# Topical Peer Review 2017

# National Assessment Report

# Norway

Contents

# 1. General information

There are two research reactors in operation in Norway, the Halden Boiling Water Reactor (HBWR) and the JEEP II reactor. Both are owned and operated by Institute for Energy Technology (IFE). IFE is an independent research foundation for energy and nuclear technology. IFE's work is primarily concentrated in the fields of energy and nuclear technology.

An important part of IFE's activities is the large international research program that they lead known as "The OECD Halden Reactor Project" (HRP). Part of its budget is financed by the Government through the Ministry of Trade, Industry and Fisheries and the rest is from research contracts with industry and other research institutions.

**HBWR**

The Halden reactor is a 25 MW heavy water moderated and cooled boiling water reactor. It went into operation in 1959 and has an operating temperature of 240 ºC and an operating pressure of 33.6 bars. The reactor is cooled by natural circulation. The 14 tonnes of heavy water circulates in a closed pipe circuit, the primary circuit, and releases heat to a secondary closed light water circuit, which is connected to a tertiary circuit.

The reactor is located in a rock cavern hewn into the mountain on the northern side of the River Tista, 2 km from the mouth of the river in the Idde Fjord in Halden. The facility has an area of 7000 $m^2$. The HBWR area is fenced in and to some degree is closed off by buildings.

The mountain hall excavated in the rock that stretches 100 m into the mountain, and is covered by 30-50 m of rock. When the reactor is in operation, the hall is closed off by a lock gate. The volume inside the lock gate is 4,500 $m^3$. The reactor hall is 10 m wide and 30 m long and it has a total height of 26 m, of which 11.5 m is above the floor in the hall. The reactor hall also contains fuel pits for storing spent fuel.

**JEEP II**

JEEP II is a 2 MW heavy water moderated and cooled tank type reactor. The research reactor went into operation in 1967. JEEP II was built to satisfy Norway's need for its own source of neutrons for use in the country's reactor physics experiments, basic research in physics and for the production of isotopes for medical and industrial purposes.

The JEEP II facility has certain special characteristics that set it apart from conventional industrial facilities and that are mirrored in the condition monitoring program:

- The reactor contains heavy water and radioactive products. This not only requires extensive safety measures against rupturing, but also carries safety requirements against leakage from the primary circuits (the heavy water circuits).
- The level of radioactivity in the facility is monitored continually, and the content of tritium facilitates the detection of leaks from the heavy water system.

The reactor is cooled with heavy water contaminated with radioactivity, which is considered a hazardous substance in the Norwegian regulation. The reactor and the heat transfer circuits at JEEP II therefore also come under the ”regulations on the handling of flammable, reactive and pressurized substances, and equipment and facilities used in their handling” of 8 June 2009 [1] established by the Norwegian Directorate for Civil Protection (DSB), the authority responsible for regulatory oversight of pressurized equipment. The requirements established in these regulations set the framework for the condition monitoring program at the JEEP II reactor.

### 1.1. Nuclear installations identification

| Name | HBWR | JEEP II |
|---|---|---|
| Licensee | IFE | IFE |
| Type of Reactor | Heavy water moderated boiling water reactor. Uranium oxide fuel, 6 %, with zircaloy cladding | Heavy water moderated and cooled tank reactor. Uranium oxide fuel, 3.5 %, in Al cladding. |
| Power output | License – 25 MWt, Normal operation 16 – 20 MWt | License – 2 MWt, normal operation 2 MWt |
| Year of first operation | 1959 | 1967 |
| Scheduled permanent shutdown | Undecided. Current license until 2021. | Undecided. Current license until 2019. |

### 1.2. Process to develop the national assessment report

The Norwegian Radiation Protection Authority (NRPA) has been responsible for the development of the national assessment report. The report has been prepared by NRPA with the support and cooperation of the IFE. IFE has provided a report which provided NRPA with information for the report, including the text in the sections “Licensee’s experience”. Its preparation has taken into account the Terms of Reference [3] and the technical specifications that were prepared by WENRA for this review. It constitutes the Norwegian output of the first phase of the review process, i.e. the national assessment reports performed by Member States.

## 2. Overall Ageing Management Programme requirements and implementation

### 2.1.National regulatory framework

All nuclear activities in Norway are regulated by three legal instruments, the Atomic Energy Act 12 May 1972 [4], the Radiation Protection Act 12 May 2000 [5] and the Pollution Control Act 13 March 1981 [6].

The Atomic Energy Act regulates the licensing regime, general requirements for licences, inspection regime and the legal basis for the regulatory body. The Act also establishes the liability regime according to the Paris Convention of 29 July 1960 as amended and related international legal instruments. The last part of the Act regulates confidentiality and penalties in case of non-compliance. NRPAs requirements relevant to ageing management of nuclear facilities are incorporated in the licenses.

The licence of JEEP II is valid from 1 January 2009 until 31 December 2018. The license for HBWR is valid from 1 January 2015 until 31 December 2020. The main basis for the licence is the Safety Analysis Reports for the two reactors and the connected auxiliary facilities.

The license conditions include some conditions related to ageing.

Current license conditions for HBWR (2015-2020) related to ageing:

- IFE shall control the condition of safety classified equipment after a program approved by DSB with special focus on ageing of the reactor vessel and the sub cooler pipe extending to the stop valve. Inspection reports are sent to the NRPA after the inspections.

Current license condition for the JEEP II reactor (2009-2018) related to ageing:

- IFE shall continue the current program of inspecting and monitoring the reactor tank and primary system at Kjeller. The program shall encompass all Systems, Structures and Components (SSCs) that have bearing on safety.
- IFE shall continually monitor how the reactor tank at Kjeller is affected by radiation and the possible consequences of this.

IFE has applied for a new license for the nuclear facilities at the Kjeller site, including the JEEP II reactor, from 1 January 2019. NRPA is currently reviewing the application, and will specifically take ageing management into account in the license conditions.

## 2.2. International standards

International codes and standards are used by IFE as guidelines for developing ageing management at HBWR and JEEP II. This applies especially to the SSCs of the facility that have a safety relevance. The guidelines are primarily taken from the IAEA and ASME (American Standards for Mechanical Engineering) (see section 2.3.2). The use of the various regulations is described in the Safety Analysis Report (SAR).

The main principles for IFE’s monitoring of ageing are described by the IAEA in [7] as well as a description of maintenance, periodic testing and condition monitoring [8]. In addition to this, certain national standards are also used [9, 11].

## 2.3. Description of the overall ageing management programme (AMP)

### 2.3.1. Scope of the overall AMP

**Commonalities to both research reactors**
Through a program of maintenance, periodic testing and condition monitoring, the ageing management programme at IFE is required to ensure that there is satisfactory access to a facility that is up and running and operational, and that the facility is able to satisfy the requirements of:

- Regulatory authorities Requirements from the time that the facility was constructed;
- The Safety Analysis Report;
- Values established in the facility's Operating Limits and Conditions
- Operations staff and the board

*Quality Control System*
IFE have a common overarching quality control system for both the HBWR and JEEP II. Reactor operations are conducted under a set of operational procedures that describe how the reactors should be operated. These procedures also describe how the reactor systems should tested, inspected and monitored as part of operations.

This system and its implementation was reviewed by NRPA in recent years, and several improvements were identified for IFE, e.g. more active use of the Deviation Management System. However, most of these were not directly related to ageing management. This is a long-term process and will be followed-up by NRPA in the coming years.

**HBWR**
HBWR was built at the end of the 1950s and was put into operation for the first time in 1959. HBWR has had an AMP for the RPV ever since start-up of the reactor in 1959. The regulatory framework for experimental reactors was limited at that time and the plant was constructed according to the non-nuclear industrial regulations that existed at the time. In time, as both the national and international regulatory framework was developed, new rules and requirements were established for the reactor plant, entailing a continual upgrading of the facility and ongoing changes in the routines for running it. This has resulted in continual adjustments and changes over the years in the ageing management program and these are reflected in the revisions of the SAR that have been carried out.

The scope of the AMP has been broadened and now include all SSCs relevant to safety, in particular the secondary and tertiary circuit, including the heat exchangers. The use of international standards and guidelines, as well as feedback from international peer reviews, such as the INSARR (Integrated Safety Assessment of Research Reactors) mission in 2007 (with a follow-up in 2010), have been incorporated in the effort to review and develop the

AMP for HBWR. The use of new technologies with regards to surveillance methods in the methods of inspection, registration and follow-up of SSCs, along with the introduction of new electronic maintenance system at the beginning of the 2000, have also played an important role in the development of AMPs.

a) **Assignment of responsibilities within the licensee's organisation to ensure an overall AMP is developed and implemented;**

The Reactor Manager at HBWR is in charge of the AMP at HBWR. Follow-up on condition monitoring of the various facility systems is delegated to the Safety Coordinator and the Head of Maintenance and Installations. The Safety Coordinator is responsible for following up on regulations and for contact with the third party organization, while the Head of the Maintenance and Installations Group is responsible for the practical implementation.

The daily follow-up of preventive and corrective maintenance is delegated to the Head of Maintenance and Installations, which is responsible for:

- Organising and carrying out the daily maintenance;
- Developing short-term and long-term plans for maintenance work on the facility;
- Ensuring that the necessary spare parts are available;
- Ensuring that the relevant procedures and work descriptions are available;
- Responsible for preparing the relevant work orders;
- Ensuring that the necessary tools and equipment are available;
- Presiding over the morning meeting;
- Preparing the work sheets according to procedure.

The Head of the Reactor Operations Group is responsible for resetting the various SSC for operations after maintenance and condition monitoring inspections according to description on the work sheet. The Reactor Operations Group is also responsible for carrying out various inspection rounds in the facility, both during periods of operation and of maintenance.

The Senior Reactor Chemist at HBWR is responsible for defining the limits with respect to water quality, and the Head of the Reactor Chemistry Group is responsible for daily follow-up according to given specifications. The Reactor Chemistry Group also carries out inspection rounds in those parts of the reactor facility in operations and maintenance periods.

b) **Methods used for identifying SSCs within the scope of overall AMP;**

The main philosophy is to avoid the possibility for accidents and focus on maintaining those components and systems where faults or failure would have the most severe consequences. Experience from earlier maintenance is used in preparing the maintenance plan, as well as results from periodic testing, operational data and experiences, risk assessments, requirements from the authorities, and observations from monitoring.

All systems and components are drawn in on flowcharts. These flowcharts are divided into different series. Series “A” concerns the primary circuit, Series “B” concerns the secondary and tertiary system, Series “C” the cooling circuit, Series “D” and “F” deal with the experimental systems, Series “E” is about the ventilation system, Series “G” is the monitoring systems and Series “K” deals with the safety systems. Each component has a unique code that appears on the drawing, and the component is also marked in the facility. An overview of all systems is given in the flowcharts. The operations section is responsible for making sure that the overview is updated.

All components and systems are registered in the electronic maintenance system. All systems and components are registered with their own item number and name. Bearings and fastenings of components are registered as a part of the component, whereas larger frames/structures are considered to be part of the buildings and are registered as such. The maintenance program contains information about the component as well as a log of maintenance work that has been done and new tasks that are planned for that system/component. Once a task is reported as complete, the information is registered as a log. The log is registered and kept by those who did the work or by their nearest supervisor. Fault messages from the control room are registered in the system by control room personnel and the Head of Maintenance and Installations Group decides what further action should be taken.

All work forms are stored electronically in the division’s electronic filing system. The maintenance system is also utilised to plan preventive maintenance work by plotting in new tasks ahead of time.

All SSC are classified according to their importance to safety. The SSCs are divided into four classes, taking the probability and consequences into account:

1. Malfunction that may lead Loss of Coolant Accident (LOCA)
2. Malfunction that may lead to loss of heavy water and release of radioactivity to the reactor hall
3. Malfunction that may lead to a small loss of heavy water and small release to the reactor hall
4. Malfunction which do not lead to release of radioactivity and may lead to personal injuries or stop of operation

The assessment of ageing of SSCs at HWBR is based on results and observations during maintenance or from tests and condition monitoring in combination with the class that the SSC belongs to.

**c) Grouping methods of SSCs in the screening process;**

Regarding ageing management and the process of monitoring ageing at the facility, all SSCs at HWBR are classified according to the possible scale of damage and the consequences thereof.

The group of a given SSC will come under in the maintenance system depends on the consequence to operations that the component will cause in the event of failure. In grouping the SSC’s, the inaccessibility of the reactor hall during operations is taken into account and that repairs will necessitate shutdown.

**d) Methodology and requirements for evaluation of the existing maintenance practices and developing of ageing programmes appropriate for the identified significant ageing mechanism;**

All components and systems are registered in the electronic maintenance system. All systems and components are registered with their own item number and name. Bearings and fastenings of components are registered as a part of the component, whereas larger frames/structures are considered to be part of the buildings and are registered as such. The maintenance program contains information about the component as well as a log of maintenance work that has been done and new tasks that are planned for that system/component. Once a task is reported as complete, the information is registered as a log. The log is registered and kept by those who did the work or by their nearest supervisor. Fault messages from the control room are registered in the system by control room personnel and the Head of Maintenance and Installations Group decides what further action should be taken.

All work forms are stored electronically in the division’s electronic filing system. The maintenance system is also utilised to plan preventive maintenance work by plotting in new tasks ahead of time.

**e) Quality assurance of the overall AMP in particular**

The main quality control system at HBWR is described in the SAR and underlying reference documents. These include the procedures and work descriptions, reports that describe the scope of inspections and status reports.

The Quality Control system contains a number of Key Performance Indicators (KPI) such as days of operations per year, availability and number of SCRAMs. However, there are no KPIs specifically related to the AMP.

Records of the maintenance history are archived in IFEs electronic filing system as well as in the electronic maintenance system. For online monitoring of reactor parameters, the ProcSee system is used. Procsee is a system developed by IFE for presentation of experimental and plant signals.

There is a procedure that describes how to handle non-conformances. Non-conformances are recorded in an electronic deviation management system and followed-up.

**JEEP II**

JEEP II was built in the middle of the 1960s and first entered operations in 1967. There were only limited regulations for research reactors at that time and the reactor was built in accordance with the non-nuclear industrial regulations that existed at that time. In time, as both national and international regulations for research and power reactors were developed, new requirements came into effect for the reactor facility, entailing a continual upgrading of the facility and changes in the routines for running them.

The AMP at JEEP II was formally established in 2016. However, a maintenance program has been in place for JEEP II since the reactor came into operation. The AMP is focused on the reactor tank, primary coolant circuit, vertical primary piping components, the gas room, gas compensators, heat exchangers, and the material surveillance programme visual inspection programme and the pressure testing for leaks.

However, following the recommendations from the INSARR mission to the JEEP II in 2017 [11], the AMP will be revised further. The INSARR team observed that not all the elements of a systematic ageing management programme are included at JEEP II, such as scoping and screening of SSCs with respect to safety, identification of applicable ageing degradation mechanisms, systematic identification of SSCs and associated ageing mechanisms and evaluations from experience and historical maintenance records and trends, and identification and implementation of mitigating actions. However, the INSARR team acknowledged the considerable efforts made by the JEEP II to implement ageing management activities by including in-service inspection, periodic testing, and minimizing the ageing effects on SSCs through operational practices.

A program for maintenance, periodic testing and condition monitoring of the JEEP II reactor is described within the reports that make up the SAR and these contain detailed instructions and procedures. There procedures covers areas including maintenance and periodic testing. A condition monitoring program is developed in cooperation with IFE’s third party organization and addresses the reactor tank and the primary circuit.

**a) Assignment of responsibilities within the licensee’s organisation to ensure an overall AMP is developed and implemented;**

The Reactor Manager has the overarching responsibility for ageing management at JEEP II. The responsibility for follow-up on condition monitoring of the various systems at the facility is delegated to the Head of the Mechanical Maintenance Group. The Head of the Mechanical Maintenance Group and the Head of the Electric Maintenance Group are responsible for follow-up of regulations, contact with the third party organization, reporting and practical implementation in their respective are in the following areas:

- Organise and perform the daily maintenance;
- Work out short term and long-term maintenance plans for the facility;
- Ensure that the necessary spare parts are available;
- Ensure that the relevant procedures and work descriptions are available. Responsibility for working out relevant work specifications;
- Ensure that the necessary tools and equipment are available;
- Develop work sheets according to procedure.

**b) Methods used for identifying SSCs within the scope of overall AMP;**

The INSARR team noted that the ageing management at JEEP II is more a physical condition assessment of the SSCs. Following the recommendations from the INSARR team, there is an on-going process to develop a comprehensive AMP for the JEEP II reactor. IFEs plan is that this should be developed and implemented before 2019. This work will be followed-up by the regulatory body but also at the follow-up INSARR which is planned to be held in 2019-2020.

IFE use a third party organization to support them in the development of the AMP. The revised AMP will be sent to IFEs Safety Committee for review before it is implemented.

**c) Grouping methods of SSCs in the screening process;**

There is currently no formal grouping methods for SSC related to ageing. However, in the development of the comprehensive AMP it is planned to divide all components and systems of the facility into groups depending on the consequences of faults or errors. The main philosophy is to focus on maintaining those components and systems where faults or failure would have the most severe consequences.

**d) Methodology and requirements for evaluation of the existing maintenance practices and developing of ageing programmes appropriate for the identified significant ageing mechanism;**

All components and systems are registered in the electronic maintenance system, . All systems and components are registered with their own item number and name. The maintenance program contains information about the component as well as a log of maintenance work that has been done and new tasks that are planned for that system/component. Once a task is reported as complete, the information is registered as a log. The log is registered and kept by those who did the work or by their nearest supervisor.

All work forms are stored electronically in the electronic filing system. The maintenance system is also utilised to plan preventive maintenance work by plotting in new tasks ahead of time.

There is currently no formal methodology for evaluation of existing maintenance practices. Internal maintenance experience is used to update the planned maintenance in the electronic maintenance system. However, an annual report on the operation and maintenance of the reactor is reviewed by IFEs Safety Committee, and any feedback from them will be implemented.

**f) Quality assurance of the overall AMP in particular**

The main quality control system at JEEP II is given in the SAR and underlying reference documents. These include the procedures and work descriptions, reports that describe the scope of inspections and status reports.

Records of the maintenance history are archived in IFEs electronic filing system as well as in the electronic maintenance system.

There is a procedure that describe how to handle non-conformances. Non-conformances are recorded in an electronic deviation management system and followed-up.

### 2.3.2. Ageing assessment

**HBWR**

a) **How key standards, guidance and manufacturing documents are used to prepare the overall ageing management programme;**

The reactor vessel and its associated components and pipe systems are considered a “boiler installation” and are regulated by the Norwegian “Act on flammable goods and pressurised fluids and gasses” [12].

The reactor vessel and other pressurised parts of the facility were for the most part constructed and built in the period 1956-59 in accordance with the regulations and codes for boilers and pressurized equipment that were in existence at the time. From the start, the construction, inspection, trials and approval of the reactor facility were followed up and approved by the Inspectorate for Boilers (the name changed in 1961 to the Norwegian Labour Inspection Authority’s Inspection Unit for Boilers and Pressurised Vessels). The first certificate for the reactor issued on 29.05.58 refers to the «Regulations on boilers of 11 September 1925”. The Inspectorate for Boilers/Norwegian Labour Inspection Authority’s Inspection Unit for Boilers and Pressurised Vessels were the applicable authorities at the time with respect to the construction and approval of the reactor facility.

Besides the regulations on boilers and pressurised equipment that were in effect in the 1950’s, the Inspectorate for Boilers utilised the Swedish Pressure Vessel Norms in its computational requirements. For example, the strength of different parts of the reactor vessel (end base bottom, cylinder section/shell plating, top cover was calculated on the basis of the Swedish Pressure Vessel Norms. The welding work was done according to the Norwegian “Regulations for welding boilers, containers and pipelines of 23 December 1943».

The analysis of the terms of operation for the reactor vessel at HWBR use the following standards:

- USNRC Regulatory Guide 1.99 - Radiation Embrittlement to Reactor Vessel Materials [13].
- USNRC 10 CFR Appendix G to Part 50 - Fracture Toughness Requirements [14a].
- ASME XI Appendix G - Fracture Toughness Criteria for Protection Against Failure [15].

- NUREG-0800, NRC Standard Review Plan Section 5.3.2 Pressure-Temperature Limits [16].

Electric installations are constructed and maintained in accordance with Norwegian regulations, which are normed and based on European standards. The following regulations apply:

- Regulation on electrical supply systems [17]
- Regulation on low voltage electrical installations [18]
- NEK 400, Low voltage electrical installations [19]
- FSE, Safety regulations for work and operations at electrical facilities [20]

Regardless of classification, all pressurised equipment is covered by the following Norwegian regulations issued by DSB:

- Regulation on pressurised equipment (FTPU) [1], which covers the design, manufacture and completion inspection.
- Regulation on the handling of flammable, reactive and pressurized substances and the equipment and facilities used in their handling [2], which covers inspections when the equipment is taken into use, repairs/replacements and inspections after repairs/replacements.

According to the attachments in [2], pressurised equipment for nuclear uses must be constructed, manufactured, equipped and carried out professionally in compliance with [6]. International regulations are utilised in an advisory capacity for SSCs included in HBWR class 1.

The reactor facility is therefore classified according to international codes and this classification is approved by DSB.

The material monitoring program for the reactor vessel at HWBR is regulated in accordance with the "ASME Code Section XI" [15] and by the "Nuclear Regulatory Commission's (NRC) Regulation 10 CFR Part 50" [14]. Parts of these regulations give procedures on how to conduct analyses that will yield conservative estimates so that older facilities comply with the new safety requirements. The operational limits for HBWR will therefore satisfy the same safety requirements that are made for new facilities.

**b) Key elements used in plant programmes to assess ageing;**

The key elements of the ageing assessment are the programmes to ensure detection and monitoring of ageing effects to ensure that the adequacy of the technical condition of the SSCs can be evaluated. Examples are material testing, water monitoring and visual inspections.

**c) Processes/procedures for the identification of ageing mechanisms and their possible consequences;**

The process of follow-up of ageing mechanisms at the facility provides continual updating on the kind of ageing mechanisms that occur and what sort of maintenance should be carried out, whether corrective or preventive.

Ageing management is a combination of maintenance, periodic testing and the condition monitoring program. Aging mechanisms are evaluated as part of the regular revision of the general AMP under supervision by a the third party organization on behalf of the regulators. IFE

**d) Establishment of the acceptance criteria;**

The acceptance criteria for the facility are determined on the basis of both Norwegian and international standards. They are also based on internal experience and input from the third party organization. The acceptance criteria are informed by the OLCs. IFE also use specifications from the manufacturers to establish acceptance criteria for components relevant to safety.

**e) Use of R&D programmes;**

IFE is a research organization and therefore perform a large amount of research and development related to operation and maintenance of nuclear facilities. However, there is currently not a specific research program on AMP directly related to HBWR.

**f) Use of internal and external operating experience.**

The ability to identify mechanisms of ageing in facility components at HBWR has been attained through long experience in operating the facility. A third party organization support IFE with external experience. HBWR hosted an INSARR mission in 2007 with a follow-up in 2010.

**JEEP II**

**a) How key standards, guidance and manufacturing documents are used to prepare the overall ageing management programme;**

In the AMP, the various pipes and components are briefly described, along with any particular aspects pertaining to the inspection of the pipes or components. An account is also given of the inspection methods that are used and which parts of the pipes and components are being inspected.

Electrical installations at the reactor are constructed and maintained according to Norwegian regulations and are standardized on the basis of European standards. The following regulations are followed:

- Regulations on low voltage electric plants [18]
- NEK 400, Low voltage electric installations [19]
- Safety regulations for work and operations at electric facilities [20]

The ageing process for the various parts and components of the facility has been observed in different analyses and through long experience in operating the facility. Annual follow-up of ageing mechanisms for the facility ensures continual updates to the various conditions.

**b) Key elements used in plant programmes to assess ageing;**

The key elements of the ageing assessment are the programmes to ensure detection and monitoring of ageing effects to ensure that the adequacy of the technical condition of the SSCs can be evaluated. Examples are material testing, water monitoring and visual inspections.

**c) Processes/procedures for the identification of ageing mechanisms and their possible consequences;**

Ageing management is a combination of maintenance, periodic testing and the condition monitoring program. There is not a specific procedure to identify ageing mechanisms, but this is done on a case-by-case basis, based on internal experience.

Following the results of the INSARR-mission in 2017, a need was identified to identify applicable ageing degradation mechanisms and to evaluate the maintenance of all SSCs in a more systematic way.

**d) Establishment of the acceptance criteria;**

Acceptance criteria are based on international guidelines, internal and external experience. IFE also use specifications from the manufacturers to establish acceptance criteria for components relevant to safety. However, many visual inspections use qualitative acceptance criteria, based on experience.

The acceptance criteria are informed by the OLCs. However, as was identified by the INSARR team in 2017, there is a need to update the limiting value/condition of the OLCs and the justification of their selection. This work will also have impact on the acceptance criteria in the AMP.

**e) Use of R&D programmes;**

IFE is a research organization and therefore perform a large amount of research and development related to operation and maintenance of nuclear facilities. However, there is currently not a specific research program on AMP.

**f) Use of internal and external operating experience.**

The ability to identify mechanisms of ageing in facility components at JEEP II has been attained through long experience in operating the facility. A third party organization support IFE with external experience. JEEP II hosted an INSARR mission in 2017 with a planned follow-up in the coming years.

In the work on ageing processes, the experience on corrosion at the Petroleum Department at IFE has been used**.**

### 2.3.3. Monitoring, testing, sampling and inspection activities

**HBWR**

**a) Programmes for monitoring condition indicators and parameters and trending ;**

Routine monitoring and inspection rounds are carried out by the reactor operators, maintenance and technical staff with specific areas of responsibility. In these inspection rounds, there is particular emphasis on checking the reactor for leaks or any irregular sounds. If non-conformances are discovered, they are reported into the maintenance system and the Head of the Maintenance and Installations Group decides what further action should be taken.

There is a program for monitoring the water quality, and there is an online monitoring of reactor parameters (the ProcSee system).

**b) Inspection programmes;**

The maintenance and operations personnel at HBWR have a continual awareness of the status and condition of the facility through the regular inspection rounds that they conduct. This is further reinforced by the inspection round forms that they fill out and/or their clearly defined areas of responsibility. These are personnel who have long experience with the facility, and whose attention is always focused on the safety of the facility.

Periodic testing is conducted by the groups for reactor operations, design and development, and reactor chemistry. Testing is done to maintain and improve the accessibility of the SSCs and to ensure that they satisfy the requirements laid down in the OLC. Periodic testing may be carried out by testing components or systems for functionality or comparing instrumentation with other corresponding signals or earlier trends.

Among the tasks of the Reactor Chemistry Operations Group is the monitoring of the water quality in all of the HWBR systems. Senior Reactor Chemist determine the water quality requirement in each systems, and the reactor chemistry group ensures the daily follow-up. On-line instrumentation ensures continual monitoring of water levels, temperature, pressure, and conductivity as well as the level of hydrogen and oxygen in certain systems. Samples and chemical analyses during operations and maintenance periods help to determine the quality of the water. Satisfactory water quality is important in minimizing corrosion and thereby reducing the risk of degradation of pipes and components as a result of exposure to chemicals.

Condition monitoring of the various facility systems is followed up by the operations division’s procedures for condition monitoring. For smaller components or systems, condition monitoring is followed up by the electronic maintenance systems. Here the Head of Maintenance and Installations Group is in charge. Condition monitoring of the larger systems at the reactor facility is addressed in special documentation devoted to the topic where the condition of the system and the system components are described. The documents for each system at the facility are revised according to a specific plan or when needed.

The methods of inspection and the intervals of inspection are determined based on both the descriptions in the documents and on experiences from working with HBWR.

**c) Surveillance programmes where appropriate;**

Surveillance programs are established after observations during normal inspections, or following a reported deviation.

**d) Any provisions for identifying unexpected degradation.**

Routine inspections are undertaken and inspection rounds made of the reactor facility by shift personnel, and by maintenance and technical personnel, all of whom have very specific areas of responsibility. During these inspections, there is great emphasis on checking for leaks or unusual sounds. When a deviation is discovered, this is reported into the maintenance system and will result in an error message. Subsequently, the Head of Mechanical and/or Electrical Maintenance Group decide what action should be taken.

**JEEP II**

**a) Programmes for monitoring condition indicators and parameters and trending ;**

As described above, there is an on-going process to develop a comprehensive AMP for the JEEP II reactor.

The inspections consist of a mix of visual inspections, volumetric inspections, such as ultrasonic testing and surface techniques, such as dye penetrant testing.

**b) Inspection programmes;**

Testing is done to maintain and improve the accessibility of SSC and to ensure that they are within the requirements laid down in the OLC. Periodic testing may be carried out by functionality testing of components or systems or by comparing instrumentation with other corresponding signals or earlier trends.

Condition monitoring of the different systems at the facility is followed up by the operations division which regularly carries out inspection and monitoring procedures. For smaller facilities, monitoring and inspection is followed up by the electronic maintenance system. Here the Head of the Operations Group for Mechanical Maintenance is in charge.

**c) Surveillance programmes where appropriate;**

Surveillance programs are established after observations during normal inspections, or following a reported deviation.

**d) Any provisions for identifying unexpected degradation.**

Routine inspections are undertaken and inspection rounds made of the reactor facility by shift personnel, and by maintenance and technical personnel, all of whom have very specific areas of responsibility. During these inspections, there is great emphasis on checking for leaks or unusual sounds. When a deviation is discovered, this is reported into the maintenance system and will result in an error message. Subsequently, the Head of Mechanical and/or Electrical Maintenance Group decides what action should be taken.

Maintenance and operations personnel at JEEP II have as part of their daily routine a continual assessment of the facility's status and condition. These are people who have long experience with the facility and whose attention is focused entirely on the safety of the facility. Consequently, they will immediately pick up on irregular sounds or when moving around in the facility.

### 2.3.4. Preventive and remedial actions

**HBWR**

*Planning:*

The Head of the Maintenance and Installations Group is responsible for developing long-term plans for future maintenance needs, upgrades and new installations. Maintenance is planned with a view to safe and reliable operation of the facility. The components and systems at the facility are divided into groups depending on the consequences of faults or errors, and this is used in the planning of preventive maintenance and remedial actions.

The long-term plan is worked out in cooperation with other operations groups in the operations division and other divisions in the sector. The overview of planned tasks is a separate document and has a timeline of about 3-5 years. The overview is upgraded at least once a year before the budget for the following year is determined. The plan is approved by the Reactor Manager.

For larger maintenance tasks, an interdisciplinary project group is appointed to prepare the basis for the work. This group reports to the Reactor Manager who makes the final decision on implementing the project.

For projects that have implications for safety, safety assessments are made. The procedure is described in IFE's HSE manual. The method is an aid in assessing risk at the facility in a systematic way that lays special emphasis on the safety of the personnel. Furthermore, projects and matters that have bearing on safety at facilities subject to licensing are also investigated and processed by IFE's Safety Committee.

The reactor is in operation about 50 % of the year, with two major maintenance periods of about 8-10 weeks in the spring and the fall. Large chunks of the shutdown time are devoted to loading fuel and loading experiments in and out of the reactor. For every shutdown, the Head of Maintenance and Installations Group makes an overview of the maintenance tasks to be carried out. The maintenance list is based on this document, along with error messages from the control room, regular routine tasks, and requests from other groups and divisions, not to mention the results and findings from periodic testing and inspections.

The Head of Maintenance and Installations Group, along with team leaders and other technical staff, assesses how much time is needed to carry out the various tasks and determines the length of the shutdown on that basis. This is also used as the basis for working out the radiation dose budget. The Radiation Protection Division is responsible for registering and following up on radiation doses to reactor personnel.

Every day a morning meeting is held, and representatives from the control room, Reactor Chemistry Group, fuel handling, Electrical Group, Mechanical Group and Radiation Protection Division all participate in this. At the meeting, the participants report on the activities of the last 24 hours and everyone is informed about planned and ongoing activities. The Maintenance and Installations Group is divided into two subgroups, Mechanical and Electrical, each of which has its own group leader. In addition to maintenance, the Mechanical Group is also responsible for all work in handling the fuel.

The task of the Reactor Chemistry Group is to monitor the water quality in all of the systems at HBWR. The Senior Reactor Chemist determines the water quality needs in the different systems, and the Reactor Chemistry Group is responsible for the daily follow-up and ensures that these requirements are met. On-line instrumentation facilitates continual monitoring of water level, temperature, pressure, and conductivity as well as the hydrogen and oxygen level in certain systems. The continual taking of samples and chemical analyses in operations and maintenance periods helps in determining the quality and character of the water. The correct quality of water is important in minimising corrosion and thereby reducing the risk of degradation of pipes and components due to exposure to chemicals.

The Radiation Protection Division is responsible for ensuring that all radiation protection matters are taken care of. All work forms must be approved by the Radiation Protection Division before work begins to ensure the radiation safety of the personnel and the facility. The Radiation Protection Division is also responsible for ensuring that all monitors and other radiation protection equipment are in good working order.

*Maintenance and periodic testing:*
Maintenance work at HBWR is based on a combination of preventive and corrective maintenance, depending on the historical knowledge of and experience with the components and systems at the facility. The main principles governing maintenance work are defined by the IAEA in [8]. The normal practice is that employees are given responsibility for their own part of the facility system or subsystem. For example, one worker might be responsible for following up on changing the air filters, while another is responsible for following up on the stuffing box seals, and so forth. The description of maintenance and periodic testing for the various SSCs is given in conjunction with the description of the particular SSC.

*Preventive maintenance:*
Preventive work at HBWR consists of regular inspections, tests, service, overhauling and replacement of SSCs. The aim is to increase reliability, discover and prevent faults, and ensure that the reactor facility SSCs meet the requirements for safety and operational reliability. Examples of preventive maintenance activities are as follows:

- Regular inspection rounds of the facility;
- Regular measurements and registration of operations data;
- Oil changes;
- Replacement of filters;
- Regular replacement or overhaul of components;
- Surface treatments and painting.

Preventive work is planned depending upon which group the particular SSC is categorised under. Basically, preventive maintenance is concentrated around the SSC is groups "A" and "B". When new components are installed, the need for maintenance and inspection is registered on the basis of requirements and recommendations from their construction and production, requirements in the regulations and procedures, internal experience with similar SSCs and the recommendations of the supplier.

Preventive maintenance is carried out as cooperative effort between the Maintenance and Installation Group and other operational groups and divisions at the facility.

*Corrective maintenance:*
Corrective maintenance is done on SSCs that have failed during their service. In many instances, corrective maintenance is done without a long planning period and depends on parts being in stock or readily available. The amount of corrective maintenance that is carried out depends on the quality of the SSC and the effect of the preventive maintenance. It is particularly desirable notable that there is little need of corrective maintenance for SSCs in groups A and B, as this has the greatest implications for the safety of the facility and its operational availability.

Examples of systems where corrective maintenance can be performed for the most part consists primarily of remedial maintenance include: the water preparation treatment systems and a part of the cooling water systems.

**JEEP II**
*Planning:*
The Heads of the Mechanical Maintenance Group and of the Electrical Maintenance Group are responsible for determining maintenance needs into the future and identifying the need for upgrades and new installations. Maintenance is planned with a view to safe and reliable operation of the facility. The components and systems of the facility are divided into groups depending on the consequences of faults or errors, and this is used when planning preventive

maintenance. The main philosophy is to focus on maintaining those components and systems where faults or failure would have the most severe consequences. In preparing the maintenance plan, experiences from earlier maintenance that has been carried out, results from periodic testing, operational data and experiences, risk assessments, requirements laid down by the authorities, and monitoring are used.

For larger maintenance tasks, a special interdisciplinary project group is appointed to work out the basis for carrying out the work. This group reports to the Reactor Manager who makes the final decision on what is to be done.

Safety assessments are carried out for all projects that have bearing on safety. The method of procedure is described in IFE's HSE (Health, Safety and Environment) handbook. This method is a systematic aid in gauging risk at a facility and strongly emphasises the safety of personnel.

The reactor is in operation for 50-60 % of the year. There is a major shutdown in the summer for maintenance and shorter halts in operations at Christmas and Easter. For every stop in operations, the operations leader of the Group for Mechanical Maintenance prepares an overview document of maintenance work that must be carried out. The maintenance list is based on this document, error messages from the control room, regular routine jobs, registered requests from other groups and divisions, and results from periodical tests and inspections. The operations group leaders and other technical personnel assess the amount of time required for the various tasks and determine how long the reactor should be shut down. The Radiation Protection Division is responsible for registering and following up on radiation doses to facility personnel. Besides maintenance, the Mechanical Group is also responsible for carrying out work that involves handling the fuel. JEEP II also has a program for following up on water quality to minimize corrosion and thereby reduce the risk of pipes and components degrading as a result of being exposed to chemicals. The Radiation Protection Division is responsible for ensuring that all matters of radiation protection are taken care of. Maintenance work at JEEP II is based on a combination of preventive and corrective maintenance, depending on the historic knowledge of and experience with the components and systems at the facility. The responsibility rests with the Head of Maintenance for the relevant area, however, all the employees, both operational staff in addition to the maintenance staff, participate in the follow-up and actual work on site.

All employees at the facility have the basic theoretical and practical background and/or education that are relevant to their position. They also receive general training upon being hired, as well as further education through relevant internal courses. The skills and competence needs at the facility and the training plan in the operations division relevant to the area of responsibility are described in the safety report and internal directives. Much of the training is done "on the job" by working closely alongside and learning from experienced employees.

The maintenance program contains information about a given component as well as a log of maintenance work carried out earlier and new tasks planned for the system/component. After the task is reported as complete, the information is logged and registered, primarily by the Head of Maintenance. The work is registered in the log by those who carried out the work or the closest line manager. Error messages from the control room are registered in the system by control room personnel, and the Head of the Reactor Operations decides what further treatment may be necessary in consultation with the head of the division.

All work forms are filed electronically in the division's filing system. The maintenance system is also utilized to plan preventive maintenance tasks by plotting in new tasks ahead of time.

*Preventive maintenance:*
Preventive maintenance. Preventive maintenance consists of regular inspections, tests, service, overhauling and replacing SSC. The aim is to increase reliability, identify and prevent faults, and ensure that the reactor facility's SSC meet the requirements for safety and reliability of operations that have been set for it. Examples of preventive maintenance are:

- Regular inspection rounds of the facility.
- Regular measurement and registration of operations data.
- Changing filters.
- Regular replacement or overhauling of components.
- Surface treatment and painting.

*Corrective maintenance:*
Corrective maintenance is performed on the SSC due to failure, or due to any other reason related to quality, performance, reliability or function that may justify action taken.. In many instances, corrective maintenance is performed without a long planning period and depends on the availability of parts or that parts are readily accessible.

## 2.4. Review and update of the overall AMP

**Commonalities of both research reactors**

This section is similar to both JEEP II and HBWR. There are some differences which are highlighted below.

**a) How licensee audit and inspection findings are implemented;**
Most findings from inspections are reported in the deviation management system. In some cases, e.g. INSARR missions, findings result in a dedicated report which includes a plan to be followed up. The findings from all external audits are presented to the Safety Committee.

**b) Evaluation of plant specific and others' operating experiences;**
IFE has no regular cooperation or exchange of experience on ageing management with other reactor operators, but cooperation is done on a case-by-case basis. IFE also use experience from third parties with experience from other nuclear facilities, especially in Sweden.

c) **Evaluation of plant modifications that might influence the overall ageing management programme;**

There is a procedure for how all safety related modifications at the facility should be made. All such modifications should be based on a safety evaluation from the Safety Committee of IFE. There is no specific procedure on modifications related to ageing. IFE also have close cooperation with third party organization who provide assessments on modifications.

d) **Evaluation and measurement of the effectiveness of ageing management;**

There is no formal procedure to evaluate and measure the effectiveness of the ageing management. The condition monitoring program is under continuous evaluation using both internal and external input.

e) **Evaluation of ageing analyses that are time limited;**

There is no formal procedure to evaluate ageing analyses that are time limited but this is based on experience or on suggestions from the manufacturer.

f) **How current "state-of-art", including R&D results, is taken into account;**

IFE work closely with a third party organization which provide useful experience. In special cases when procuring new SSCs, IFE give thorough considerations on the relevant topic.

g) **Consideration within the overall ageing management programme of modifications in the current licensing or regulatory framework;**

IFEs follows modifications to the regulatory framework continuously, but there is also an annual review. The AMP is evaluated in relation to the modifications, and revised if necessary. All modifications to the regulatory framework will be reviewed by the Safety Committee as they might affect several parts of the organisation.

h) **Identification of need for further R&D.**

The need for further R&D is identified from operation experience, maintenance program etc.

i) **Strategy for periodic review of the overall AMP including potential interface with periodic safety reviews;**

There is a general review, including AMP, as part of the license application process for each of the reactors.

For JEEP II, there are annual meetings with a third party organization, where the AMP is evaluated and updated, in accordance with the findings and with planned updates for completing the program based of already performed inspections.

For HBWR, there are fixed intervals for updating the AMP. For HBWR, there are programs with different intervals for updating:

- *Non-destructive Testing (NDT) of pressurised equipment.* The ageing management program concerning non-destructive testing of pressurised equipment is reviewed on an annual basis in cooperation with the third party organization in connection with the summary of the year's inspections. The technical inspection unit follows up closely on any revisions of the standards or the issuing of new standards that have bearing on HBWR.

- *Material surveillance.* The material surveillance program is evaluated and revised after each part of the test program on the basis of the test results and the available material samples. It is important to do this with respect to:
  - Fluence level of the material samples relative to the fluence of the vessel.
  - Change of position of the material samples to influence the accumulation rate (increase or decrease).
  - Revision of relevant standards.
  - Evaluation of test techniques, with respect to required results as well as material use.
- *The material surveillance program of the reactor vessel.* This program is reviewed every third year.
- Other programs, e.g. water chemistry, are evaluated continuously.

**j) Incorporation of unexpected or new issues into the AMP;**

The AMP is updated and review due to unexpected or new issues as needed.

**k) Use of results from monitoring, testing, sampling and inspection activities to review the overall AMP;**

IFE analyse the results from the monitoring and inspection activities together with the third party organization. The annual report on the operation and maintenance is reviewed by the Safety Committee, which provide feedback and recommendations.

**l) Periodic evaluation and measurement of the effectiveness of ageing management.**

The general AMP for HBWR and JEEP II is included in the SAR and is thereby updated as an integral part of updating the SAR, as a rule every third year. Furthermore, the AMP is updated when experience and findings from maintenance, periodic testing or inspections indicate this. External input such as:

- new standards
- new information or knowledge
- requirements from the authorities

will also result in revision and upgrading of the general AMP.

## 2.5.Licensee's experience of application of the overall AMP

**HBWR**

The AMP at HBWR has been developed over the course of several years and is based on a solid foundation of experience and knowledge about the ageing of various materials and components.

The general AMP provides HBWR with a good straightforward tool that ensures compliance with the requirements and that standards are maintained and complied with in the monitoring and management of ageing at the facility.

Close cooperation with the third party organization when developing and carrying out the gap analyses in accordance with current national regulations also contributes to objectivity and quality. The AMP ensures competence in following up, running and developing the operations at the reactor facility. A good and consistent filing system contributes to this, along with routines for overlap of different positions and functions on the various elements of the AMP.

Preventive maintenance programs and corrective maintenance are run and documented in the electronic maintenance system. The water chemistry program, which is based on EPRI's Guidelines [21], is updated upon any changes in the given guidelines, or in the event of new knowledge and upgrades of various reactor systems. The Senior Reactor Chemist in charge of drawing up the water chemistry program, also plays a central role in IFE's R&D work on HBWR and in this capacity is well-informed of new developments in the area.

**JEEP II**

The AMP at JEEP II was formally established in 2016 based on experience gained in the operation of HBWR. This is not yet a comprehensive AMP as it does not cover all SSCs important to safety, e.g. electrical installations are not included. There is on-going work on this topic, and the plan is to have established a comprehensive AMP before 2019. To complement the ongoing effort, the ageing management program will be revised in accordance with the IAEA safety standards to include identification of applicable ageing degradation mechanisms, operating practices to minimize ageing degradation, identification and implementation of mitigation actions (e.g. refurbishment, modification, replacement, etc.), and periodical evaluation of the program for its continuous improvement. This assessment is based on the conclusions from the the INSARR mission in 2017 to the JEEP II reactor.

The close cooperation with a third party organization in following the ageing program contributes to objectivity and quality. The establishment of the AMP also helps to secure competence with respect to the follow-up, practice and development of the operation of the reactor facility. A further positive effect of establishing an AMP is also the focus on documentation and systematic recordkeeping.

## 2.6. Regulatory oversight process

NRPA supervise the safety of IFEs nuclear facilities through regulatory inspections and assessments as deemed necessary between the reporting milestones. In total, NRPA do 15-20 on-site inspections per year at IFE, including the two research reactors.

DSB is currently the authority responsible for oversight of the pressurized equipment at HBWR. However, it is proposed that from 1 July 2018, this responsibility will be transferred to NRPA.

Besides these inspections, NRPA monitor the operation of the research reactors through weekly and annual reports on the operation of all nuclear facilities.

HBWR is required to use a third party for independent inspections and safety assessments on the condition of the SSCs important to safety. The results from these inspections are reported to NRPA and DSB. NRPA is in a process to implement a similar requirement on JEEP II as a condition in the next license. This is in line with the challenge identified as part of the review meeting of the Convention of Nuclear Safety in 2014, where Norway was requested to establish an effective ageing management program. In the review meeting in 2017, this challenge was considered closed for HBWR but remain open for JEEP II.

NRPA make use of input from external reviews, such as INSARR missions. There have been INSARR missions to HBWR in 2007 with a follow-up in 2010 and to the JEEP II in 2017 with a planned follow-up in the coming years.

Following a small leakage in the primary circuit, NRPA had a regulatory inspection in 2016 where the ageing management was one of the topics. The incident showed that there was a need to revise the condition monitoring program at JEEP II. Besides, the third party inspections, NRPA commissioned an external evaluation in 2013-2014 to inform their assessment of the ageing management programme at HBWR. The review included all SSCs but focused on ageing of metallic materials relevant for safety. The results from this inspection were used as conditions for the current HBWR license.

## 2.7. Regulator's assessment of the overall ageing management programme and conclusions

<u>HBWR</u>

As required by the regulator, IFE has an established AMP for HBWR. The program is based on IFE's experience and knowledge. IFE are utilising a third party organization to inform the development of their ageing management programme. IFE have a long standing relationship with the third party organization and they provide an independent review of their AMP informed by relevant experience from the nuclear industry.

HBWR has no formal, regular cooperation or exchange of operating experience relating to ageing management with other reactor operators, but cooperation projects are established on a case-by-case basis. IFE do not have any of their own dedicated research and development programmes relating to ageing management. There have been international peer reviews through the INSARR missions to HBWR in 2007 and 2010 which resulted in recommendations to address their ageing management programme. NRPAs assessment is that IFE should systematically seek best practice and relevant operating experience to continuously improve its AMP through engaging with other operators and experience sharing forums. In particular because Norway has a small nuclear industry.

HBWR have linked their AMP to the SSCs, are sourcing relevant safety criteria from a variety of sources, such as international standards, internal experience and manufacturer recommendations, to inform their acceptance criteria and have used this to enhance maintenance and safety at site as a result. NRPAs assessment is that IFE have established methods to establish acceptance criteria.

HBWR have a program for maintenance, including preventive and remedial actions, and a program for inspection and monitoring. NRPAs assessment is that these programs are established and implemented properly.

IFE are developing their AMP to inform ongoing maintenance at their operational sites. It is important that there are clear metrics used to identify how well it is performing, and that learning is shared not only at the site concerned, but throughout their organisation and externally too.

*Overall Assessment for HBWR*
NRPA have made use of the third party inspections and the external evaluation in 2013-2014 when assessing the AMP at HBWR. Through this review process it is identified that there should be more focus on this area in the coming years The assessment is also based on information provided by IFE.

NRPAs assessment is that the overall AMP at HBWR is established and that the scope covers all SSCs that are necessary to fulfil the fundamental safety functions. However, it is observed that there are significant gaps, for example electric cables. It is also assessed that IFE is working continuously to improve and develop the AMP, through use of internal and external experience.

<u>JEEP II</u>
The current ageing management at JEEP II has a limited scope and does not cover all relevant SSCs. An AMP at JEEP II was formally established in 2016 and will be extended to a comprehensive AMP. There is no requirement for the AMP to be the same at HBWR and JEEP II and NRPA thinks it is positive that JEEP II may benefit from the more advanced state that HBWR are at with their AMP. The recommendations from the INSARR-mission in 2017 related to ageing are also important in this respect. NRPA think that is it essential that a comprehensive AMP will be established.

JEEP II has established a relationship with the same third party organization as used by HBWR, which will provide relevant experience from the nuclear industry as well as independent input

JEEP II has no formal, regular cooperation or exchange of operating experience relating to ageing management with other reactor operators, but cooperation projects are established on a case-by-case basis. IFE do not have any of their own dedicated research and development programmes relating to ageing management. IFE have hosted international peer reviews through the INSARR missions to JEEP II in 2017, which resulted in recommendations to address their ageing management programme. NRPAs assessment is that IFE should systematically seek best practice and relevant operating experience to continuously improve its AMP through engaging with other operators and experience sharing forums. In particular because Norway has a small nuclear industry.

JEEP IIs acceptance criteria are based on a variety of factors: international standards, internal experience and manufacturer recommendations. NRPAs assessment is that acceptance criteria based on established international codes is a good practice

JEEP II have a program for maintenance, including preventive and remedial actions, and a program for inspection and monitoring. NRPAs assessment is that these programs are established and implemented properly.

*Overall Assessment for JEEP II*
Following a small leakage in the primary circuit, NRPA had an inspection in 2016 where ageing management was one of the topics. The incident showed that there was a need to revise the condition monitoring program.

Through this review process it is identified that NRPA should have more focus on ageing management in the coming years, including dedicated inspections. However, NRPA can make an assessment of the AMP at JEEP II based our reviews of external reviews, such as the INSARR mission in 2017. The assessment is also based on information provided by IFE.

NRPA observe that the AMP at JEEP II is under development, has limited scope and does not cover all relevant SSCs relevant to safety. NRPA will be taking a keen interest in the development and implementation of the AMP at JEEP II in the coming years.

# 3. Electrical cables

## 3.1. Description of ageing management programmes for electrical cables

### 3.1.1. Scope of ageing management for electrical cables

**Commonalities of both reactors**
IFE maintains stringent follow-up on the condition of electric cables at HBWR and JEEP II based on its experiences on its respective facilities. Some of the cables were installed at the time the facilities were constructed and are still in use. These cables are monitored continuously. The cables that are subject to physical wear and tear are followed up and replaced through preventive maintenance, or if any degradation is discovered.

**HBWR**
At HBWR, there are about 7000 cables, and the number varies in line with the number of experiments that are carried out. Some cables have been removed and replaced by new cables in connection with experiments and renewal of installations.

a) **Methods and criteria used for selecting electrical cables within the scope of ageing management;**

A number of cables have been selected for testing. There are no formal, internal criteria for how to select electrical cables to test for ageing. Cables are selected based on experience and load in the AMP.

b) **Processes/procedures for the identification of ageing mechanisms related to cables;**

IFE is currently using thermography and LIRA-technology (Line Resonance Analysis) together with visual inspections to identify ageing mechanisms. All these methods are in regular use. Thermography of cables that has been deemed to be relevant to safety are tested two times per year.

Previously, cable samples were sent for testing. This was done last time in 1995 and there are currently plans to continue that practice.

c) **Grouping criteria for ageing management purposes.**

IFE has no formal grouping criteria for grouping of cables for ageing management purposes.

**JEEP II**

a) **Methods and criteria used for selecting electrical cables within the scope of ageing management;**

A number of cables have been selected for testing. There are no formal, internal criteria for how to select electrical cables to test for ageing. Cables are selected based on experience and load.

b) **Processes/procedures for the identification of ageing mechanisms related to cables;**

IFE use thermography and visual inspections to identify ageing mechanisms. Some cables are included in the electronic maintenance system, for example, cables which are known from experience to need to be changed regularly.

c) **Grouping criteria for ageing management purposes.**

IFE has no formal grouping criteria for grouping of cables for ageing management purposes. At JEEP II, there are plans to establish a special AMP for electrical installations, as part of the implementation of the comprehensive AMP.

### 3.1.2. Ageing assessment of electrical cables

**HBWR**

a) **Ageing mechanisms requiring management and identification of their significance;**

The ageing mechanism in the AMP is based on mainly neutron irradiation, wear and tear, moisture and heat.

Regular inspections, continuous monitoring and external testing have shown that there is no sign of degradation in the electrical cables.

b) **Establishment of the acceptance criteria related to the ageing mechanisms.**

There are no formal acceptance criteria related to the ageing mechanisms, but are based on experience.

**JEEP II**

a) **Ageing mechanisms requiring management and identification of their significance;**

The ageing mechanism in the AMP is based on mainly neutron irradiation, wear and tear, moisture and heat. However, there is no formal identification of ageing mechanisms, which was also identified by the INSARR-team in 2017.

b) **Establishment of the acceptance criteria related to the ageing mechanisms.**

There are no formal acceptance criteria related to the ageing mechanisms, but are based on experience. This was also identified by the INSARR-team in 2017.

### 3.1.3. Monitoring, testing, sampling and inspection activities for electrical cables

**HBWR**

All electrical cables are continually checked, along with other electrical installations and the insulation monitoring systems. The system reveals insulation faults in the electrical installations, an alarm is activated in the control room and a search is made for the fault. Troubleshooting is carried out by IFE’s own professional team of electricians.
Cables are divided into zones, which in turn are registered in IFE’s electronic maintenance system. The cables are checked for professional workmanship and covering and on their proximity to heat generating installations.

The cables in the reactor hall are thermographed during run-up for the reactor start-up to check for high temperatures in the cables. This inspection is carried out a minimum of twice a year. Loading is at its greatest during run-up of the reactor, and thereby the possibility of high temperatures in the cables.

The cables in the cable supports outside the reactor hall are thermographed once a year to check for high temperatures.

In 1995, pieces from 15 cables of differing ages were removed for testing at an independent test facility. None of the cables showed any sign of damage or degeneration. In 2007, 17 cables were tested by IFE using the LIRA technology, an ageing assessment method developed by IFE. None of the cables showed signs of damage or degeneration.

**JEEP II**
Cables that are subject to physical wear and tear are checked and replaced through preventive maintenance, or if degeneration is detected. Other cables are not routinely followed up, but are regularly replaced (especially those that are exposed to radiation) when they cease to function properly (signal cables). There is no formal frequency for checking cables, but is based on experience. Electrical cabinets are thermographed annually by an independent third party.

Signal cables are tested by checking the instrument which the cable is connected to functions properly.

Monitoring for ground faults uncovers insulation faults in electrical cables and electrical installations. Troubleshooting is carried out by IFE's own electrical technicians.

### 3.1.4. Preventive and remedial actions for electrical cables

**Commonalities for both reactors**
There is a continual effort to improve the conditions for electrical cables at HBWR and JEEP-II. It is important how the cables are installed. The cables must not be covered, there must be good access to air to assure cooling, and they should not lie close to heat sources.

Electrical facilities at IFE are under the authority of the Norwegian authorities, more specifically, DSB. External companies conduct inspections of the electrical facility at 8-10 year intervals, as well as examining the documentation on work that is being done. At these inspections, virtually all of the electrical installations at the facility are inspected and monitored.

**HBWR**

Electrical staff and in some cases personnel from control room check if there are some problems with high temperature on some cables e.g. following transformer inspections. There are temperature criteria specific for each cable. If needed, remedial work will be done as soon as possible.

There is continual work to remove cables that are no longer in use wherever this is possible. This improves the conditions for the remaining cables in that the cable bridges become more airy. Several kilometres of cables have been removed over the years.

In 1991 there were about 10,000 electrical cables at the reactor plant. This number was brought down to about 9,000 cables as a result of clean-up efforts in reactor shutdowns during the early 1990s. In later clean-ups, as well as in a major clean-up around the year 2010, the number of cables that are currently installed is about 7,000. Obviously, this has a clear beneficial effect on the cables that are in the facility today.

To summarize: the removal of cables, no proximity to heat sources and good ventilation are important elements in improving the conditions for cables since heat has a negative effect on the insulation.

Most parts of the IFE reactor plants are accessible at any time, and electrical work is carried out around the facility on a continual basis. Consequently there will always be, if not on a daily basis, then certainly very often, reactor personnel present in various places throughout the facility. Hence, they will observe electrical cables and installations and will thereby detect any impending faults at an early stage. Their observations are registered in the electronic maintenance system and if necessary, any faults or problems are corrected.
IFE has an electronic deviation management system for logging deviations in the event a deviation is observed.

**JEEP II**
There is continual work to remove cables that are not in use wherever this is possible. This improves conditions for those cables that remain. For example, there is more air between the cable bridges making more room in the cable rack.

Most of the JEEP II reactor facility is accessible at any time of day. Hence there will always be employees present in the different areas of the reactor, if not daily, then certainly very frequently. They will naturally be keeping an eye on electrical cables and installations, and will thereby detect eventual faults at an early stage. If any deviation is observed, the Operation Division has a computer-based deviation management system in which deviations are registered. However, there is no formal procedure for preventive actions regarding electrical cables.

## 3.2. Licensee’s experience of the application of AMPs for electrical cables

**HBWR**

IFE's ongoing work to follow-up on the electrical cables at HBWR has resulted in the implementation of measures to improve the conditions for both new and older cables. As a link in this work, an older transformer, along with its associated cables and wiring closet, was replaced in the fall of 2016. There are also ongoing systematic efforts to reduce the load on power cables.

IFE is satisfied with the current AMP for electric cables, but due to the age of the facility there is ongoing need for improvement. Especially, there will be more focus on power cables in the future.

**JEEP II**
IFE's on-going follow-up and monitoring of the electrical cables at JEEP II is deemed satisfactory given the limited number of cables and the fact that they are for the most part readily accessible for inspection (both visual and technical). IFE is in a process to develop a comprehensive AMP and that will include establishing a more systematic program at JEEP II that includes electrical installations and instrumentation.

IFE is satisfied with the current AMP for electric cables, but due to the age of the facility there is ongoing need for improvement.

## 3.3. Regulator's assessment and conclusions on ageing management of electrical cables

HBWR
HBWR has an established program for maintenance, including preventive and remedial actions, and a program for inspection and monitoring of cables. These programs are focused on cables with high load, but it does not include all cables that are relevant to safety. NRPAs assessment is that the program should be extended to include all cables relevant to safety.

HBWR has no formal acceptance criteria for which cables to test for ageing, but this is based on experience. There are also no formal grouping criteria for cables. HBWR plans to extend the program to include power cables in the future. NRPAs assessment is that an area for improvement is to establish more formalized procedures for which cables that are selected to test for ageing.

HBWR has since the 1990s worked to reduce the number of cables at the facility. The work was intensified further after the INSARR missions in 2007 and 2010 recommended to continue the work due to the fire hazard. NRPA think this is positive that HBWR continuous to have focus on this topic and that the practice to reduce the number of cables should continue.

*Overall Assessment for HBWR*

NRPA have not had any inspections focussing on electrical cables at HBWR in recent years. NRPAs assessment of the AMP for electrical cables at HBWR is based primarily on reports to NRPA and information that IFE provided in the course of this review process.

NRPAs overall assessment is that whilst HBWR has established an AMP for electric cables, this does not meet the expectations of a comprehensive AMP. The scope of the AMP needs to be extended to cover all nuclear safety significant electric cables. Having no assessment criteria indicates that the safety assessments are not complete and that there is a reliance on informal staff know how and competence in this topic area. Assessment criteria are recommended to be sourced from recognised best practice and relevant operating experience to enhance the AMP.

JEEP II

An AMP was formally established at JEEP II in 2016 and will be extended to a comprehensive AMP. NRPA will follow-up the development and implementation of the comprehensive AMP at JEEP II, which is expected to include electrical cables.

The maintenance program includes testing of electric cables but there is not currently a formal process for grouping these cables according to the AMP.

*Overall Assessment for JEEP II*

NRPA have not had any inspections focussing on electrical cables at JEEP II in recent years. NRPAs assessment on the ageing management for electrical cables at JEEP II is based primarily on reports to NRPA and information that IFE provided in the course of this review process.

NRPAs assessment is that there need to be a formal process for identifying which cables are nuclear safety significant and subject to the AMP. Assessment criteria are recommended to be sourced from recognised best practice and relevant operating experience to enhance the AMP.

# 4. Concealed pipework

## 4.1. Description of ageing management programs for concealed pipework

### 4.1.1. Scope of ageing management for concealed pipework

**HBWR**

**a) Methods and criteria used for selecting concealed pipework within the scope of the ageing management;**

There is a small amount of concealed piping in HBWR (see description below). Except for a small pipe in the primary circuit, the concealed piping is not safety related.

b) **Processes/procedures for the identification of ageing mechanisms related to concealed pipework ;**

Since there is only a small amount of piping in the facility, there has not been made any difference between concealed piping and other piping in the AMP, or in the Condition Monitoring Program. The inside of the pipes are monitored as part of the water chemistry program.

c) **Grouping criteria for ageing management purposes.**

Due to the small amount of piping, there has not been any grouping of the concealed piping.

The reactor hall is located in a mountain cavern. Access in gained through a tunnel. A sluice has been constructed in this tunnel with two sluice walls and their corresponding sluice gates. Pipes going through the 1 m thick sluice walls are available for inspection on both sides of the sluice walls.

When mapping the covered and concealed pipework at the plant, an effort is made to distinguish between the various facility systems.

*Primary circuit:*

The whole primary circuit is placed in the reactor hall. There are no concealed pipes in the primary circuit or its associated systems, with the exception of 3 meter of concealed piping in the air atmosphere between the reactor vessel and the screen shield circuit.

*Secondary circuit:*

The secondary circuit is located in the reactor hall and Olavshallen (a hall outside the reactor containment). The steam piping from the steam generator is covered by a ventilation channel such that it is not visible, but can be inspected as needed. Parts of the stretch of pipework of the circulation pumps lie beneath the floor in Olavshallen. This stretch of piping is not visible but can be reached easily if needed. All secondary pipes that penetrate and pass through the sluice wall lie in double pipes with flanges and seals.

*Spent fuel pit:*

The spent fuel pit consists of three fuel pools localized in the reactor hall. There are concealed drainage pipes in the concrete leading from all three pools. These are no longer in use for pit 1 and pit 2 because new stainless steel pipes has been mounted in these two storage pools

*Waste pit:*

The storage pool for water is located in the reactor hall. A feed water pipe goes to the Waste Pit from the delay system through both sluice walls. There is also a pipe that goes from the pump in the Waste Pit through the inner sluice wall to the emergency filters in the sluice.

*Shield circuit:*

The shield circuit is divided into an upper and lower part. The lower part cannot be accessed except for the visible part in the tunnel beneath the reactor vessel. Parts of the upper shield circuits are accessible from the reactor pit, that is, only the one side of the upper shield circuit. The piping that is connected to the shield circuit is accessible.

*Coolant:*

Water from the paper factory or Halden municipality supplies all of the cooling circuits in the reactor hall via a pipe that goes through the two sluice walls. No piping is concealed except for the part that goes through the sluice walls.

*Sink:*

A system of pipes ensures the drainage of mountain water from the lowest point in the reactor hall and out to the delay system. This water is pumped out to the delay tanks via two pipelines. There are no concealed pipes except for those going through the sluice walls. Double piping is used through the sluice walls.

*Delay system:*

Water from the sink is conducted to the delay system via a pipe that goes through both sluice walls. Parts of this stretch of piping lie below the sheeting plates in Olavshallen, but this is readily accessible for inspection if needed. Otherwise, there are no concealed pipes.

*Sprinkler system:*

The sprinkler system consists of nozzles mounted throughout the entire roof of the reactor hall. The system is supplied by water from Olavshallen through a pipe. There are no concealed pipes, only the passage through both sluice walls. The passage through the sluice walls has double pipes.

*Emergency cooling:*

The emergency cooling system consists of one part heavy water and one part light water. The heavy water part is located in the reactor hall and covers the immediate need for cooling. All components for emergency cooling with heavy water are located in the reactor hall, and there are no concealed pipes in this system. If there is a need for sustained cooling with light water, the water supply is started from Olavshallen. This system consists of a pipe that goes through both sluice walls.

*Ventilation:*

The main ventilation in and out of the reactor hall goes through the containment and the piping is visible on both sides.

*Cavity:*

The air cushioning system maintains a slight overpressure above the roof in the reactor hall relative to the reactor hall. The supply of air to this system comes from Olavshallen in a pipe which goes through both sluice walls.

*Process air*

Process air for work and instruments in the entire reactor facility is supplied from the compressor room in Olavshallen. The system consists of two pipelines that go through both sluice walls. The passage through the sluice walls has double pipes with flanges and seals.

**JEEP II**

**a) Methods and criteria used for selecting concealed pipework within the scope of the ageing management;**

The Condition Monitoring Program is currently focused on the primary circuit. During the current revision of the AMP, it will be expanded to other areas. In general, pipes important to safety are included in the AMP, but there are no formal criteria of which pipes that are included, this is based on experience.

**b) Processes/procedures for the identification of ageing mechanisms related to concealed pipework ;**

There are no special procedures for concealed piping, but for all pipes important to safety, cameras are used to perform visual inspection inside the pipes. It is also planned to do thickness measurements of pipes using ultrasonic testing.

For other pipes, a check by X-ray inspection of welds is done every fifth year, as described in the present program, completed in accordance with requests from the third party.

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**c) Grouping criteria for ageing management purposes.**

There are some areas at the JEEP II facility with limited access. Below is a list of concealed piping at the JEEP II (main structures):

- In the primary circuit, the inlet/outlet to the reactor tank, placed under the tank, is not readily available
- Light water: pipes connected to the fuel storage in the reactor hall, and piping in the thermal shield around the RPV
- Pipe underground to the waste tank outside the reactor building, transporting low and medium active water.
- The “gas room”, which is the space between the outer wall of the reactor tank and the thermal shield constructed of black steel. This space is filled with helium and has a flow rate of 25 litres per hour to dry out the “gas room”. The thermal shield is filled with water. Stainless steel axial compensators are positioned beneath the bottom shielding to accommodate the thermal movement in the tank and associated pipes.
- Control station rod tubes; Al-piping welded to the RPV

In addition, of less size and importance, there is a small pipe from the heat exchanger room (heavy water) that is inaccessible. This pipe is used as water level indicator.

Due to the small amount of piping, there has not been any grouping of the concealed piping.

### 4.1.2. Ageing assessment of concealed pipework

**HBWR**

Experience from accessible piping that is subject to the same stresses, sets the framework for when maintenance and inspections. IFE’s main philosophy is to focus on maintaining those components and systems where faults or failure would have the most severe consequences. Experiences from earlier maintenance that has been carried out along with results from periodic testing, operational data and experiences, risk assessments, requirements laid down by the authorities, and monitoring are used in preparing the maintenance plan.

**a) Ageing mechanisms requiring management and identification of their significance;**

The international codes and standards mentioned in 2.3.2 are used as a basis, but there is not a specific procedure to identify ageing mechanisms. This is done on a case-by-case basis, based on internal experience.

**b) Establishment of the acceptance criteria related to the ageing mechanisms.**

There are no formal acceptance criteria, but internal criteria and use of original specifications are used.

**JEEP II**

**a) Ageing mechanisms requiring management and identification of their significance;**

The ageing mechanisms have not been formally identified. This fact was also commented by the INSARR-team in 2017 [11].

**b) Establishment of the acceptance criteria related to the ageing mechanisms.**

There are no formal acceptance criteria, but internal criteria and use of original specifications are used. This fact was also commented by the INSARR-team in 2017.

### 4.1.3. Monitoring, testing, sampling and inspection activities for the concealed pipework

**HBWR**

One of the main measures to monitor the pipes is through the monitoring of the water quality. The Reactor Chemistry Group has the task of monitoring the water quality in all of the systems at HBWR according to a defined program. The monitoring of water quality, temperature, conductivity and oxygen levels is done by instrumentation. Sampling and chemical analyses of the water from the different systems are carried out both during operations and maintenance periods. Such characterization of the water quality is important with respect to maintaining good water chemistry in the various systems and thereby reducing the risk of degradation in pipes and components from having been exposed to chemical affects.

**JEEP II**

The AMP is currently focused on the primary circuit. During the current revision of the AMP, it will be expanded to other areas. In general, pipes important to safety are included in the AMP, but there are no formal criteria of which pipes that are included, this is based on experience.

### 4.1.4. Preventive and remedial actions for concealed pipework

**Commonalities for both reactors**

There is a small number of concealed piping at the reactor facilities. Replacing stretches of pipework is a continual process, and this is carried out during corrective and preventive maintenance on the associated system. However, there is not a formalized process for this.

## 4.2. Licensee's experience of the application of AMPs for concealed pipework

**HBWR**

All of the concealed piping at HBWR has been surveyed, and the overview shows that there are very few critical pipes that are hidden. Improving the program for monitoring concealed pipes is a continual process, and the work is entered into the maintenance system on a continual basis. Thus, there is no special AMP for concealed piping, but the AMP for piping in general is used.

As part of the ageing management program and in connection with the reconstruction of the shield circuit in the fall of 2016, inspections were made of those parts of the circuit that have not been accessible for inspection before. Old piping that had been removed was also inspected. The inspection was carried out by a third party organization in cooperation with IFE.

As there is small amount of concealed piping and that only one item that is important to safety, it is concluded that the AMP used for general piping is also applicable to the concealed piping.

It is concluded that there is adequate control of concealed pipework. Few critical pipes are concealed and these pipes will be followed up through future in-service inspections.

**JEEP II**
Inspections of the thermal shielding have helped to provide an overview of the corrosion processes connected with the thermal shield, and this will be followed up as part of the review of the AMP in 2018. As part of the systematic AMP, a more regular follow-up inspection regime has been established.

There is a process to develop a comprehensive AMP, and concealed piping will be considered in this process.

All of the concealed piping at JEEP II has been surveyed, and the overview shows that there are very few critical pipes that are hidden. Improving the program for monitoring concealed pipes is a continual process, and the work is entered into the maintenance system on a continual basis.

Few critical pipes are concealed and these pipes will be followed up through future in-service inspections.

## 4.3. Regulator's assessment and conclusions on ageing management of concealed pipework

<u>HBWR</u>
HBWR has an established program for maintenance, including preventive and remedial actions, and a program for inspection and monitoring of all piping at the facility.

There are only a small number of concealed pipes at the facility relevant to nuclear safety. These pipes have been identified. Due to the small amount, it has not been necessary for grouping criteria, and there is also not a dedicated AMP for concealed piping. The AMP for general piping has been assessed by IFE to be applicable also for concealed piping.

*Overall Assessment for HBWR*
NRPA have not had any inspections specific to concealed piping at HBWR in recent years. NRPAs assessment on the ageing management for concealed piping at HBWR is primarily based on reports to NRPA and information that IFE provided in the course of this review process.

NRPAs assessment is that IFEs as part of continual improvement should review the need to develop a specific AMP for concealed pipes based on best practice and relevant operating experience.

<u>JEEP II</u>
JEEP II has an established program for maintenance, including preventive and remedial actions, and a program for inspection and monitoring of all piping at the facility.

There are only a small number of concealed piping at the facility relevant to nuclear safety. These pipes have been identified. Due to the small amount, it has not been necessary for grouping criteria, and there is also not a dedicated AMP for concealed piping. The AMP for general piping has been assessed by IFE to be applicable also for concealed piping.

*Overall Assessment for JEEP II*
NRPA have not had any inspections specific to concealed piping at HBWR in recent years.. NRPAs assessment on the ageing management for concealed piping at JEEP II is based on reports to NRPA and information that IFE provided in the course of this review process.

An AMP was formally established at JEEP II in 2016 and is expected to be extended to a comprehensive AMP. NRPA will follow-up the development and implementation of the comprehensive AMP at JEEP II, which should include general piping, and concealed piping as appropriate.

NRPAs assessment is that IFEs current program on concealed piping is developing, considering that only a very small amount of concealed piping is relevant to nuclear safety.

# 5. Reactor pressure vessels

## 5.1. Description of ageing management programmes for RPVs

### 5.1.1. Scope of ageing management for RPVs

**HBWR**
The reactor vessel is made of steel plates that are welded together into a cylindrical element. This in turn is welded to a curved bottom piece pressed out of a single stock and a flange ring. The lining on the inside of the cylindrical reactor vessel is made of stainless steel. The welds on the reactor vessel were 100% checked by x-ray after fabrication, and the vessel was pressure tested with cold water. The reactor vessel has longitudinal welds and circumferential weld seams.

The cover is flat and bolted to the flange ring. The seal between the reactor vessel and the cover is made of aluminium gaskets.

The aging management program for the RPV at HBWR consists of two parallel programs:
- NDT (in-service inspection) of pressurized equipment
- Material surveillance

**a) Methods and criteria used for selecting components within the scope of ageing management;**

The reactor and the accompanied heat transfer circuits are subject to the «Regulations for pressurised equipment» [1] and the ”Regulations on the handling of flammable, reactive and pressurised substances and the equipment and facilities utilised in their handling» of 8 June 2009 [1], established by DSB. In addition, relevant international codes [14, 15] are also consulted concerning the nuclear parts of the facility described in the SAR.

**b) Processes/procedures for the identification of ageing mechanisms for the different materials and components of the RPV.**

The condition monitoring of pressurised equipment that is done at HBWR today is a direct continuation of the three-year main inspections that were carried out in the period from 1976 to 2003 on the orders directions of DSB. The program is determined in cooperation with the third party organization, and includes the components that are subject to third party inspections. The renewed authorization for use for the facility is granted on the basis of the completed inspections by the third party organization in accordance with the «Regulations on handling flammable, reactive and pressurized substances and the equipment and facilities utilized in their handling» [3]. The preliminary work for the inspections in 2003 and 2006 included a revision and review both of inspection methods and scope, with the aim of broadening the scope of the condition monitoring inspection and ensuring that inspections are carried out in accordance with the regulatory framework mentioned above. Broadening the scope has bearing on the practical execution of condition monitoring efforts, and IFE has increased inspection intervals in keeping with the current regulations. The condition monitoring program has been revised in cooperation with the third party organization and assessed in a GAP analysis. This work showed that the inspection interval had been much stricter than international regulations, whereas inspections had been less strict in areas that included component parts and so forth. IFE has adjusted the scope and interval of inspections in view of this.

The changes made following the GAP analysis of 2006 include the following points:

- Inclusion of the internal parts of the reactor vessel, cover, and most of the welding work;
- Greater emphasis on stretches of piping;
- Better traceability between inspections;
- A plan for replacing inspected welds on stretches of piping if defects do not appear over the course of two inspections;
- Generally increased interval from 3 to 9 years (the requirement is 10 years).

Condition monitoring of pressurised equipment thus includes all parts of the reactor facility that are covered by the regulation [2] and with a representative range of welds.

The program of condition monitoring is continually evaluated in response to both internal and external input. The INSARR inspection in 2007 recommended a six-year interval for the reactor vessel, while ASME code specifies an inspection interval of ten years [15]. After the INSARR inspection, IFE elected to follow ASME recommendations for most of the components of the facility, with a nine year inspection interval in order to follow other stipulated routines at the facility and reporting to the authorities. The INSARR recommendations of a six year inspection interval are being followed for the reactor vessel and the sub-cooler (from the reactor vessel to the first shut-off valve). The reason for this is that it is difficult to change these components in the reactor as an element of preventive maintenance.

The accept criteria for the facility are extracted from [15] for piping and components in Class 1. Leakage testing is carried out in the form of continual monitoring for leakage. After the main inspection, the facility is granted approval for use by a technical inspection authority.

*Material surveillance:*
The material properties of ferritic steel change when exposed to a neutron flux. The yield- and ultimate stresses will increase and the material becomes more subject to brittle fracture. These changes in mechanical properties are dependent upon chemical composition, microstructure, irradiation temperature as well as the flux level and spectrum. A material surveillance program was established as early as 1958 to be able to follow and continuously evaluate these changes ahead of the irradiation levels of the pressure vessel. In later years, the program has made use of 10 CFR Appendix H to Part 50 [14b] as a guideline. The criteria for the surveillance of the beltline region of the vessel are:

- III.B.1: Development of the surveillance program and irradiation of the material samples with respect to ASTM E 185-82 [22]
- III.B.2: Material samples must be localised close to the vessel wall to duplicate:
    - Neutron spectrum
    - Temperature history. Maximum neutron flux on the inner side of the vessel
      III.B.3: Unloading of samples must be technically based.

It is also specified that the reporting of test results should include:

- Data specified by ASTM E 185-82 [22]
- All results from fracture toughness testing of both irradiated and un-irradiated material.

The RPV should be proved within regulation 10 years ahead of the next operational permit.

The material surveillance program at HBWR is based on samples produced during the construction of the reactor pressure vessel. The samples represent the base material, welds and heat-affected zone (HAZ). In the period from 1958 to 1966, the material surveillance program was based on Charpy-V testing of irradiated and non-irradiated material.

During the test program, a large number of tested samples have been stored, making available ½ and ¼ sized samples with varying irradiation levels. Over time, these can be utilized due to the development of new testing techniques and equipment.

A revised material surveillance program was established in 1988, where irradiated and non-irradiated samples were tested and reloaded in the vessel for further irradiation. The revision of the surveillance program was based on the need to supplement the program with respect to increased irradiation levels. This is done so that the Halden Reactor Project (HRP) at all times meets the given demands [17] within the program and with respect to future irradiation of the vessel.

In the period from 1988 to 1994, material testing was performed every third year, while between 1994 and 2006 testing was conducted every sixth year. An additional test was performed in 2009.

The material surveillance program consists of two parts:

- Base material correlating to the average and the maximum fluence (at 180° and 300°) received by the reactor vessel;
- Heat affected zone correlating to the weld with the highest accumulation rate (i.e. at 315°).

Each part is based upon available material samples and estimated sample fluence.

Testing performed prior to 1988 showed that the weld and lid/flange material has a considerably lower reference temperature than the base material and the HAZ in the non-irradiated condition. The irradiation- induced shifts in transition temperature are also smaller for the weld material. The weld material is therefore not included in the ongoing material surveillance program.

In the material testing program the whole dataset is used as reference with respect to estimated accumulation of fluence.

The program is also governed by the desire to be able to test representative material within the lifetime of the reactor vessel.

**JEEP II**

The reactor tank is constructed of pure aluminium in the quality 2S (EN-AW 1200) It is cylindrical in shape and graduated. The internal diameter for the lower and upper ends respectively is 1700 mm and 1840 mm. The tank has a bevelled end base and the walls are 10 mm thick. The tank hangs in a carrier flange, which allows for expansion downwards. A sealing flange is welded to the carrier flange to clamp down a seal between the tank and the top lid. The carrier flange also serves as a support for the reactor lid by means of a stainless steel ball bearing.

The reactor tank has six welded circular joints, of which the five uppermost joints are «covered» by the lid. The lower circular joint is located right above the curved bottom of the tank. The lower cylindrical part of the reactor tank has one long joint. The long joints for the remaining cylindrical parts are not identified. It is the lower round joint and the long joint in the lower cylindrical part of the reactor tank that receive the greatest amounts of radiation. These welds are seen as representative of the other less exposed welds.

The final inspection of the reactor tank before it came into operation included materials, welds, tightness tests with helium and water pressure tests.

The top cover is shaped as a cylindrical graduated aluminium container with an outer diameter of 1695/1932 mm and a height of 1650 mm. There are 18 graduated intake and discharge pipes welded in for fuel assemblies, control rods, radiation pockets and experimental equipment. In addition, pipe leads are welded for the recombination and pressure equalization circuits and for the sprinkler system. The circular groove for the control rods in the middle of the underside of the top cover is 600 mm in height and 720 mm in diameter. The aluminium container is filled with concrete, lead and steel for shielding purposes. The temperature of the concrete can be measured to places in the lid. The shielding plugs for the intake and discharge pipes are made of graduated aluminium piping filled with lead and heavy concrete.

The top cover rests on a stainless steel ball bearing positioned on the main flange of the reactor tank. The lid is submerged in heavy water to cool the lower part of the cover. The water level is 2.15 m above the lower part of the active core (fuel), which gives a clearance of 1.35 m over the fuel. The different internal parts are the following:

- Lower grid plate
- Upper grid plate
- Beam channels (numbered 1 to 10)
- Upper part of the outlet pipe
- Upper part of the sprinkling pipe

Vertical pipes in the lower part of the reactor tank, including the flange: The circulation pipes for heavy water go vertically through the floor of the tank. The intake pipe comes in through the centre of the tank, where the water is distributed to the fuel assemblies beneath the lower grid plate. The discharge pipe goes out from the outer tank area so that the excess pipe runs 100 mm beneath the upper edge of the active fuel length. There are six welded conductor pipes at the bottom of the tank for the monitoring stations, along with a flush pipe connected to a ring pipe for flushing away any sludge that accumulates at the bottom of the reactor tank. The flushing pipe serves as a suction line in the auxiliary cooling circuit. For safety reasons, the flushing pipe is equipped with an external sleeve pipe which is welded to the outside of the tank. The extensions for water circulation are welded to the bottom of the tank, and those for the monitoring stations are bolted and tightly welded.

The reactor has been in operation since 1966 and the annual operations time is about 5000 hours. Calculations carried out with WINS give a fast flux (0.821 – 10 MeV) on the tank wall of about $6 \times 10^8$ n $cm^{-2}$ $s^{-1}$.

Even though JEEP II is not a pressurized reactor, there are design factors at the facility that make the reactor and the heat transfer circuits subject to compliance with regulations that have bearing on pressurized equipment, cf. Regulations on Pressurized Equipment of 29 May 2002 [1]. These regulations cover facilities with an overpressure of 0.5 bars or higher. The highest overpressure in the primary circuit of the reactor is 1.6 bars.

**a) Methods and criteria used for selecting components within the scope of ageing management;**

The ageing management program for the reactor tank and it associated components consists of two parallel programs:

- Monitoring of material (samples, visual inspections)
- Inspection of relevant valves and pipes

The selection of components is based on a risk-based assessment and on the design-base accident.

**b) Processes/procedures for the identification of ageing mechanisms for the different materials and components of the RPV.**

Ageing mechanisms are identified through internal experience, literature surveys and use of the experience of the third party organization.

### 5.1.2. Ageing assessment of RPVs

**HBWR**

**a) Ageing mechanisms requiring management and identification of their significance;**

The estimation of the reactor vessel lifetime is based on the mechanical properties of the vessel material and thereby the calculated fluence level where the fracture toughness criteria for protection against failure [14] fails with respect to the current operation of the reactor.

In practice, this means that if there is a 25 mm deep crack around the circumference of the vessel, the material can no longer withstand growth of the crack. However, the vessel undergoes in-service inspection every sixth year, during which ultrasonic investigation testing along the welds and base material are performed. No indications of cracks have been found during these examinations.

The fluence level at which the RPV material stresses goes above the allowable stresses have been calculated. The estimation is based on the current operational conditions and accumulated flux thereof. An estimate of when this fluence level will be reached for the HBWR RPV has been made, based on current operation practice and thus current accumulation of flux.

At present, the estimated time goes beyond the year 2200 for safe operation of the RPV.

The required mechanical properties of the reactor pressure vessel are given in 10 CFR Appendix G to Part 50 [14a], and through this ASME III Division 1 [23] and ASME XI [15].

**b) Establishment of the acceptance criteria related to the ageing mechanisms.**

*Charpy Upper-Shelf Energy:*

The material in the belt line region of the reactor pressure vessel must have a Charpy Upper-Shelf energy of at least:

- 75 ft-lb. (102 J) initially
- 50 ft-lb. (68 J) through the lifetime of the vessel

To fulfil these requirements, adequate safety margins with respect to fracture toughness are documented in accordance with [15]. Such fracture toughness testing is required for the HBWR and the analysis must include a set of temperature transients.

Fracture toughness testing gives an adequate description of the material and it is recommended by VTT to use only these as a means to prolong the sample availability. The fracture toughness testing is performed according to [24].

Pressure-/ temperature limits as well as the minimum temperature for the vessel are found in accordance with [15].

**JEEP II**

**a) Ageing mechanisms requiring management and identification of their significance;**

The WINS calculations referred to above (5.1.1) give an estimated fluence on the reactor tank wall of 5.5 $10^{17}$ n $cm^{-2}$ as of December 2017.

The performed calculations show that the material stresses that are occurring still lie below the stresses that are permitted.

Fracture mechanics studies of tests utilising the same materiel, and with virtually the same fluence as the tank materiel, were carried out in 2001 at VTT Manufacturing Technology in Finland. The test results show that the mechanical strength properties and ductility is satisfactory for further operations. The ductile properties will probably not change, because saturation regarding neutron exposure has been reached.

**b) Establishment of the acceptance criteria related to the ageing mechanisms.**

Acceptance criteria has been established, based on an internal report from the 2001.

There are no acceptance criteria for the visual inspections, but comparison is made to original and earlier inspections.

### 5.1.3. Monitoring, testing, sampling and inspection activities for RPVs

**HBWR**

*NDT of pressurised equipment:*

IFE invested in new equipment for inspection of the longitudinal seams in 2000 and for the lower girth seams in 2007. The inspection equipment is serviced and tested well ahead of the time it is to be taken into use to allow sufficient time to make any necessary improvements.

Video equipment capable of gauging the radiation environment in the reactor vessel has been in use since 2012. The video camera is positioned directly over the reactor vessel and provides quality pictures with good resolution when carrying out video inspections. The equipment was qualified for use in 2012, and a formal set of operating instructions and procedure for use have been prepared.

The reactor vessel welds are inspected every third year by ultrasound (pulse-echo and Time-of-Flight-Detection (ToFD)) This inspection includes:

- 59 % of the longitudinal welds with those parts of the welds that are exposed to 90-100 % of maximum neutron irradiation.
- Up to 2003, the lower circumferential weld seams were inspected in the connection to the longitudinal seams with 250 mm to each side. From 2007, new equipment for inspection with ToFD was included and 67% of the lower circumferential weld seams have been inspected.
- The upper circumferential weld seams are considered representative of the lower circumferential weld seams.

In view of not having experienced any fatigue fractures in reactor vessels after 20 to 50 years of commercial operations, it is considered not very likely that fracturing will occur in the reactor vessel at HBWR. This reactor vessel is in operation about 50% of its possible operational time and it is run at lower power and fluence levels than commercial reactor vessels. Damage to internal parts can occur at welds and in areas with vibrations.

In addition, there are video camera inspections on a yearly basis of the RPV lining, stay tubes, shielding plates, the passage between the vessel and cover and the vessel cover. The welds sealing the vessel cover are all inspected, using a video camera internally and visual inspection externally. An inspection is made of all 12 stay tubes with a six-year interval for each stay tube. All of the stay tubes are inspected alternately from different positions.

The main flange bolts are examined every third year by ultrasound with regard to breakage. If damage is detected, inspection of the bolts is revised. The threads are assumed to be intact in view of the fact that the minimum temperature of the reactor vessel is 70 °C. The threaded portion of the bolts is thereby dry and corrosion is not very likely. Calculations show that only 21 bolts are necessary to hold the cover in place and maintain gasket pressure.

*Material surveillance:*
All material samples were originally machined for Charpy testing. Through the different parts of the material surveillance program, a large number of these samples have been tested and there are mainly ½ and ¼ samples available today. However, reconstitution techniques allow all the samples to be included in the test program. Charpy testing has not been performed since mid-1990s. The conclusion from the Charpy testing was that there are no mechanisms

that could shorten the lifetime of the RPV. Currently material samples are fracture toughness tested to reveal changes in the Adjusted Reference Temperature. These tests give the same conclusion with respect to ageing of the RPV material. It is shown that the material of the RPV do not set any operational limits in several decades

Fluence levels for the vessel and the material samples located in the vessel are updated on a yearly basis. Future irradiation is estimated based on the accumulation history, and lead factors (ratio between flux ($N/cm^2d$) of the samples relative to the vessel are evaluated with respect to required changes in accumulation rates for the material samples.

The lead factor (ratio between flux ($N/cm^2$) at the material samples and the inner vessel wall with either time or fluence as constants) is recommended by US standards to be between 1 and 3 [14]; however, VTT recommends a lead factor of less than 10. Research from Japan shows that the accumulation rate is equally important, and that there is a limit of ~5 $x10^{12}$ $n/cm^2/s$ [25].

**JEEP II**

In the period 1997 to 2015, internal visual inspections of the reactor tank have been performed frequently, periodically annually, however, mostly on biannual basis. Starting in 2016, the interval between the inspection and the scope of the condition monitoring was determined upon in cooperation with the third party organization and the inspections are based on the Norwegian regulations [1] as well as operational experiences in running the facility. During a period of five years, two inspection campaigns are performed, covering the reactor tank. The interval between inspections is normally five years, and the question of whether inspections should be conducted more frequently is decided in cooperation with the third party organization based on operational experiences and inspection findings. The results of inspections of the reactor tank and the primary circuit suggest that a five-year interval is satisfactory. In the inspection in 2016, half of the accessible welds were inspected and no anomalies were reported. The remaining half is scheduled to be inspected in 2018.

The thickness of the reactor tank, in addition to outlet/ inlet pipes and beam channels, was checked most recently in 2000 using ultrasound, without significant deviations from original plate thickness.

Video equipment capable of assessing the radiation environment in the reactor tank has been in use since 2012. The video camera is positioned directly over the reactor tank and provides quality pictures with good resolution when carrying out video inspections. The equipment was qualified for use in 2012, and a formal operating instructions and procedure for use have been prepared.

Inspections of the “gas room”, the space between the outer wall of the reactor tank and the thermal shield, are carried out at more frequent internals in view of the findings from 1994 . In 1994, corrosion products were registered, and the $CO_2$-gas was replaced with He-gas, due to the fact that water had entered the gas room in an incident in 1993. Later inspections (visual) has not identified any moisture, though, more thorough inspections are planned in

2018 as part of the AMP. How the various inspections will be carried out in practice will be identified in consultation with the third party organization early 2018.

Inspections of the inner tank wall, condition of the welds and internal reactor parts are carried out every five years. The pressure equalization valves and return valves are tested every five years in accordance with the maintenance program. Inspections intervals of the inlet/ outlet and discharge pipes will be identified in 2018 as part of the AMP review.

### 5.1.4. Preventive and remedial actions for RPVs

**HBWR**

The reactor vessel at HBWR is a steel vessel in which there is a small degree of change in the mechanical qualities of the alloy related to irradiation. Calculations show that the stresses that arise in the reactor vessel with the temperature gradients are well within what the material is capable of absorbing and consequently fractures as a result of metal fatigue are improbable.

The water chemistry in the primary circuit, and thereby the reactor vessel, is followed up by the Reactor Chemistry Operations Group. On-line instrumentation ensures continual monitoring of conductivity, as well as the concentrations of hydrogen and oxygen in the water. Samples are collected and chemical analyses of the water are carried out according to a specific program, both in periods of maintenance and when the reactor is in operation. The data and measurements are followed up in light of defined “Operational Limits” and “Safety Limits”, and these in turn are based on [21]. This regime of monitoring makes it possible to maintain the proper water quality in the reactor vessel and thereby minimize the risk of degradation and corrosion.

Over the course of the 1980’s, the reactor core was compressed. Furthermore, in 1990-1991, shielding bolts were mounted in those areas of the reactor vessel that had the highest fluence levels. Both of these actions reduce irradiation of the reactor vessel and subsequent degrading of the mechanical qualities.

Thus, except for water chemistry parameters, there are no formal, specific procedures for taking action regarding the RPV. Any deviations are discussed with a third party organization before any actions are taken.

**JEEP II**

The reactor tank at JEEP II is an aluminium tank where both low temperatures and close atmospheric pressure are present at the same time, and its mechanical capabilities are little affected by radiation. Calculations show that the stresses that arise in the reactor tank caused by temperature gradients are within the limits of what the material can absorb and that fatigue cracks are therefore rather improbable.

The water chemistry in the primary circuit, and thereby the reactor tank, is monitored and controlled to prevent processes that could weaken material structures.

There are no formal, specific procedures for taking action regarding the RPV, but all safety related modifications are reviewed by the Safety Committee.

## 5.2. Licensee's experience of the application of AMPs for RPVs

**HBWR**

HBWR has had an AMP for the RPV ever since start-up of the reactor in 1959. The AMP is regularly revised and developed further in step with both international and national requirements and regulations, and in cooperation with a third party organization. In addition, the development of new inspection techniques and calculation methods has led to continual changes in the scope and accuracy. An AMP having this foundation for RPV imbues confidence in the safety assessments that are made. The ageing phenomena have proceeded as expected.

IFE has long experience with the ageing management program, including good cooperation with a third party organization since 1976. IFE considers the current AMP for the RPV to be adequate for the time being. IFE will continue to develop the AMP based on new knowledge and technology.

**JEEP II**

Aging issues for the JEEP II tank has been followed up since the first start of the reactor, and this has been followed up more systematically since 1997. JEEP II has since 2015 established a good cooperation with the same third party organization as HBWR.

In 2016, an AMP for the tank was incorporated into a systematic program of condition monitoring, not only for the entire primary circuit but for the facility as a whole. It was useful when implementing this program to already have a program in place for the reactor vessel. An AMP with such a foundation gives confidence in the safety assessments that have been made. The AMP is still under establishment, thus the inspection frequency, methods applied and inspection areas may be further developed.

It is concluded that IFE has good control of the AMP and it is kept under continuous review.

## 5.3. Regulator's assessment and conclusions on ageing management of RPVs

HBWR

As required by the regulator, HBWR has an AMP for the RPV, with a scope that covers all relevant parts. The program hasa nine year inspection interval.

HBWR has an established program for maintenance, including preventive and remedial actions, and a program for inspection and monitoring. The program is regularly revised, taking national and international standards and requirements into account. The inspection indicate that the RPV in HBWR is in adequate condition.

*Overall Assessment for HBWR*

Besides the third party inspections, NRPA commissioned an external evaluation by a consultant company in 2013-2014. The authority responsible for pressurized equipment, DSB, has performed inspections on implementation of the approved condition monitoring program, most recently in 2013. This inspection did not result in any findings.

NRPAs assessment on the ageing management of the RPV at HBWR has been informed by the external evaluation and inspection, including reports from IFEs third party organization, in addition to information that IFE provided in the course of this review process.

NRPAs overall assessment is that an adequate ageing management program has been established for the RPV at HBWR.

JEEP II

JEEP II has an AMP for the reactor tank, with a scope that covers all relevant parts.

There is an AMP for the reactor tank and this will be incorporated into the comprehensive AMP under development at JEEP II. After the establishment of the AMP in 2016, the interval inspections of the reactor is currently set to five years, but this will be reviewed based on the result of the next inspections.

JEEP II has an established program for maintenance, including preventive and remedial actions, and a program for inspection and monitoring. The program is regularly revised, taking national and international standards into account. The inspections indicate that the reactor tank in JEEP II is in adequate condition.

The AMP is not for a pressurised vessel. Whilst an AMP has been established this process has identified areas for improvement, for example there are no formal acceptance criteria.

## 6. Calandria / pressure tubes (CANDU)

Not relevant.

# 7. Concrete containment structures

## 7.1. Description of ageing management programs for concrete structures

### 7.1.1. Scope of ageing management for concrete structures

**HBWR**

The reactor facility was built in the last half of the 1950s and the concrete is from the same period. In that the mountain rock serves as a pressure barrier in the containment, it is only a small part near the sluice where the concrete serves as a pressure barrier. The concrete in the sluice is inspected on a regular basis.

The concrete surrounding the steel shielding around the reactor vessel serves as a foundation for the steel shielding and the reactor vessel. The concrete is exposed to radiation only to a limited degree because the water-filled steel shielding protects against radiation from the reactor vessel. Furthermore, this is the part of the concrete that carries the shielding and the reactor vessel, and it is localized in an area beneath the vessel where the radiation levels are extremely low. Large areas of the concrete around the vessel are accessible for visual inspection.

**a) Methods and criteria used for selecting components within the scope of the ageing management;**

The scope of the AMP is the concrete inside of the mountain hall. In large areas of the lower part of the hall, the concrete is cast directly on the mountain rock and secured with steel bolts. In the upper parts and in the ceiling, there is an opening between the concrete and the rock wall of the mountain. The total volume of this space is about 150 $m^3$. The concrete wall and the ceiling are built to withstand an outward overpressure of 0.5 bars. To ensure that the pressure in the cavity does not exceed the limits, there is a water lock to relieve the pressure against the Reactor Hall at $\Delta P > 0.2$ bars of overpressure in the cavity. Furthermore, a safety hatch has been installed in the roof, and this opens towards the cavity at $\Delta P > 0.05$ bars of internal overpressure.

The reactor hall is closed off by two steel doors at the containment entrance. The area around the sluice is reinforced by injecting concrete up to 7 m into the mountain.
Only that part of the concrete that is against the sluice is weight-bearing. The rest of the concrete in the reactor hall is cast against mountain rock, along with the walls and floors. The steel shielding that both surrounds and forms a foundation for the reactor is mounted on concrete and rock at the lowest part of the reactor hall.

**b) Processes/procedures for the identification of ageing mechanisms for the different materials and components of the concrete containment structure.**

The AMP over concrete structures is based on visual inspections and pressure tests. The concrete in the sluice is regularly followed up in connection with the annual pressure tests of the reactor containment. During the visual inspections there is focus on scaling and rusting.

**JEEP II**
Part of the reactor block which lies above the floor of the reactor hall, is made of heavy concrete and is covered externally by 10 mm of steel plate. Besides the reactor tank, the outermost steel structure also houses a pool of water and various storage wells for spent fuel assemblies and other active components.

The fixed shielding of steel and concrete that surrounds the reactor tank, water pool, and storage wells at JEEP II is what constitutes the reactor block. It was constructed to shield against ionizing radiation and to satisfy the experimental physicists' need for low background radiation.

The reactor block is placed off-centre in the steel housing, with the largest part over the reactor hall floor. The foundation of the block rests on the floor in the basement of the steel housing and forms a shield for the reactor's primary main cooling circuit. Beneath the reactor tank, the foundation is shaped as a hollow cylinder, allowing space for the feedthroughs of the control rods, the intake and discharge pipes for the tank, and the $D_2O/H_2O$ leakage tank. The cylinder-shaped space reaches up to the bottom screen of the reactor. Around the reactor tank, the block is formed as a prism drilled through with ten horizontal beam channels and ten underlying chamber channels. The channels are bolted to the thermal shielding and to the outer part of the steel formwork, and under the concrete castings they were fixed to a concrete ring lying right between the outer and inner steel structure.

All of the channels mentioned above are made of stainless steel to prevent the spreading of activity if corrosion should loosen from the surface. Otherwise, all of the channels are equipped with shielding plugs made of steel cast concrete. The shielding plugs for the horizontal channels are equipped with rollers to ease handling when positioning the plugs in or out of the channels. The block also has a vertical conduit that connects the loop room in the basement with the mezzanine shelf in the reactor block. From the area above the mezzanine shelf, there are also several conduits into the space between the reactor lid and the top shielding. This makes it possible to conduct pipes and wire in electrical cables into the lid and into the reactor without having to go through the top shielding.

Channels and wells in which there is a risk of the air being irradiated are put in negative pressure in relation to their immediate surroundings. This is done by connecting them to the ventilation system of the steel housing. This does not apply to the inner space between the reactor tank and the thermal shielding (see Chapter 4 above).

With regards to the beam and chamber channels, the ventilation air from the reactor hall is sucked in through the ring gaps between the channels and the plugs. From here the air goes between the gaps around the vertical sluice plugs and up to the space between the lid and the top shielding. The channels that do not have vertical sluice plugs have separate ventilation pipes that connect the channels with the above-mentioned space. This space is coupled to the ventilation system of the steel housing so that the evacuated air passes through filters before being blown out through the ventilation shaft. In order to protect the thermal shielding from corrosion and to minimise the induced argon activity in the ventilation air, the volume of the gap between the reactor tank and the thermal shielding is filled with helium gas. The lead-through lines out from the gap space are achieved with gas-tight connections to the reactor block. All beam and chamber channels are closed off from the gas volume by aluminium caps that are flanged to the thermal shielding. The aluminium caps are quite short and only in two instances do they protrude into the beam channel pocket in the reactor tank. The continuous beam channel is separated from the gas volume by means of continual pipelines that are flanged to the thermal shielding on both sides of the tank. Eventual leaks of gas are removed with the exhaust air from the beam channels.

*Pool:* The pool connected to the reactor is intended for use in various kinds of experiments, including experiments on shielding. For this reason, a horizontal channel (called the intermediate tank) passes through between the shielding wall between the pool and the reactor tank so that the reactor can be used as a radiation source in experiments. The pool are is made of 6 mm quality 2S aluminium plates that are outwardly stiffened with aluminium flat profiles embedded in concrete outside the pool. The upper part of the pool is shaped to accommodate metal walkways and concrete shielding blocks. At the bottom of the pool there is a drainage canal and two longitudinal aluminium crane rails which enable experimental setups to be moved around in a cart. The cart is dismantled. The pool is filled with water and connected to a purification system.

In the northern end of the pool (that which lies furthest from the reactor), storage pockets have been installed for the storage of active components such as irradiation pockets, plugs and so forth that must be removed from the reactor when turning the lid. Furthermore, various other active components can also be stored here. Storage safes are installed at a point that is roughly in the middle of the pool for irradiated racks and for special non-irradiated racks used Si crystals.

*Intermediate tank*
A graded, square-shaped aluminium container known as the intermediate tank is placed in the horizontal channel between the pool and the reactor tank. The smallest opening measures 700 mm x 700 mm. In order to avoid damage to the concrete, the intermediate tank is encased in a water-cooled steel sheath or thermal shield. Generally speaking, the intermediate tank serves as a thermal column and is normally closed on the end towards the pool by two hatches that with seals lying between are screwed to a flange around the opening. Because of the problems in sealing the hatches, a third hatch was installed in January 2005 that surrounds the outer hatch. The intermediate tank is equipped with air and risers, as well as tubes for taking temperature measurements. A vertical experimental channel measuring 200 mm in diameter leads from the intermediate tank to the top of the reactor.

*Gamma irradiation well*: Different kinds of gamma irradiation experiments may be carried out in the gamma radiation well using spent fuel assemblies. The gamma irradiation well is located in the northern end of the reactor block and consists of two stainless steel containers, one inner and one outer, that stand vertically in the block. The outer container takes the form of a cylindrical pipe with a bottom and a widening at the top to accommodate a protective cover. The diameter of the container is about 600 mm and it is about 4.2 m in height. The container is filled with water that can be circulated through a heat exchanger to cool the fuel assemblies in the space between the inner and outer container. There is room for six fuel elements, and these can be raised and lowered relative to the inner container. Raising and lowering the assemblies is accomplished through the use of a screw and nut construction which, through a gear transfer, can be serviced from the top of the reactor. The insertion of the material is done through a hole in the centre of the shielding cover. The shielding cover is also penetrated by six holes for the fuel elements. Normally all of these holes are closed with shielding plugs. The shielding cover is made of heavy concrete encased in stainless steel. In the shielding wall between the gamma irradiation well and the façade of the reactor block at the northern end there are two horizontal experimental channels cast in concrete measuring at least 150 mm in diameter. For shielding purposes the channels are graded and are normally sealed off with steel-clad shielding plugs made of heavy concrete.

a) **Methods and criteria used for selecting components within the scope of the ageing management;**

The AMP over concrete structures is based on visual inspections and pressure tests.

b) **Processes/procedures for the identification of ageing mechanisms for the different materials and components of the concrete containment structure.**

There is no formal procedure for identification of ageing mechanism for concrete.

A condition monitoring program for other parts of the facility such as the pool and various wells is due to be established in 2017 (storage wells, gamma irradiation well, along with other installations that normally do not contain fuel, such as the pool and decontamination tank.

### 7.1.2. Ageing assessment of concrete structures

**HBWR**

a) **Ageing mechanisms requiring management and identification of their significance;**

Inspections thus far have shown that the concrete in the reactor hall is generally in good conditions and there is no sign of scaling in the concrete around the metal reinforcement rods from corrosion. In certain parts of the reactor hall, the concrete is exposed to moisture due to of water seeping in from the mountain, but also here there are no indications of peeling or scaling. However, in certain instances cracks and fissures may develop around certain pipe passages. These cracks are small and are repaired by pumping sealant sealing compound into the wall.

The concrete in the sluices is in a dry area, with room temperatures and not exposed to high radiation flux. The foundation of the shield circuit is also in dry area with moderate temperate and low radiation flux.

There is no formal identification of ageing mechanisms, which was also identified by the INSARR-team in 2017.

**b) Establishment of the acceptance criteria related to the ageing mechanisms.**

Inspections of the concrete in the sluices is done through visual inspections and pressure testing. The annual pressure and leakage tests of the reactor containment include the concrete in the sluices. The acceptance criteria for the rate of leakage should be below 200 $Nm^3$/(h ato). For the visual inspections are based on expert judgment and there are acceptance criteria.

**JEEP II**

**a) Ageing mechanisms requiring management and identification of their significance;**

The ageing mechanism relevant to the concrete in the JEEP II is radiation, moisture and corrosion of iron.

**b) Establishment of the acceptance criteria related to the ageing mechanisms.**

The reactor facility was built in the middle of the 1960s and the concrete is from the same time period. The concrete used in the reactor block has not been exposed to high levels of radiation since the neutron flux is low.

### 7.1.3. Monitoring, testing, sampling and inspection activities for concrete structures

**HBWR**

Pressure testing of the mountain hall is carried out annually in connection with the maintenance shutdowns, and this testing reveals the degree of gas tightness of the reactor containment. Leakage tests, which are based on pressure measurements, have shown that the rate of leakage can be held below 200 $Nm^3$/(h ato), and this in turn forms the basis for the safety assessments. Assessments of leakage are made on the basis of measurements of the pressure drop in the reactor hall after three hours from an overpressure of 2650 mm $H_2O$.

**JEEP II**

Both the reactor top and the mezzanine shelf are covered with sheeting plates whereby a 100 mm space between the plates and the top of the concrete shielding is created. This space is used to run pipes and electrical cables to the top of the reactor. The sheeting plates can be dismantled and lifted away when cleaning the underlying concrete surface. This is done regularly. However, there is no formalized inspection or monitoring program for the concrete in the JEEP II.

### 7.1.4. Preventive and remedial actions for concrete structures

**HBWR**

Two areas in particular have an important safety function: the concrete wall in the sluice and the foundation of the shield circuit, which in turn safeguards the reactor tank. Both of these areas are inspected visually, and in addition, the concrete wall in the sluice is tested for leakage every year.

The concrete in the sluice is regularly followed up in connection with the annual pressure tests of the reactor containment and the ensuing visual inspection. On two occasions, sealant has been injected into the concrete to reduce the leakage rate. The action was taken as a precautionary measure, based on expert judgement rather than a quantitative criterion. This has been effective at keeping the leakage rate within the specified levels.

**JEEP II**

There is no formalized inspection or monitoring program for the concrete in the JEEP II.

## 7.2. Licensee's experience of the application of AMPs for concrete structures

**HBWR**

HBWR was built at the end of the 1950s and the concrete construction is from that period. Condition monitoring of the structure is based on visual inspections and pressure tests. The concrete is for the most part fully accessible for inspection and there are no signs of degradation.

Experience has shown that the ageing phenomena have developed as expected. However, continuous consideration is given to the scope for improving the AMP.

**JEEP II**

JEEP II was built at the end of the 1960s and the concrete structure is from that period.

There is no formalized inspection or monitoring program for the concrete in the JEEP II, but visual inspections are made based on experience. Based on this, there are no signs of degradation in the concrete. IFE is considering the development of ageing management program for concrete in cooperation with the third party organization.

There is a process to develop a comprehensive AMP, and concrete will be considered in this process.

## 7.3. Regulator's assessment and conclusions on ageing management of concrete structures

<u>HBWR</u>

HBWR has an established program for maintenance, including preventive and remedial actions, and a program for inspection and monitoring of all concrete relevant to safety at the facility.

There is only a small amount of concrete relevant to safety at the facility. These concrete structures have been identified. Due to the small amount, it has not been necessary for grouping criteria.

*Overall Assessment for HBWR*
NRPA have not had any inspections on concrete at HBWR in recent years. NRPAs assessment on the AMP for concrete at HBWR is based on reports to NRPA and information that IFE provided in the course of this review process.

NRPAs assessment is that IFEs current AMP on concrete is developing, considering that there is only a small amount of concrete is relevant to safety.
However, it is observed that the R&D programmes could be better utilised to understand the lifetime aspects of concrete relevant to the facility

JEEP II

JEEP II has an established program for maintenance, including preventive and remedial actions, and a program for inspection and monitoring of concrete.

The concrete structures relevant to safety have been identified. Due to the small amount, it has been assessed not to be necessary for using grouping criteria.

*Overall Assessment for JEEP II*
NRPA have not had any inspections on concrete at JEEP II in the recent years. NRPAs assessment on the ageing management for concrete at JEEP II is based on reports to NRPA and information that IFE provided in the course of this review process.

An AMP was formally established at JEEP II in 2016 and will be extended to a comprehensive AMP. NRPA will follow-up the development and implementation of the comprehensive AMP at JEEP II, which should include concrete where this is relevant.

NRPAs assessment is that IFEs current program on concrete is developing, considering that there is only a small amount of concrete relevant to safety.

## 8. Pre-Stressed Concrete Pressure Vessels (AGR)

Not relevant to Norwegian reactors.

# 9. Overall assessment and general conclusions

The ENSREG review process, which this report is a part of, forms an integral part of the regulatory activities of NRPA and on the continuous improvement of the AMPs at HBWR and JEEP II.

<u>Commonalities for both reactors</u>
It is positive that IFE use relevant safety criteria from a variety of sources, such as international standards, internal experience and manufacturer recommendations, to inform their acceptance criteria. NRPAs assess that IFE have established methods to establish acceptance criteria. However, this process has identified there are areas for improvement, and acceptance criteria have not been adequately assessed for establishment in the overall AMPs at IFE. In particular this has been noted for electric cables.

Neither HBWR nor JEEP II has any formal, regular cooperation or exchange of operating experience relating to ageing management with other reactor operators, but cooperation projects are established on a case-by-case basis. There have been international peer reviews through the INSARR missions in 2007, 2010 and 2017 which resulted in recommendations to address their ageing management programme. IFE have a long standing relationship with a third party organization and they provide an independent review of their AMP informed by relevant experience from the nuclear industry.

NRPAs assessment is that IFE should continue to further enhance the international cooperation and systematically seek best practice and relevant operating experience to continuously improve its AMP through engaging with other operators and experience sharing forums. In particular because Norway has a small nuclear industry.

It is positive that IFE is working continuously to improve and develop the AMP, through use of internal and external experience. This could be improved further by use of external experience, by liaising with other research reactor operators, other licensees and through R&D.

<u>HBWR</u>
NRPAs overall assessment is that whilst HBWR have established an AMP there are areas for improvement that have been identified by this process, to enhance the comprehensiveness of it.

NRPAs assessment on the areas covers in this report is

- That there is an established ageing management program for the RPV at HBWR.
- That the current AMPSs on concealed piping and concrete at HBWR are developing, considering that only a very small amount of concealed piping and concrete is relevant to safety.

- That the scope of the AMP for electrical cables at HBWR need to be extended to cover all cables relevant to safety. There is also identified a need to develop more formalized procedures for grouping and selection of cables.

JEEP II

The current ageing management at JEEP II has a limited scope and does not cover all relevant SSCs relevant to safety. An AMP at JEEP II was formally established in 2016 and will be extended to a comprehensive AMP. NRPA will be taking a keen interest in the development and implementation of the AMP at JEEP II in the coming years.

NRPAs regulatory activities

In its regulatory activities, NRPA performs its own regulatory inspections, reviews documents, and weekly and annual reports. NRPA performs 15-20 regulatory inspections per year at IFE. Besides the third party inspections, there has been few inspections only dedicated to ageing in recent years. NRPA conclude that there is a need to focus on the AMPs at HBWR and JEEP II, and ensure that all SSCs are included. In particular, there should be more focus on electric cables.

HBWR is required to use a third party for independent inspections and safety assessments on the condition of the SSCs important to safety. NRPA in the process to implement sa similar requirement on JEEP II as a condition in the next license. This is in line with the challenge identified as part of the review meeting of the Convention of Nuclear Safety in 2014, where Norway was requested to establish an effective ageing management program. In the review meeting in 2017, this challenge was considered closed for HBWR but remain open for JEEP II.

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## 11. Annex: Abbreviations

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| AMP | Ageing Management Program |
| ASME | American Society of Mechanical Engineers |
| ASTM | American Section of the International Association for Testing Materials |
| DSB | Norwegian Directorate for Civil Protection |
| EPRI | Electric Power Research Institute |
| HAZ | Heat-Affected Zone |
| HBWR | Halden Boiling Water Reactor |
| HRP | Halden Reactor Project |
| HSE | Health, Safety and Environment |
| IFE | Institute for Energy Technology |
| IAEA | International Atomic Energy Agency |
| INSARR | Integrated Safety Assessment of Research Reactors |
| JEEP II | Joint Establishment Experimental Pile II |
| KPI | Key Performance Indicators |
| LIRA | Line Resonance Analysis |
| LOCA | Loss of Coolant Accident |
| MWt | Mega-Watt thermal effect |
| NDT | Non-Destructive Testing |
| NRPA | Norwegian Radiation Protection Authority |
| OECD | Organisation for Economic Co-operation and Development |
| OLC | Operating Limits and Conditions |
| RPV | Reactor Pressure Vessel |
| SAR | Safety Analysis Report |
| SF | Norske Skog Saugbrugsforeningen |
| SSC | Systems, Structures and Components |
| ToFD | Time-of-Flight-Detection |
| USNRC | Nuclear Regulatory Commission of the United States |
| WENRA | Western European Nuclear Regulators Association |