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**COMMISSION STAFF WORKING DOCUMENT**  
*Accompanying the document*

**Report of the Commission to the Council and the European Parliament 'Operation of  
the High Flux Reactor in the period 2012-13'**

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## **COMMISSION STAFF WORKING DOCUMENT**

### **Accompanying the Report of the Commission to the Council and the European Parliament ‘Operation of the High Flux Reactor in the period 2012-13’**

This staff working document is a companion document to the Commission’s report on ‘Operation of the high flux reactor in the years 2012-13’, 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 European Atomic Energy Community (Euratom) owns the plant (leased from the Dutch state for 99 years). The HFR is owned by the European Commission and is operated by the Nuclear Research and Consultancy Group (NRG). The close cooperation between the JRC and the NRG has led to a unique system of managing the HFR, involving both organisations.

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 Joint Research Centre (JRC).

This document reports on the results of the scientific and technical work carried out in 2012-13. 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**

### **Operating schedule**

#### **2012**

In 2012, the planned cycle pattern consisted of a scheduled number of 296 operation days and one maintenance period of 31 days in March. The in-service inspection of the north and south reducer, welds of the reactor vessel and the annual leak test of the reactor containment were performed during this period. In reality, the HFR was in operation 253 days (or 6090:57 min — Table 1). This corresponds to an actual availability of 85.26%, as compared with the original schedule. Its nominal power was at 45 MW, and the total energy production for 2012 was approximately 11 313 MWd, corresponding to a fuel consumption of about 14.12 kg U-235. The 30-day planned cycles 2012-10 and 2012-11 were cancelled. One of the reasons for this was the detection of tritium in the groundwater around the reactor building, which was traced back to an underground leak in a water pipeline. The other reason was the detection of a leak path between the primary cooling water system and the bottom plug cooling system (part of the pool cooling system). Both issues were independently investigated and repaired and the reactor was restarted safely.

Figure 2 shows the total discharged activity of tritium and noble gases in 2012 compared with values since 1999. The license limit is 100 RE/year. The total discharged activity in 2012 was approximately 11 RE (Note: RE: amount of radioactivity causing a dose of 1 Sv if inhaled or ingested)

#### **2013**

In 2013, the planned cycle pattern consisted of a scheduled number of 166 operation days and a maintenance period of 18 days during the month of August. During the repair and maintenance period between 1 January 2013 and 10 June 2013, the tritium level which appeared in the groundwater around the reactor building decreased. A small cooling water leak from the basin cooling water system to the primary cooling water system, caused by a broken seal in the bottom plug liner, was repaired by installing a second seal and leak detection system.,

The planned cycles 2013-04, 2013-05 and 2013-06 were cancelled due to problems with the structural integrity of three control rods. The problem was investigated during an extended root cause analysis. The reactor, meeting all safety requirements, was authorised by KFD to return to service at the beginning of 2014.

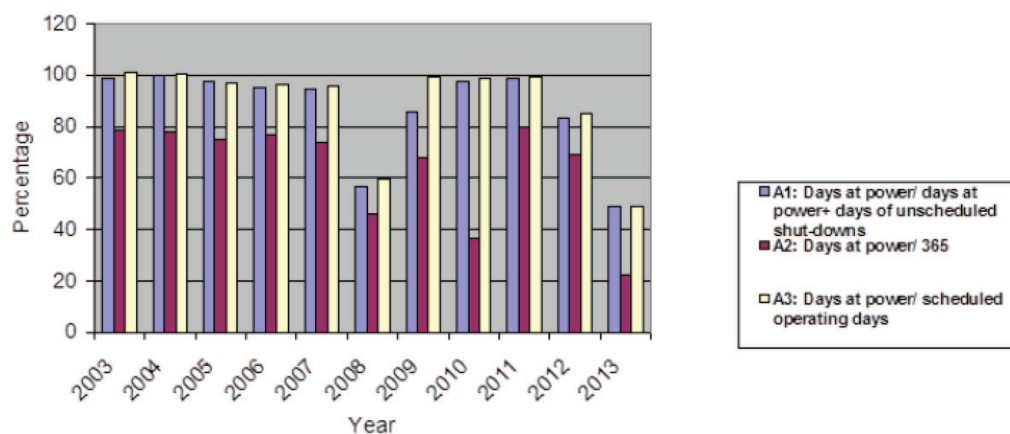
During the year, the HFR was in operation during about 81 days (or 1956:49 min — Table 2). This corresponds to an actual availability of 49.07%, as compared with the original schedule. Its nominal power was 45 MW, and the total energy production in 2013 was approximately 3661 MWd, corresponding to a fuel consumption of about 4.57 kg U-235.

Generated Energy [MWd]	Planned [h]	Low Power [h:min]	Nominal Power [h:min]	Other Use [h:min]	Total [h:min]	Planned [h:min]	Un-planned [h:min]	Stack Release (of Ar-41) [ $10^{11}$ Bq]
11313.55	7144	21:43	6028:14	41:00	6090:57	1476:41	1216:22	38.12
Percentage of total time in 2012 (8784 h):		0.25	68.63	0.47	69.34	16.81	13.85	
Percentage of planned operating time (7144 h):		0.30	84.38	0.57	85.26			

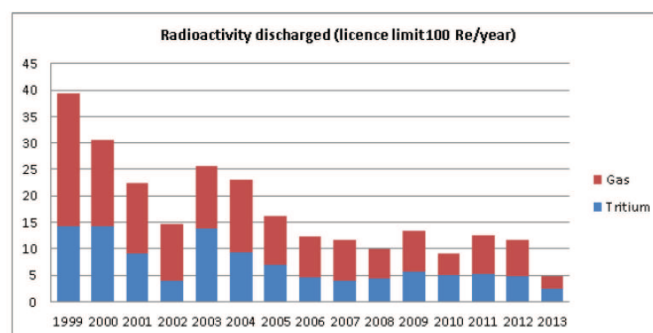
**Table 1:** Summary of HFR operation in 2012

Generated Energy [MWd]	Planned [h]	Low Power [h:min]	Nominal Power [h:min]	Other Use [h:min]	Total [h:min]	Planned [h:min]	Un-planned [h:min]	Stack Release (of Ar-41) [ $10^{11}$ Bq]
3661.80	3988	9:12	1947:37	0	1956:49	4761:57	2041:14	13.1
Percentage of total time in 2013 (8760 h):		0.11	22.23	0	22.34	54.36	23.30	
Percentage of planned operating time (3988 h):		0.23	48.84	0	49.07			

**Table 2:** Summary of HFR operation in 2013



**Figure 1:** HFR availability since 2003



**Figure 2:** Radioactivity (noble gas and tritium) emitted since 1999

## **Maintenance activities**

### **2012 and 2013**

In 2012 and 2013, 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 main activities carried out during the maintenance period were the following:

- Periodic leak test of the containment building, as one of the licence requirements (0.05 MPa overpressure for 48 h) — 2012.

Periodic leak test of the containment building, as one of the licence requirements (0.02 MPa overpressure for 24 h) — 2013.

The in-service inspection of the north and south reducers and the welds of the reactor vessel.

The in-service inspection of a part of the primary system in the primary pump building.

Regular repair maintenance of the concrete pipeline for secondary cooling water between the North-Holland Canal and the HFR secondary pump building.

Extension of the secondary outlet pipeline further into the North Sea.

Completion of the remote monitoring system which is used to monitor important reactor parameters during emergency cases.

Completion of the alternative shutdown system which can be used if the normal shutdown system is not functioning.

These activities were successfully completed.

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

### 1.1. 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.

### MARIOS

Part of the FAIRFUELS project, MARIOS is an irradiation test dealing with heterogeneous recycling of minor actinides (MAs) in sodium-cooled fast reactors. MAs, such as americium and curium, are long-lived radioactive isotopes in high-level nuclear waste, and are currently not recycled. The aim of MARIOS is to investigate more closely the behaviour of MA targets in a uranium oxide matrix and to compare dense fuel to fuel with a tailored porosity. In these targets, large amounts of helium are produced and cause swelling and significant damage to the material under irradiation. It is the first time that americium ( $^{241}\text{Am}$ ) is included in a (natural) uranium oxide matrix to conduct an experiment to assess helium production and swelling.

The MARIOS irradiation started on 19 March 2011 and successfully finished on 2 May 2012 after 11 reactor cycles (~304 full power days). The irradiation was completed and disassembled in the NRG hot cells in Petten and was ready for PIE in 2013. Pellet integrity, helium and fission gas release and results from gamma scans were reported for pellets of two different densities irradiated at well-defined temperatures. The pellets were allowed to swell freely during irradiation. Helium production (characteristic for americium containing fuel) and fuel burn-up were determined using calibrated post-irradiation calculations.

The fuel with tailored porosity behaved like the less porous fuel. A ~100% helium release was observed for all four capsules, showing that the threshold for high helium release lies below 1000°C. Finally, dismantling one of the four fuel pins revealed that five out of six pellets had broken into two parts of about equal size. This was probably due to thermal stresses built up during irradiation.

### 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 would resume operation. The SPHERE irradiation started on 28 August 2013 in the HFR core and lasted for approximately 300 full power days. The temperatures obtained were in line with predictions and target values. In 2013, a pre-irradiation neutron radiograph was taken, to be compared with a neutron radiograph after the first cycle. This made it possible to verify the expected fuel restructuring in the sphere-pac. The first irradiation cycle was completed in 2013.

### HELIOS

The HELIOS irradiation was performed as part of the terminated FP6 EUROTRANS integrated project on partitioning and transmutation (2005-10) and dealt with the irradiation of U-free inert matrix fuels containing americium with the objective of incinerating this MA. The main objective of the HELIOS irradiation was to assess the in-pile behaviour of ceramic matrices and metallic matrix fuel targets in order to gain knowledge about the role of microstructure and temperature on helium gas release and fuel swelling. During the irradiation of such fuel, a significant amount of helium is produced due to the transmutation of americium. Understanding the gas release mechanisms is vital to maximising the transmutation yield and to achieving an optimum performance for these fuels. Two different approaches were followed to reach early helium release and thus to keep fuel damage low:

- (1) Providing release paths for helium to plenum gas by creating open porosity in the fuel. Therefore, a composite target with an MgO matrix containing a network of open porosity was included in the HELIOS test plan.

Increasing the target temperature in order to promote the release of helium from the matrix. Americium- or americium/plutonium-zirconia-based solid solutions and CerMet targets were included in the test plan to investigate the effects of temperature.

Post-irradiation examination (PIE) of irradiated HELIOS fuel was planned as part of the FP7 FAIRFUELS project.

In 2012, the post-irradiation examination of NRG hot cells was finalised. All five pins were punctured to analyse the gas pressure (to determine the helium release fraction) and the isotopic distribution in the fuel. Destructive PIE was performed in collaboration with the CEA. The pin with an MgO matrix was to be examined by the CEA but transport issues prohibited this. The CEA therefore visited the NRG to perform the examination together. The pin showed very stable behaviour where the increased porosity stimulated the release of fission gas (around 43% of it) most of which was helium. The swelling of the pellets was acceptable, with a volumetric swelling of less than 3 % for a burn up of 5.11 %.

For the pins containing molybdenum matrix fuel, optical microscopy and SEM examinations

were performed at the NRG. For these pins, there was a clear temperature effect. Although the pin irradiated at roughly 500 °C showed very stable behaviour, almost no swelling and limited gas release, the pin at a high temperature (up to 1200 °C) showed the opposite. Although helium gas release was measured as relatively high, it was insufficient to avoid significant fuel swelling, and pellet-cladding interaction therefore occurred.

## MARINE

MARINE is planned as part of the FP7 PELGRIMM project. MARINE 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.

In 2012-13, the design of MARINE was finalised with the development of a new system to connect the pressure transducer (produced in Halden) with the fuel pins (produced at the JRC). Safe connection and transportation of the fuel pins with the pressure transducers will be managed in Petten with the use of burst discs sealing the fuel pins. After connection of the pressure lines in Petten, the burst discs will be intentionally broken to allow gas to freely expand from the pins to the pressure transducers. Preliminary nuclear and thermo-mechanical assessments have been performed and led to the decision to irradiate the experiment in a specific position of the HTR where the blankets of an SFR (power, temperature, helium production) can be reproduced as closely as possible.

### **1.2. 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.

## HFR-INET

Based on experience related to the German HTR programme in the 1980s, in which the HFR had played a crucial role, a licensing strategy was developed and includes: (1) fuel irradiation at specific temperatures to a specific burn-up target and (2) successive heating tests of the irradiated fuel under simulated accident conditions. For the fuel to be considered acceptable in both types of tests, the measured fractional release of fission gas must remain below the licensing thresholds.

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.

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. It makes it possible to control the temperature of the fuel elements and to monitor fission gas release during irradiation by gamma spectrometry. 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 continued in 2013. It will continue to 2014-15, until the required burn-up level is achieved. After irradiation, non-destructive PIE will be performed in the NRG hot cells.

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.

### 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 (cf. Figure 7), 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 three HFR cycles were completed in September 2013, with dismantling completed and the first PIE measurements carried out by the end of 2013. Measurements continued until mid-2014.

### **1.3. 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.

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 an irradiation of an estimated six HFR cycles in February 2014, with measurements completed by December 2014.

#### 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 (cf. Figure 8). 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 Nickel, Silicon, Chromium and Manganese 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 Nickel, 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 are 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.

However, the experiment had to be put on hold to repair a leak in a gas line used for temperature control, resumed at the end of 2014.

### **1.4. Irradiations for fusion technology**

#### ITER PRIMUS

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. This was necessary to comply with the limits for activity in the JUDITH facility. New irradiation design calculations were performed using the new geometry, and the irradiation proposal was drafted. This led to a design with a clamping system of aluminium blocks to allow for radial heat dissipation during irradiation. The temperature on the Cu-Be interface during irradiation will be 225 °C and the accumulated irradiation dose after five cycles of irradiation will be 1 dpa. Irradiation started in 2014.

### CORONIS

In 2011, a new project started under F4E, focusing on ITER's material development and characterisation.

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.

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. 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. The experiments started irradiation at the end of 2013.

CORONIS 02 aims to accumulate 0.7 dpa corresponding to a three-cycle irradiation in the HFR.

All post-irradiation experiments will be performed at the NRG hot cells. The project runs from

1 January 2011 to October 2015.

### 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<sup>2</sup> and enhanced heat flux (EHF) for loading up to 5 MW/m<sup>2</sup>. 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<sup>2</sup>.

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..

## **1.5. 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.

In 2012, NeT developed new activities on residual stresses in welds of nickel-based alloys and aluminium specimens. These materials are relevant for new types of dissimilar metal welds in nuclear piping systems and to welds in research reactor installations.

In 2013, NeT prepared summary reports and publications on its work on a three-bead weld in an austenitic stainless steel plate. This work is likely to be the most comprehensive experimental and computational round robin type investigation on welding residual stresses currently in existence. NeT is going to complement this work with similar activity on welding in a nickel base alloy. The specimen design for this new activity has been agreed on and specimens were available for measurements in 2014.

### 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. In 2013, a proposal was submitted to ISO Technical Committee 135 on Non-

Destructive Testing to set up a working group charged with the review of the document and subsequent submission for adoption as a full standard. Five member countries from three continents agreed to participate. The working group was set up in 2014.

#### PhD on neutron diffraction stress measurements in welded components performed at the HFR

On 12 November 2013, a scientist from the JRC concluded his PhD research entitled ‘Residual stresses in thick bi-metallic fusion welds: a neutron diffraction study’. The neutron diffraction work on which the PhD thesis is based had been performed using the HFR residual stress measurement facilities. The components investigated were multi-pass fusion welds designed as scaled mock-ups of real nuclear components. The need to penetrate wall thicknesses of up to 51 mm with the neutron beam pushed the technique almost to its limits. The work demonstrated the feasibility of such investigations and presented a novel approach to the assessment of the measurement uncertainty for such cases.

### **ISOTOPE PRODUCTION**

Isotope production was severely affected by the disruption of the HFR’s operation between 2012 and 2013.

Until mid-November 2012 when the HFR was shutdown for repairs, isotope production operated normally. Therefore only nine full cycles of normal isotope production were achieved and 1.5 cycles of production were lost.

Until the HFR shutdown for repairs, the value of isotopes and associated services supplied was higher than in the preceding year. A number of interesting new product development ideas continued to progress, both in conventional application areas and in some ground-breaking areas of medical technology. For example, neutron transmutation doped (NTD) silicon came back into production. NTD silicon products can be found in important applications such as high-voltage power electronics, high-speed trains, and green technologies, e.g. wind, solar and hybrid cars.

A severely disrupted year of operation for isotope production was experienced at the HFR in 2013, with only around 49% of the normal operating schedule available. Nevertheless, the HFR still performed an important role in ensuring the supply of vital medical isotopes and other industrial isotopes in Europe during a period when other research reactors were out of operation.

The HFR’s outages reinforced the need to support the coordinated efforts necessary to minimise the future risks to the security of supply of critical medical isotopes. The NRG fully supports the recommendations of the OECD/NEA High Level Group on the security of supply of medical isotopes. It continued to work closely with other actors in the medical isotope supply network, as well as with the medical community, governments, the European Commission, AIPES, and the IAEA on important issues such as full-cost recovery pricing, outage reserved capacity provision, future infrastructure investment and conversion to low enriched uranium targets for Mo-99 production.

## FINANCIAL CONTRIBUTIONS TO THE PROGRAMME'S IMPLEMENTATION

In 2012-13, the following financial contributions were received from Member States for the implementation of the supplementary programme:

- Belgium: EUR 300 000 (2012) + EUR 300 000 (2013),

France: EUR 300 000 (2012) + EUR 300 000 (2013),

The Netherlands: EUR 7 250 000 (2012) + EUR 7 250 000 (2013),

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 2013 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. As of 31 December 2013, the total amount in the decommissioning fund is EUR 15 639 000.

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.<sup>1</sup>

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 345 000

HFR support costs (e.g. legal advice): EUR 66 000

utilities (e.g. electricity, water, heating): EUR 993 000

spent fuel management costs: EUR 1 902 000

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<sup>1</sup> 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