European Commission

JRC SCIENCE AND POLICY REPORTS

Operation and Utilisation of the High Flux Reactor

Annual Report 2014

Editor:
Michael A. Fütterer

JRC Main Contributors:
Elio D'Agata, Carsten Ohms,
Jean-Marc Lapetite, Alan van de Sande

NRG Main Contributors:
Tjark van Staveren, Lida Magielsen, Ralph Hania,
Jelmer Offerein, Steven Knol, Maurits Heijna,
René Meekel

2015

Joint Research Centre

Report EUR 27340 EN

European Commission
Joint Research Centre
Institute for Energy and Transport

Contact information
Dr. Giovanni Federigo De Santi
Address: Joint Research Centre, P.O. Box 2, NL-1755 ZG Petten, The Netherlands
E-mail: giovanni.de-santi@ec.europa.eu
Tel.: +31 224 565147
Fax: +31 224 565601

https://ec.europa.eu/jrc

JRC96509

EUR 27340 EN

ISBN 978-92-79-49418-5 (PDF)

ISSN 1977-2289/1831-9424 (online)

doi:10.2790/829498

Luxemburg: Publications Office of the European Union, 2015

Abstract

The High Flux Reactor (HFR) at Petten is managed by the Institute for Energy and Transport (IET) of the European Commission's Joint Research Centre (JRC) and operated by the Nuclear Research and consultancy Group (NRG) which is also the licence holder and responsible for its commercial activities. The High Flux Reactor (HFR) operates at 45 MW and is of the tank-in-pool type, light water cooled and moderated. It is one of the most powerful multi-purpose materials testing reactors in the world and one of the world's leaders in target irradiation for the production of medical radioisotopes.

Operation and Utilisation of the High Flux Reactor
Annual Report 2014

Editor:
Michael A. Fütterer

JRC Main Contributors:
Elio D'Agata
Jean-Marc Lapetite
Carsten Ohms
Alan van de Sande

NRG Main Contributors:
Tjark van Staveren
Ralph Hania
Steven Knol
René Meekel
Lida Magielsen
Jelmer Offerein
Maurits Heijna

Table of Contents

List of Figures

1 HFR Operation

1.1 Operating Schedule

The reactor was scheduled to return 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 (see Figure 1). 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.

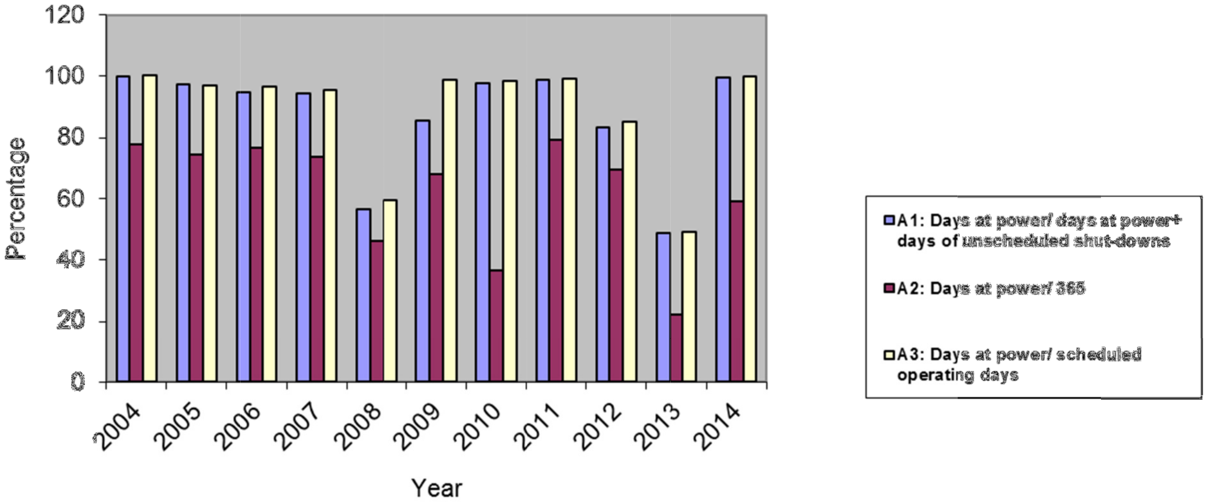

Figure 1: HFR availability since 2004

1.2 Maintenance Activities

In 2014 the maintenance activities consisted of the preventive, corrective and break down maintenance of all Systems, Structures and Components (SSC's) of the HFR as described in the annual and long-term maintenance plans. These activities are executed with the objective to enable the safe and reliable operation of the HFR and to prevent inadvertent scrams caused by insufficient maintenance.

Maintenance was performed successfully and comprised:

- 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 reactor vessel, the outlet reducers, the bottom plug and primary piping in the Primary Pump Building;
- Cleaning of the secondary cooling system;
- Two week training for the HFR operator staff.

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

2 The HFR as a Tool for Research on Reactors, Materials and Fuel Cycles

2.1 Towards a more sustainable fuel cycle with less nuclear waste: The FAIRFUELS and PELGRIMM Projects

In the frame of the EURATOM 7th Framework Programme (FP7), the two closely linked 4-year projects FAIRFUELS (Fabrication, Irradiation and Reprocessing of FUELS and targets for transmutation, http://www.fp7-fairfuels.eu) and PELGRIMM (PELlets vs. GRanulates: Irradiation, Manufacturing and Modelling, http://www.pelgrimm.eu) 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 manner producing less and shorter-lived radioactive waste.

The FAIRFUELS consortium consists of 10 European research institutes, universities and industry. The project started in 2009 and is coordinated by NRG. The PELGRIMM consortium consists of 12 European research institutes, universities and industry. The project started in 2012 and is coordinated by CEA.

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

2.1.1 SPHERE

Objective:

The irradiation test SPHERE was planned as part of 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 fabrication process. Especially when dealing with highly radioactive minor actinides, dust-free fabrication processes are essential to reduce the risk of contamination.

To assess the irradiation performance of Sphere-Pac fuels compared to conventional pellet fuel, an americium-containing driver fuel for fast reactors (both in pellet- and sphere-pac form) was fabricated at JRC-ITU in Germany. These fuels are irradiated in the HFR in a dedicated test facility which is a novelty because such fuel has never been irradiated before.

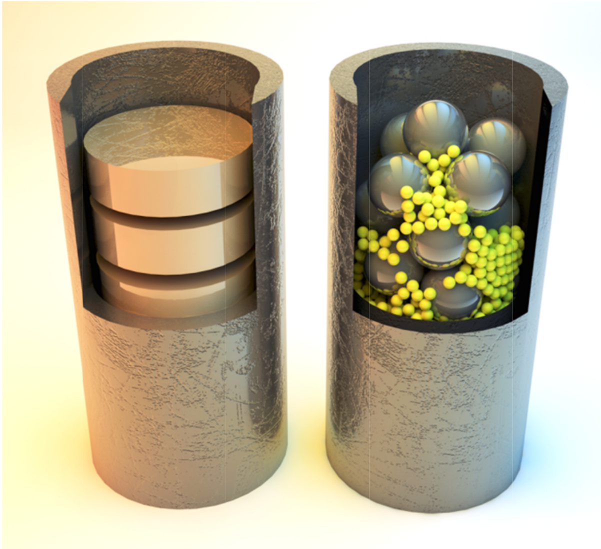

Figure 2: Pellet versus Sphere-Pac concept

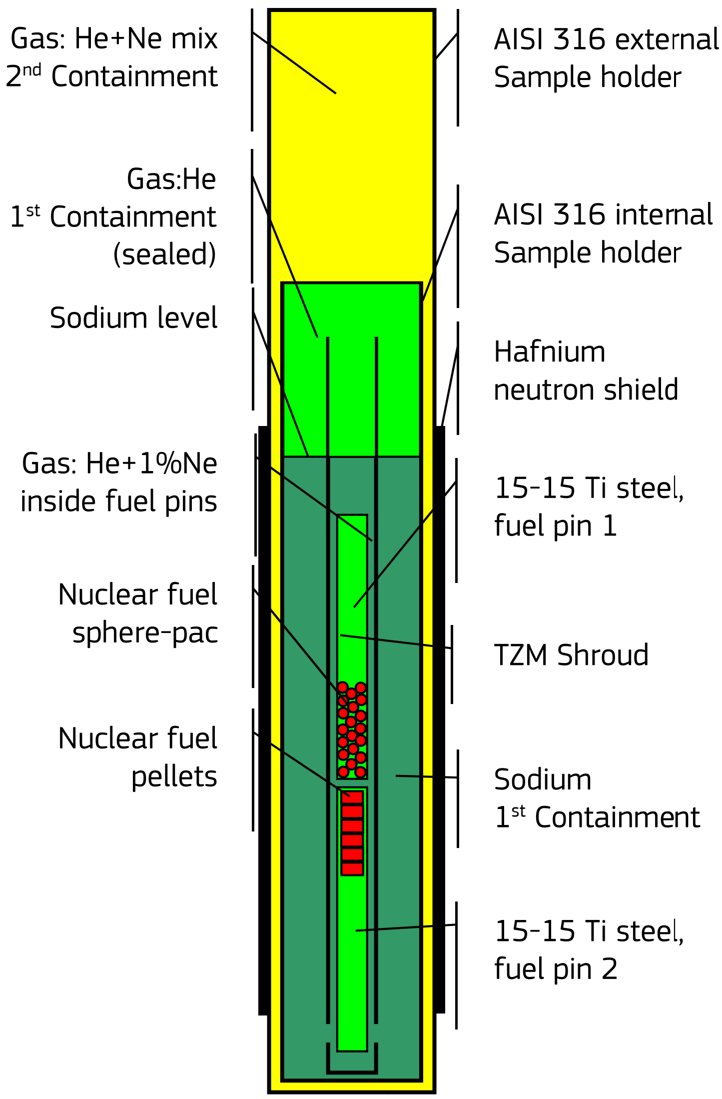

Figure 3: Schematic view of the SPHERE irradiation experiment

Achievements:

The SPHERE irradiation continued throughout 2014 (for another 7 cycles) in position G7 of the HFR core and is planned to last 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.

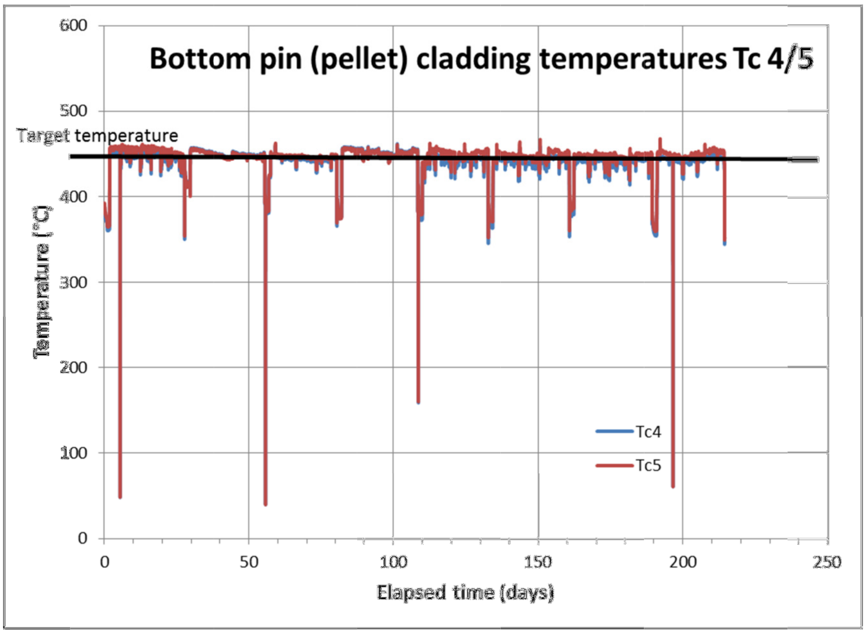

Figure 4: Cladding temperature reading until end-2014 for SPHERE (pellet fuel).

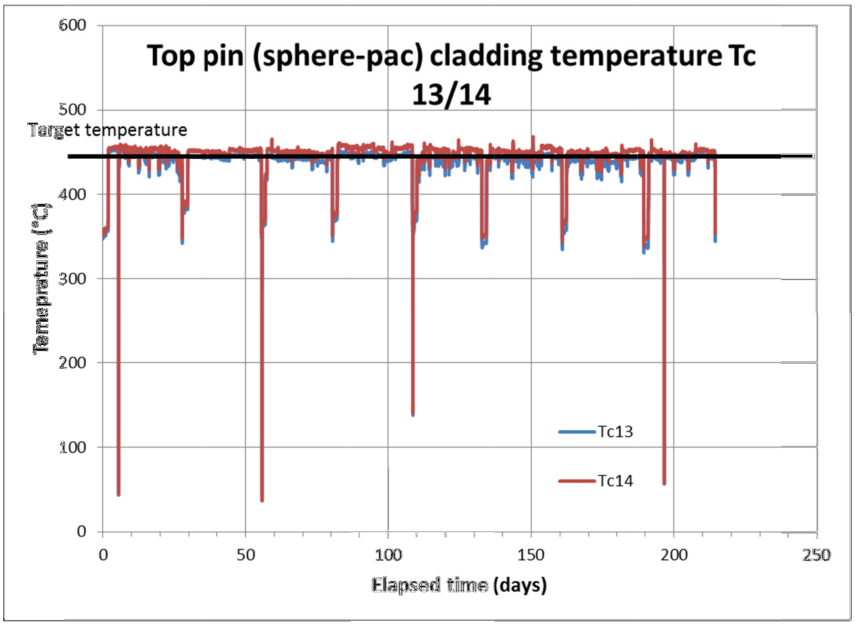

Figure 5: Cladding temperature reading until end-2014 for SPHERE (sphere-pac fuel).

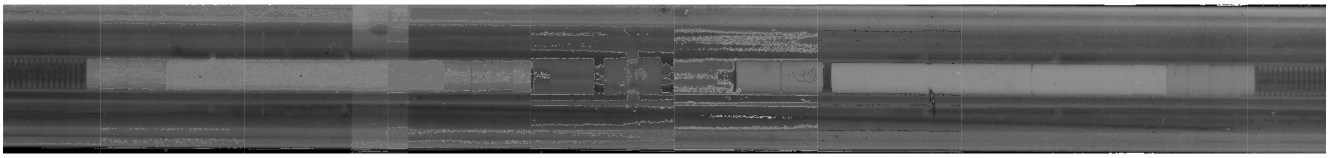

Figure 6: Pre-irradiation neutron radiograph of the two SPHERE pins (left: sphere-pac, right: pellet fuel)

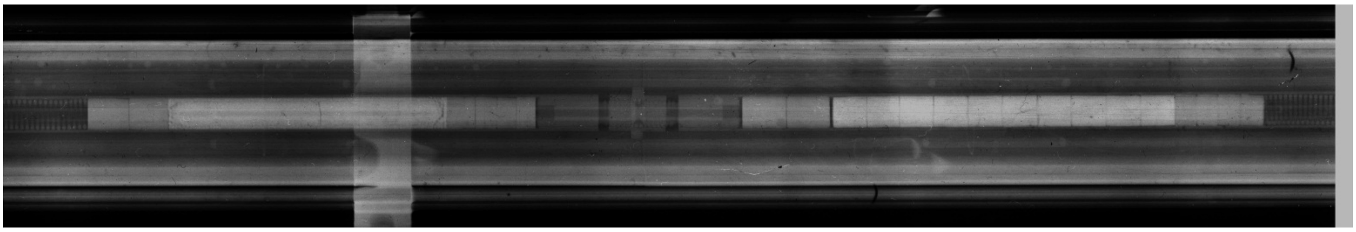

Figure 7: Neutron radiograph after one irradiation cycle (left: sphere-pac, right: pellet fuel)

2.1.2 MARINE

Objective:

MARINE is planned as part of the FP7 PELGRIMM project. MARINE has been designed to compare conventional pellet-type fuels with the so-called Sphere-Pac fuels described above. The goal of the MARINE irradiation is to determine He release behaviour and fuel swelling in $^{241}Am_{0.15}U_{0.85}O_{2-x}$, which is representative of the minor actinide bearing blanket (MABB) material to be used for transmutation in Sodium Fast Reactors (SFR).

Americium-containing fuel will be fabricated at JRC-ITU in Germany. These fuels will be irradiated at the HFR in a dedicated test facility. The irradiation will be equipped with internal pressure sensors monitoring 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.

Achievements:

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 thermo-mechanical analysis is on-going. The experiment will be irradiated in position H8 where the conditions in the blanket of a Sodium Fast Reactor (power, temperature, He 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.

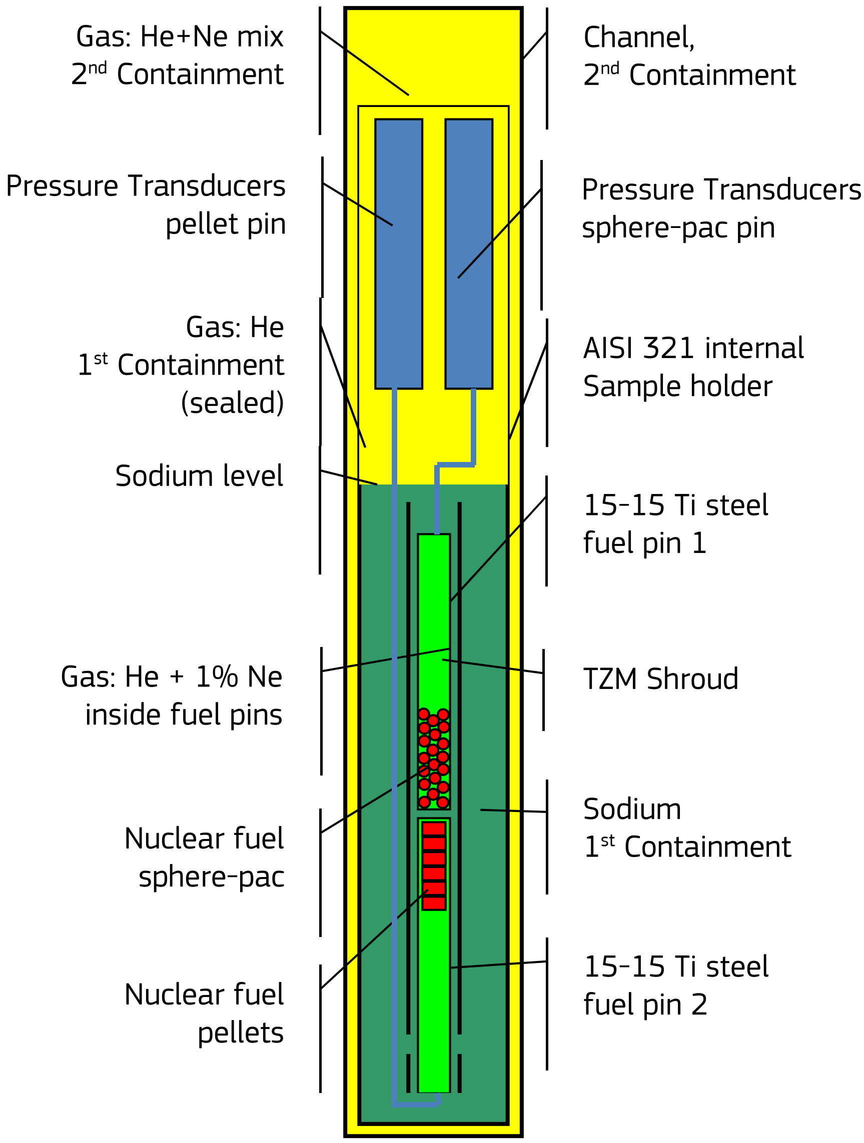

Figure 8: Schematic view of the MARINE irradiation experiment

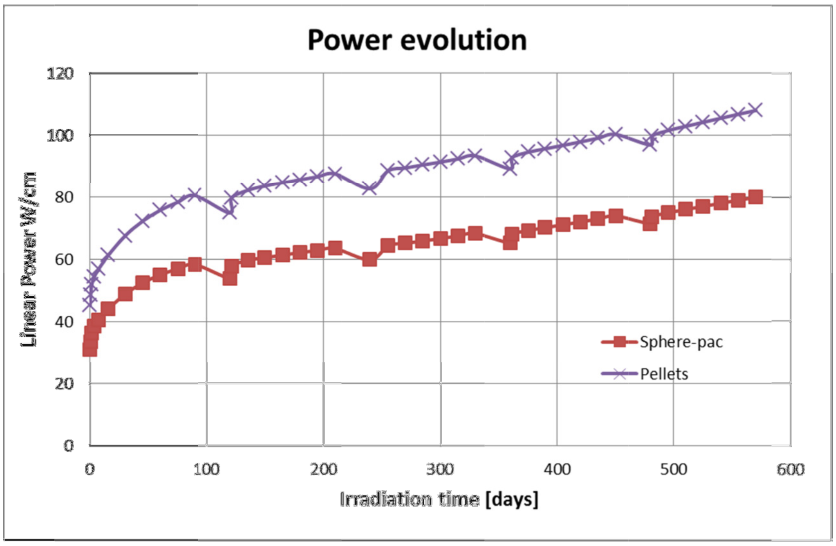

Figure 9: Preliminary calculated power evolution of MARINE irradiation experiment.

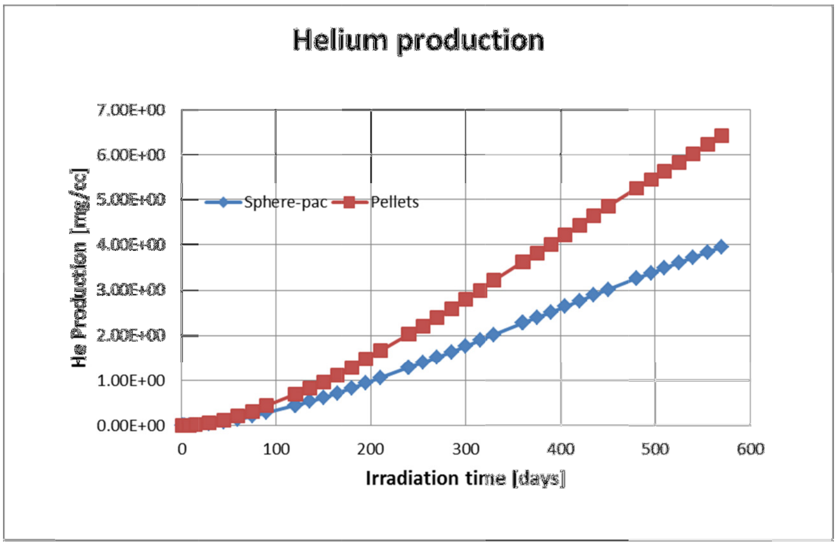

Figure 10: Preliminary calculated helium production of MARINE irradiation experiment.


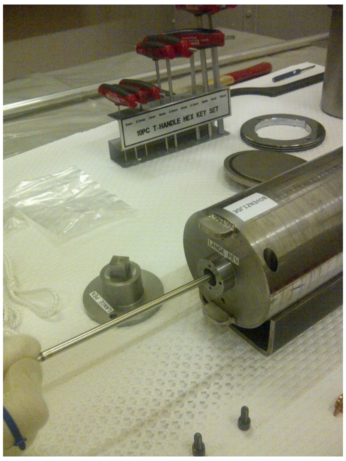
Figure 11: Reception of the MARINE pins fabricated at JRC-ITU. From left to right: opening of the inner shielding pot of the Croft container, measurement of dose rate, insertion of MARINE pin in shielding block.

2.2 Fuel and Graphite Qualification for High Temperature Reactors

High Temperature Reactors (HTR) are being investigated in a number of countries as a safe and efficient source of energy, in particular for cogeneration of industrial process heat and electricity. Related new demonstration projects are either existing or envisaged in several countries (e.g. Japan, China, US, South Korea) and are subject to current R&D in Europe. The HFR is used in particular for the qualification of fuel and graphite which are decisive elements for the benign safety performance of this type of reactor.

2.2.1 HFR-INET

The Institute of Nuclear and New Energy Technology (INET) of the Tsinghua University in Beijing, China is currently constructing the Chinese Modular High Temperature Gas-cooled Reactor Demonstration Plant (HTR-PM). The fuel for the HTR-PM is being manufactured by INET. INET requires qualification of their fuel to support licensing of the HTR-PM reactor systems.

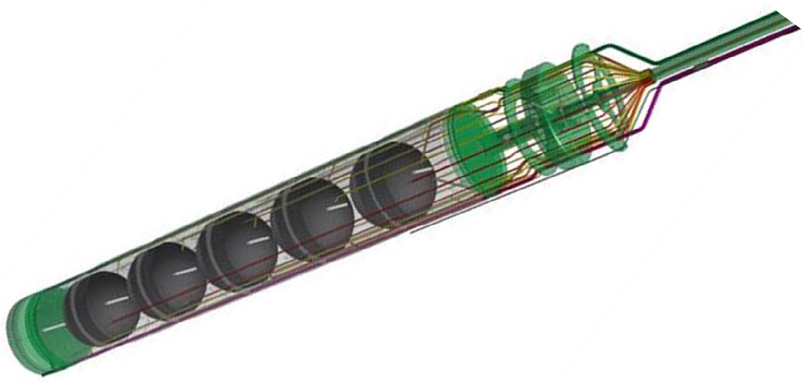

Figure 12: HFR-INET irradiation rig.

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 constant central pebble temperature, while fission gas release is measured online using the Sweep Loop Facility which was developed and built by JRC-IET. Fission gas release during irradiation is an important measure for fuel performance and quality under operational conditions, and forms an essential part of the fuel qualification. For the qualification irradiation a dedicated irradiation test facility was designed and manufactured. The irradiation started in September 2012 in a high flux in-core position of the HFR and was finished on 30 December 2014 when the irradiation targets were met. In 2015, the irradiation rig will be dismantled, and non-destructive Post Irradiation Examinations (PIE) will be 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 (under accidental conditions), the five HTR pebbles will be individually subjected to a heating test at JRC-ITU, Karlsruhe in Germany, in the so-called KÜFA-facility, again with fission gas release measurements. These heating tests simulate a temperature transient during a postulated severe accident of this type of reactor. Low radioactive release from the pebbles under these conditions then demonstrates the integrity and proper performance of irradiated HTR fuel.

2.2.2 INNOGRAPH-1C

Graphite is used as moderator and reflector material in a High Temperature Reactor and is known to first shrink and then swell under irradiation. This behaviour depends on temperature, neutron dose and graphite grades. Its understanding is required to enable proper design of such reactors and to put the graphite manufacturing industry in a position 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, www.archer-project.eu). Following earlier irradiation tests, it completes the data set for different graphite grades at different 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 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.

2.3 Materials Irradiations

2.3.1 AGR graphite irradiations BLACKSTONE and ACCENT

In the United Kingdom a fleet of Advanced Gas-cooled Reactors (AGR) is operated by EdF Energy. Graphite degradation is considered to be one of the key issues determining the remaining service life of the AGRs. Graphite data at high irradiation dose and weight loss is required to allow prediction and assessment of 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 subject them to accelerated degradation in the HFR by simultaneous irradiation and oxidation. The tests are designed to enable the future condition of the AGR graphite to be predicted with confidence.

After BLACKSTONE Phase I, 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. Phase II meanwhile completed irradiation after 12 and 16 irradiation cycles on the two capsules. The first capsule was dismantled in late 2012, with measurements finished in 2013. The second capsule has successfully been dismantled in February 2014, and measurements on the graphite specimens were performed throughout 2014.

The ACCENT irradiations also contain samples trepanned from AGR core graphite. The ACCENT modules make use of gas-filled bellows to apply a load on the specimens (cf. Figure 13 and Figure 14). By applying a stress, the graphite specimens are subjected to irradiation creep. Post-irradiation characterisation is carried out on the graphite specimens to measure a broad selection of material properties. The dimensional change that is induced by irradiation creep is determined accurately by measuring the dimensions of stressed and un-stressed specimens.

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

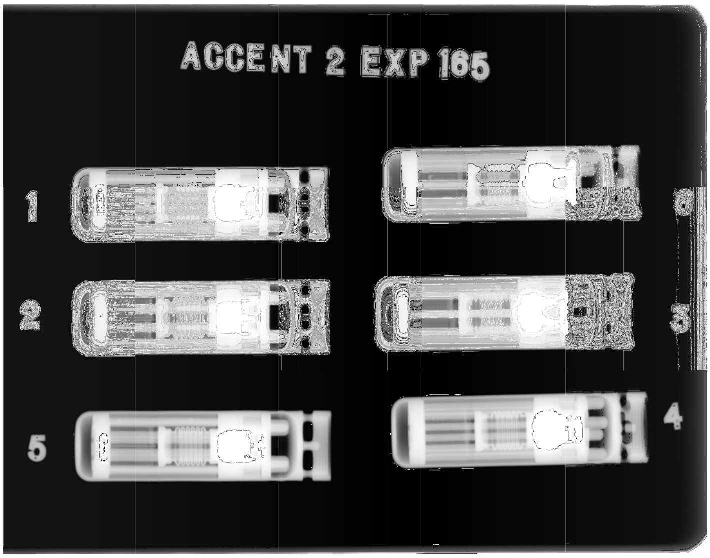

Figure 13: X-ray image of ACCENT modules.

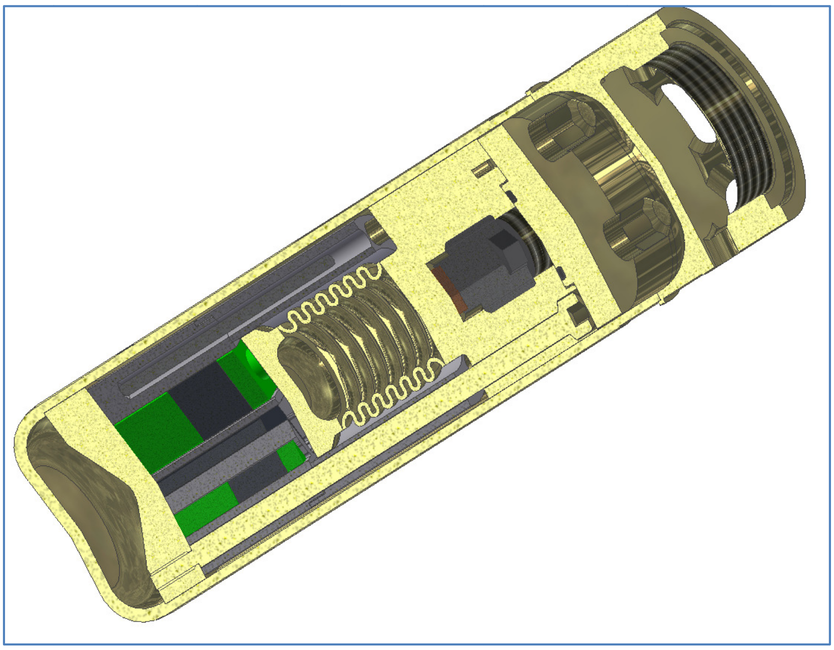

Figure 14: Cross section of ACCENT module.

2.3.2 LYRA-10

The LYRA irradiation rig is used in the framework of the European Network AMES (Ageing Materials and Evaluation Studies). Its main goal is the understanding of irradiation behaviour of reactor pressure vessel (RPV) steels, thermal annealing effects and sensitivity to re-irradiation damage. The LYRA-10 experiment housed in the Pool Side Facility (PSF) of the HFR consists in the irradiation of different specimens representative of reactor pressure vessel materials, namely model steels, realistic welds and high-nickel welds. The model steels comprise 12 batches of steels with the basic, typical composition of WWER-1000 and Western PWR RPV materials used by JRC-IET with the scope of understanding the role and influence of Ni, Si, Cr and Mn as alloying elements and certain impurities such as C and V on the mechanical properties of steels. The realistic welds are created at eight different heats, specially manufactured on the basis of typical WWER-1000 weld compositions with variation of certain elements, such as Ni, Si, Cr and Mn. They are of importance 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. In 2013 it was irradiated for two more HFR cycles and up to now underwent eight HFR cycles at an average temperature of 283°C with an accumulated fast neutron fluence in the samples of ~45×10^{22} n m^{-2} (E > 1 MeV). It was originally planned to irradiate LYRA-10 for 5 more cycles to achieve a fast fluence of approx. 60×10^{22} n m^{-2} (E > 1 MeV).

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 the experiment is expected to restart in the end of 2015.

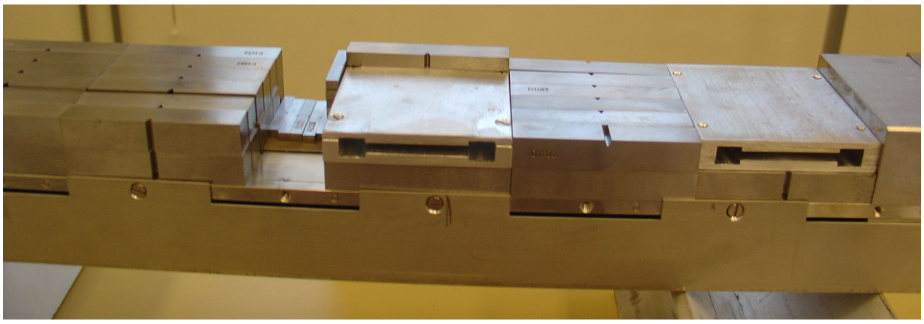

Figure 15: LYRA-10 specimens during assembly.

2.4 *Irradiations for Fusion Technology*

2.4.1 ITER PRIMUS

Objectives:

In 2005 an experiment was defined with the European Fusion Development Agency (EFDA) to test thermal fatigue of normal heat flux modules for ITER during irradiation. This has been planned in a pool side facility position for the duration of 22 cycles. The experiment had to be designed in a way that the stress conditions and temperatures would reflect ITER first wall conditions. Between 2005 and 2007 multiple iterations and adjustments have been made to replicate the ITER conditions in the best possible manner. These iterations led to a final design in 2008, but could not continue because of 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 thermal cycling in the HFR was not possible due to the intrinsic design of the Automatic Control Rod system. Therefore, it was discussed with F4E to perform a stagnant in-pile experiment instead to first irradiate to 1 dpa in beryllium and to perform the thermal cycling afterwards in the JUDITH facility in Jülich.

To perform this irradiation, a new experiment has been designed called PRIMUS. In 2012 a new conceptual design has been presented to F4E. Here, the mock ups will be loaded in an in-core REFA facility and will be irradiated for 5 cycles in position H2.

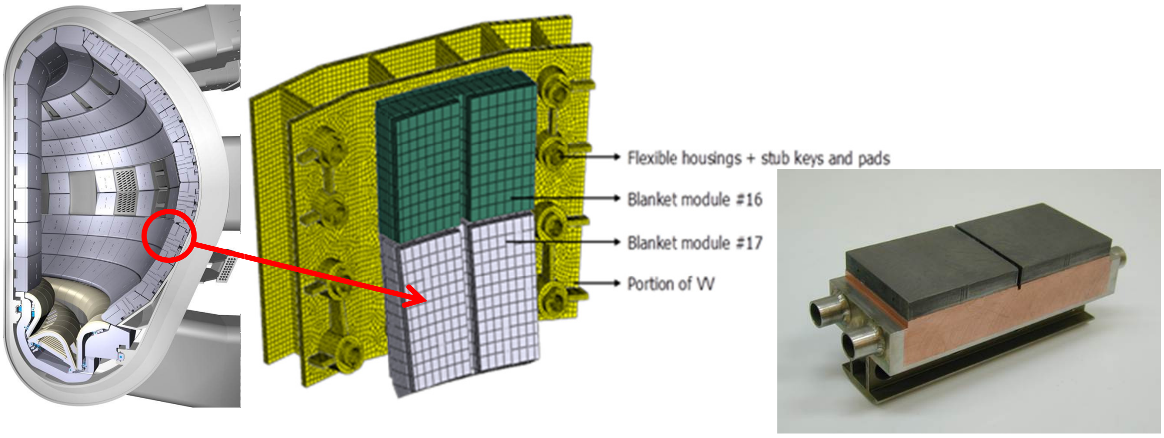

Figure 16: ITER FW panel and ITER PRIMUS heat flux module design.

Achievements:

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 will be clamped between aluminium filler material to enhance dissipation of heat to the primary coolant of the HFR. The irradiation rig will be instrumented with 23 thermocouples and dosimeter sets to register temperature and dose levels obtained during irradiation. The irradiation targets are 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. Irradiation will start in 2015.

2.4.2 CORONIS

Objectives:

In 2011 a new project started in the area of material development and characterisation for ITER. This project is conducted in the framework of F4E, the European Joint Undertaking for fusion energy, founded in 2007.

The objective is to measure the tensile, fatigue and Charpy impact properties of CuCrZr material and CuCrZr/316L joints before and after irradiation to 0.01, 0.1 and 0.7 dpa at 250°C. This material is foreseen for the shielding blanket in ITER because of the high heat dissipation of CuCrZr to the ITER cooling water. Obviously, this function could be jeopardised should the material fail during its service life in ITER.

The irradiation will be performed with the Hungarian Institute AEKI, which will take care of the low level dose irradiation (0.01 dpa). All post irradiation experiments will be performed in the NRG Hot Cells. The project runs from 1 January 2011 to October 2015. The project is co-financed by the Dutch Ministry of Economic Affairs and F4E.

Achievements:

In 2014 the irradiation of CORONIS 01 and 02 was started in the first cycle and were fully completed during the year. The summarised cycle information for the CORONIS-01 and CORONIS-02 is shown in Table 1 and Table 2, respectively. The average of thermocouple temperatures measured at each axial level of the sample position in CORONIS experiments is plotted in Figure 17. After a cool-down period the rigs were transported to HCL for dismantling and Post irradiation testing of the specimens included.

Table 1: Summarised cycle information of CORONIS-01.

Cycle no.	1	2	3
Reactor Cycle	14-02	14-03	14-04
In-core position	G7	G7	G7
Orientation TRIO Capsule	South	South	South
Placed in Channel no.	3	3	3
Start-up date	18-03-14	25-04-14	01-06-14
start-up time (> 43MW)	16:40	19:00	14:20
Shut down date	16-04-14	20-05-14	29-06-14
Shut down time	7:00	16:00	16:00
Irradiation days	28.60	24.88	28.03
Cumulative irradiation days	28.60	53.48	81.51

Table 2: Summarised cycle information of CORONIS-02.

Cycle no.	1
Reactor Cycle	14-01
In-core position	H2
Orientation TRIO Capsule	South
Placed in Channel no.	2
Start-up date	14-02-14
start-up time (> 43MW)	15:50
Shut down date	14-03-14
Shut down time	15:50
Irradiation days	28.0
Cumulative irradiation days	28.0

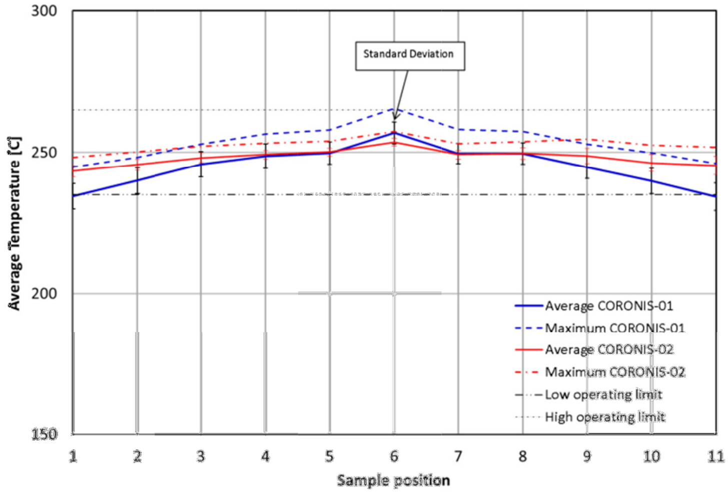

Figure 17: Average and maximum temperatures measured at each axial level for CORONIS-01 and CORONIS-02.

2.4.3 FIWAMO

Objectives:

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

The ITER first wall is manufactured 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 FW plasma facing surface is made of beryllium tiles that are joined to a CuCrZr heat sink using hot isostatic pressing or brazing. The heat sink is attached to a supporting steel structure. The current contract concerns only the component manufactured by using EHF FW technology.

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.

Achievements:

In 2014 the second phase, did not start due to delayed fabrication of the mock- ups.

The mock-up geometry with beryllium tiles joined to a CuCrZr heat sink by hot isostatic pressing or brazing is shown in Figure 18. The mock-ups will be clamped between aluminium bodies 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 placed in a REFA rig and irradiated in position H2 to doses of respectively 0.1 and 0.6 dpa. For the second phase of the project, the detailed design will start in 2015. Irradiation is planned for 2016.

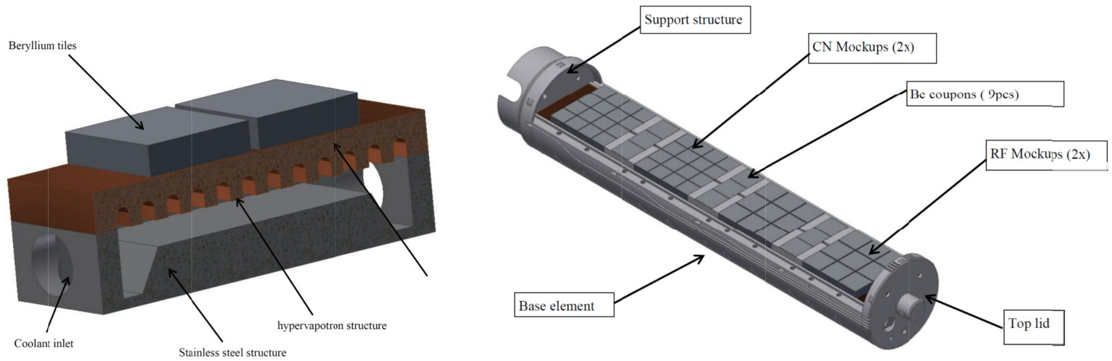

Figure 18: ITER First wall design mock-up (right) and FIWAMO design (left).

2.5 *The HFR in support of standardisation in materials research*

2.5.1 NeT: The network on standardization of neutron techniques for structural integrity assessment

The European Network on Neutron Techniques Standardization for Structural Integrity (NeT) mainly supports progress towards improved understanding and prediction of residual stresses in welds for enhanced integrity assessment of nuclear power plant components. 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 JRC organizes and manages the Network and it contributes to the scientific work through residual stress measurements using its beam tube facilities at the HFR.

In 2014, NeT members have issued a comprehensive overview paper on the activities around the single bead on plate weld[1]. A dedicated issue of a scientific journal on NeT Task Group 4 (three beads in a slot weld) is in preparation; and finally the first specimens of Task Group 6 on a weld in a Nickel base alloy plate have been procured.

2.5.2 Standardization of neutron diffraction for residual stress analysis

Neutron diffraction is used as a technique for measurements of residual stresses in materials and components. At the HFR this technique is employed at two beam lines mainly for the investigation of residual stresses in nuclear grade welds. Standardization of the method has been underway for more than 15 years. A new Working Group has been established 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; and in accordance with standard ISO timelines the draft document should be ready for submission in 2016.

2.5.3 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. Figure 19 shows a section of Mock-up no. 3 during measurements at neutron beam HB4. This specimen 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. Figure 20 shows the residual stresses calculated at mid-thickness in the ferritic section of Mock-up 2. This specimen is a short section, 29 mm long, of a bi-metallic weld representative of a PWR reactor of French origin. Compression in all three directions is shown here near the ferrite-buttering layer interface. While these two specimens were made from similar materials, the welding geometries and restraint conditions during

[1] M.C. Smith, A.C. Smith, R.C. Wimpory, C. Ohms, A review of the NeT Task Group 1 residual stress measurement and analysis round robin on a single weld bead-on-plate specimen, International Journal of Pressure Vessels and Piping, Vol. 120-121, Aug-Sep 2014, pp. 93-140, doi: 10.1016/j.ijpvp.2014.05.002.

manufacturing were quite different. Therefore, the residual stress results are going to be different and the first data obtained indicated this to a certain extent.

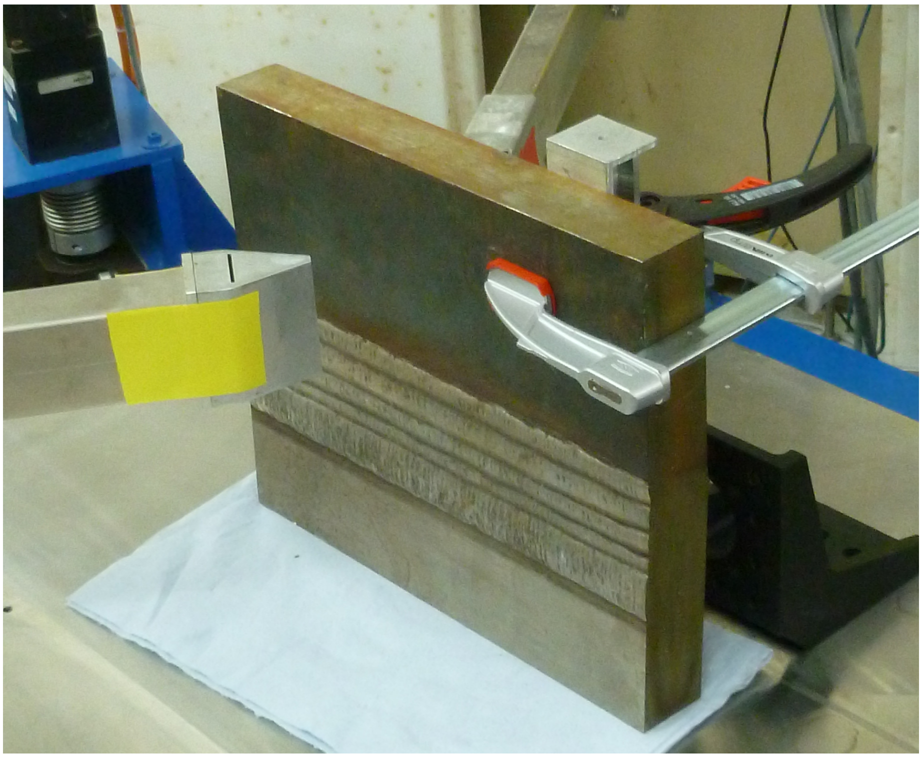

Figure 19: Section of Mock-up no. 3 on diffractometer at HB4 during measurements in the welding longitudinal direction; the width of the weld on the upper specimen surface is well visible.

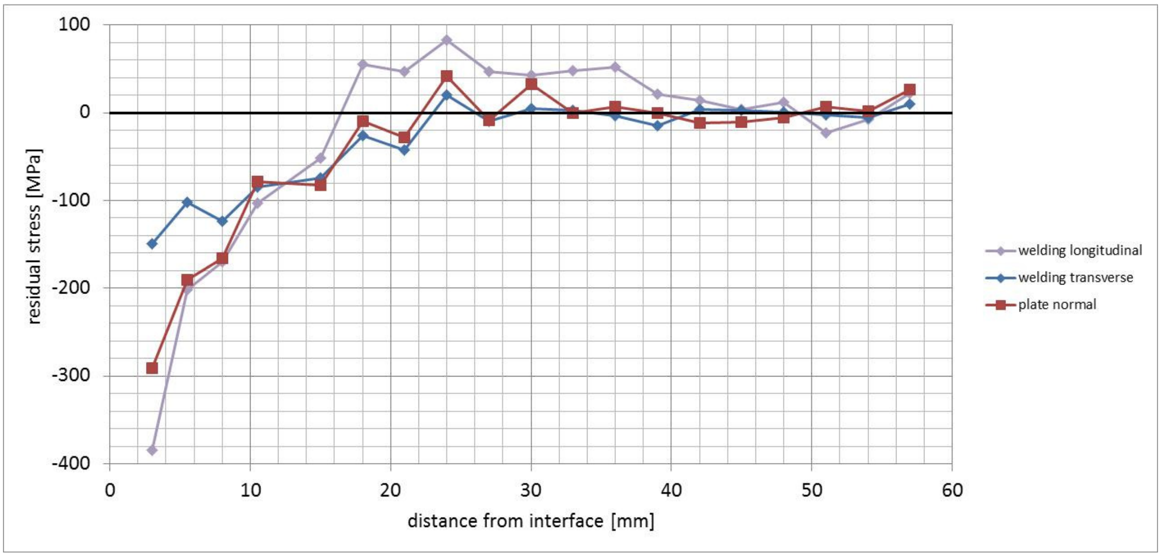

Figure 20: Estimate of residual stresses in the low-alloy-steel in Mock-up no. 2 as a function of distance from the ferrite-buttering layer interface; measurement taken along the line at mid-thickness of the plate; stress calculations based on the assumption of zero stress at 55 mm distance.

3 Isotope Production Performance

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. Obviously, 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 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 is thus back on the international scene as one of the major producers of medical isotopes worldwide.

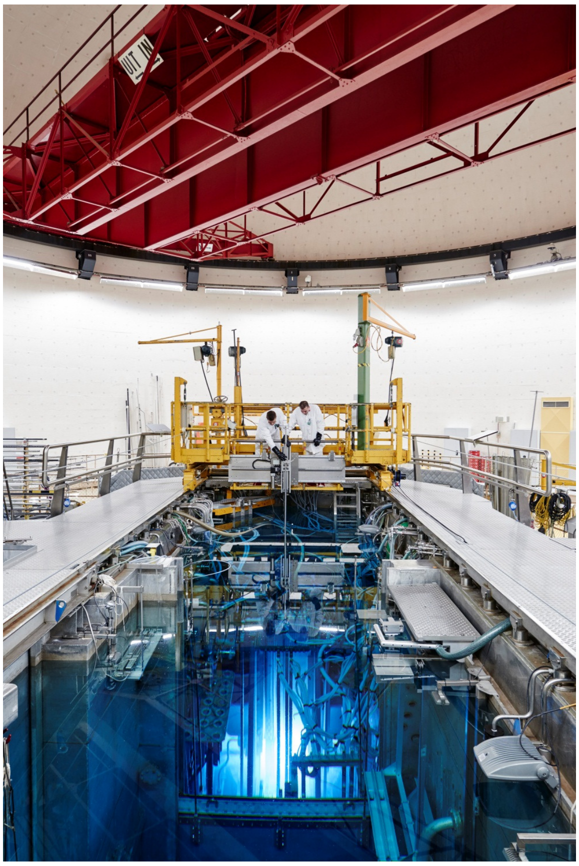

Figure 21: Operators manipulating isotope production equipment in the HFR pool.

4 Glossary

AIPES	Association of Imaging Producers and Equipment Suppliers
APD	Automatic Power Decrease
ARCHER	Advanced High-Temperature Reactors for Cogeneration of Heat and Electricity R&D
DG	Directorate General
dpa	displacements per atom
EC	European Commission
EU	European Union
FAIRFUELS	Fabrication, Irradiation and Reprocessing of FUELS and target for transmutation
FP	Framework Programme
F4E	Fusion for Energy (the European Union's Joint Undertaking for ITER and the development of fusion energy)
HB	Horizontal Beam Tube
HEU	High Enriched Uranium
HFR	High Flux Reactor
INET	Institute for Nuclear and New Energy Technology (Tsinghua University Beijing, China)
ISI	In-Service Inspection
ISO	International Organisation for Standardisation
ITER	International Thermonuclear Experimental Reactor
JRC-IET	JRC Institute for Energy and Transport, Petten, The Netherlands
JRC-ITU	JRC Institute for Transuranium Elements, Karlsruhe, Germany
LEU	Low Enriched Uranium
MA	Minor Actinides
NRG	Nuclear Research and consultancy Group, Petten (NL)
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

European Commission
EUR 27340 EN – Joint Research Centre – Institute for Energy and Transport

Title: **Operation and Utilisation of the High Flux Reactor - Annual Report 2014**

Authors:
Editor: Michael A. Fütterer
JRC Main Contributors:
Elio D'Agata, Carsten Ohms, Jean-Marc Lapetite, Alan van de Sande
NRG Main Contributors:
Tjark van Staveren, Lida Magielsen, Ralph Hania, Jelmer Offerein, Steven Knol, Maurits Heijna, René Meekel
Luxemburg: Publications Office of the European Union

2015 – 19 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1977-2289/1831-9424 (online)

ISBN 978-92-79-49418-5 (PDF)

doi:10.2790/829498

LD-NA-27340-EN-N

JRC Mission

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

Serving society
Stimulating innovation
Supporting legislation

doi:10.2790/829498

ISBN 978-92-79-49418-5

Publications Office