European
Commission

JRC SCIENCE AND POLICY REPORTS

Operation and Utilisation of the High Flux Reactor

Annual Report 2015

Editor:
Michael A. Fütterer

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

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

2016

Joint
Research
Centre

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

JRC102543

ISBN 978-92-79-60861-2

doi:10.2789/515620

Luxemburg: Publications Office of the European Union, 2016

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 2015

Editor:
Michael A. Fütterer

JRC Main Contributors:

Elio D'Agata
Jean-Marc Lapetite
Carsten Ohms
Alan van de Sande

NRG Main Contributors:

Jelmer Offerein
Lida Magielsen
Sander van Til
René Meekel
Tjark van Staveren
Steven Knol
Ralph Hania

Table of Contents

List of Figures

1 HFR Operation

1.1 Operating Schedule

The HFR was scheduled to operate for 9 cycles in 2015. Planned full power days were 271 of which 230 were realized (see Figure 1). 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.

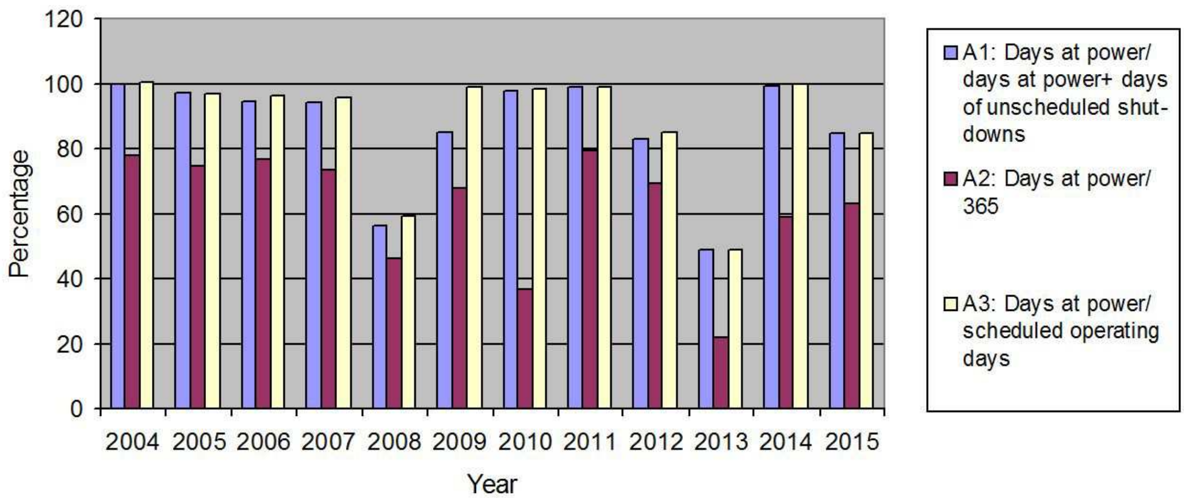

Figure 1: HFR availability since 2004

1.2 Maintenance Activities

In 2015 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 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 among others

- Scheduled regular preventive maintenance
- Periodic leak testing of the containment building as one of the license requirements
- In Service Inspection of the safety relevant parts of the primary system
- Revision of the emergency power diesels
- Cleaning of the secondary cooling system

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

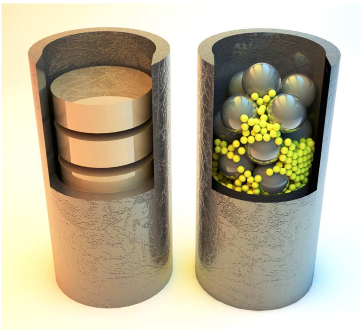

Figure 2: Pellet versus Sphere-Pac concept

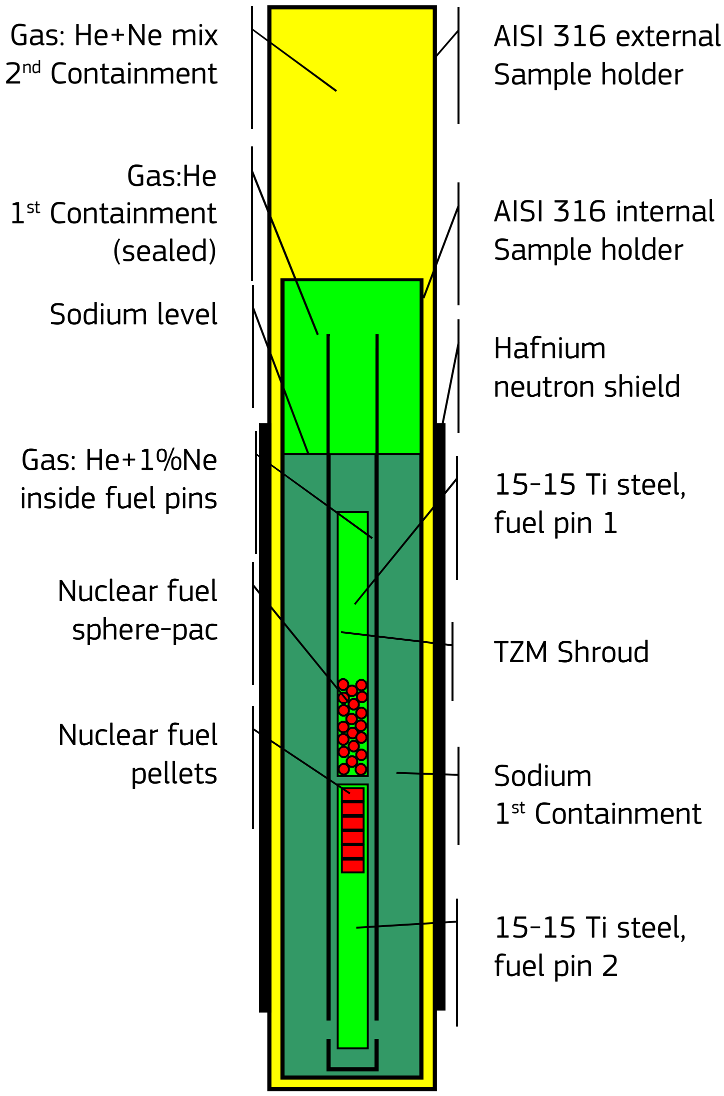

Figure 3: Schematic view of the SPHERE irradiation experiment

Achievements:

After irradiation throughout 2014, the SPHERE irradiation continued in 2015 for another 3 reactor cycles in position F2 of the HFR core. The irradiation was completed after approximately 300 full power days 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.

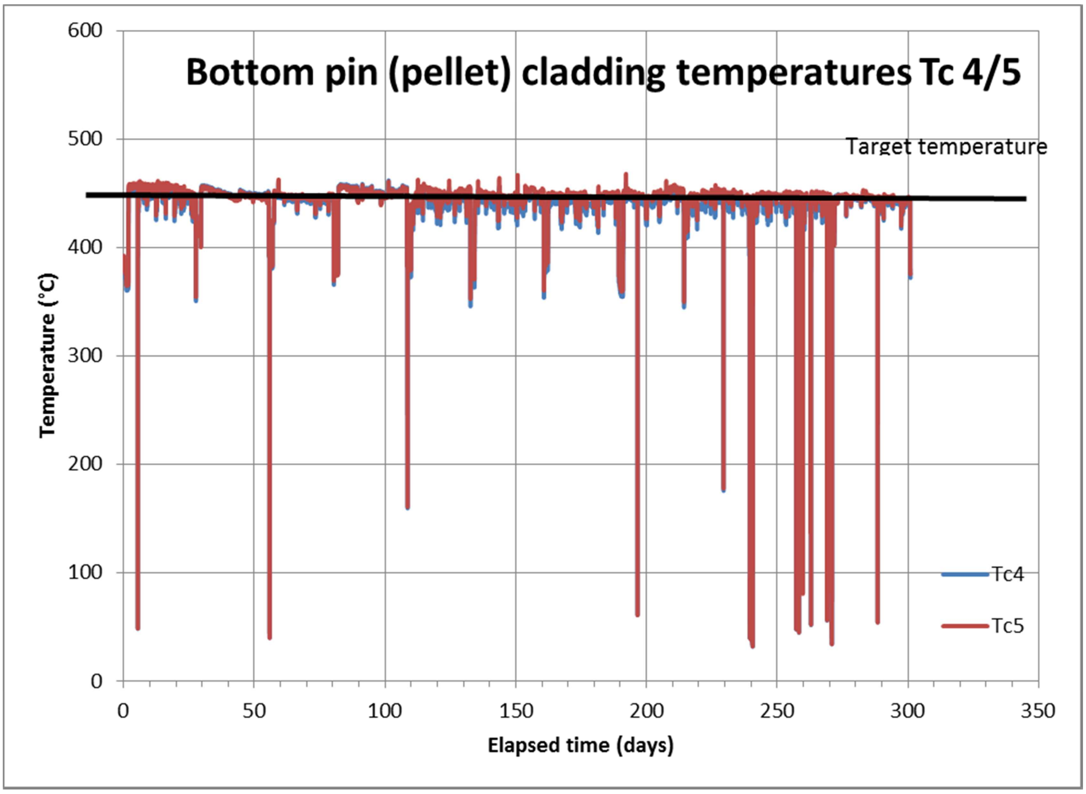

Figure 4: Cladding temperature reading for SPHERE (pellet fuel).

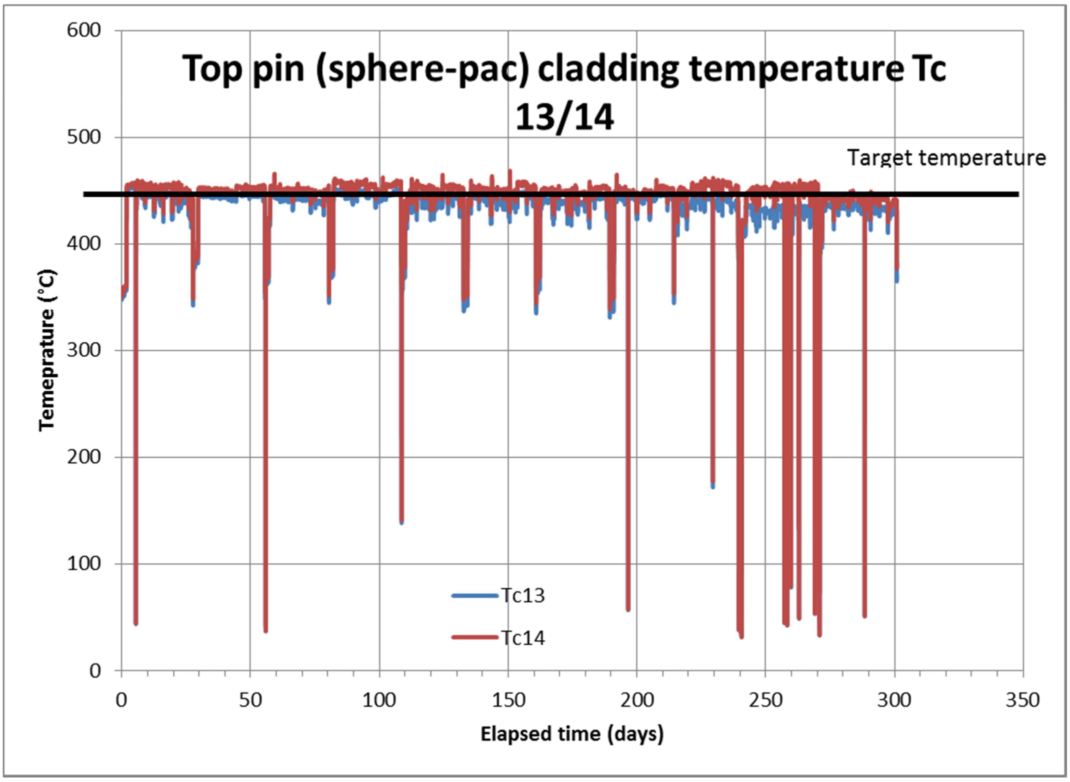

Figure 5: Cladding temperature reading for SPHERE (sphere-pac fuel).

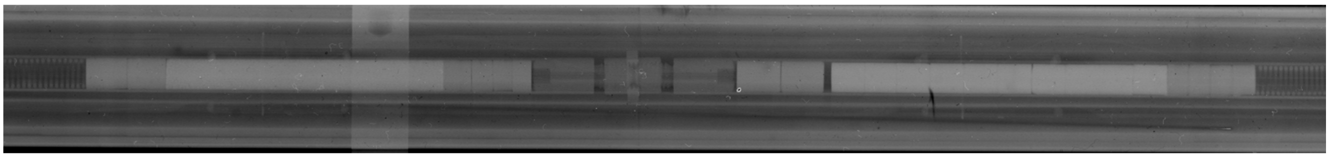

Figure 6: Pre-irradiation neutron radiograph of the two SPHERE pins (left: sphere-pac, right: pellet fuel)

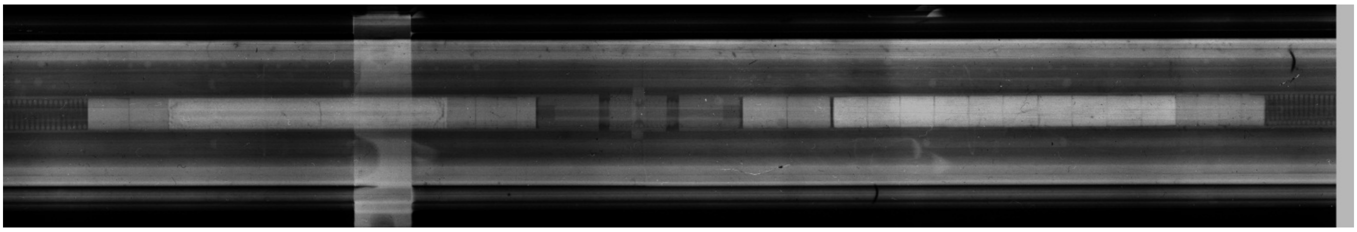

Figure 7: Neutron radiograph after one irradiation cycle (left: sphere-pac, right: pellet fuel)

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 was 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 was initially expected to start in early 2015 for approximately 300 full power days.

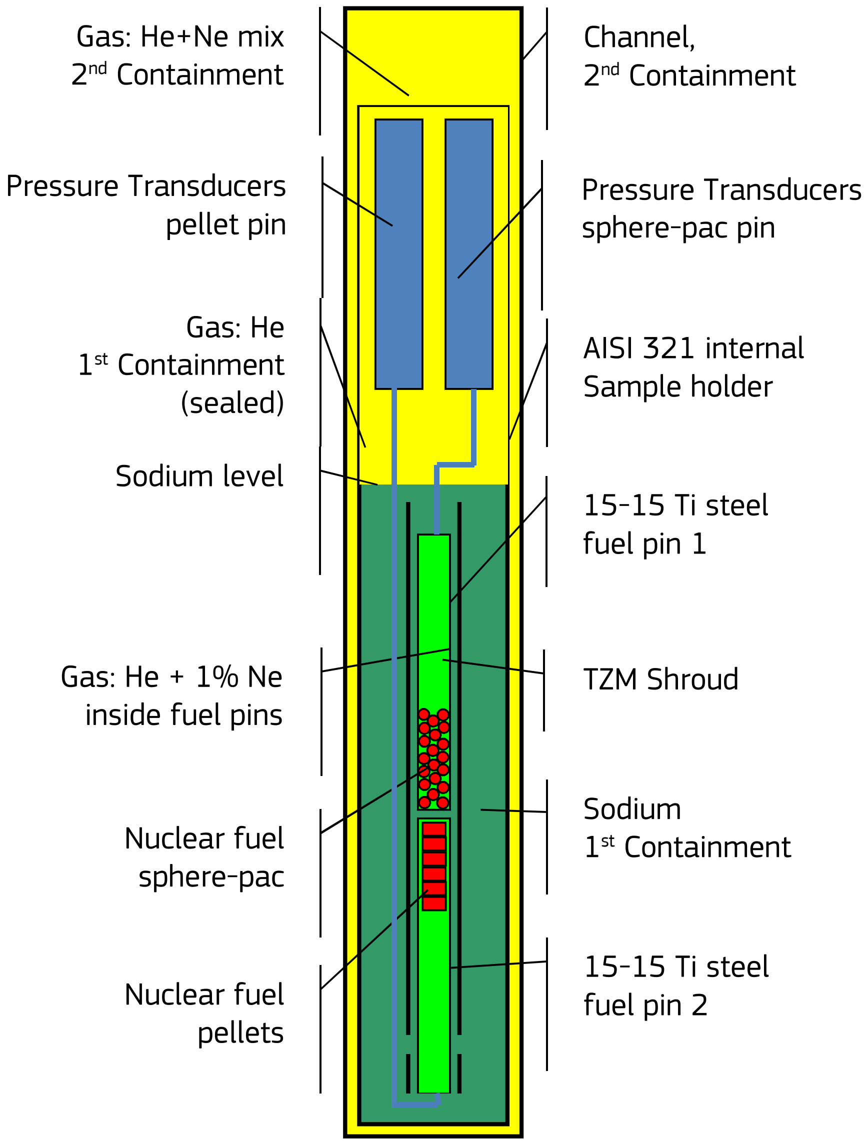

Figure 8: Schematic view of the MARINE irradiation experiment

Achievements:

During 2015, the design of MARINE was finalized. Unfortunately, the start of the irradiation was significantly delayed, mostly as a consequence of NRG's return to service program and subsequent reorganization of NRG. The experimental rig was assembled and commissioned and is ready to be irradiated in 2016 in position H8 where the conditions in the blanket of a Sodium Fast Reactor (power, temperature, He production) can be most closely reproduced.

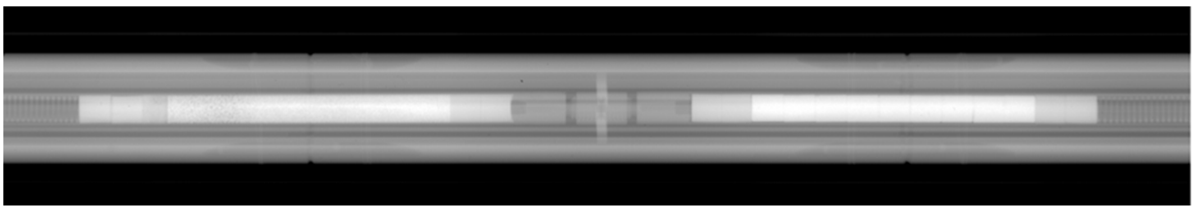

Figure 9: X-ray of the MARINE pins (sphere-pac left, pellets right).

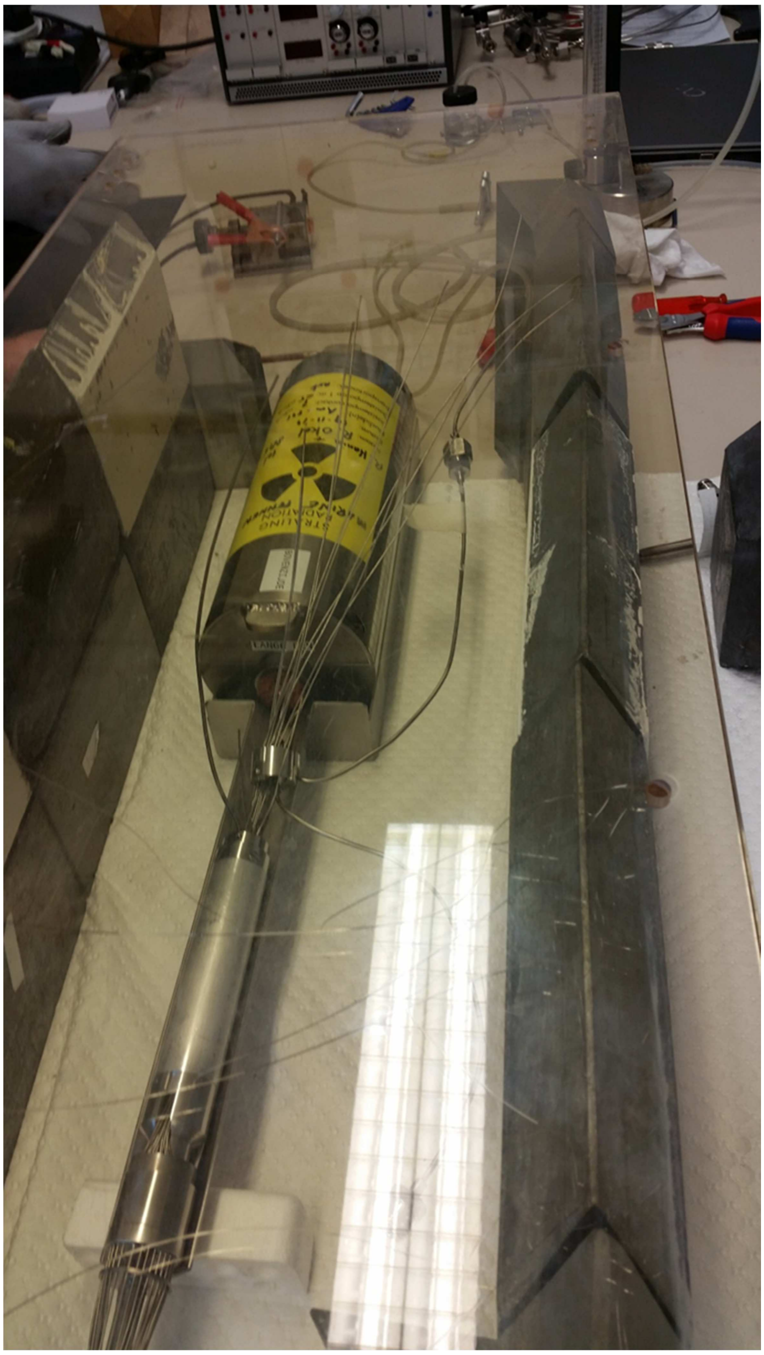

Figure 10: MARINE final assembly in the actinide lab.

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 HTR-PM Fuel Qualification

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) at the Shidao Bay site in Rongcheng, Shandong Province, China. The fuel for the HTR-PM is being manufactured and requires qualification to support licensing of the HTR-PM reactor systems.

Figure 11: HFR-INET irradiation rig.

The first step in the fuel qualification (under operational conditions) was performed by NRG between 2012 and 2014. Similar to earlier tests for related European projects, five spherical HTR fuel elements (pebbles) were 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.

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 consisted of dimensional and weight measurements, gamma scanning and visual inspection.

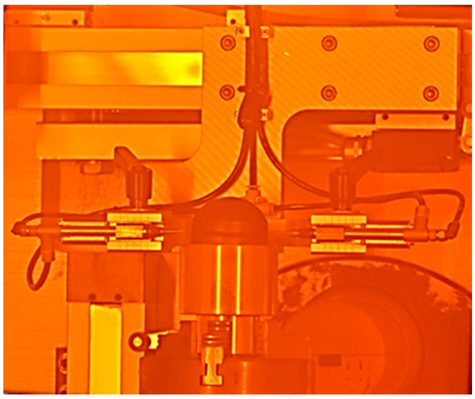

Figure 12: Dimensional measurements on the irradiated pebbles.

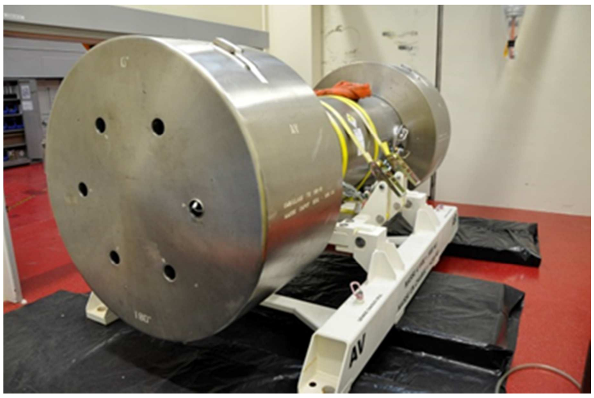

Figure 13: Transport cask for shipping irradiated pebbles.

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 which is a licensing requirement.

In 2015, the transport from Petten to Karlsruhe was prepared with an expected target date in Spring 2016.

2.2.2 SALIENT

Molten salt fuel forms (Figure 14) have received a significantly growing interest in the past years. NRG has started a collaboration with JRC-ITU 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.

Figure 14: Representations of the SALIENT-01 sample holder containing 4 salt-filled and 1 empty graphite crucible (top), and of one graphite crucible (bottom).

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 was completed in 2012, EDF Energy successfully used the data from this project to support an updated safety case for their AGR power stations. In addition to that, all data and methods that were used during the project have been evaluated by the UK nuclear regulator. Phase II has since completed in early 2015, with the last irradiation completed in February 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 was born from BLACKSTONE, and applies a load to the samples during irradiation to investigate the effect of irradiation creep. The ACCENT design consists of an irradiation capsule that is loaded with modules each containing a selection of specimens. A gas filled bellows is included in each module to apply a compressive load on the sample during irradiation (see Figure 14 and Figure 15). Following irradiation the samples are characterised, and a broad range of material properties is measured. The dimensional change induced by irradiation creep is determined accurately by measuring the dimensions of stressed and unstressed specimens.

ACCENT phase 1 took place in 2013, and following this success three subsequent phases of irradiation have been performed. Phase 2 lasted 6 HFR cycles in 2014, Phase 3a took 4 cycles between March and August 2015, and Phase 3b will last 3 cycles from December 2015 to March 2016. Between phases, the modules were dismantled and the samples characterised. The modular concept 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.

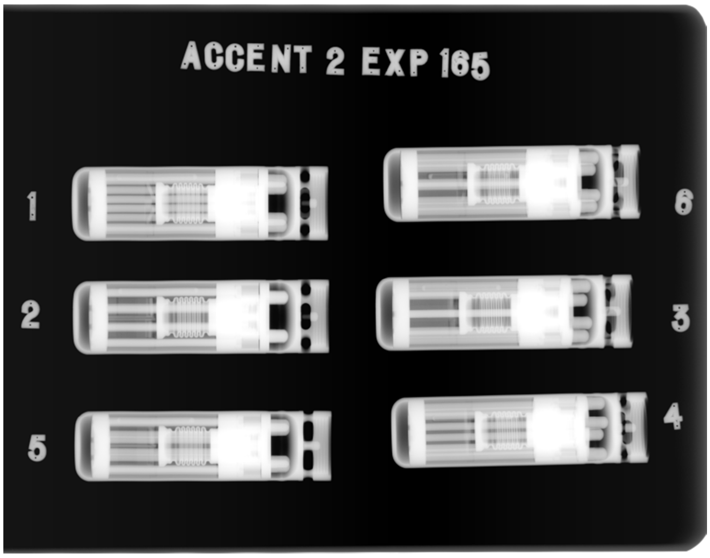

Figure 15: X-ray image of ACCENT modules.

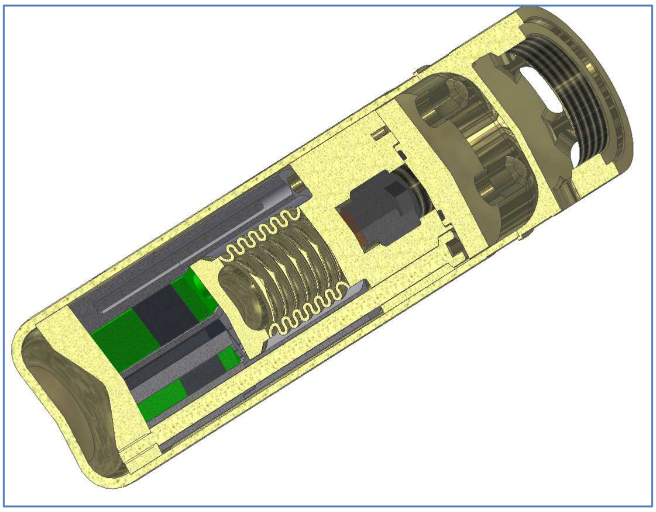

Figure 16: Cross section of ACCENT module.

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 was on hold in 2014 for repair of a certain number of components. 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.

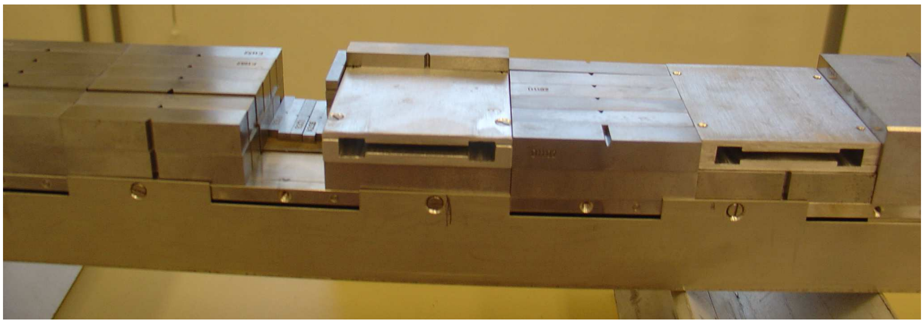

Figure 17: LYRA-10 specimens during assembly.

2.4 *Irradiations for Fusion Technology*

2.4.1 ITER PRIMUS

Objectives and Background

The ITER fusion reactor is a large-scale experiment that is designed to demonstrate the scientific and technological feasibility of fusion power. ITER is based on the 'tokamak' concept of magnetic confinement in which the fusion plasma is contained in a doughnut-shaped vacuum vessel. The blanket covers the interior surfaces of the vacuum vessel, providing shielding to the vessel and the superconducting magnets from the heat and neutron fluxes of the fusion reaction. The neutrons leaving the plasma are slowed down in the blanket where their kinetic energy is transformed into heat and removed by the coolants. The ITER First Wall (FW) blanket is one of the most critical and technically challenging components in ITER: together with the divertor it directly faces the hot plasma, with heat fluxes up to 10 MW/m^2.

The ITER FW panels consist of beryllium tiles that are joined to a CuCrZr heat sink and 316 steel back structure by Hot Isostatic Pressing (HIP) technique. The irradiation PRIMUS (PRimary ITER first wall Mock UpS) is a new experiment designed to irradiate this first wall component for ITER. The goal is to achieve a dose of 1 dpa in Beryllium at a temperature of 250°C. The objective is to evaluate the effects of neutron irradiation on the material properties and in particular, the effect on the beryllium/CuCrZr joint during High Heat Flux testing under ITER-like conditions.

Achievements in 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. In Figure 16, some steps of the design, manufacturing and commissioning of the irradiation rig are presented. 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.

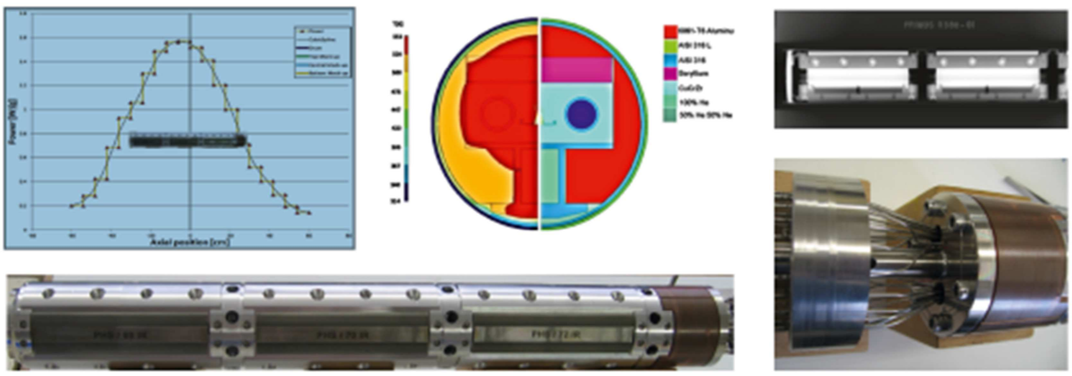

Figure 18: Top Left: Nuclear heating curve for PRIMUS, Top middle: Outcome of thermos-mechanical modelling, Bottom left and right: Pictures taken during the rig manufacturing phase, Top Left: Commissioning of experiment, X-ray inspection.

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 Standardisation for Structural Integrity (NeT) mainly supports progress towards improved understanding and prediction of welding residual stresses for better assessment of the integrity of nuclear power plant components. 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. The JRC organizes and manages the network and contributes whenever possible with residual stress measurements at the beam tube facilities at the HFR.

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.

2.5.2 European Energy Research Alliance – Joint Programme on Nuclear Materials, Pilot Projects

The residual stress measurement facilities at the HFR beam tubes are involved with two Pilot Projects under EERA-JPNM. The first project, established in 2014, deals with residual stresses and miniaturized testing (small punch and nano-indentation) in welded specimens made from ferritic-martensitic steel grade P91. The specimens for this project have been obtained from the Euratom FP7 project MATTER. In 2015 the first tests have been undertaken at the HFR and are expected to be completed in 2016.

The second project, called RESTRESS, was prepared in 2015 and approved by EERA-JPNM at the end of the year. RESTRESS is going to be a collaboration between 8 European partners to investigate the dependence of welding residual stresses in austenitic stainless steel (316 L(N)) welds on weld procedure and post-weld treatments. These studies relate to the sodium-cooled fast breeder demonstration reactor project ASTRID. Both, experimental and numerical approaches will be applied here.

NeT and the JPNM pilot projects are expected to bring the lion's share of the planned experimental activities to the HFR beam tube facilities in the coming years.

2.5.3 Standardization of the neutron diffraction method for residual stress measurement

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 welds. Standardization of the method has been underway since a worldwide pre-normative research activity was started in 1996 under the umbrella of VAMAS. Since December 2014 a new Working Group under ISO/TC 135/SC 5 has been working on drafting an International Standard for the method based on the existing Technical Specification ISO/TS 21432. JRC has been entrusted with the convenorship of this Working Group, which has nominated members from the UK, Germany, Greece, South Africa and Canada plus additional invited experts from Germany, the UK and the USA. 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, D, and in Grenoble, F. 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.

2.5.4 Residual stress measurements in a 40 mm thick dissimilar metal weld plate

The members of the FP7 MULTIMETAL Project have performed research in the area of integrity assessment of bimetallic welds for nuclear applications. Mock-up no. 3 from this programme concerns a 40 mm thick ferritic steel plate welded to an austenitic stainless steel plate using austenitic stainless steel weld consumables. The materials used in the case were Russian grade steels, as this specimen is representative of a VVER type reactor. Measurements have continued at HB4 in 2015, whereby a lot of 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. Figure 19 shows the reference specimen that has been specifically cut for these investigations by EDM machining.

Figure 19: Reference specimen for residual stress measurement.

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 continue in 2016 on the austenitic side of the component after repair of the neutron monochromator at the HFR neutron beam HB4.

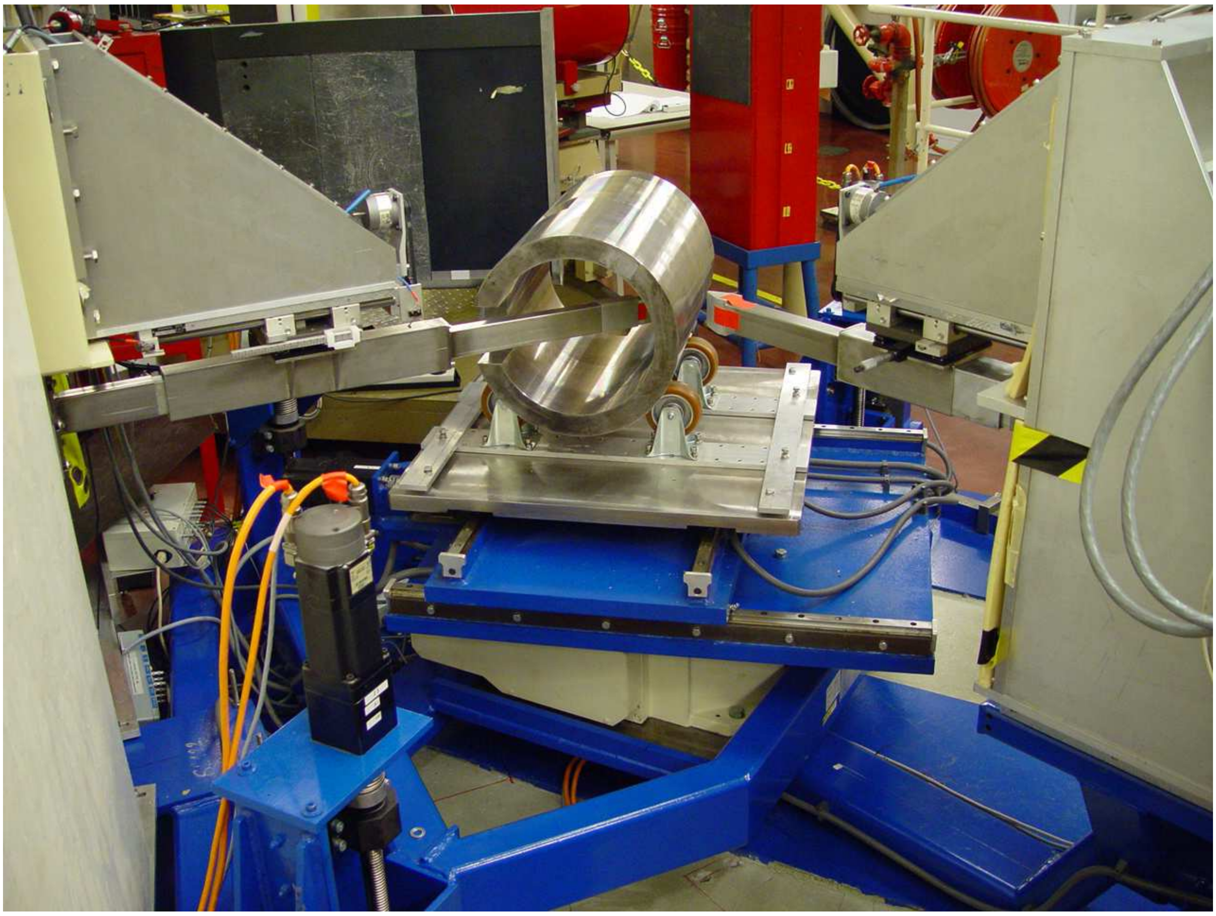

Figure 20: Residual stress measurement set up on a thick weld at neutron beam HB4.

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 2015, the HFR missed one production cycle in October but could be restarted in December. 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

Europe Direct is a service to help you find answers to your questions about the European Union
Freephone number (*): 00 800 6 7 8 9 10 11
(*) Certain mobile telephone operators do not allow access to 00 800 numbers or these calls may be billed.

A great deal of additional information on the European Union is available on the Internet.
It can be accessed through the Europa server http://europa.eu.

How to obtain EU publications

Our publications are available from EU Bookshop (http://bookshop.europa.eu),
where you can place an order with the sales agent of your choice.

The Publications Office has a worldwide network of sales agents.
You can obtain their contact details by sending a fax to (+352) 29 29-42758.

European Commission
Joint Research Centre – Institute for Energy and Transport

Title: **Operation and Utilisation of the High Flux Reactor - Annual Report 2015**

Authors:
Editor: Michael A. Fütterer
JRC Main Contributors:
Elio D'Agata, Carsten Ohms, Jean-Marc Lapetite, Alan van de Sande
NRG Main Contributors:
Jelmer Offerein, Tjark van Staveren, Lida Magielsen,
Steven Knol, Sander van Til, Ralph Hania, René Meekel

Luxemburg: Publications Office of the European Union

2016 – 18 pp. – 21.0 x 29.7 cm

ISBN 978-92-79-60861-2

doi:10.2789/515620

LC-04-16-647-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:10.2789/515620

ISBN 978-92-79-60861-2

Publications Office