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Commission Staff Working Document

Accompanying the document

Report from the Commission to the Council and the European Parliament

"Operation of the High Flux Reactor in the years 2014-15"

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Accompanying the Report from the Commission to the Council and the European Parliament 'Operation of the high flux reactor in the years 2014-15'

This staff working document is a companion document to the Commission's report on 'Operation of the high flux reactor in the years 2014-15', sent to the Council and the European Parliament.

The high flux reactor (HFR), located in Petten (The Netherlands), is one of the most powerful multi-purpose materials-testing reactors in the world. The reactor is of the tank-in-pool type, light water cooled, moderated and operated at 45 MW. In operation since 1961, the reactor provides a variety of irradiation location possibilities (reactor core, reflector region and in the poolside). Horizontal beam tubes are available for research with neutrons as well as gamma irradiation facilities. Furthermore, fully equipped on-site hot cell laboratories make it possible to carry out post irradiation examinations (PIEs).

The close cooperation between the European Commission Joint Research Centre (JRC) and the NRG has led to a unique system of managing the HFR, involving both organisations. The European Atomic Energy Community (Euratom) owns the plant (which is leased from the Dutch state for 99 years) but is operated by the Dutch Nuclear Research and Consultancy Group (NRG). As of February 2005, the NRG has become the holder of the operation licence granted under the Dutch Nuclear Energy Law.

Over the last three decades, the HFR has been operated and partly financed through supplementary research programmes which were regularly discussed and unanimously approved by the European Council on the basis of Article 7 of Euratom Treaty. On 13 November 2012, the Council adopted a four-year (2012-15) supplementary research programme for the HFR (Council Decision 2012/709/Euratom — OJ L321/59, 20.12.2012), to be implemented by the JRC.

This document reports on the results of the scientific and technical work carried out in 2014-15. It also provides information on the financial contributions received for implementing the programme and the annual contribution to the decommissioning fund provided by the supplementary research programme.

1. HFR: Reactor Management

The HFR's operating licence for the reporting period was granted by the Dutch national regulator, the Kernfysische Dienst.

1.1. HFR safety, operation and related services

<u>Operating schedule</u>

<u>2014</u>

The HFR returned to service in February 2014 after an unplanned shutdown period of about 4 months. In 2014 the regular cycle pattern consisted of a scheduled number of 216 operation days, regular 4-day reactor stops and a larger shutdown period of 65 days in October and November. This corresponds to an actual availability of almost 100% with reference to the original scheduled operation plan. Nominal power has been 45 MW.

During the reporting period, the annual 30 MW reactor training for the operators and the yearly flux measurements have been carried out in December 2014.

2015

The HFR was scheduled to operate for 9 cycles in 2015. Planned full power days were 271 of which 230 were realized. The main cause for the lost full power days was the cancellation of cycle 2015-08 in October. This cycle was skipped because of a deviation in the control rod system. Inspection and analyses revealed a marginal play in one of the reactor control rods used to adjust the reactor power. While this play did not affect the functionality of the control rod nor reactor safety in any way, preventively a new procedure for assembly, commissioning and maintenance/inspection of the control rods has been developed to avoid such effects in the future. This has been included in the safety case which was evaluated by the Reactor Safety Committee and by the ANVS, the Dutch nuclear regulator The ANVS provided a formal statement of no objection to reactor restart. The HFR was safely restarted in December 2015.

Nominal power was 45 MW. During the reporting period the annual 30 MW reactor training for the operators and the yearly flux measurements have been carried out as scheduled.

Maintenance activities

2014 and 2015

In 2014 and 2015, maintenance activities consisted of the preventive, corrective and breakdown maintenance of all systems, structures and components (SSC) of the HFR, as described in the annual and long-term maintenance plans. These activities were carried out to ensure the HFR's safe and reliable operation and to prevent inadvertent scrams caused by insufficient maintenance. The following activities were successfully completed:

- Scheduled Regular preventive and corrective maintenance;
- Periodic leak testing of the containment building as one of the license requirements (0.02 MPa overpressure for 24 h);
- In Service Inspection of the safety relevant parts of the primary system (reactor vessel, the outlet reducers, the bottom plug and primary piping in the Primary Pump Building);
- Cleaning of the secondary cooling system;
- Revision of the emergency power diesels
- Two week training for the HFR operator staff.

Concerning the total discharged activity of noble gas and tritium in the license limit is 100 RE/year. The total discharged activity in 2014 was approximately 13 RE and approximately 11 RE in 2015.

2. HFR AS A TOOL FOR RESEARCH ON REACTOR MATERIALS AND FUEL CYCLES

2.1. Towards a fuel cycle with less nuclear waste: the FAIRFUELS AND PELGRIMM projects

The two closely linked 4-year projects FAIRFUELS (fabrication, irradiation and reprocessing of fuels and targets for transmutation, and PELGRIMM (pellets vs granulates: irradiation, manufacturing and modelling) run under the EURATOM 7th Framework Programme (FP7) indirect actions. They aim at a more efficient use of fissile material in nuclear reactors by implementing transmutation. Transmutation provides a way to reduce the volume and hazard of high-level radioactive waste by recycling and converting the most long-lived components into shorter-lived species. In this way, the nuclear fuel cycle can be closed in a sustainable way, producing less and shorter-lived radioactive waste.

The FAIRFUELS consortium consists of 10 European research institutes, universities and industry representatives. The project started in 2009 and is coordinated by the NRG. The PELGRIMM consortium consists of 12 European research institutes, universities and industry representatives. The project started in 2012 and is coordinated by the Centre d'Etudes Atomiques (CEA), France.

The NRG and the JRC work closely together on the HFR irradiations that are scheduled as part of the FAIRFUELS and PELGRIMM projects.

SPHERE

The SPHERE irradiation test was planned under the FP7 FAIRFUELS project. SPHERE was designed to compare conventional pellet-type fuels with so-called sphere-pac fuels under similar irradiation conditions. The latter have the advantage of an easier, dust free production process. Especially when dealing with highly radioactive minor actinides, dust-free production processes are essential to reducing the risk of contamination.

To assess the irradiation performance of sphere-pac fuels compared with conventional pellet fuel, an americium-containing driver fuel for fast reactors (both in pellet- and sphere-pac form) was produced at the JRC in Germany. These fuels are irradiated in the HFR, in a dedicated test facility. This is the first irradiation test of this kind, as americium-bearing sphere-pac driving fuel has never been irradiated before.

In 2012, SPHERE’s design was finalised; the fuel was produced by JRC and delivered to NRG in the summer of 2012. The production, assembly and commissioning of the irradiation experiment was completed so that SPHERE was ready for irradiation as soon as the HFR resumed operation in 2013. The SPHERE irradiation in the HFR core started on 28 August 2013 and lasted for approximately 300 full power days before finishing on 26 April 2015. In 2014, after the first irradiation cycle, a neutron radiograph was taken and compared with a neutron radiograph made before the irradiation. The formation of the expected fuel restructuration in the sphere-pac could be confirmed. Central hole formation was clearly observed in the sphere-pac fuel indicating initial central fuel temperatures above 2000°C. Pellet fuel only showed cracking, an indication of significantly lower central temperatures. In 2015, after the cool-down period, dismantling of SPHERE started at the NRG Hot Cell Labs for post-irradiation examinations.

MARINE

MARINE is planned as part of the FP7 PELGRIMM project. The MARINE experiment was designed to compare conventional pellet-type fuels with the so-called sphere-pac fuels described previously. The goal of the MARINE irradiation is to determine helium release behaviour and fuel swelling in an element which is representative of the minor actinide-bearing blanket material to be used for transmutation in sodium fast reactors (SFR).

Americium-containing fuels will be produced at the JRC and they will be irradiated at the HFR in a dedicated test facility. The irradiation will use internal pressure sensors to monitor online the production of helium, which is characteristic of this kind of americium-containing fuel. The MARINE irradiation is expected to start in early 2015 and will last for approximately 300 full power days.

During 2014 the design of MARINE was finalized. Unfortunately, the start of the MARINE irradiation had to be significantly delayed until fall 2015, mostly as a consequence of NRG's return to service program and subsequent reorganization of NRG. The fuel was fabricated and delivered to Petten. The nuclear analysis was completed; the thermomechanical analysis is on-going. The experiment will be irradiated in 2016 in position H8 of the HFR where the conditions in the blanket of a Sodium Fast Reactor (power, temperature, Helium production) can be most closely reproduced. Since the pins of MARINE must be connected to a pressure transducer, a detailed document for the assembly and welding in the Actinide Laboratory and at ECN had to be prepared.

2.2. Fuel and graphite qualification for high-temperature reactors

High-temperature reactors (HTRs) are being investigated in a number of countries as a safe and efficient source of energy, in particular for the cogeneration of industrial process heat and electricity. Related new demonstration projects are either in place or planned in several countries (e.g. Japan, China, US, South Korea) and are the subject of current R&D being carried out in Europe. The HFR is used in particular for the qualification of fuel and graphite which are key to ensuring that this type of reactor performs safely.

<u>HFR-INET</u>

The Institute of Nuclear and New Energy Technology (INET) of the Tsinghua University in Beijing, China is currently building the Chinese Modular High Temperature Gas-cooled Reactor Demonstration Plant (HTR-PM). The fuel for HTR-PM is produced by INET. INET requires qualification of their fuel to support the licensing of HTR- PM. The HFR-INET irradiation is the first step in the HTR fuel qualification process for HTR-PM and is being carried out by the NRG.

The first step in the fuel qualification (under operational conditions) is performed by NRG. Similar to earlier tests for related European programs, five spherical HTR fuel elements ('pebbles') are irradiated under controlled conditions in the HFR, at almost constant central pebble temperature, while fission gas release is measured continuously online using the sweep loop facility. This sweep loop facility was developed and in the past used by the JRC and is currently being used by the NRG. Fission gas release is an important measure for fuel performance and quality under operational conditions, and forms an essential part of the fuel qualification process. A dedicated irradiation test facility was designed and produced for the qualification irradiation process.

The irradiation started in September 2012 in a high flux in-core position of the HFR and finished on 30 December 2014, when the irradiation targets were met. In 2015, the irradiation rig was dismantled, and non-destructive Post Irradiation Examinations (PIE) were performed in the NRG Hot Cells. This non-destructive PIE consists of dimensional and weight measurements, gamma scanning and visual inspection.

For the second step of the fuel qualification process, the five HTR pebbles are subjected to a heating test at the JRC in Karlsruhe in Germany, in the so-called KÜFA-facility. The heating test is to demonstrate the integrity and proper performance of irradiated HTR fuel under accident conditions. Low radioactive release from the pebbles under these conditions then demonstrates the integrity and proper performance of irradiated HTR fuel which is a licensing requirement. In 2015, the transport from Petten to Karlsruhe was prepared with an expected target date in spring 2016.

INNOGRAPH-1C

Graphite is used as a moderator and reflector material in an HTR and is known to first shrink and then swell under irradiation. This behaviour depends on temperature, neutron dose and graphite grades. An understanding of graphite is required for the proper design of HTRs and to enable the graphite manufacturing industry to produce suitable graphite grades with stable properties over longer periods of time.

The INNOGRAPH-1C irradiation is performed as part of the FP7 ARCHER project (advanced high-temperature reactors for cogeneration of heat and electricity R&D). It follows earlier irradiation tests, and will complete the data set for different graphite grades at various temperatures, under a range of neutron doses. The experiment is a technical building block for nuclear cogeneration using HTRs as an alternative to fossil fuels.

The experiment was successfully commissioned for irradiation in 2012.The irradiation of 3 HFR cycles was completed in September 2013. Post-irradiation examination was completed in 2014. These examinations include for instance irradiation- induced dimensional change, dynamic Young's modulus, and coefficient of thermal expansion. Next to that, a selection of specimens was used for further examinations with optical microscopy, electron microscopy, and x-ray diffraction.

SALIENT

Molten salt fuel forms have received a significantly growing interest in the past years. NRG has started a collaboration with JRC and the TU Delft with the aim to develop molten salt technology and investigate the feasibility of molten salt reactors, under the program name LUMOS (Learning to Understand MOlten Salts).

The first step in the LUMOS program is the preparation and execution of an in-pile irradiation test of molten salts, followed by dedicated post-irradiation examinations to generate experimental data. This first irradiation is proposed under the name SALIENT (SALt Irradiation and Examination of Nuclide Trapping). The purpose of the SALIENT irradiation can be summarized as follows:

- to gain experience in handling and irradiating molten fluoride salts, and in treating the associated waste;
- to confirm claims of high fission product stability compared to oxide fuel, in particular with respect to Cs and I, which dominated the release of activity during the Fukushima accident;
- to assess uptake of Xe and other fission products by the graphite crucibles;
- to measure the size distribution for noble metal particles and develop techniques for removing the noble gas and noble metal fission products from the salt mixture;

In SALIENT, 4 fluoride salt samples are to be irradiated in graphite crucibles within triple containment. Small metal specimens will be included in some of the crucibles. In 2015, preparations were made for this irradiation which is scheduled to start in the course of 2016

2.3. Materials irradiation

BLACKSTONE

The United Kingdom's EdF Energy operates a fleet of advanced gas cooled reactors (AGRs). Graphite degradation is considered to be one of the key issues that determine the remaining service life of an AGR. Data on graphite's behaviour at high irradiation doses and weight loss is required to make it possible to predict and assess the behaviour of AGR graphite cores beyond their currently estimated lifetimes, thus ensuring continued safe operation and lifetime extension. The BLACKSTONE irradiations use samples trepanned from AGR core graphite and subjects them to accelerated degradation in the HFR. The tests are designed to make it possible to predict the future condition of the AGR graphite with confidence.

After phase I of BLACKSTONE, which finished in 2012, EdF Energy have successfully used this data to support an updated safety case for their AGR power stations, following an evaluation of the data and methods used by the UK nuclear regulator. In the meantime, phase II was also completed, with the irradiation of the two capsules for 12 and 16 irradiation cycles. The first capsule was dismantled in late 2012, with measurements being taken throughout 2013. The second capsule was dismantled in February 2014, with measurements being taken until October 2014. Following these successes a Phase III is now planned with irradiations starting in the second half of 2017. New material that is extracted from AGR power stations has been transported and received in the NRG hot cell laboratories to machine specimens and perform pre-characterisation

ACCENT

The ACCENT irradiations also use samples trepanned from AGR core graphite and apply pressure to the sample during irradiation. These tests aim to predict microscopic variation in the size of the material, to make it possible to predict the future condition of the AGR graphite with confidence.

Phase I of ACCENT began at the very end of 2012, with the design and construction completed in time for the first irradiation of one HFR cycle in the summer of 2013. The sample was dismantled and measurements completed in the autumn of 2013. Following the success of Phase I, Phase II began with an irradiation lasting 6 HFR cycles between February and August 2014. Post-irradiation characterisation on the specimens was successfully carried out in September 2014.

Phase 3a then followed, taking 4 cycles between March and August 2015. Phase 3b lasted 3 cycles: from December 2015 to March 2016. Between phases, the modules were dismantled and the samples characterised. The modular concept of the experiment has allowed for flexibility in the design: In Phases 3a and 3b a module without bellows was added so as to allow previously stressed samples to be irradiated without load. This enabled the study of creep recovery in graphite by an irradiation anneal.

LYRA-10

The LYRA irradiation rig is used in the framework of the European AMES (Ageing Materials and Evaluation Studies) network activities with the main goal of understanding the irradiation behaviour of reactor pressure vessel (RPV) steels, thermal annealing efficiency and sensitivity to re-irradiation damage. The LYRA-10 experiment carried out in the pool side facility of the

HFR consists of the irradiation of different specimen types representative of reactor pressure vessel materials, namely model steels, realistic welds and high-nickel welds. The model steels are grouped into 12 batches with the basic, typical composition of WWER-1000 and PWR reactor pressure vessel materials studied by the JRC to understand the role and influence of Nikel, Silicon, Chromium and Manganesen as alloying elements and certain impurities such as Carbon and Vanadium on the mechanical properties of steels. The realistic welds are created at eight different heats, specially manufactured based on typical WWER-1000 weld composition with variation of certain elements, such as Nikel, Silicon, Chromium and Manganese. It is important to investigate the role and synergisms of alloying elements in the radiation-induced degradation of RPV welds.

The LYRA-10 irradiation campaign started in May 2007 and was interrupted due to technical problems several times; it has so far included six HFR cycles at an average temperature of 283 °C. The original plan included the irradiation of seven more cycles to achieve a fast fluence, but it was decided during the LYRA-10 outage that at least 10 more HFR cycles were required to determine whether a ‘late-blooming’ effect occurs in the irradiated materials. ‘Late blooming’ is a possibly increased effect on material properties at higher irradiation doses, e.g. a stronger decrease of ductile-to-brittle transition temperature in materials which would not match currently used correlations.

In order to proceed with the resumption of the LYRA-10 experiment, a number of actions were carried out in 2012 to make the rig fit for irradiation. The experiment should have started at the end of 2012 but due to the HFR shutdown, it was delayed into 2013. In 2013, it was irradiated for two more cycles, for a total of eight HFR cycles at an average temperature of 283 °C. It is planned to continue the irradiation for five more cycles to achieve the fast fluence requested.

The experiment is currently on hold. In 2014, a certain number of components had to be repaired, among them the temperature controller of the heater to maintain stable irradiation conditions. After updating and approval of the safety documentation and related analyses, the experiment was approved for restart in the Pool Side Facility of the HFR in the beginning of 2016.

2.4. Irradiations for fusion technology

<u>ITER PRIMUS</u>

In 2005, an experiment was defined with the members of the European Fusion Development Agreement (EFDA) to test thermal fatigue of normal heat flux modules for ITER during irradiation. This experiment was planned to take place at the HFR pool side facility position for the duration of 22 cycles. It had to be designed in a way so that the stress conditions and temperatures would reflect ITER first wall conditions. Between 2005 and 2007, multiple iterations and adjustments have been made to achieve the ITER conditions. These led to a final design in 2008, but could not continue because of an HFR outage. In 2009, the position in the HFR pool side facility was not available. In 2010, the Reactor Safety Committee gave the feedback that the thermal cycling in the HFR was not possible due to the intrinsic design of the automatic control rod system.

This issue was discussed with the Joint Undertaking 'Fusion for Energy' (hereinafter F4E) as EFDA ceased to exist by end of December 2013 and instead a stagnant in-pile experiment was proposed, to achieve 1 dpa in beryllium, and to perform the thermal cycling afterwards in the JUDITH facility in Jülich was proposed.

To perform this irradiation, a new experiment called PRIMUS was designed.

In 2012, a new conceptual design was presented by F4E and extensive activation calculations showed that the mock ups were too active to be handled in the JUDITH facility. Therefore, a proposal was made to cut the steel back from the mock-ups, without jeopardising the stress conditions on the beryllium/CuCrZr interface.

This led to a proposal which reduced the activation to levels acceptable for JUDITH. The mock-ups were sent back to France, where the cutting procedure started.

In 2013 the adapted first wall mock-ups were delivered by F4E. The stainless steel part on the back of the mock-up was reduced by 60% to decrease the activation after irradiation. New irradiation design calculations were performed using the new geometry, and the irradiation proposal was drafted.

In 2014 the conceptual design of the mock- up irradiation was completed and the irradiation proposal was sent to the Reactor Safety Committee for information. In this conceptual design the mock-ups were be clamped between aluminium filler material to enhance dissipation of heat to the primary coolant of the HFR. The irradiation rig was instrumented with 23 thermocouples and dosimeter sets to register temperature and dose levels obtained during irradiation. The irradiation targets were 265°C at the interface of the CuCrZr and Be at a dose of 1 dpa. Due to the Return to Service program of NRG the project was delayed until 2015.

In 2015 the irradiation capsule for the PRIMUS mock-ups was fabricated and assembled and the design and safety report was approved by the reactor safety committee. After the irradiation approval was given, the irradiation started on 20 August 2015. The target temperatures were met in two cycles conducted in 2015. The other three irradiation cycles will be performed in 2016.

CORONIS

In 2011, a new project started under F4E, focusing on ITER's material development and characterisation. The project was co-financed by the Dutch Ministry of Economic Affairs and F4E and ran from 1 January 2011 to October 2015.

The objective was to measure the tensile, fatigue and Charpy impact properties of shielding blanket material and shielding blanket joints before and after irradiation to 0.01, 0.1 and 0.7 dpa at 250 °C. This material is planned to be used in the shielding blanket in ITER because of its high heat dissipation. This property could be jeopardised if the material fails during its operational lifetime in ITER.

The irradiation was also performed with the Hungarian Institute AEKI, which took care of the low level dose irradiation (0.01 dpa). All post irradiation experiments were be performed in the NRG Hot Cells.

In 2013, the CORONIS 01 and CORONIS 02 experiments were developed, assembled and commissioned. After filling with sodium in the ECN workshop, the experiments were transferred to the HFR for irradiation.

- CORONIS 01 will be irradiated for one cycle corresponding to 0.1 dpa.
- CORONIS 02 aims to accumulate 0.7 dpa corresponding to a three-cycle irradiation in the HFR.

Both experiments are carried out at a homogeneous temperature of 250 °C. The materials in CORONIS 01 and 02 are ones which will be used as heat sink material for ITER's first wall shielding modules.

In 2014 the irradiation of CORONIS 01 and 02 was started in the first cycle and were fully completed during the year. After a cool-down period the rigs were transported to HCL for dismantling and Post irradiation testing of the included specimens. The examination is ongoing

FIWAMO

In July 2012, a new contract was signed between ITER International Organization, Forschungszentrum Jülich (FZJ) and the NRG for the irradiation and high heat flux testing of eight enhanced heat flux first wall modules for ITER.

The ITER first wall is produced using two technologies, normal heat flux (NHF) for loading up to 2 MW/m^2 and enhanced heat flux (EHF) for loading up to 5 MW/m^2. The plasma-facing surface of the first wall is made of beryllium tiles that are joined to a heat sink using hot isostatic pressing or brazing. The heat sink is attached to a supporting steel structure.

The scope of this project is to perform a pre-irradiation screening of the modules, from SWIPP (China) and NIIEF (Russia), irradiation in the HFR to 0.1 and 0.7 dpa at 200-250 C and to perform post irradiation high heat flux testing in the JUDITH facility at FZJ up to 5 MW/m^2.

In 2013, Phase 1 of the contract was concluded with the submission of a final design proposal for the irradiation capsule.

The mock-ups consists of beryllium tiles that are joined to the heat sink using hot isostatic pressing or brazing technology. They will be clamped between aluminium blocks to allow for radial heat dissipation during irradiation. The interface between the copper and beryllium will be held at 225 C. The mock-ups will be irradiated to doses of 0.1 and 0.6 dpa, respectively.

In 2014 the second phase, did not start due to delayed fabrication of the mock- ups. For this second phase of the project, the detailed design will start in 2015 and irradiation is planned for 2016.

2.5. HFR support for research on the standardisation of materials

Network on Neutron Techniques Standardisation for Structural Integrity (NeT)

The European Network on Neutron Techniques Standardisation for Structural Integrity (NeT) fosters performance and safety improvements in European nuclear power plants. NeT mainly supports progress towards improved understanding and prediction of welding residual stresses relevant for the integrity of nuclear power plant components.

The JRC organises and manages NeT and contributes to the scientific work through neutron scattering for residual stress measurement using its beam tube facilities at the HFR.

The NeT members have met twice in 2014, once at EdF Research near Paris and once at Bilgi University, Istanbul, to review the work progress and to agree on the way forward. The NeT members have issued a comprehensive overview paper on the activities around the single bead on plate weld. A dedicated issue of a scientific journal on NeT Task Group 4 (three beads in a slot weld) was prepared; and the first specimens of Task Group 6 on a weld in a Nickel base alloy plate have been procured.

The NeT members have met twice in 2015, once hosted by RATEN ICN/Pitesti in Bucharest and once at Helmholtz-Zentrum Berlin, to review the work progress and to agree on the way forward.

NeT is currently mainly working on its Task Groups (TGs) 4 and 6. In TG4 residual stresses around a 3 bead in a slot weld in an austenitic stainless steel plate have been studied, while TG6 deals with a similar specimen geometry, but with a nickel base alloy as base material. TG4 is already in the process of being summarized, whereas TG6 is still in its early stages. In 2015, the first experimental and numerical results have been reported.

The partners in NeT have initiated an activity to compile and document the achievements of the Network. In view of the upcoming 15th anniversary of NeT in 2017 it was considered a reasonably well-timed action. NeT has produced more than 60 scientific papers, including a dedicated issue of the International Journal of Pressure Vessels and Piping (with another one currently in preparation). NeT has contributed to at least 10 PhD theses in several European countries and, last but not least, NeT output has been included as an example in the weld modelling guidelines of the R6 defect assessment procedure.

Standardisation of the neutron diffraction method for residual stress measurement

The scientific and engineering community use neutron diffraction as a technique for measuring residual stresses in materials and components. Work on the development of a standard for the method has been in progress for about 15 years. The JRC has been involved from the beginning with its two dedicated diffractometers at the HFR. An ISO technical specification about the method was published in 2005. The activity is now entering its final phase, where the method's technical specification is being upgraded to an international standard.

In 2012, negotiations were undertaken with the ISO and several national neutron beam facilities in order to set up a working group that would thoroughly review the existing specification.

The new Working Group has been established in 2014 under ISO/TC 135/SC 5 charged with the drafting of an International Standard for the method based on an existing Technical Specification. JRC has been entrusted with the convenorship of this Working Group with nominated members from the UK, Germany, Greece, South Africa and Canada plus one observing member from Japan. The first meeting of the group took place in December 2014 in Berlin, Germany. The Working Group is meeting as frequently as possibly in order to keep the relatively tight standard ISO timelines. In 2015 eight meetings have taken place, including two in-person meetings held in Berlin, and in Grenoble. For 2016, a similar number of meetings is envisaged, in order to prepare the draft standard for submission to TC 135/SC 5 before the end of the year 2016.

Residual stress measurements for the Euratom Framework Programme project MULTIMETAL

The members of the MULTIMETAL project jointly embarked on the advancement of knowledge in the area of integrity assessment of bimetallic welds for nuclear applications. Three different components have been studied in the programme; and sections from two of these components have been at the HFR in 2014 for residual stress measurements by neutron diffraction. Mock-up no. 3 is 40 mm thick and comprises a ferritic steel plate welded to an austenitic stainless steel plate using austenitic stainless steel consumables. The materials used are Russian grade steels, as this specimen is representative of a VVER type reactor. Mock-up 2 is a short section, 29 mm long, of a bi-metallic weld representative of a PWR reactor of French origin. While these two specimens were made from similar materials, the welding geometries and restraint conditions during manufacturing were quite different. Therefore, the residual stress results were going to be different and the first data obtained indicated this to a certain extent.

Measurements have continued in 2015, whereby several repeat measurements have been made in the ferritic steel part of the component. In these repeat measurements long counting times of up to 15 hours have been used in order to reduce the scatter in the data previously observed..

The experts from Bay-Logi in Hungary have in the meantime undertaken the first comparison of the measured results with their numerical predictions and have found a relatively good agreement already with the first attempts.

The measurements will continue in 2016 on the austenitic side of the component after repair of the neutron monochromator at the HFR neutron beam.

ISOTOPE PRODUCTION

Worldwide, approximately 25.000 patients per day depend on medical radio-isotopes produced in the HFR in Petten for diagnosis and therapy.

NRG delivers these medical isotopes to mainly radio-pharmaceutical companies. Molybdenum-99 is by far the most important of these isotopes. It is a precursor of Technetium-99m which represents the most widely used medical isotope for imaging, accounting for 80% of nuclear diagnostic procedures. It performs a critical role in the diagnosis of heart disease, and is also used in cancer diagnosis through bone and organ scans. In addition, new treatment methods are being developed thus leading to ever increasing demand for (new) isotopes. Given the half-life of the produced isotopes and the high demand for treatment, a well-oiled just-in-time logistic infrastructure is essential.

The Dutch expertise from NRG, URENCO and TU Delft in the area of medical radioisotopes has been recently bundled into the association "Dutch Isotope Valley" (DIVA) where knowledge, skills, capacity and alternative production methods for (medical) isotopes have attained sufficient weight to serve the world market. Considering that the NRU reactor at Chalk River, Canada will stop routine production of Mo-99 in 2016 and will is planned to be shut down in 2018 and that Canada will concentrate on domestic demand as opposed to export, this represents an excellent opportunity for DIVA to fill the production gap.

In order to carry out the asset integrity program which is a prerequisite to run the HFR and its ancillary installations until 2024, the Dutch government has granted NRG a loan (through its parent company ECN). In parallel, NRG has successfully increased prices for its entire service package and these were accepted by all customers. In particular, NRG's top 6 isotope customers have expressed their confidence in NRG through signing long-term supply agreements. This was a successful step into the direction of financial robustness and viability.

In 2014, the HFR restarted its operation on 14 February and has performed its production schedule as planned during the rest of the year. The HFR was thus back on the international scene as one of the major producers of medical isotopes worldwide. In 2015, the HFR missed one production cycle in October but could be restarted in December.

FINANCIAL CONTRIBUTIONS TO THE PROGRAMME'S IMPLEMENTATION

In 2014-15, the following financial contributions were received from Member States for the implementation of the supplementary programme:

- Belgium: EUR 300 000 (2014) + EUR 300 000 (2015),
- France: EUR 300 000 (2014) + EUR 300 000 (2015),
- The Netherlands: EUR 7 250 000 (2014) + EUR 7 250 000 (2014),

for a total of EUR 15 700 000. Note that these contributions cover the expenses specified under Annex II of Council Decision 2012/709/Euratom. The Commission does not cover any operational deficits, including potential costs of maintenance or repair.

Since 2004, due to a re-evaluation of decommissioning costs, the annual contribution of the supplementary programme to the decommissioning fund increased from EUR 400 000/year to EUR 800 000/year. This amount is taken from (a) the regular budget of the supplementary research programme and (b) the interest earned on the bank account of the decommissioning fund of the supplementary research programme. For example, in 2014 the estimated amount of interest generated by the decommissioning fund was EUR 145 000. Therefore, only EUR 655 000 was added from the regular supplementary research programme budget to reach the EUR 800 000/year. The total amount in the decommissioning fund is EUR 17 239 000. This fund will contribute to the future decommissioning costs of the HFR (to be borne by Euratom), estimated at EUR 72 600 000 in the most recent decommissioning study available.[1]

Other expenditure incurred by the JRC during the reporting period and paid from the supplementary research programme budget includes:

- direct staff costs (e.g. HFR supplementary research program management): EUR 257 000
- HFR support costs (e.g. legal advice): EUR 166 000
- utilities (e.g. electricity, water, heating): EUR 1040 000
- spent fuel management costs: EUR 2 450 000

[1] Communication from the Commission to the Council and the European Parliament on Decommissioning of Nuclear Installations and Management of Radioactive Waste: Management of Nuclear Liabilities arising out of the Activities of the Joint Research Centre (JRC) carried out under the Euratom Treaty — COM(2013) 734 final.

Glossary and Acronyms

AIPES	Association of Imaging Producers and Equipment Suppliers
ARCHER	Advanced High-Temperature Reactors for Cogeneration of Heat and Electricity R&D
dpa	displacements per atom
Euratom	European Atomic Energy Community
FAIRFUELS	Fabrication, Irradiation and Reprocessing of FUELS and target for transmutation
F4E	Fusion for Energy (the European Union's Joint Undertaking for ITER and the development of fusion energy)
HFR	High Flux Reactor
IAEA	International Atomic Energy Agency
INET	Institute for Nuclear and New Energy Technology (Tsinghua University Beijing, China)
ISO	International Organisation for Standardisation
ITER	International Thermonuclear Experimental Reactor
JRC	Joint Research Centre
MA	Minor Actinides
MARIOS	Minor Actinides in Sodium-cooled Fast Reactors
NeT	EU Network on Neutron Techniques Standardisation for Structural Integrity
NRG	Nuclear Research and consultancy Group
OECD/NEA	Organisation for Economic Cooperation and Development / Nuclear Energy Agency
PELGRIMM	PELlets versus GRanulates: Irradiation, Manufacturing & Modelling
PIE	Post Irradiation Examination
RE	1 RE: amount of radioactivity causing a dose of 1 Sv if inhaled or ingested