— Since then, modification works have been underway for about seven years, to comply with the new regulatory standards instituted after the Fukushima accident. During that period, equipment preservation management has been taken according to the condition of each equipment.

II-3.3. Ageing during extended shutdown

II-3.3.1. Scope of SSCs covered in ageing management

Ageing management activities under normal conditions have been continued for systems such as the residual heat removal system and the fuel pool cooling and clean-up system and plant auxiliary systems (e.g. air conditioning and ventilating systems, waste treatment systems), which need to be operated even while a plant is out of operation during extended shutdown. Systems that do not need to be operated during plant shutdown, such as the main steam system and condensate or feed water systems, have been kept in preservation after taking necessary ageing management measures such as removing water out of the piping and/or filling up with nitrogen. Equipment in this category has been excluded from the scope of ageing management.

II-3.3.2. Preventive actions to minimize and control ageing effects

For plant maintenance and management, including ageing management, the operator has an equipment inspection plan. It is called the ‘maintenance plan’ and its content is reported to the government. It is required that the plan includes the details of inspections and repairs to be implemented during normal operation and short outage. If the plant is in extended shutdown condition, it is required that the plan, which is referred to as the ‘special maintenance plan’, includes also ageing management and preservation control, in addition to the normal maintenance plan. The ‘special inspection plan’ includes preservation management and maintenance activities such as overhaul to be performed in accordance with the preservation conditions described in this Annex.

TEPCO has internal rules to develop a special maintenance plan to comply with regulatory standard if it is known in advance that plant shutdown is expected to continue for a year or longer, or if the plant has remained out of operation for more than 300 days and the shutdown period is likely to reach or exceed one year. Equipment within the scope of the special maintenance plan is that does not need to be operated during extended shutdown and that requires preservation managements.

The basic policy for equipment preservation managements during extended plant shutdown is as follows:

— For preservation managements during extended shutdown, standard measures are developed to eliminate degradation stressors which accelerate degradation phenomena associated with corrosion caused by contained substances;
— For an active component which is not operated during extended shutdown, operation and functional checks basically confirm its availability and prevent the malfunction because there is concern that it could become inoperable due to standstill;
— If operational or functional checks during shutdown are not possible, the risk of functional failures is reduced by, for example, supplying lubricant or removing and storing driving and sliding parts.

The degradation mechanism for mechanical equipment expected during a shutdown period is mainly corrosion, due to substances contained in the equipment. Therefore, preservation management suitable for the contained substances are taken. Practical examples of preservation managements appropriate for different types of contained substance are shown in Table II–6.

For special equipment, the following measures are taken:

— Equipment that contains resin such as demineralizers are kept in preservation by filling up with de-aerated water, in order to prevent resin degradation due to desiccation;
— Equipment that contains catalysts, such as gaseous waste treatment system recombiners, are kept in preservation by heating and desiccating by means of heaters, in order to prevent catalyst degradation due to poisoning;
— For active components of mechanical equipment, which pose concern about possible functional failures such as sticking resulted from extended shutdown, the measures shown in Table II–7 are taken in addition to the preservation measures mentioned above.

TABLE II–6. PRESERVATION MEASURES

Contained substance	Expected degradation mechanism	Preservation measures
Seawater	Corrosion due to dissolved oxygen, chlorides, microorganisms or hydrogen sulphide	Drained preservation. (The inside is washed because desiccation after draining causes concentration of chlorides.) Equipment that has any opening to the atmosphere is isolated by curing, to prevent the intake of moist atmosphere into the equipment. No preservation managements are required to be implemented for equipment made of fibre-reinforced plastic and lined equipment.
Seawater	Sticking or clogging due to marine organisms growing on equipment	Drained preservation (same as above). Removal of marine organisms before resuming the use of equipment.
Pure water (demineralized water)	Corrosion due to dissolved oxygen	Drainage. Deaeration of water (filled up with deaerated water, injection of rust preventing agent). Nitrogen sealing for equipment that does not permit even a slight degree of corrosion. Ventilation of corrosive atmosphere (continuous supply of dry air, periodic water flow). No preservation managements are required to be implemented for equipment made of stainless steel and lined equipment.
Oil	Corrosion due to dissolved oxygen or chlorides	Oil film formation by periodic operation. Nitrogen sealing. No preservation managements are required to be implemented for equipment made of stainless steel.
Steam	Treated in the same manner as pure water (demineralized water)	

TABLE II–7. MEASURES FOR ACTIVE COMPONENTS

Component	Expected degradation mechanism	Preservation managements
Rotating machine, compressor	Deflection, sticking, inadequate lubrication	Periodic operation (inching motion)
Other than above	Sticking	Confirmation operation before resuming the use of equipment
Component that is impossible to be confirmed its functionality during shutdown	Sticking	Periodic lubrication, Mechanical seal removal before preservation (for pumps)

Electrical equipment degradation phenomena expected during a shutdown period include insulation degradation due to moisture absorption or surface condensation, rusting and deformation of heavy equipment. Therefore, preservation managements appropriate for the individual expected degradation mechanism are taken. Practical examples of preservation managements taken for different types of expected degradation mechanism are described in Table II–8.

TABLE II–8. MEASURES FOR ELECTRICAL COMPONENTS

Expected degradation mechanism	Target component	Preservation managements
Insulation degradation	Control panel	Installation of space heaters
	Electric motor	Desiccant agent (e.g. silica gel) installation Nitrogen sealing Curing with flame retardant sheet
Rusting	Generator collector ring Control panel	Filling with rust preventing oil, protection with antirust paper
Deformation	Generator rotor	Periodic turning

Instrumentation and control equipment degradation phenomena expected during shutdown includes performance degradation due to moisture and dust. Therefore, preservation managements appropriate for the individual expected degradation phenomena are taken. Preservation managements for instrumentation and control equipment are as follows:

— Keeping the equipment energized to maintain its integrity;
— Equipment installed in a favorable environment is stored in a deenergized condition to prevent degradation;

— At places where dust is generated by operations, curing is used for preservation.

II-3.3.3. Detection of ageing effects

Following are the methods of detection of ageing effects on SSCs used for extended shutdown:

— Rotating machines, large equipment is overhauled or periodically operated to check their integrity;
— Periodic management activities (replacement of desiccants and rust preventing agent, cleaning, replacement of curing);
— For equipment that is not operated during shutdown and equipment whose condition does not change during shutdown, operability is checked before resuming their use.

II-3.3.4. Monitoring and trending of ageing effects

TEPCO has experienced one year or longer shutdowns at a number of plants (detection of SCC of reactor core shroud and reactor coolant system piping in 2003, Chuetsu–oki Earthquake in 2007, the Great East Japan Earthquake in 2011).

The maintenance activities conducted at the plants restarted following these shutdowns have been checked and evaluated for adequacy. At Kashiwazaki–Kariwa unit 1 and unit 7 mentioned at the beginning of above, no malfunction resulted from degradation phenomena due to extended shutdown has been found in the operation cycles after the resumption of operation.

For some equipment, the maintenance method has been changed from time based maintenance to condition based maintenance. If condition based maintenance is chosen, criteria of integrity are obtained from ISO criteria. For example, pump vibration (acceleration) is measured and compared with ISO vibration criteria.

II-3.3.5. Mitigating ageing effects

Because mechanical equipment degradation mechanism expected during a shutdown period is mainly corrosion due to substances contained in the equipment, preservation managements suitable for the contained substances are taken. This is already mentioning in previous section in this annex.

II-3.3.6. Acceptance criteria

Periodical effectiveness evaluation is conducted to confirm the adequacy of the maintenance activities, such as preservation management and overhaul inspections, in accordance with a special maintenance plan. This effectiveness evaluation confirms whether appropriate equipment maintenance is conducted by self-assessment, which considers the trend of long term monitoring of maintenance data and ageing effects, operating experience, and results of ageing management technical evaluation and PSR. In this evaluation, parameters such as the number of ‘maintenance preventable functional failure’, component unavailable time, and functional failure resulted from ageing degradation are determined. If the values of these parameters are not zero or if they increase, changes in the maintenance plan will be considered. Additional information about acceptance criteria for fitness for service can be found in Ref. [II–10].

II-3.3.7. Corrective actions

Based on the result of above effectiveness evaluation, update of special maintenance plan and/or reflect the result to the plan if needed. Examples of updates are as follows:

- The category change from preservation management target to maintenance target, or maintenance frequency increase if unexpected malfunction occurs during extended shutdown;
- The category change from maintenance target to preservation management target if no degradation trend is found during periodical inspection;
- Thus, equipment integrity is maintained by updated special maintenance plan based on the result of effective evaluation.

II-3.3.8. Operating experience feedback

In view of the experience of extended plant shutdowns, two manuals, 'Manual for Extended Plant Shutdown' and 'Equipment Preservation Guide during Extended Plant Shutdown', were developed, these manuals were developed in line with requirements of Refs [II–11, II–12].

II-3.3.9. Quality management

In view of the experience of extended plant shutdowns, two manuals, 'Manual for Extended Plant Shutdown' and 'Equipment Preservation Guide during Extended Plant Shutdown', were developed, these manuals were developed in line with requirements of Refs [II–11, II–12].

II-3.3.10. Specific practices identified for extended shutdown

The maintenance (inspection) results obtained thus far are similar with the results of normal periodic inspections, and no unusual degradation due to extended shutdown such as, unusual corrosion of mechanical equipment, corrosion or deformation of electrical equipment, or performance degradation of instrumentation equipment has been found. Therefore, the implementation of existing special maintenance plan (preservation measures, maintenance (inspection) is effective.

II-3.3.11. Experience to bring the unit back after the extended shutdown

Each equipment and component were maintained and/or preserved based on special maintenance plan during extended plant shutdown. The plant operator needs to check the functional integrity evaluation of each system before restarting the plant.

Evaluation of system functional integrity includes the following:

- Pump capacity and head;
- Valve move automatically with a logic of interlock;
- Annunciator test.

Each system function based on safety requirements is confirmed using two evaluations, 'system level integrity evaluation' and 'plant level integrity evaluation'. System level integrity evaluation is for integrity check of each system, such as feed water, reactor core isolation cooling, residual heat removal, and off gas. Plant level integrity evaluation is for total plant health checkup that includes parameter comparison with the previous cycle.

II-4. PAKISTAN

II-4.1. Description of the plant(s)

The main technical details of the plant are presented in Table II–9.

TABLE II–9. SUMMARY OF INFORMATION OF THE PLANT

Plant name	Karachi NPP unit 1
Member State	Pakistan
Operator	Pakistan Atomic Energy Commission
Reactor Type	PHWR
Model	CANDU–137 MW
Power	90 MW_e
Start of Operation	1972
Start of the extended shutdown mode	14/09/2018
End of the extended shutdown mode	31/03/2019
Current Status	Operational

II-4.2. Ageing during extended shutdown

II-4.2.1. Scope of SSCs covered in ageing management

The AMP of Karachi NPP unit 1 is applicable to SSCs that need to meet operational safety requirements. The SSCs have been identified on the basis of primary function and support function required for mitigation of the consequences of design basis events. Other systems and structures, whose failure result in significant loss of power production capability, are also included.

II-4.2.2. Preventive actions to minimize and control ageing effects

Preventive actions to minimize and control ageing effects during extended shutdown are taken as follows:

- Nitrogen blanketing is performed in steam generators;
- Silica jell is placed in the hot well side of the main condenser;
- Helium purge is maintained in PHT pumps seals and surge tank;
- Steam blanketing is performed in heat exchangers by switching ON de-aerator heaters;
- Fan coil units in reactor buildings are covered with cotton cloth in order to protect their fins from deposition of dust during boiler room purging;

— Anti-condensation heaters of feed water and service water systems pump motors are kept ON preventing ingress of moisture;
— Turbine main stop valves are operated weekly to check freedom of movement;
— Turbine generator barring gear is taken in service weekly;
— Hydrogen gas pressure is maintained in generator casing; if required, hydrogen gas is purged with carbon dioxide and carbon dioxide is purged with instrument air;
— During turbine generator overhauling, dismantled parts (e.g. rotor, stator) are properly covered with polythene sheets;
— Turbine lubricating oil separator taken in service weekly for 24 hours;
— Passive auto catalytic recombiners equipment is properly covered in order to protect them from environment during boiler room purging.

II-4.2.3. Detection of ageing effects

Ageing effects are detected through inspection and testing as follows:

— Inspection of steam generators covered in the ISI programme of third interval included eddy current testing of tubes, ultrasonic testing of vessel welds, visual examination of primary and secondary side internal (lower and upper);
— Inspection of main condenser including eddy current testing of tubes and visual examination of hot well side;
— Inspection of feeders includes measurement of wall thinning due to FAC, visual examination of support hangers and other support elements, inspection for clearance between a feeder and other elements like another feeder, end-fitting, instrumentation tubing, support rods slings, and visual examination;
— Karachi NPP has prepared an action plan for fuel channel life management, according to which volumetric and dimensional inspections and body-of-tube scrape sampling will be performed on 11 channels to confirm that the assumptions in the assessment reports are still valid to justify continued operation to the evaluation period (155 000 effective full power hours ~2020);
— Inspection of equipment piping in nuclear island in accordance with the ISI programme;
— Inspection of various plant buildings (civil structures) such as tendon gallery, diesel generator rooms, exhaust stack, emergency control center, alternate emergency control center, radioactive waste storage area, reactor building, service building, administration building, turbine hall, switchyard, auxiliary building, intake and outfall structures.

II-4.2.4. Monitoring and trending of ageing effects

Monitoring and trending of ageing effects is conducted through inspection and testing. Performance monitoring of safety equipment and safety related equipment is also conducted in accordance with the equipment performance monitoring programme.

II-4.2.5. Mitigating ageing effects

Ageing effects are mitigated through refurbishment and replacement in accordance with the ageing management work plan.

II-4.2.6. Acceptance criteria

Acceptance criteria are described in relevant documents (programmes, procedures, technical manuals and assessment reports).

II-4.2.7. Corrective actions

Suggestion or recommendation of ageing management reports and other reports are implemented through AMP work plan and planning section work plan.

II-4.2.8. Operating experience feedback

Internal and external operating experience feedback are studied and implemented if applicable at Karachi NPP unit 1.

II-4.2.9. Quality management

Quality management is performed in accordance with the quality assurance programme.

II-4.2.10. Specific practices identified for extended shutdown

In accordance with approved documents and procedures.

II-4.2.11. Experience to bring the unit back after the extended shutdown

- Special shutdown surveillance programme is developed for some impending, underlying, suspected issues exist with some equipment which become problematic during shutdown;
- Special procedures in respect of intricate isolations, for special activities like fuel channel integrity assessment, to be followed during shutdown; are prepared and approved well before shutdown;
- Timeline for activities to be followed is also build accordingly;
- Isolations, deisolations and commissioning procedures for SSCs, undergone on maintenance, are prepared in accordance with the work plan;
- In management meetings, detailed presentations are given to review the ongoing critical jobs; Issues especially requiring management decisions, corporate support and assistance are discussed in these meetings; Presentations on both internal and external operating experience feedback related to shutdown events are given to analyze and assess embedded risks for the ongoing activity at the plant;
- Detailed discussion is held with coordinator regarding plans, priorities, teamwork, requirements, responsibilities and jobs to be taken up;
- Special start up surveillance programme is developed for startup activities, having seen any critical job(s) to monitor leakages, performance and identity issues with the equipment overhauled;
- Commissioning procedures are prepared for all overhauled equipment;
- Overhauled equipment is commissioned and brought into service when plant system conditions permit;
- A job site survey is conducted by all interested parties for jobs which are of very critical nature and jobs which are carried out after a long time;
- All special procedures of safety and safety related systems are also reviewed according to quality assurance documents and requirements from other concerned departments;
- Lay-up programme for idle SSCs established to prevent their degradations.

REFERENCES TO ANNEX II

[II–1] ARMENIAN NUCLEAR REGULATORY AUTHORITY, ANRA Supervisory requirements for ageing management of systems, structures and components important for the safety of nuclear power plants, Yerevan, Armenia (2008).

[II–2] Appendix to Decision of the Government of RA No. 1085 dated 08/23/2012 on Design Life Extension Requirements Unit 2 of the Armenian NPP, Yerevan (2012).

[II–3] STO 1.1.1.01.006.0327–2015 LTO Standard Organizations STO1.1.1.01.006.0327–2015 Extended Life Block Atom Station, Yerevan, Armenia (2015).

[II–4] RD EO 1.1.2.22.0283–2008 Guiding document of the operating organization Comprehensive inspection of a nuclear power unit typical programme, Yerevan, Armenia (2008).

[II–5] ATOMIC ENERGY REGULATORY BOARD, AERB Safety Guide No. AERB/NPP/SG/O–14: Life Management of Nuclear Power Plants, AERB, Mumbai, India (2005).

[II–6] ATOMIC ENERGY REGULATORY BOARD, AERB Safety Guide No. AERB/NPP/SG/O–2: In-service Inspection of Nuclear Power Plants, AERB, Mumbai, India (2004).

[II–7] ATOMIC ENERGY REGULATORY BOARD, AERB Safety Guide No. AERB/SG/O–8: Surveillance of Items Important to Safety in Nuclear Power Plants, AERB, Mumbai, India (1999).

[II–8] ATOMIC ENERGY REGULATORY BOARD, AERB Safety Guide No. AERB/NPP/SG/O–7: Maintenance in Nuclear Power Plants, AERB, Mumbai, India (2005).

[II–9] ATOMIC ENERGY REGULATORY BOARD, AERB Safety Guide No. AERB/SG/QA–5: Quality Assurance during Commissioning and Operation of Nuclear Power Plants, AERB, Mumbai, India (1993).

[II–10] JAPAN SOCIETY OF MECHANICAL ENGINEERS, JSME Codes for Nuclear Power Generation Facilities – Rules on Fitness-for-Service for Nuclear Power Plants, JSME S NA1 (2016).

[II–11] NUCLEAR REGULATION AUTHORITY, NRA Guide for Pre-Service Inspection, Facility Periodic Inspection and Periodic Operator’s Inspection on the Rules for Commercial Nuclear Power Reactors concerning the Installation, Operation, No. 13061923 (2013).

[II–12] NUCLEAR REGULATION AUTHORITY, NRA Guide for Ageing Management Implementation on the Rules for Commercial Nuclear Power Reactors concerning the Installation, Operation, No. 1306198 (2013).

ANNEX III.

EXPERIENCES OF MEMBER STATES WITH AGEING MANAGEMENT DURING PERMANENT SHUTDOWN PRIOR TO DECOMMISSIONING

III-1. GERMANY

III-1.1. Description of the plant(s)

The experience is a collection from several German PWR and BWR plants having operating periods ranging from 30 to 35 years.

III-1.2. Historical Aspects

Due to a government decision in March 2011, nine nuclear power plants ceased their operation permanently without reaching their design life. Currently they are in different stages of the so-called 'post-operational phase', which designates in Germany the time range between permanent shutdown and the beginning of the decommissioning stage. The BFE (Federal Office of the Safety of Nuclear Waste Management) states the following [III–1]:

— The measures in the post-operational phase are covered by the operating license held by the NPP owner. Generally, the following activities are conducted in the post-operational phase:
  - o Unloading of fuel elements from the reactor;
  - o Reloading of the fuel elements into storage containers and storage in the on-site interim storage facilities;
  - o Treating and removal of radioactive waste having accrued in the operational phase;
  - o Decontamination of facility and systems;
  - o Taking samples from systems and components required for application for decommissioning.

It is the operator's decision to apply to the competent nuclear licensing and supervisory authority for further adjustments in the post-operational phase, taking into account the relevant risk potential [III–2].

III-1.3. Ageing management during permanent shutdown

III-1.3.1. Scope of SSCs covered in ageing management

During the post-operational phase, the necessary precaution against damages are taken using the state of the art of science and technology. As in the operational phase, the radioactive material is enclosed, and the radiation exposure limited.

As long as fuel elements are in the NPP core, precautions continue to cool the fuel elements and to control the reactivity. The control of reactivity ensures that after shutting down the reactor will not become critical.

Systems where it could be shown that they are no longer needed were decommissioned and released from the scope of ageing management.

III-1.3.2. Preventive actions to minimize and control ageing effects

The precautions in the post-operational phase are covered by the operational license which is still in force. Reduction of the scope could be requested by the licensee.

III-1.3.3. Detection of ageing effects

Methods of the preventive inspections and maintenance remain the same as under operation conditions. Due to the fact that the operational license is still in force, all inspection and maintenance procedures are still valid.

The following degradation effects were detected in plants during permanent shutdown:

- Change in operation mode of safety pumps (increased working hours per year) lead to wear, consequently the maintenance intervals are adjusted;
- Auxiliary steam system: steam is produced by boilers continuously (sometimes the system is only designed for outages) – giving potential to increased flow induced corrosion degradation;
- Change in temperatures introduces new degradation modes that could be excluded before, e.g. microbiological induced corrosion;
- Due to the change in thermal performance, the risk of freezing is reanalyzed.

III-1.3.4. Monitoring and trending of ageing effects

No changes to the operational phase. The ageing management guideline KTA 1403 is still valid since the plant is under operational license [III–3].

III-1.3.5. Mitigating ageing effects

No changes to the operational phase. The ageing management guideline KTA 1403 is still valid since the plant is under operational license.

III-1.3.6. Acceptance criteria

No changes to the operational phase. The ageing management guideline KTA 1403 is still valid since the plant is under operational license.

III-1.3.7. Corrective actions

No changes to the operational phase. The ageing management guideline KTA 1403 is still valid since the plant is under operational license.

III-1.3.8. Operating experience feedback

No changes to the operational phase. The ageing management guideline KTA 1403 is still valid since the plant is under operational license.

III-1.3.9. Quality management

No changes to the operational phase. The ageing management guideline KTA 1403 is still valid since the plant is under operational license.

III-1.3.10. Specific practices identified for permanent shutdown

Due to the unplanned permanent shutdown by a governmental decision and a long process until the decommissioning license is granted, the post-operational phase can last up to ten years. This means 10 additional years of operation for some SSCs. For German plants where the shutdown was forced early, this is less relevant. For plants with LTO this is taken into account.

III-1.3.11. Challenges identified for permanent shutdown

Specific effects due to (unplanned) shutdown by governmental order:

- The utilities were not prepared, or documents were not ready;
- Not enough storage casks were available to get the spent fuel quickly out of the plant;
- Not enough intermediate level waste storage facilities were available for future decommissioning activities.

These effects increase the duration of the post-operational phase. From an ageing management perspective, it is desired to keep this period as short as possible. Therefore, a detailed planning before the permanent shutdown is recommended.

III-2. INDIA

III-2.1. Description of the plant(s)

The main technical details of the plant are presented in Table III–1.

TABLE III–1. SUMMARY OF INFORMATION OF THE PLANT

Plant name	Rajasthan NPP unit 1
Member State	India
Reactor Type	PHWR
Model	CANDU 220
Power	220 MW_e (net)
First Criticality Date	11.08.1972
Permanent shutdown	October 2004
Current status	In permanent shutdown

III-2.2. Historical Aspects

Rajasthan NPP unit 1 was the first CANDU reactor in India based on CANDU 220 MW_e technology. The plant faced major component failures like end shied leak, rupture of the over pressure rupture disk and boiler hair pin leaks. These components were repaired from time to time and the unit was brought back to operation after long outages. It was decided to go for permanent shutdown in 2005 due to repeated leaks of hair pins and end shield, which needed specific repairs and hair pin replacements. General details of plant life management procedures are provided in Ref. [III–4].

III-2.3. Environmental stressors of plant site and/or storage facilities where the SSCs have been kept

Main environmental parameters are as follows:

— Riverside site with mild weather (no sea fog, no freezing cycles, annual average temperature variations from 5°C in winter to 47°C in summer);
— Average humidity: 32% (annual average);
— Maximum humidity: 70% (during rainy season);
— Average annual rainfall: 761 mm.

III-2.4. Ageing management during permanent shutdown

III-2.4.1. Scope of SSCs covered in ageing management

Structures (including structural elements) and components subject to ageing management were categorized under the following broad categories:

Category 1 — Major critical SSCs limiting plant life and not replaceable

The major critical components are those for which integrity and functional capabilities is ensured. These have the highest safety significance. These components are non-replaceable and control the plant life, for example: calandria, end shield components, calandria tubes, in-core components for reactivity mechanisms, moderator system piping (inside calandria vault) All major civil structures also fall under this category.

Category 2 — Critical SSCs

These components also have high safety significance. Usually they are difficult to replace due to radiation exposure, long shutdown period and high cost, for example: PHT system piping and equipment, pressure tubes, steam generators, primary coolant pumps, PHT feeders, ECC system piping and equipment, shutdown cooling, moderator cooling heat exchangers and pumps.

Category 3 — Important SSCs

For these components, preventive maintenance and condition monitoring or assessment is carried to mitigate ageing, for example: end shield cooling system equipment, Calandria vault cooling system components, PHT feed pumps, turbine generator system, process water systems piping and equipment, feed water system piping and equipment, secondary cycle heat exchangers, condensers, diesel generators, uninterruptible power supplies and batteries.

Category 4 — Other SSCs

These are miscellaneous items not covered under above three categories and managed by planned preventive maintenance and condition monitoring.

A set of condition indicators was defined as shown in Table III–2.

TABLE III–2. CONDITION INDICATORS

Condition Indicators	Susceptible Materials and Components/SSCs
General corrosion, pitting, Crevice corrosion	Crevice and hide out region, low and no flow components, service water systems, service water heat exchangers, anchor bolts
SCC on internal surface (low and high temperature)	Weld vicinity in components (outside normal chemistry conditions)
SCC on external surface (chloride related; low and high temperature)	Steam generators, outdoor equipment in coastal area, weld heat effected zone
Microbial influenced corrosion	Water systems
Radiation embrittlement	Components subjected to high flux
Corrosion fatigue (low and high temperature)	Thermal mixing regions, special carbon and alloy steels
Erosion, FAC	High fluid velocity, temperature components
Weld related cracking (lack of fusion, ferrite depletion, crevice formation; (low and high temperature)	Weld, wrought materials to casting, seam weld
Sensitization	Stainless steel and cast components
Mechanical wearing, fretting (low and high temperature)	Rotating equipment, relative motion
Wear and tear	Components within pumps and valves
Insulation embrittlement and degradation	Cables, motor windings, transformers
Temperature effects and irradiation effects	Cables, elastomers
Vibration	Rotating equipment, high velocity piping
Corrosion of reinforcement, carbonation, spalling, cracking of concrete, loss of pre-stressing force due to long term losses	All civil structures

III-2.4.2. Preventive actions to minimize and control ageing effects

Guidelines for preservation of systems for permanent shutdown were issued at the plant. Separate procedure and checklist were prepared for of preservation. Few examples of the preventive actions, specified in preservation procedures are as follows:

- Drying of the SSCs drained for long time, with instrument air;
- Blowing of dry instrument air, whenever possible, on monthly basis, to maintain the desired dew point;
- Maintaining required water flow in reactor systems, related to core cooling, along with maintaining chemistry parameters and required flow in purification circuits;
- Generator is drained, dried and plugged;
- Maintaining lubricant oil flow through all bearings of the turbine generator set; turbine generator hand barring is done periodically;
- Space heaters of standby and non-operating motors, to be ensured in ON condition to prevent insulation degradation, due to moisture ingress;
- Periodically functional tests on equipment, wherever possible, to detect ageing effects;
- Silica gel and moisture desiccants replacement, at increased frequency, in oil filled transformers and in isolated phase bus ducts;
- Use of operating procedures to control degradation of SSCs within acceptable limits that contribute to the ageing.

III-2.4.3. Detection of ageing effects

Specifications of parameters along with expected values are defined in individual SSCs procedures, which are used, to detect ageing effects in various systems.

Programmes used for detection of ageing effects are as follows:

- Preventive maintenance programme;
- ISI programme;
- FAC programme;
- Surveillance and functional testing and monitoring programme for the components which are in service and for components which remains out of service;
- Chemistry programme aims to reduce corrosion;
- Condition monitoring of SSCs which includes the following:
  - Ferrography;
  - Vibration measurement;
  - Thermography;
  - Physical and chemical analysis of oil;
  - Dissolved gas and Furan analysis of transformer oil;
  - Diagnostic testing such as partial discharge measurement, capacitance and Tan delta test for insulation, dielectric power loss measurement, recovery voltage measurement tests and frequency response analysis on power transformers for monitoring paper insulation condition;
  - Insulation resistance, hardness and polarization index on cables;
  - Current signature of motorized valves;
  - Capacity test and high rate discharge test on station batteries.

Specific information about procedures for maintenance, inspections and related programmes is provided in Refs [III–5 to III–7].

III-2.4.4. Monitoring and trending of ageing effects

Ageing effects are monitored through indicators and parameters, such as:

- High temperatures in electrical and process systems may be due to deterioration in conductor joints or valve seats erosion;
- Oil condition indicators such as dissolved gas analyzes, physical and chemical properties in transformer oil, presence of moisture and other contaminants in turbine side systems, grease parameters in large rotating equipment;
- Vibrations, during functional testing of equipment, indicating problems in bearings or shafts;
- Insulation parameters of electrical equipment;
- Chemistry parameters in process systems to indicate various contaminants;
- Thickness gauging of system piping;
- Corrosion;
- Erosion;
- Irradiation effects;
- Creep;
- Fatigue;
- Mechanical wear and fretting;
- Humidity;
- Insulation degradation in electrical systems;
- Degradation of civil structures, ion exchange columns, strainers, circuit breakers, relays, control and power cables.

III-2.4.5. Data collected and assessment methods for monitoring ageing

Data were gathered from various systems using different monitoring technologies, as mentioned above. The 'as found' values of data were compared with expected values defined is equipment procedures, manufacturers instruction manuals, Indian standards, to detect ageing effects. The data gathered were analyzed and trended to identify ageing effects. Analysis is performed based on comparative methods for similar equipment condition at the station and other station similar equipment condition.

III-2.4.6. Mitigating ageing effects

Based on the observations through monitoring methodologies, mitigatory measures were taken, such as:

- Replacement of elastomers, wherever applicable;
- SSCs' overhauling;
- Oil condition improvement by filtering and hot circulation of oil in the system;
- Improving the lubrication of equipment;
- Replacement or repair of equipment;
- Improving the environmental conditions surrounding the equipment.

III-2.4.7. Acceptance criteria

- Diagnostic and functional testing of SSCs is performed;
- Acceptance criteria are defined in procedures for individual SSCs.

III-2.4.8. Corrective actions

Suitable corrective actions are taken if component fails to meet the acceptance criteria.

III-2.4.9. Quality management

The implementation of the AMP on different SSCs is done at the station, by respective sections. Section heads have an administrative control that documents the implementation of the AMP. The implementation is done through documented procedures and software programmes.

To facilitate the evolution and improvement of the AMP, various indicators are monitored and trended. Example of such indicators are as follows:

- Number of low level events reported related to ageing of SSCs;
- Trends of data relating to failure and degradation;
- Status of compliance with inspection programmes.

The activities, evaluations, assessments and results related to ageing management related are documented such as:

- Ageing management study reports;
- Procedures and checklists;
- Data monitoring and trend analysis reports;
- Review of effects of ageing and systems performance in periodic safety review reports;
- Ageing related issues in station business plans.

III-2.4.10. Specific practices identified for permanent shutdown

- The main nuclear systems are drained, dried and preserved with instrument air. The negative dew point is ensured;
- All critical motors are kept with space heaters on. Regular electrical checks are being done;
- Turbine generator lube oil system is kept operational;
- Containment systems are retained functional;
- Fire water system is kept functional with modified scheme;
- A surveillance programme is devised to ensure the health of SSCs;
- The fire systems, engineered safeguard system and radiation monitoring systems are kept operational;
- A special technical specification is made for the plant to ensure the required nuclear, radiological and industrial safety;
- A modified ISI programme is devised and implemented for the systems remaining functional.

III-3. SWITZERLAND

III-3.1. Description of the plant(s)

The main technical details of the plant are presented in Table III–3.

TABLE III–3. SUMMARY OF INFORMATION OF THE PLANT

Member State	Switzerland
Plant name	Mühleberg NPP unit 1
Reactor Type	BWR
Model	BWR/4, Mark–I Containment
Power	373 MW_e (net)
Construction history (including relevant major milestones)	1. 1967: Start of construction 2. 1972: Commercial commissioning 3. 1984–1990: Construction of bunkered emergency building 4. since 2011: Construction of an additional emergency core cooling system as well as additional fuel pool cooling and filling systems
Operational history (including prolonged outages and/or extended shutdowns)	1. 1972: Commercial commissioning 2. No prolonged outages (>3 months) 3. since 2012: LTO (>40 years) with defined end of operation in December 2019
Permanent shutdown (including relevant major milestones)	1. Permanent shutdown: December 20, 2019 2. Transition phase: Jan – Sep 2020 3. Dismantling Phase 1: 2020 – 2024 (control of fuel in the SFP) 4. Dismantling Phase 2: 2024 – 2030 (control of low level waste) 5. Dismantling Phase 3: after 2030 (no radiological hazard)
Current status	In permanent shutdown since December 20, 2019

III-3.2. Ageing management during permanent shutdown

III-3.2.1. Scope of SSCs covered in ageing management

— Reactor building;
— Bunkered emergency building;
— SFP cooling;
— Emergency power supply;
— Auxiliary cooling systems for above mentioned SSCs;
— Electrical equipment of above mentioned SSCs.

III-3.2.2. Preventive actions to minimize and control ageing effects

— Maintenance in accordance with practice and experience until 2019;
— Surveillance of water chemistry in the SFP.

III-3.2.3. Detection of ageing effects

— Buildings: periodic inspections;
— Mechanical components: maintenance, periodic NDT, periodic test runs;
— Electrical equipment: maintenance and periodic tests.

III-3.2.4. Monitoring and trending of ageing effects

— Periodic NDT, periodic test runs;
— Surveillance of water chemistry in the SFP.

III-3.2.5. Mitigating ageing effects

Maintenance in accordance with experience until 2019.

III-3.2.6. Acceptance criteria

— Same criteria (if applicable) as during full power operation.
— Special criteria for water chemistry in the SFP according to plant specific guidelines.

III-3.2.7. Corrective actions

In accordance with maintenance experience until 2019.

III-3.2.8. Operating experience feedback

— Still member of national AMP working groups;
— Observing the state of the art of science and technology;
— Maintaining a plant deputy for operating experience.

III-3.2.9. Quality management

Maintenance and NDT are still under quality management of the plant.

III-3.2.10. Challenges and specific practices identified for ageing management during permanent shutdown

The Swiss regulatory body, ENSI, promotes the abandonment of a full AMP (in accordance with regulator's guideline) in case of a short duration (less than 5 years) of the permanent shutdown phase [III–8]. The knowledge of the full power AMP is implemented directly in the maintenance programme.

REFERENCES TO ANNEX III

[III–1] BUNDESAMT FÜR KERNTECHNISCHE ENTSORGUNGSSICHERHEIT: Statusbericht zur Kernenergienutzung in der Bundesrepublik Deutschland 2018, Report No. BfE-KE-04/19, Salzgitter, Germany (2018).

[III–2] GESELLSCHAFT FÜR ANLAGEN- UND REAKTORSICHERHEIT, Decommissioning of Nuclear Facilities, 2nd edition, Report No. GRS-S-58, Cologne, Germany (2017).

[III–3] KERNTECHNISCHER AUSSCHUSS, KTA 1403: Alterungsmanagement in Kernkraftwerken, KTA Geschäftsstelle, Salzgitter, Germany (2017).

[III–4] ATOMIC ENERGY REGULATORY BOARD, AERB Safety Guide No. AERB/NPP/SG/O–14: Life Management of Nuclear Power Plants, AERB, Mumbai, India (2005).

[III–5] ATOMIC ENERGY REGULATORY BOARD, AERB Safety Guide No. AERB/NPP/SG/O–2: In-service Inspection of Nuclear Power Plants, AERB, Mumbai, India (2004).

[III–6] ATOMIC ENERGY REGULATORY BOARD, AERB Safety Guide No. AERB/SG/O–8: Surveillance of Items Important to Safety in Nuclear Power Plants, AERB, Mumbai, India (1999).

[III–7] ATOMIC ENERGY REGULATORY BOARD, AERB Safety Guide No. AERB/NPP/SG/O–7: Maintenance in Nuclear Power Plants, AERB, Mumbai, India (2005).

[III–8] EIDGENÖSSISCHES NUKLEARSICHERHEITSINSPEKTORAT, Gutachten zum Stilllegungsprojekt des Kernkraftwerks Mühleberg, ENSI 71/39, ENSI, Brugg, Switzerland (2017).

ABBREVIATIONS

AMP	Ageing Management Programme
ARDM	Ageing Related Degradation Mechanisms
BWR	Boiling Water Reactor
COG	CANDU Owners Group
ECC	Emergency Core Cooling
EPRI	Electric Power Research Institute
FAC	Flow Accelerated Corrosion
FME	Foreign Material Exclusion
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit (Germany’s central expert organization in the field of nuclear safety and radioactive waste management)
HVAC	Heating Ventilation and Air Conditioning
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
IGALL	International Generic Ageing Lessons Learned
INPO	Institute of Nuclear Power Operations
ISI	In-service Inspection
JSC OKB	Joint Stock Company Design Bureau
LTO	Long Term Operation
NDT	Non-Destructive Testing
NPP	Nuclear Power Plant
NRA SR	Nuclear Regulatory Authority of Slovak Republic
PHT	Primary Heat Transport
PHT	Primary Heat Tank
PHWR	Pressurized Heavy Water Reactor
PWR	Pressurized Water Reactor

RPV	Reactor Pressure Vessel
SC	Structures and Components
SCC	Stress Corrosion Cracking
SFP	Spent Fuel Pool
SSC	Structures, Systems and Components
SS–SIS	Safety System – Safety Important System
VGB	VGB PowerTech e.V. (international lobby of power plant operators)
WANO	World Association of Nuclear Operators
WWER	Water Water Energetic Reactor

CONTRIBUTORS TO DRAFTING AND REVIEW

Abreu, R.	Eletronuclear, Brazil
Baghdasaryan, H.	ANPP, Armenia
Bernhoft, S.	Electric Power Research Institute, USA
Gadgil, S.	NPCIL, India
Giura, A.	SNN, Romania
Ilio, A.	OPG, Canada
Jhamtani, S.	NPCIL, India
Khavari, P.	OPG, Canada
Klemenz, M.	BKW, Switzerland
Krivanek, R.	International Atomic Energy Agency
Kunito, S.	International Atomic Energy Agency
Marchena, M.	International Atomic Energy Agency
Miller, S.	COG, Canada
Nakamura, R.	JANUS, Japan
Niazi, A.	PAEC, Pakistan
Petofi, G.	International Atomic Energy Agency
Pourkheylaee, M.	TAVANA, Iran
Remias, V.	Slovenské elektrárne, Slovakia
Sedghkerdar, A.	INRA, Iran
Skuce, M.	Bruce Power, Canada
Taniguchi, A.	TEPCO, Japan
Wildner, U.	Framatome, Germany
Zander, A.	Framatome, Germany

Technical Committee Meetings

Vienna, Austria, 24 – 27 July 2018.

Toronto, Canada, 5 –8 February 2019.

Bern, Switzerland, 6 – 9 August 2019.

IAEA
International Atomic Energy Agency

No. 26

ORDERING LOCALLY

IAEA priced publications may be purchased from the sources listed below or from major local booksellers.

Orders for unpriced publications should be made directly to the IAEA. The contact details are given at the end of this list.

NORTH AMERICA

Bernan / Rowman & Littlefield

15250 NBN Way, Blue Ridge Summit, PA 17214, USA

Telephone: +1 800 462 6420 • Fax: +1 800 338 4550

Email: orders@rowman.com • Web site: www.rowman.com/bernan

REST OF WORLD

Please contact your preferred local supplier, or our lead distributor:

Eurospan Group

Gray's Inn House
127 Clerkenwell Road
London EC1R 5DB
United Kingdom

Trade orders and enquiries:

Telephone: +44 (0)176 760 4972 • Fax: +44 (0)176 760 1640
Email: eurospan@turpin-distribution.com

Individual orders:

www.eurospanbookstore.com/iaea

For further information:

Telephone: +44 (0)207 240 0856 • Fax: +44 (0)207 379 0609
Email: info@eurospangroup.com • Web site: www.eurospangroup.com

Orders for both priced and unpriced publications may be addressed directly to:

Marketing and Sales Unit
International Atomic Energy Agency
Vienna International Centre, PO Box 100, 1400 Vienna, Austria
Telephone: +43 1 2600 22529 or 22530 • Fax: +43 1 26007 22529
Email: sales.publications@iaea.org • Web site: www.iaea.org/publications

21-00858E

International Atomic Energy Agency
Vienna