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SURVEILLANCE PROGRAMME AND UPGRADING OF THE HIGH FLUX REACTOR PETTEN

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ABSTRACT

The High Flux Reactor (HFR) at Petten (The Netherlands), a 45 MW light water cooled and moderated research reactor in operation during more than 30 years, has been kept up to date by replacing ageing components. In 1984, the HFR was shut down for replacement of the aluminium reactor vessel which had been irradiated during more than 20 years.

The demonstration that the new vessel contains no critical defect requires knowledge of the material properties of the aluminium alloy Al 5154 with and without neutron irradiation and of the likely defect presence through the periodic in-service inspections.

An irradiation damage surveillance programme has been started in 1985 for the new vessel material to provide information on fracture mechanics properties.

After the vessel replacement, the existing process of continuous upgrading and replacement of ageing components was accelerated. A stepwise upgrade of the control room is presently under realization.

1. INTRODUCTION

The High Flux Reactor (HFR) at Petten, The Netherlands, is one of the few high power multi-purpose research reactors still in operation in Europe. It is a 45 MW water-cooled and moderated tank-in-pool reactor of the Oak Ridge Reactor (ORR) design [1]. The reactor is the property of the Commission of the European Communities (CEC) and belongs to the Institute for Advanced Materials (IAM) of the Joint Research Centre (JRC) of the CEC.

The HFR programme is predominantly funded by the governments of The Netherlands and Germany [2]. In continuous and successful operation during more than 30 years, the HFR has been kept up-to-date by replacing ageing components. In this respect, the HFR was shut down in 1984 for replacement of the aluminium reactor vessel which had been irradiated during more than 20 years [3].

The design for the new aluminium 5154 alloy reactor vessel has been based on the fact that the reactor can operate provided there is evidence that the vessel contains no critical defects. Knowledge of materials properties and likely defect presence and size is therefore requested for the assessment of the HFR vessel integrity.

2. VESSEL MATERIAL TESTING PROGRAMME

The changes of materials properties with neutron exposure are obviously of particular importance for the HFR aluminium vessel.

The loss of ductility of irradiated aluminium alloys is caused by :

- hardening by displacement damage to a minor extent,
- precipitation hardening for the major part.

Displacement damage is realized through the interaction between the atoms in the crystal lattice and fast neutrons by collision and is shown by formation of lattice defects like interstitial atoms, vacancies and eventually dislocation arrays which harden the metallic matrix and reduce the material ductility.

However, precipitation hardening by finely dispersed Mg_2Si is mainly responsible for the loss of ductility of irradiated aluminium alloys. Mg_2Si originates from a reaction of Mg in the alloy with thermal-neutron-transmutation-produced Si.

Data on the mechanical properties of the aluminium alloy Al 5154 with and without neutron irradiation are necessary for the safety analysis of the HFR vessel at the beginning of the service life (BOL) and at the end of the design life time (EOL).

The construction material of the old HFR vessel is a modified aluminium-magnesium alloy with 3.5 - 3.9% Mg content, close to the specification for type 5154 aluminium alloy.

For the replacement vessel, mainly in order to benefit from the experience provided with the old vessel, 5154 aluminium alloy was chosen with a restriction on Mg content to 3.5% in view to improve ductility at high neutron doses.

In order to confirm the material properties of the replacement vessel, various test programmes were carried out. In addition, the behaviour of the new vessel material under irradiation has been investigated in advance with the data provided by the old vessel material.

Fatigue, fracture mechanics (crack growth and fracture toughness) and tensile properties have been obtained from several experimental testing programmes with materials of the new and the old HFR vessel [4][5].

In particular, at the request of the Dutch licensing authority, low-cycle fatigue testing has been carried out on non-irradiated specimens from stock material of the new HFR vessel. The data obtained confirm that operation of the HFR is fully justified with the specified design parameters.

3. SURVEILLANCE PROGRAMME

An irradiation damage surveillance programme called SURP has been set up in 1985 at the restart of the HFR for the new vessel material to provide information on fracture mechanics properties. The objective is to survey the degradation of specific material properties in the most critically affected areas of the core box, which are located in the West and the South walls. This will be realized through selective mechanical testing of representative material specimens which are taken from selected irradiation positions periodically during the operational life of the HFR.

The material for the fabrication of the specimens has been taken from the forged cut-offs left from the core box manufacture.

Two capsules containing 15 compact tension (CT) specimens with a thickness of 25 mm and 10 tensile specimens are being irradiated respectively in an in-core and a pool side facility (PSF) position.

The in-core position has been chosen for the proper simulation of the neutron flux conditions in the West wall central area while the PSF position reflects the irradiation of the critical area of the South wall due to a typical thermal to fast flux ratio.

The capsules are of the reloadable type to allow for periodic removal of specimens and flux monitors. Neutron monitor sets are replaced every 3 years. The irradiated specimens are scheduled to be tested at different intervals of the reactor vessel life. The first testing campaign is planned end of 1995 with the removal of three CT and two tensile specimens from each capsule after an irradiation time of 10 years. Their thermal neutron exposure is reaching about 4.10^{26} n/m^2 in 1995.

4. IN-SERVICE INSPECTIONS OF THE HFR VESSEL

The design of the new HFR vessel takes into account the ability to inspect in-service [3]. The welds are positioned in accessible areas and the internal surface of the core box is machined flat.

In 1984, during its installation in the HFR containment building, the replacement vessel was subject to a Pre-Service Inspection (PSI) [6]. The periodical in-service inspections are performed on the basis of a 3 years interval, the first one being in 1988 [6], the second in 1991 and the third one in 1994.

4.1. Purpose and extent of the reactor vessel inspection

The reactor vessel is an all welded aluminium structure about 5 m high which includes the core box, the core box support structure and the cooling water inlet plenum (see fig. 1). The core box is a rectangular shaped construction fabricated from 50 mm thick forged material joined by electron beam welding. The other vessel areas use 40 mm thick plate material with MIG welds. The goal of the in-service inspection of the HFR vessel is to demonstrate that all parts assuring the core geometry and the control rod alignment will not fail in service. Ultrasonic examination is then required for a selection of welds and for the most highly exposed core box walls. An eddy current testing is also conducted on core box walls and corners for surface and near surface defects. The ISI also includes dimensional checks for the control rod alignment, visual inspection using t.v.- cameras for the general condition of the vessel and any surface flaw and penetrant testing of primary coolant inlet.

4.2. Inspection equipment

The ultrasonic inspection is carried out using the water immersion technique by means of a cylindrical mast suspended from a support frame placed on the reactor vessel top flange. The scanning mechanism mounted on this mast is remotely controlled from the pool adjacent floor. Specific probe arms are attached to this mechanism in order to achieve the requested beam angles in the test material of 45, 60, 70 and 0 degrees. The inspection is conducted in compliance with the ASME XI code requirements using the 6dB drop sizing technique and calibration blocks with side drilled holes. Ultrasonic signal treatment is realized through a data processing system, allowing the real time data display from the top and the side view of the inspected part together with data storage and evaluation of data off-line. The scanning system is also used for the eddy current inspection to check by means of absolute type probes the core box walls and corners. Calibration is carried out with an aluminium calibration block displaying various EDM notches, the reporting level being established from a 20 mm long by 3 mm deep notch.

4.3. Inspection results

Comparing the indications found during the 1994 ultrasonic inspection with those of 1991, 1988 and 1984, it can be established that a very good correlation exists between the inspections. The maximum amplitudes of the reportable indications are generally within ± 2dB with no significant change in length. No additional reportable indications and no size increases from the defects - all from the manufacturing stage - were found.

No significant defect indications were detected from the visual and dimensional inspections and from the liquid penetrant testing. The eddy current testing did not detect in 1984, 1988, 1991 and 1994 any reportable indications. The next ISI has to be carried out during summer 1997.

5. RECENT HFR UPGRADES

By implementing the policy of preventive maintenance, refurbishing and upgrading, after the vessel replacement, other major components of the reactor have been replaced, such as the primary and pool heat exchangers, the beryllium reflector elements and the guaranteed power supply. The major HFR upgrades are summarized in Table 1. The most recent projects are developed below.

5.1. Renewal of ion drain and storage tanks

Corrosion damage led to the replacement of the tanks of the ion drain system. In 1992 and 1993, the new ion drain and storage tanks have been installed, instrumented and put into operation.

5.2. Renewal of HFR Mains Power Distribution Cabinet

Rearrangements of the electrical power installations at the HFR have necessitated adaptation of the mains distribution cabinet. Furthermore, spare parts of the existing cabinet were no longer available, endangering future reliability. Several cable routings have been modified for fire protection reasons.

The new distribution cabinet was installed during the 1993 spring stop. All mains supply and user cables were renewed. Electrical supply to essential parts of the installation during the replacement was provided by temporary provisions from the site diesel-driven emergency supply station.

5.3. Renovation of the secondary cooling water outlet

In 1993, it became necessary to carry out the renovation of the secondary cooling water outlet pipeline. The work was performed during the summer maintenance stop.

The original concrete piping was internally relined with synthetic interconnected pipe sections over the last 200 meters from the outlet. These sections were pushed in from the dune side in seaward direction. For this operation the outlet pipe was cut on purpose at the foot of the dunes and closed afterwards.

The remaining space between the outside of the relining piping and the inside of the original concrete pipe was filled with a special fluid pumped in under pressure thereby replacing the present water. This fluid, a suspension in water with concrete, marl, clay and plaster, starts hardening after 6 to 7 hours. The outlet stop valve was renewed and relocated 75 meters inland to compensate for dune displacement over past years. The actual outlet diffuser grid was completely renewed.

The breakwater, in which the last part of the piping is situated, was repaired and its stop was covered with concrete on request of the authorities. This concrete coverage should also prevent future cracking of the outlet piping.

5.4. Renewal of the Chlorine Injection System of the secondary cooling

To avoid algae growth in the piping and heat exchanger systems of the HFR, chlorine was injected. On request of the Dutch Labour Inspection authorities the use and storage of chlorine has to be avoided, so alternatives had to be investigated.

Sodium hypochlorite has been chosen for safe handling and storage and for improved environmental effects. An investigation of the dose of sodium hypochlorite needed to avoid algae growth has been carried out.

Building adaptation for and installation of the new sodium hypochlorite injection system comprising the tank, the dosage pump and associated valves and instrumentation was completed in 1993.

5.5. Control room upgrading

Re-configuration and upgrading of the HFR control room functions and equipment became necessary in the beginning of the nineties in order to replace outdated equipment and to introduce modern ergonomic principles in the fields of display and easier access to reactor and experimental data.

The technical requirements and lay-out for a modernized control room have been drawn up. Due to the estimated price for the upgrading and to prevent loss of operation time during the reconstruction it was decided to carry out the upgrading in a stepwise approach.

The main objectives for the new control room are to permit the operators to monitor the performance of the reactor and experiments, to optimize the performance during normal conditions and to control the installation during planned and unplanned operational conditions.

To facilitate monitoring of the experiments the computers and terminals of the experiment data handling system DACOS had to be incorporated near the control room within the physical protected zone. This sub-project has been completed in 1993.

Due to the lack of spare parts and since the old system needed more and more maintenance the distribution board has to be renewed as a first step. The outdated 25 years old annunciator system has then to be replaced. The annunciator system itself will be modernized and a Data Acquisition System (DAS) will be introduced. After testing, the installation of the new annunciator system is planned for the summer stop of 1995.

After this installation, the specialized annunciator system for the interlocking of the experiments will then be renewed. This is planned for the summer of 1996. Presently the interlock is placed in the control desk and has to be replaced due to ageing of the components and a lack of spare parts. The new interlock will be situated in a separate cabinet in the basement of the control room.

The Data Acquisition System (DAS) will be an additional information system for the operators of the HFR. All information from an annunciator signal will be presented on the DAS. It is also planned to present the required operator actions on the DAS in case of an alarm. The DAS will also be a supplement to the present instrumentation and warning systems which will give the operators additional information to optimize the operational parameters. In the future several operational parameters will be available for the experimentators. Based on technical specifications the hardware has been ordered and delivered. A pilot system showing the possibilities has been developed and will be placed in the computer room in the near future. After the review of the operator experience with DAS the final version will be specified and finally built.

Also in the framework of the control room upgrading the main part of the nuclear instrumentation has been renewed: replacement of start-up channels, renewal of off-gas monitor and N-16 equipment, introduction of a second set of safety channels working in a two out of three mode and replacement of the old set of safety channels (scheduled for the summer of 1995), replacement of cladding rupture monitor by a two out of three system, and replacement of low and high activity gas monitor system.

Finally, with the renewal of the control desk, which will be redesigned and adapted to the latest ergonomical principles, planned in 1997, the HFR will be equipped with a new control room and will remain an up-to-date reactor ready for its mission for the next 10 years.

6. CONCLUSIONS

Routine in-service inspections are being performed on the High Flux Reactor vessel at Petten in accordance with the operating licence requirements. The results from the periodic inspections carried out in 1984, 1988, 1991 and 1994 have shown that there has been no change in the overall reactor vessel integrity since its installation in 1984.

The irradiation damage surveillance programme comprises specimens from the new vessel material. Several samples are planned to be removed from irradiation in 1995 and then subsequently tested.

Information on likely defect sizes together with knowledge of the material properties including the effects of irradiation on the 5154 aluminium alloy allows to demonstrate that there is no critical defect and then to assess the integrity of the HFR vessel.

After more than 30 years of operation, the HFR Petten, one of the most powerful multi-purpose research reactors in Europe, can still be regarded as a modern and up-to-date research tool, as a result of continuous preventive upgrading, refurbishment of outdated components and modernization. This is reflected by the high availability of the reactor of on average more than 250 days per year, even reaching 280 days in the recent past years, and by the efficient utilization of the diverse irradiation positions.

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TABLE 1 - HFR PETTEN, HISTORY, MAIN UPGRADINGS AND RENOVATIONS

1958-1961	Design and construction
1961	First criticality of HFR
1962	Transfer from RCN to EURATOM - Maximum power 20 MW
1966	Power increase to 30 MW
1970	Power increase to 45 MW
1972	Introduction of burnable poison
1974-1977	Feasibility study for replacement of reactor vessel
1978	Decision to replace reactor vessel
1980-1981	Design of the new reactor vessel
1982-1983	New reactor vessel manufacture
Nov. 83-feb. 85	Reactor vessel replacement
1987	Replacement of the primary heat exchangers (3 x 22 MW)
1988	Replacement of the start-up channels
1988	Guaranteed power supply replacement
1988	Extension of the HFR building complex
1988	Upgrading of the central data acquisition system DACOS
1989	Replacement of the pool heat exchangers (2.6 MW)
1989-1990	Replacement of the Beryllium reflector elements
1990	Installation of the Second Reactor Power Protection System
1991	Renovation of the high construction hall and the secondary pump building
1992-1993	Ion Exchanger drain and storage system replacement
1992-1993	Renewal of the Chlorine Injection System of the secondary cooling
1993	Renovation of the secondary cooling water outlet
1993	Renewal of HFR Mains Power Distribution cabinet
1995	Renewal of original Overpower Protection System
1993-1997	HFR Control Room upgrading

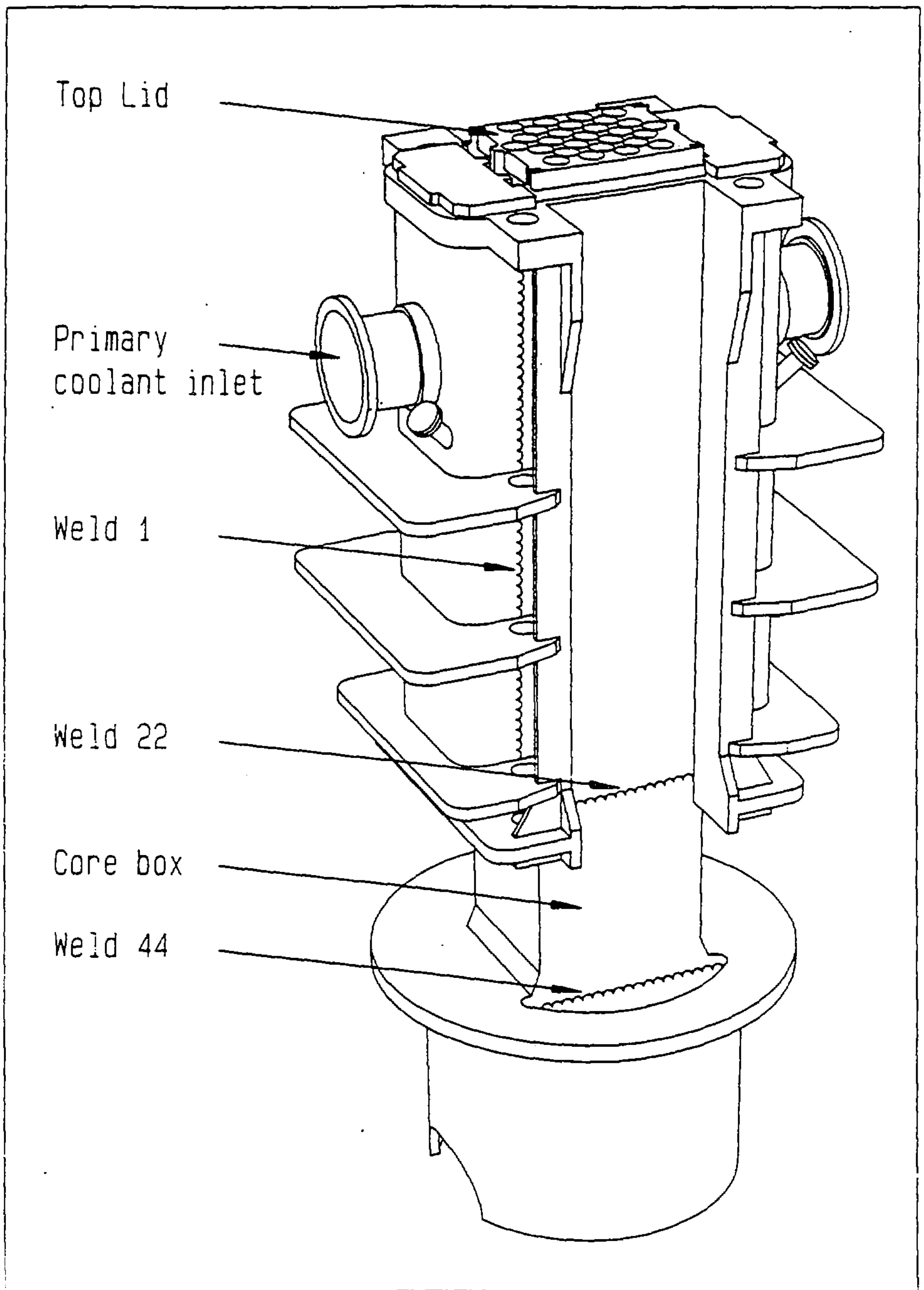

Fig. 1 : HFR Reactor Vessel