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**COMMISSION STAFF WORKING DOCUMENT**

[...]

*Accompanying the document*

**Report from the Commission to the Council and the European Parliament**

**“Operation of the High Flux Reactor in the period 2020-23”**

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## INTRODUCTION

This staff working document is a companion document to the Commission's report on 'Operation of the High Flux Reactor in the years 2020-23, 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 and moderated, which is operated at 45 MW. The HFR is used by the Commission in accordance with the Petten Site agreement between Euratom and The Netherlands of 25 July 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 research fields are nuclear materials and fuel science with the aim to improve the safety of nuclear reactors (both fission and fusion), investigations on reactor ageing and life management, research on advanced fuel cycles and waste management. The HFR acts also as a training facility hosting doctoral and post-doctoral fellows which perform their research activities through national or European Programmes. The reactor is also used for the commercial production of radioisotopes.

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

Over the last six decades, the HFR has been operated and partly financed through Supplementary Research Programmes which were regularly discussed and unanimously approved by the European Council based on Article 7 of Euratom Treaty. On 29 June 2020, the Council adopted a four-year (2020-23) Supplementary Research Programme for the HFR <sup>(1)</sup> to be implemented by the JRC.

The contribution for the 2020-2023 Supplementary Research Programme was financed entirely out of contributions from France and the Netherlands, through the CEA and NRG, respectively, with a total budget of EUR 27,854,000 in the four-year period. This amount included the provisions for the annual contributions to the decommissioning fund.

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<sup>(1)</sup> OJ L211 of 3.7.2020, p. 14

This document reports on the operation, safety, financial contributions, and results of the scientific and technical work carried out in the period 2020-23.

## 1. HFR OPERATION

### 1.1. *Operating Schedule and maintenance*

The HFR was scheduled to operate around 70% of the time (see table 1). Of this planned time, the HFR was operational around above 90% of the time each year, showing a robust operational capability and high reliability.

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.

**Table 1: HFR operating time 2020-2023**

	"# full power days (operational/planned)"
2020	257/262
2021	258/271
2022	238/257
2023	238/256

The main causes for the lost full power days each of the 4 years were:

- Year 2020: A delay in a mix of activities during a long maintenance outage was mainly responsible for the missed unplanned full power days.
- Year 2021: Malfunctioning equipment before reactor start caused a few delays and were mainly responsible for the missed unplanned full power days.
- Year 2022: Large part of one cycle missed due to a leakage in a primary facility system in the concrete. A new system has been designed and commissioned to restore primary integrity.
- Year 2023: Two reasons provoked loss of full power days:
  - Leakage in the reactor pool liner. Safety assessment (including inspections) has been made and submitted to regulator. After approval the HFR was started for safe and reliable operation.
  - Replacement of heat exchanger plates took longer than expected.

In the reported period 2020 to 2023, maintenance activities consisted of the preventive and corrective maintenance of all systems, structures, and

components (SSC) of the HFR, as described in the annual and long-term maintenance plans. These activities were carried out to ensure the HFR's safe and reliable operation and to prevent inadvertent scrams caused by insufficient maintenance.

The following activities were successfully completed:

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

## **1.2. Safety of the HFR**

During the reported operational period 2020-2023 there has been several events, all of them classified as Level 0 (without safety significance/below scale) in the INES (International Nuclear and radiological Event Scale) scale.

### (1) Year 2020:

5 Notifications to the regulator. Two related to higher dose than anticipated during molybdenum (Mo-99) production and Dismantling (DM) -cell activities, overfilling of tritium tanks, test failure of a coal filter and a leakage in a fuel element. All events were classified INES 0. The individual and collective dose are well within expectations and legal limits.

### (2) Year 2021:

2 Notifications to the regulator. Related to temporary unavailability of the secondary activity monitor and a larger than approved irradiation period in one of the production facilities. All events were classified INES 0. The individual and collective dose are well within expectations and legal limits.

### (3) Year 2022:

3 Notifications to the regulator. Related to a contamination in a pump cellar, temporary breach of reactor containment (during outage because of maintenance activities and a degraded functionality of two activity monitors. All events were classified INES 0. The individual and collective dose are well within expectations and legal limits.

(4) Year 2023:

1 Notification to the Dutch regulator (ANVS) related to a leakage in the reactor pool liner. Safety assessment was made and submitted to the Dutch regulator. It was classified INES 0. The individual and collective dose are well within expectations and legal limits.

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

### **2.1. Advances in nuclear safety – on-line measurement of fuel creep**

#### **Fuel Creep II / INSPYRE irradiations**

Nuclear fuel is at the heart of all nuclear systems and constitutes an essential component of their performance and safety. A better understanding of the properties of fuel and of the mechanisms underlying their changes under irradiation is key to the development of more accurate and predictive codes for the simulation of fuel elements.

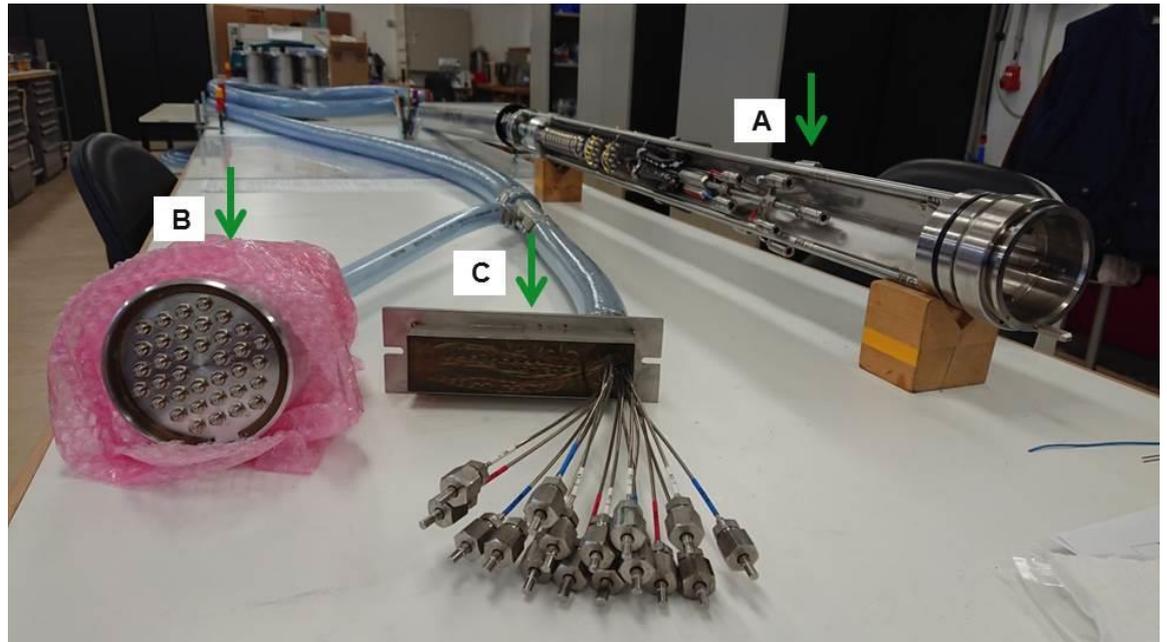
These codes are now an essential tool for design, qualification, and independent assessment of the fuels. INSPYRE is the path forward to cost effective nuclear fuel licensing and improved safety, through a thorough understanding of fuel performance issues.

In the previous reporting period, in September 2017, the Horizon2020 project INSPYRE (Investigations Supporting Mixed Oxide (MOX) Fuel Licensing in ESNII Prototype Reactors) was launched. The project included a creep experiment bearing MOX discs. INSPYRE used a modified proof of principle irradiation that was performed in 2017, with added features to exert an axial load on the samples and recording integral stack lengths by using a Linear Variable Differential Transformer (LVDT). In the reporting period the experiment was built and assembled and subsequently irradiated.

In parallel, a second, accompanying experiment (named Fuel Creep II) was built outside the scope of INSPYRE, bearing UO<sub>2</sub> discs. The designs of Fuel Creep II and INSPYRE were identical, and irradiation conditions were to be as similar as possible. The samples of both experiments were produced by JRC and tailored such that the expected power density was similar, for direct comparison of the data from the two experiments.

The fuel discs were to be subjected to variable axial loads up to 100 MPa at average temperatures between 481°C and 1130°C. This range of temperatures can be achieved by carrying out the irradiation in two different in-core positions in the HFR. By switching core position, both higher temperatures due to higher heating rates, as well as higher fission rate density are achieved, leading to higher creep rates.

**Figure 1: INSPYRE/Fuel Creep II irradiation rig. The instrument head allows simultaneous connection of three creep capsules. The head that is still connected to the sample is still open in the figure (A). Two connectors on the other end of the blue hose carry the wiring and tubing to access panels in the HFR. The round plug head (B) has the coax connectors for 3x6 capacitor plate sets (36 connectors). The rectangular plate (C) carries the gas lines and thermocouple wires.**



Source: JRC

After design and assembly of the experiments the irradiation was started at the end of June 2020. Unfortunately, the UO<sub>2</sub> experiment had a failure of the first containment in the first cycle. After discharging of the rig, the irradiation of the MOX experiment was continued. During the following irradiation cycles, parameters were kept as planned. Unfortunately, after four additional cycles a rapid rise in sample temperatures along with a drop in the pressure of the second containment was observed, indicating a leak to the first containment. As this meant that the safety conditions were no longer met, this also brought the irradiation of the MOX experiment to a premature end in May 2021. Due to the seemingly similar failures of the two experiments, it was decided to assess the failure modes or root causes of these failures.

An external, independent team was requested to perform root-cause analyses of the failed experiments, looking at all the phases of the project, as well as any other events or circumstances that could impact the proper functioning of the experiments. These root-cause analyses were finalized at the start of 2022. Even though no definite cause for failure could be determined, several preliminary causal factors were identified, such as the choice for the brazing alloy that was made as well as the centreless grinding method that was used

to produce the experiments' thin tubing. Additionally, a set of recommendations was made in the preliminary root cause analysis, which have been divided into pre-assembly recommendations and organizational / project management recommendations. The pre-assembly recommendations pertain to the design process, acceptance limits and inspection and testing (I&T), rather than directly to the design itself.

## **2.2. Molten Salt Reactor technology**

A molten-salt reactor (MSR) is a class of Generation IV nuclear fission reactor in which the primary nuclear reactor coolant and/or the fuel is a mixture of molten salt with a fissile material. Molten salt reactors have benefits in higher efficiencies and lower waste generation. The MSRs operate at atmospheric or low pressures, significantly reducing the risk of pressure-related accidents. MSRs also incorporate passive safety features, such as passive cooling and the potential for defueling in response to accidents which enhance the reactor's safety profile without requiring active intervention.

Molten salt fuel forms have received a significantly growing interest in the past decade. NRG has started a collaboration with JRC and the Delft University of Technology (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). For these purposes specific agreements under the umbrella of the JRC-NRG Cooperation Agreement have been drawn up. In addition, NRG has initiated supporting activities within the domain of Molten Salt Reactors (MSR) outside this Cooperation Agreement.

The overall aim of the experimental molten salt program is to gain practical experience with the handling, irradiation, post-irradiation research and waste treatment of molten salts, and then use this experience to:

- improve insight into the behaviour of fission products in molten salt in relation to accident scenarios and decommissioning.
- qualify materials and components for use in an MSR.
- develop a technique for the (partial) on-line removal of fission products ("helium bubbling").
- test and qualify measurement and control techniques required to drive MSRs.
- design, build and operate a facility for the HFR that can serve as a prototype for future first-of-a-kind reactors (a so-called "MSR loop").

### **2.2.1. SAGA**

The objective of Salt spraying off-Gas systems experiment (SAGA) is to study the gas formation that can take place when molten salt waste (fuel waste from Molten Sal Reactors) is temporarily stored before waste treatment and final disposal.

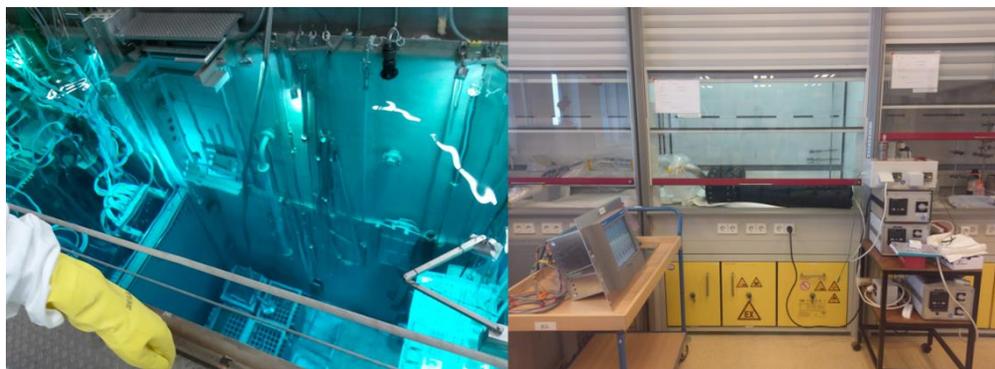
Low temperature radiolytic fluorine gas production at room temperature and up to 150 °C is an issue for future irradiation experiments in the HFR. SAGA has been designed with the objective to measure the amount of F<sub>2</sub> gas released from salt samples in a gamma field and to study the mechanism of radiolytic gas production for several salt species. The idea of the experiment is to continuously measure pressure in sealed salt-filled capsules during high-dose gamma irradiation using HFR spent fuel (at an average gamma dose rate of ~30 kGy/hour). Energy absorption is registered by ionization chambers, and temperature in the system is monitored by thermocouples (45-60 °C).

The SAGA irradiation facility is reloadable. For the first experiments, it has been loaded with samples of LiF, BeF<sub>2</sub>, UF<sub>4</sub>, ThF<sub>4</sub> and a LiF-BeF<sub>2</sub>-UF<sub>4</sub> mixture and one empty reference capsule is present as well. A collaboration with the Nuclear Research Institute Rez in Czech Republic was established for the fabrication of the fuel salts. In the previous reporting the first SAGA irradiation was started (last quarter of 2019).

The observed pressure build-up confirms the idea that heavier (higher-Z) salts absorb more energy and therefore generate more fluorine gas. In 2021, recombination tests were carried out by placing the irradiated salt-filled capsules in a tube oven, with two goals: to recombine the fluorine gas with the salt at elevated temperatures to 'reset' the samples and allow for a second round of gamma irradiation of the same samples; and to quantify the recombination rate as a function of temperature.

In 2022, the results from the first SAGA irradiation were analysed by an NRG - TU Delft Ph.D. student, and subsequently published. In addition, preparations were made for a second round of gamma irradiations (SAGA-2) to confirm and extend measurements from SAGA-1 and include a chloride salt sample (NaCl) to obtain first information on possible chlorine production, for comparison with the fluoride salts. This second irradiation was started in December 2023 and is foreseen to continue until May 2024.

***Figure 2: The SAGA facility in the spent fuel pool of the HFR for irradiation (left) and the experimental set-up for recombination tests in a fume hood in a radiological laboratory (right).***



Source: JRC

### 2.2.2. ENICKMA

Nickel-based materials are foreseen to be used in MSR components for their high corrosion resistance. Nickel is however sensitive to thermal neutron

irradiation, producing helium which may consequently weaken the material. The ENICKMA project (Evaluation of NICKel-based Materials for Molten salt reactor Applications) is performed to study the effect of helium embrittlement in nickel-based materials such as Hastelloy N, that are candidates for use in Molten Salt Reactors.

100 tensile, stress relaxation and low cycle fatigue samples are irradiated at MSR-relevant temperatures. Test results for the irradiated materials are then compared with results for reference samples.

Table 2 presents an overview of the various materials tested.

**Table 2: Overview of the various materials for the ENICKMA irradiation experiment.**

Material	Supplier
3166 L(N)	CEA (Fr)
Hastelloy N	Haynes (US)
GH3535	SINAP (Ch)
HN80MTY	COMTES FHT (Cz)
MONICR	COMTES FHT (Cz)
Hastelloy 242	Haynes (US)

In 2022, the irradiation of the ENICKMA was successfully completed after a total irradiation of 9 HFR cycles. The experiment was transported to the Hot Cell Laboratories (HCL) for dismantling. All planned tensile tests on irradiated and annealed specimens were completed in 2022. Tensile tests were performed both at room temperature and at irradiation temperature (650 °C). Also, an extensive pre-irradiation microstructural investigation (optical and electron microscopy including element analysis) on reference material and material annealed at 800°C was completed.

**Figure 3: ENICKMA dismantling in the D cell (left) and the 10 ENCIKMA drums during the dismantling procedure (right).**



Source: JRC

**Figure 4: Instrumentation head of a so-called TRIO facility with the ENICKMA experiment in one of the three channels. The instrumentation head, which is positioned a few meters above the reactor core during operation, contains the drive for vertical displacement.**



Source: JRC

## **2.3. Materials irradiations**

### **2.3.1. BLACKSTONE**

The United Kingdom's EdF (Electricité de France) Energy operates a fleet of advanced gas cooled reactors (AGRs) using graphite as the neutron moderator and carbon dioxide as coolant.

Graphite degradation is 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. Phase 3 of BLACKSTONE focuses on the graphite from the Heysham 2 and Torness reactors and is a follow-up of Blackstone Phases 1 and 2, in which graphite from other AGRs was successfully characterized to support lifetime extension. As part of the project, graphite material extracted from AGRs has been irradiated in the High Flux Reactor During the HFR irradiation both the in-core neutron and oxidation damage mechanisms that take place in an AGR are simulated and accelerated under representative conditions. Following the irradiation, graphite specimens are characterized in the NRG Hot Cell Laboratories (HCL) to provide high quality material behaviour data, providing essential input to graphite property models which are used to assess the future structural integrity of AGR cores. Phase 3, started in 2016 include 2 irradiations in C7 position, BLACKSTONE-5 and BLACKSTONE-6. Post irradiation

examinations of BLACKSTONE 5, irradiated from 2017-C05 to 2018-C06, were done in HCL. After this campaign the graphite samples were irradiated in BLACKSTONE-6. This irradiation started in 2019-07 and was completed after 2020-05. All characterization of specimens is completed, and the program was finalized in 2022.

### 2.3.2. *Graphite irradiations for HTR application*

A high-temperature reactor (HTR) is a type of nuclear reactor which uses uranium fuel and graphite moderation to produce very high reactor core output temperature. The high operating temperatures of HTGR reactors potentially enable applications such as process heat or hydrogen production.

Around the world, multiple initiatives are undertaken to deploy Generation IV High Temperature Reactors (HTR).

Building on the experience of previous graphite irradiation programs, graphite (creep) irradiations at high temperature are performed to characterize and qualify graphite grades. An inert graphite irradiation was performed for Terrestrial Energy's Integral Molten Salt Reactor. In this irradiation, 12 cycles were completed between cycles 2020-07 and 2022-02, with a range of graphite grades that are of interest for application in the IMSR. The graphite specimens were characterized in the Hot Cell Laboratories in a campaign that completed in 2023.

Another activity is the qualification of a nuclear graphite grade provided by SIAMC Advanced Materials Co. Both an inert high temperature irradiation (SAINT-01 with start 2022-08 and end 2023-04) and a first creep irradiation (SINOGRAPH-I with start 2021-06 and end 2021-09) were performed. The graphite specimens from these irradiations are characterized and follow-up irradiations are scheduled for the coming years.

### 2.3.3. *Irradiation of aluminium-based reactor materials*

The Jules Horowitz Reactor (JHR) Material Test Reactor project will provide the means needed to explore an essential scientific and technical field: testing the behaviour of materials and fuels under irradiation in order to support current and future nuclear reactors.

The JHR Material Test Reactor is currently under construction at the CEA (Commissariat à l'énergie atomique et aux énergies alternatives) Cadarache site. The reactor is being built under the framework of an international consortium of research institutes. It is led by France's CEA which provides 45% of the project's funding and includes another 9 research institutions from EU member states and the participation of European Commission with a 6% contribution to the project.

In January 2016 the Jules Horowitz Reactor (JHR) SURP project started. The JHR-SURP irradiation formed part of the French contribution to the Supplementary Program of the High Flux Reactor (HFR) 2016-2019 and 2019-2023. In the JHR SURP facility aluminium alloy samples of structural materials of the Jules Horowitz Reactor have been irradiated providing input

to the (future) surveillance program of the JHR. The irradiation forms part of the support to the industrial manufacturer of the reactor.

The irradiation started in the previous reporting period, in January 2017, and was continued in the period 2020-2023. The samples were irradiated in the HFR in a core position. The irradiation was successfully completed in December 2023. With 1764 full power days this irradiation is amongst the most longest running experiments in the history of the HFR. After irradiation the rig with the samples was removed from the HFR core and transported to the hot cells. In April 2024 the samples were transported to France for future research.

## **2.4. Outlook 2024 and onwards**

Euratom stakeholders continue to collaborate on the development of irradiation facilities for fuel and materials as new set up for experimental work at the High Flux reactor. At the time of writing, the following irradiation devices are in preparation.

### *2.4.1. ENICKMA-HTC*

ENICKMA-HTC is a follow-up irradiation to ENICKMA (section 2.2). It also assesses the mechanical performance of Molten Salt Reactor (MSR) structural materials but focuses on in-pile measurement of creep behaviour at high temperatures (~650°C). A concept design for the in-pile irradiation was made in collaboration with IFE. The design of the ‘creep unit’ was supplied by Institute for Energy Technology, Norway (IFE) and incorporated into the concept design of the full irradiation rig.

### *2.4.2. SALIENT-03*

The interest for Molten Salt Reactor (MSR) technologies is increasing worldwide. The MSR is operated at low (atmospheric) pressure in the primary circuit and in the event of overheating, the fuel would be drained into an emergency dump tank assuring subcriticality and natural removal of the decay heat.

The irradiation experiments SALIENT-03 is being carried out within collaboration between the Nuclear Research and Consultancy Group (NRG) and the Joint Research Centre (JRC). The main goal of the experiment is to assess the corrosion mechanism of selected Ni-based alloys in molten fluoride salt considered as one of the candidates for MSR fuel salt. The corrosion test will be carried out during irradiation of the fuel salt in the High Flux Reactor in Petten (The Netherlands).

SALIENT-03 is the successor of the SALIENT-01 experiment. Whereas the objective of SALIENT-01 was to acquire knowledge and experience with performing an MSR-type irradiation, including the design of a rig and the handling of irradiated fuel salts, SALIENT-03 has a more dedicated objective: the determination of corrosion rates of candidate containment materials.

Lessons learned from the SALIENT-01 experiment are incorporated in the design. SALIENT-03 is the second capsule irradiation of molten fluoride fuel

salt and is being executed in collaboration between JRC and NRG. SALIENT-03 focuses on salt corrosion of alloys used for MSR construction under known redox conditions. The design also includes a pressure sensor for noble gas release measurements and nickel electrodes for generating current-voltage plots. Start of the irradiation is scheduled for the last quarter of 2024.

#### 2.4.3. *MIDI*

The MIDI irradiation facility is a follow-up of the LYRA-facilities that have previously been used to irradiate structural materials in the pool-side-facility (PSF) of the High Flux Reactor (HFR). The facility is a reloadable device that can be used to study the irradiation performance of alloys to irradiation doses and temperatures that are representative of reactor pressure vessel conditions.

#### 2.4.4. *ATOMIC*

The Accelerated Testing of Materials in Capsules (AToMiC) irradiation project is a series of Joint ExpErimental Program (JEEP) experiments operating within the Nuclear Energy Agency's (NEA's) Framework for IrraDiation Experiments (FIDES) second triennial.

AToMiC is dedicated to the understanding of microstructural evolution of fuel materials for use in higher temperature (HTR, section 2.3), Generation IV (GenIV) type reactors (notionally referred to as advanced reactors). This project is executed by a core group with that includes NRG/JRC, Idaho National Laboratory (INL), CEA and Westinghouse. The design for a High Flux Reactor irradiation facility is performed to allow irradiation of Mixed Oxyde (MOX) fuels under controlled temperature conditions.

#### 2.4.5. *INCREASE-HFR*

The In-Core Real-Time Mechanical Testing of Structural Materials (INCREASE-HFR) irradiation project is a series of Joint ExpErimental Program (JEEP) experiments operating within the Nuclear Energy Agency's (NEA's) Framework for IrraDiation Experiments (FIDES-II) second triennial.

INCREASE-HFR is a continuation of an irradiation starting at MITR Material Test Reactor in collaboration with Idaho national Laboratory (INL). The experiment is dedicated to the quantitative evaluation of in-core real-time stress relaxation data for stainless steels in current light-water reactor (LWR). This project is executed by a core group that includes NRG/JRC, Idaho National Laboratory (INL), CEA and EPRI.

### **3. ISOTOPE PRODUCTION**

#### **3.1. Isotope production**

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

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 HFR provides isotopes for 30.000 patient doses per day of Molybdenum-99. With 991 full power days, this equals the production of more than 40 million patient doses in the reporting period 2020 – 2023.

The HFR is one of the largest molybdenum-99 producers in the world. With increasing prosperity in larger parts of the world, ever better diagnostics and the ageing population, the demand for nuclear medicine is growing, especially due to the increased use of therapeutic isotopes like lutetium-177. This growth is reflected by an increasing number of clinical trials and the registration of new therapeutic drugs.

Other medicines play an important role in the supply of isotopes as well. In addition to molybdenum-99 and lutetium-177, the HFR is a major supplier of terbium-161, yttrium-90, iridium-192 and holmium-166 for various types of medical indications.

The HFR constantly anticipates the developments within the field of medical isotopes by contributing to the development of new therapies and the development of the market for nuclear medicines. In the reporting period 2020 - 2023, new clinical trials with lutetium-177 were started and/or announced, and the HFR delivered more lutetium-177 activity to the market, allowing for more patient treatments. The registration of the first PSMA lutetium-177 drug in 2022 has started the expected growth spurt. NRG|PALLAS invested in HFR production capacity in 2022 to accommodate this growth and gain a large market share in irradiation service.

Next to the production of medical isotopes NRG|PALLAS, the operator of the High Flux Reactor, is focusing on nuclear medical innovation. In the reporting period great progress has been made in the development of competences within the field of processing of medical isotope and the required infrastructure. For this purpose, the FIELD-LAB has been established. The FIELD-LAB is an important innovation facility, that helps to accelerate the development of new nuclear medicines to shorten the time to market. The facility was opened in December 2023. With this facilities, medical isotopes produced by the HFR, will be made available for clinical trials. In other words, the new innovation-infrastructure will further enlarge the health impact of the HFR.

The continuation of the important production function of the HFR will be taken over by the PALLAS reactor in the future. In the year 2023, a decision for full financing of the PALLAS reactor was taken by Dutch Government.

### **3.2. Facilities and capacity**

The HFR has various production facilities available to produce medical isotopes:

- 3 in core facilities for molybdenum-99,
- 2 in core facilities for therapeutic isotope (lutetium-177, lutetium-177 no carrier added (n.c.a.) etc.),
- 5 pool side facilities for molybdenum-99,
- a pneumatic rabbit system for holmium-166.

With the increasing demand for isotopes, NRG|PALLAS is preparing to expand the production capacity to produce medical isotopes. This capacity expansion for the period 2022-2026 is included in the CONNECT '26 program. The objective is to develop capabilities to meet the market demand for therapeutic isotopes during the remainder of the HFR operational period and to connect as closely as possible to the (larger) production capacity of the PALLAS reactor. The approach is achieved by optimization of the irradiation process to increase the volume while maintaining the reliability of the current production chain.

In 2023, technical improvements were implemented in irradiation facilities, which increases capacity and specific activity. Together with several logistical improvements, this means that the capacity is in order for the anticipated growth.

## **4. FINANCIAL CONTRIBUTIONS TO THE PROGRAMME'S IMPLEMENTATION**

In 2020-23, the following financial contributions were received from Member States for the implementation of the Supplementary Research Programme:

- Netherlands: EUR 26.654.000
- France: EUR 1.200.000

Note that these contributions cover the expenses specified under Annex II of Council Decision 2020/960/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 Research Programme to the decommissioning fund is EUR 800 000/year. This amount is taken from the regular budget of the Supplementary Research Programme. As of 31 December 2023, the total amount in the decommissioning fund is EUR 23.639.000.

This fund will contribute to the future decommissioning costs of the HFR (to be borne by Euratom).

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 281.000 HFR; support costs (e.g. legal advice) and utilities (e.g. electricity, water, heating) EUR 2.585.000, and spent fuel management costs EUR 5.719.000.

## **Annex A            Glossary and Acronyms**

AGR	Advance Gas Cooled Reactor
AToMiC	Accelerated Testing of Materials in Capsules
ANVS	Dutch Nuclear regulator
CEA	Commissariat a l'énergie atomique (France)
EdF	Electricité de France
Euratom	European Atomic Energy Community
ENICKMA	Evaluation of NiCKel-based Materials for Molten salt reactor Applications
FIDES	Framework for IrraDiation ExperimentS
HCL	Hote Cell Laboratories
HFR	High Flux Reactor
HTR	High Temperature Reactors
IFE	Institute for Energy Technology, Norway
INES	International Nuclear and radiological Event Scale
INL	Idaho National Laboratory
INSPYRE	INvestigations SuPporting MOX Fuel Licensing in ESNII Prototype REactors
JEEP	Joint ExpErimental Program
JRC	European Commission Joint Research Centre
JHR	Jules Horowitz Reactor
LUMOS	Learning to Understand MOlten Salts
LVDT	Linear Variable Differential Transformer
MOX	Mixed Oxide
MSR	Molten Salt Reactors
NRG	Dutch Nuclear Research and consultancy Group
SAGA	Salt sprAyin off-GAs systems
SSC	Systems, Structures, and Components
TU Delft	Delft University of Technology