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Survey of high flux facilities in the HFR Petten, available for fast reactor materials testing

by

P.R. ZEISSER

1972

Joint Nuclear Research Centre
Petten Establishment - Netherlands
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Survey of high flux facilities in the HFR Petten, available for fast reactor materials testing

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ABSTRACT

The present report gives a brief survey of the high flux reactor at the Petten establishment of the joint research establishment, its principal facilities and corresponding irradiation devices available for nuclear materials testing experiments.

The report consists of four parts, each dealing with a different aspect of the subject: included is general information on the reactor and its performance, together with isotope production and ancillary facilities and the means available for materials testing for water and for high temperature reactors.

Special attention is focussed on the devices recently developed in the field of direct in-pile measurements, in particular for the study of the mechanical properties of various nuclear materials exposed to high neutron flux densities.

KEYWORD

HFR
IRRADIATION DEVICES
CAPSULES
IRRADIATION PROCEDURES
MATERIALS TESTING
MEASURING METHODS
1. INTRODUCTION

The present paper intends to give a brief survey on the High Flux Reactor of the C.C.R. Petten, its main facilities and corresponding irradiation devices available in view of its utilisation for fast reactor materials testing irradiation experiments.

In this concise edition no special attention has been given to general features such as HFR damage flux, requirements with respect to cannings and fuels of the different reactor projects etc. Facilities specially installed for applications outside this field, such as isotope carriers, water loops etc. have been disregarded.

All information is presented in the form of illustrations, tables, diagrammes and introduced, highlighting particular features, restrictions, definitions and subjects adjacent to the one treated. A repartition into three chapters is made, dealing with the reactor, the irradiation devices and the irradiation projects.

Special attention is being drawn on the facilities recently developed in the field of direct in-pile measurement of mechanical properties of various nuclear materials exposed to high neutron flux densities.
2. PARTICULAR FEATURES OF THE HIGH FLUX REACTOR

AT THE JRC PETTEN

The four illustrations shown under this heading are:

- **the reactor vessel**, which is placed in the reactor pool. The vessel is sealed and pressurized to 3.6 kPa/cm².81 MTR fuel, reflector or filler elements, including 6 control rods, are placed in the core box. The light water primary reactor coolant and moderator enters at two opposite inlets underneath the cover plate. The control rods are operated from the basement guided by grid-bars on top of the core. Access from the pool to one outer face of the core box is provided by the pool side facility chimney and table.

- **the central reactor top lid**, which is part of the reactor cover plate. It is the main access for straight in-core irradiation devices in addition to the peripheral passages for bend-experiments.

- a **vertical cross section of the reactor vessel**, which shows the main possibilities of access to the high flux facilities and some accessory equipment.

- a **view from the top of the reactor vessel onto the high flux facilities and the different ways of access**. Typical nuclear data are indicated for the different experimental positions. They are defined as follows: Nuclear heating in W/g induced by combined nuclear radiation in a typical graphite drum; thermal neutron flux density values, reduced to the 2200 m/s energy equivalent according to the Westcott convention; fast neutron flux density is the equivalent fission neutron flux density.

   It is to be noted that all supply lines, such as thermocouples, heaters, purging and sampling lines have to pass the reactor cover plate and leave the reactor pool across or above its concrete walls.
HIGH FLUX REACTOR

HFR CENTRAL REACTOR TOP LID (CRTL)

1. TOP LID
2. PLUG
3. PASSAGE FOR EXPERIMENTS
4. BAYONET - LOCK
5. INSPECTION PLUG
HIGH FLUX REACTOR
CROSS SECTION OF VESSEL

1. CORE AND REFLECTOR
2. REACTOR VESSEL
3. REFLECTOR IRRADIATION DEVICE
4. IN-CORE IRRADIATION DEVICE
   ALT. WITH VERT. DISPL. UNIT
5. CENTRAL REACTOR TOP LID
6. PSF STANDARD CARRIER
7. POOL SIDE FACILITY
8. HORIZONTAL DISPL. UNIT
3. SURVEY OF AVAILABLE IRRADIATION DEVICES

This chapter is divided into three sections, displaying devices, which are mainly used for irradiation testing of fissile materials, non-fissile or structural materials, and for in-pile measurement of mechanical properties of various nuclear materials. The chapters are preceded by explanatory notes and information on developments presently engaged. Devices are described by an illustration and a corresponding specification sheet.

3.1 Irradiation devices for fissile materials

Due to the hazard of contamination by fission products, double containment is normally required for irradiations of fissile material in the HFR. The opposite scheme shows the general operation fields of double wall capsules.

In the following two double wall capsules, EXOR and ELLAS are presented as well as the flow diagramme of a fission gas release measurement circuit which has been operated satisfactorily in conjunction with a 1500°C coated particle irradiation capsule.
NOBEL GASES

LIQUID METALS

WATER

THERMAL BOND

INNER ANNULUS

TEMPERATURE [°C]

ACTUAL LIMITS

HIGH TEMPERATURE EXOR APPLICATIONS

1000

500

0

100 200 300 400

2000

HEAT FLUX [W cm⁻²]

24mm RANGE PIN

750 1500 2250 3000

12mm RANGE PIN

380 750 1130 1500

6mm RANGE PIN

190 380 570 750

LINEAR HEAT [W cm⁻³]

EXOR SCHEMATIC SECTION OF DOUBLE WALL

ELLAS

DOUBLE WALL CAPSULES OPERATION FIELDS
IRRADIATION DEVICE SPECIFICATION SHEET.

Designation : EXOR
Application : Irradiation of fissile material
Reactor positions: Pool Side Facility
alternatively core or reflector
Basic concept : double wall capsule; gas gap between walls; inner thermal bonding by liquid metal or rare gas; open cooling circuit.

Range of utilisation:
Specimen length : 400 mm
Specimen diameter : 5 ± 20 mm (max. 60 mm)
Heat dissipation : 800 W/cm
Cladding temperature: > 500°C
Peak flux thermal\(^\times\) : 2.6 \times 10^{14} \text{ cm}^{-2} \text{s}^{-1}
Peak flux fast\(^\times\) : 3.1 \times 10^{14} \text{ cm}^{-2} \text{s}^{-1}

Special features:
Thermal calibration by electric simulation heater
Measurement of central fuel temperature
Measurement of cladding temperature
Measurement of fission gas pressure built up
Measurement of fission gas volume
Control of fission rate by Horizontal Displacement Unit
Programmed thermal cycling by H.D.U.
Temperature control by variation of gas mixture.
HIGH FLUX REACTOR

IONIZATION DEVICES

ELLAS K1:

1. INNER CAN
2. OUTER CAN
3. SHIELD
4. FUEL PIN
5. FUEL THERMOCOUPLE
6. FUEL PELLETS
7. HEATER
8. NAI THERMOCOUPLES
9. COOLING CHANNEL
IRRADIATION DEVICE SPECIFICATION SHEET.

Designation : ELLAS
Application : Irradiation of fissile material
Reactor positions : Pool Side Facility alternatively core or reflector
Basic concept : double wall capsule; gas gap between walls; inner thermal bonding by liquid metal or rare gas; open cooling circuit.

Range of utilisation:

Specimen length : 400 mm
Specimen diameter : 5±20 mm (max. 60 mm)
Heat dissipation : 1500 W/cm
Cladding temperature : $>300^\circ\text{C}$
Peak flux thermal\(^x\) : $2.6 \times 10^{14} \text{ cm}^{-2} \text{s}^{-1}$
Peak flux fast\(^x\) : $3.1 \times 10^{14} \text{ cm}^{-2} \text{s}^{-1}$ \(x\) in core

Special features:

Thermal calibration by electric simulation heater
Measurement of central fuel temperature
Measurement of cladding temperature
Measurement of fission gas pressure built up
Measurement of fission gas volume
Control of fission rate by Horizontal Displacement Unit
Programmed thermal cycling by H.D.U.
Temperature control by variation of gas mixture.
1 - Irradiation rig  2 - Counting chambers  3 - Volumetric gas sampling  4 - Charcoal traps  5 - Diaphragm pump  
6 - Vacuum pump (connected to H.F.R. exhaust)  7 - He bottle  8 - Purification system traps  9 - Heat exchangers  
10 - Gas chromatograph.

Fission gas release loop - recovering and measuring circuits.
3.2 Irradiation devices for non fissile materials

Under this heading a selection of three irradiation devices is presented, which differ in temperature range, temperature accuracy, useful specimen volume and admissible nuclear heat load (limiting their use in in-core positions). These are the devices called REFA, GRIF and SIR. Techniques developed to achieve optimum temperature control and specimen volume for low density materials irradiation in the centre core position, like vertical displacement, individual electrical heating in zones, application of gas mixtures, are equally available for fast reactor materials testing as well.

A simplified diagramme at the end of this section conveys a general impression on capsule temperature control.

A special device for irradiation of stressed steel specimen with sodium bonding is available.
HIGH FLUX REACTOR IRRADIATION DEVICES

RELOADABLE FACILITY
1. PASSAGE PLUG
2. EXTENSION TUBE
3. IN-PILE PART
4. GAS SUPPLY TUBING
5. SHIELD PLUG
6. CONNECTION BOX
7. TYPICAL INSERT (HELI)
IRRADIATION DEVICE SPECIFICATION SHEET.

Designation : REFA
Application : Multipurpose reloadable facility
Reactor positions: core or reflector, access by CRTL
Basic concept : Standard thimble for various irradiations, to be used with special inserts;
gas supply lines for temperature control incorporated;
cooling reactor primary coolant.

Range of utilisation:
Useful length : 600 mm
Useful diameter : up to 54 mm
Heat dissipation: up to 80 W/cm$^3$ (diam. dependent)
Temperature range: 200 to 2000°C
Peak flux thermal 2.6 x 10$^{14}$
Peak flux fast : 3.1 x 10$^{14}$

Special features:

May be used for all kind of irradiation, fissile or non fissile, sodium bond or inert gas atmosphere.
Choice of various diameters, shield plugs and passages.
Vertical displacement unit (coarse 100 mm)
HIGH FLUX REACTOR IRRADIATION DEVICES

RELOADABLE FURNACE GRIP
1. BIG HEAD
2. PASSAGE PLUG
3. EXTENSION TUBE
4. IN-PILE PART
5. HANSEN COUPLING
6. THERMOCOUPLE CONNECTOR
7. SHIELD PLUG
8. THERMOCOUPLES
9. SAMPLE CARRIER
10. HEATER SECTION
11. COOLING CHANNEL
IRRADIATION DEVICE SPECIFICATION SHEET.

<table>
<thead>
<tr>
<th>Designation</th>
<th>GRIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Irradiation of non fissile and fissile material</td>
</tr>
<tr>
<td>Reactor positions</td>
<td>core or reflector, access by CRTL or peripheral passage</td>
</tr>
<tr>
<td>Basic concept</td>
<td>Thimble-insert principle, thus reloadable; six hairpin heaters, spraycoated, independent, part of thimble structure, provide homogeneous temperature control; cooling by reactor primary water;</td>
</tr>
</tbody>
</table>

**Range of utilisation:**

<table>
<thead>
<tr>
<th>Useful length</th>
<th>415 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Useful diameter</td>
<td>30 mm</td>
</tr>
<tr>
<td>Heat dissipation</td>
<td>150 W/cm³</td>
</tr>
<tr>
<td>Temperature range</td>
<td>200 °C to 900°C</td>
</tr>
<tr>
<td>Peak flux thermal</td>
<td>$2.6 \times 10^{14}$ cm$^{-2}$ s$^{-1}$</td>
</tr>
<tr>
<td>Peak flux fast</td>
<td>$3.1 \times 10^{14}$ cm$^{-2}$ s$^{-1}$</td>
</tr>
</tbody>
</table>

**Special features:**

Multi purpose rig

Temperature control by variation of gas mixture and electrical heating to $\pm 3^\circ$C in space and time

Electric heater power 500 W/cm

Inert gas atmosphere up to 80 kp cm$^{-2}$

Double containment.
Steel irradiation rig

1 to the instrument panel
2 Flexible hose
3 connection box
4 Extension wire for thermocouples
5 reactor vessel penetration
6 extension tube
7 heater connection
8 inlet cooling water channel
9 vacuum line
10 primary containment
11 secondary
12 thermocouples
13 heater element
14 samples charpy V-notch or tensile
15 charpy V-notch sample
16 sodium filling piece
17 cooling water inlet
<table>
<thead>
<tr>
<th>Designation</th>
<th>Steel Irradiation Rig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Irradiation of non fissile high density materials</td>
</tr>
<tr>
<td>Reactor position</td>
<td>Core of reflector, access by peripheral passage</td>
</tr>
<tr>
<td>Basic concept</td>
<td>Bend extension tube, non reloadable; sodium bonding in inner containment; accurate temperature control by electrical heaters and gas gaps; inner and outer cooling channel using reactor primary coolant.</td>
</tr>
</tbody>
</table>

**Range of utilisation:**

<table>
<thead>
<tr>
<th>Useful length</th>
<th>330 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Useful diameter</td>
<td>about 60 mm</td>
</tr>
<tr>
<td>Heat dissipation</td>
<td>50 W/cm³ (carrier average)</td>
</tr>
<tr>
<td>Temperature range</td>
<td>400 to 700°C</td>
</tr>
<tr>
<td>Peak flux thermal</td>
<td>$2.3 \times 10^{14}$ cm⁻² sec⁻¹</td>
</tr>
<tr>
<td>Peak flux fast</td>
<td>$2.8 \times 10^{14}$ cm⁻² sec⁻¹</td>
</tr>
</tbody>
</table>

**Special features:**

- Large useful volume.
- Accurate temperature control.
- Sodium bonding
LIMITS OF CAPSULE TEMPERATURE CONTROL.
3.3 Irradiation devices for in-pile measurement of mechanical properties of nuclear materials

In this section the results of recent developments in advanced nuclear materials testing are presented. From the design point of view, a difference is made between compressive or tensile testing. From the materials point of view we distinguish ceramic fuel, graphite or carbon base materials, cladding or other structural materials, because they differ in heat release, strain, and required temperature accuracy. Properties considered under this heading are creep rate, swelling or shrinkage, yield stress, ultimate stress, Young's modulus and the coefficient of thermal expansion.

Two main components of these facilities are the loading and the measuring system. For the former a satisfactory solution has been found using pressurized calibrated bellows to apply loadings between 0 and 3000 N. The measuring system consists of a differential gauge length measuring system in conjunction with an inductive linear differential transducer. The accuracy obtained is evaluated to be better than $10^{-6}$ m.

Actually the graphite creep assembly is operational, a fuel creep assembly is being built, and a creep assembly for cladding materials is in the predesign stage.
IRRADIATION DEVICES
HIGH FLUX REACTOR
FUEL CREEP ASSEMBLY

1. REACTOR CORE
2. POOLSIDE STANDARD CARRIER
3. SPECIMEN
4. SENSOR
5. REACTION MEMBER AND INNER CONTAINMENT
6. COMPRESSION MEMBER
7. TRANSMISSION
8. TRANSDUCER COILS
9. TRANSDUCER CORE
10. TRANSDUCER CASING
11. ACTUATION BELLOW
12. LOADING BELLOW
13. SIMP. SCHEME TRANSDUCER
14. INNER THERMOCOUPLES
15. OUTER THERMOCOUPLES
16. OUTER CONTAINMENT
17. COOLING CHANNEL

REF EUR
13,151
IRRADIATION DEVICE SPECIFICATION SHEET

Designation : Compact Creep Assembly
Application : Compressive creep measurements on compact specimen under irradiation
Reactor positions : Core or reflector, using Refa thimble
Basic concept : Hollow cylindrical specimens compressed between molybdenum members; stressed by pressurized bellow; differential gauge length measured with inductive linear displacement transducer; temperature control by gas gaps and variation of gas mixture.

Range of utilisation:

Total gauge length : 100 mm
Compressive load : 0 to 3000 N
Temperature range : 600 to 1200°C
Transducer coarse : ± 2.5 mm
Transducer resolution : < 10^{-4} mm
Peak flux thermal : 2.6 \times 10^{14} \text{ cm}^{-2} \text{s}^{-1}
Peak flux fast : 3.1 \times 10^{14} \text{ cm}^{-2} \text{s}^{-1}

Special features:

Controlled load by pressure line to bellow.
Temperature variation by gas mixture.
Differential gauge length measurement by bellow actuated sensor.
Vertical Displacement Unit for temperature adjustment.
Shielding plug

Bellows

Cardan joint

Nak

Specimen

Cardan joint

Shifting mechanism connection

Transmission-rod

Displacement transducer

Flange connection

HIGH FLUX REACTOR
IRRADIATION DEVICES
CANNING CREEP ASSEMBLY
IRRADIATION DEVICE SPECIFICATION SHEET.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Canning Creep Assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Tensile Creep measurements on canning material specimen under irradiation</td>
</tr>
<tr>
<td>Reactor positions</td>
<td>core or reflector, using Refa thimble</td>
</tr>
<tr>
<td>Basic concept</td>
<td>specimen submerged in liquid metal, stressed by pressurized bellow; strain measurement by inductive linear displacement transducer; temperature control by stepped gas gaps and variation of gas mixture.</td>
</tr>
</tbody>
</table>

**Range of utilisation:**

<table>
<thead>
<tr>
<th>Total gauge length</th>
<th>100 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile load</td>
<td>0 to 2000 N</td>
</tr>
<tr>
<td>Temperature range</td>
<td>250 to 700°C</td>
</tr>
<tr>
<td>Transducer coarse</td>
<td>± 2.5 mm</td>
</tr>
<tr>
<td>Transducer resolution:</td>
<td>&lt; 10⁻⁴ mm</td>
</tr>
<tr>
<td>Peak flux thermal</td>
<td>2.6 x 10¹⁴ cm⁻² s⁻¹</td>
</tr>
<tr>
<td>Peak flux fast</td>
<td>3.1 x 10¹⁴ cm⁻² s⁻¹</td>
</tr>
</tbody>
</table>

**Special features:**

- Controlled load by pressure line to bellow
- Temperature variation by gas mixture
- Temperature adjustment by Vertical Displacement Unit.
4. IRRADIATION PROJECTS

The Irradiation Technology Division of the JRC Petten is in charge of the execution of irradiation projects on behalf of internal or external users. This comprises technical and managerial aspects, such as negotiations of contractual terms, supply of experimental equipment, coordination of work performed by associated laboratories and services.

A project leader is appointed by the division head; he is entirely in charge of one or more projects. The extent of an irradiation project is defined in a proposal, set-up by the project leader, which is followed by a contract in the case of an external client. A project normally comprises all actions from the elaboration of an irradiation programme in conjunction with the user up to post irradiation examination and final reporting.

A scheme of actions for irradiation projects is given hereunder. Main associated laboratories are the LSO of the RCN Chemistry Division for highly radioactive materials, the RML of the Euratom Petten Materials Division for slightly radioactive materials and the RMG of the RCN Physics Division for neutron metrology.
Scheme of actions for Irradiation projects

**ACTION**

- **Project Development**
- **Irradiation Techniques**
- **Reactor Utilisation**
- **Project Handling**
  - Preproject
  - Proposal
  - Contract
  - Design, Analysis
  - Safety Report
  - Manufacture
  - Assembly
  - Testing
  - Irradiation
  - Dismantling
  - P.I. Analysis
  - Final Report

**EXPL. NOTES**

- Observation of trends in reactor development and irradiation testing, information for potential users.
- Development and application of new techniques of analysis, measurement and fabrication.
- Optimisation and improvement of irradiation facilities and reactor occupation. Allocation of irradiation positions.
- Project is initiated by a user's request (letter of intent)

- for preliminary negociations
- set up by project leader
- negotiated with Contracts Div. after approval of proposal by user and direction
- of all necessary experimental equipment
- for approval by the local reactor safeguards committee to operate the equipment
- supply of equipment, subcontractors
- line-up components and functional testing
- reliability and functional testing of assembled equipment, pre-pile operation
- in-pile installation and operation, dosimetry, cycle reports
- P.I. operation, recovery of samples
- alternatively transport of samples to user's laboratories
- chronological evaluation of events and presentation of results.
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Alfred Nobel
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