EUR 4639 e

Part 3 of 4

COMMISSION OF THE EUROPEAN COMMUNITIES

HFR INFORMATIONS FOR USERS

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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Printed by Guyot s.a., Brussels
Luxembourg, May 1972

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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 establisment, 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.

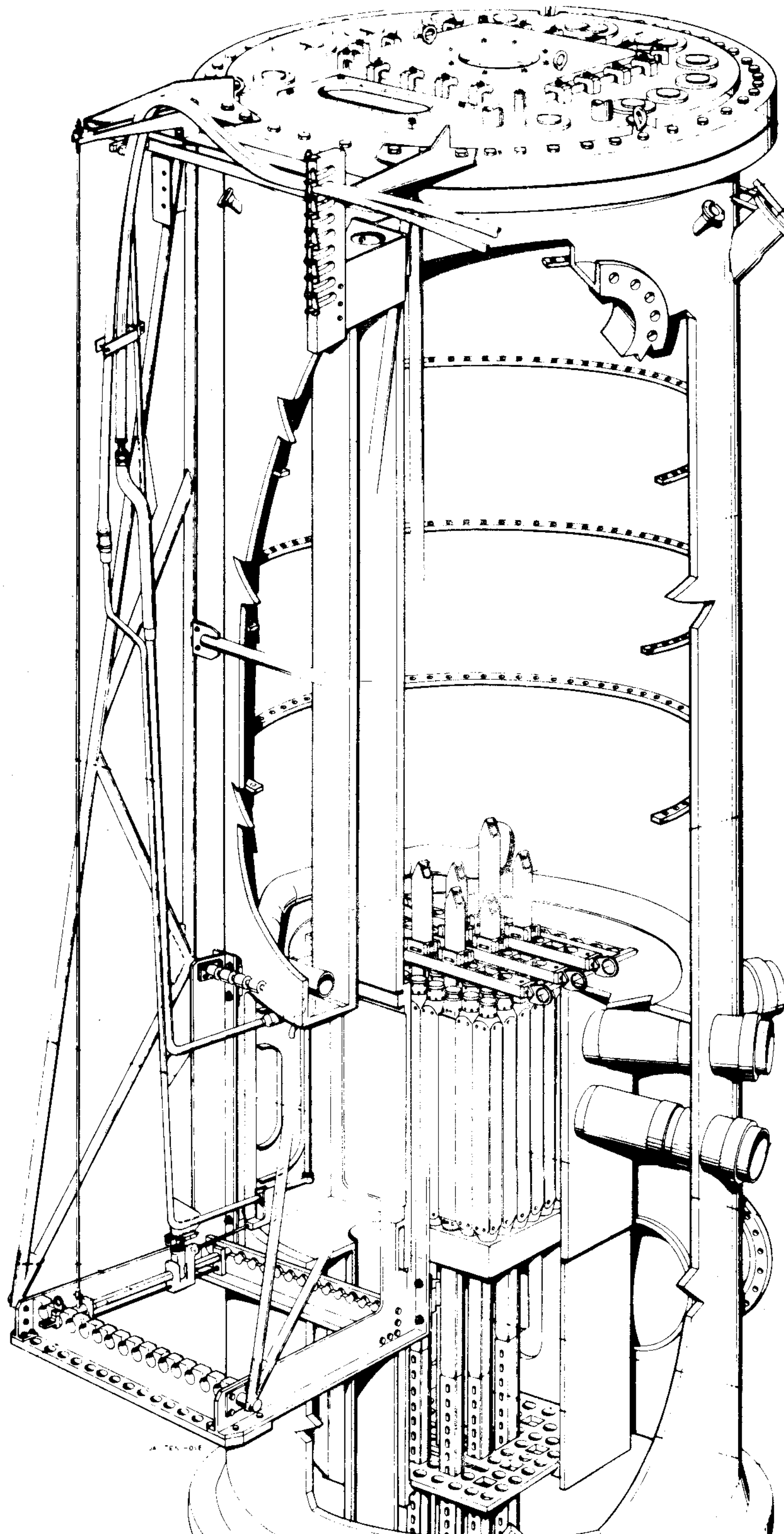
Special attention is being drawn on the facilities recently developed in the field of direct in-pile measurement of mechanical properties of various nuclear materials exposed to high neutron flux densities.

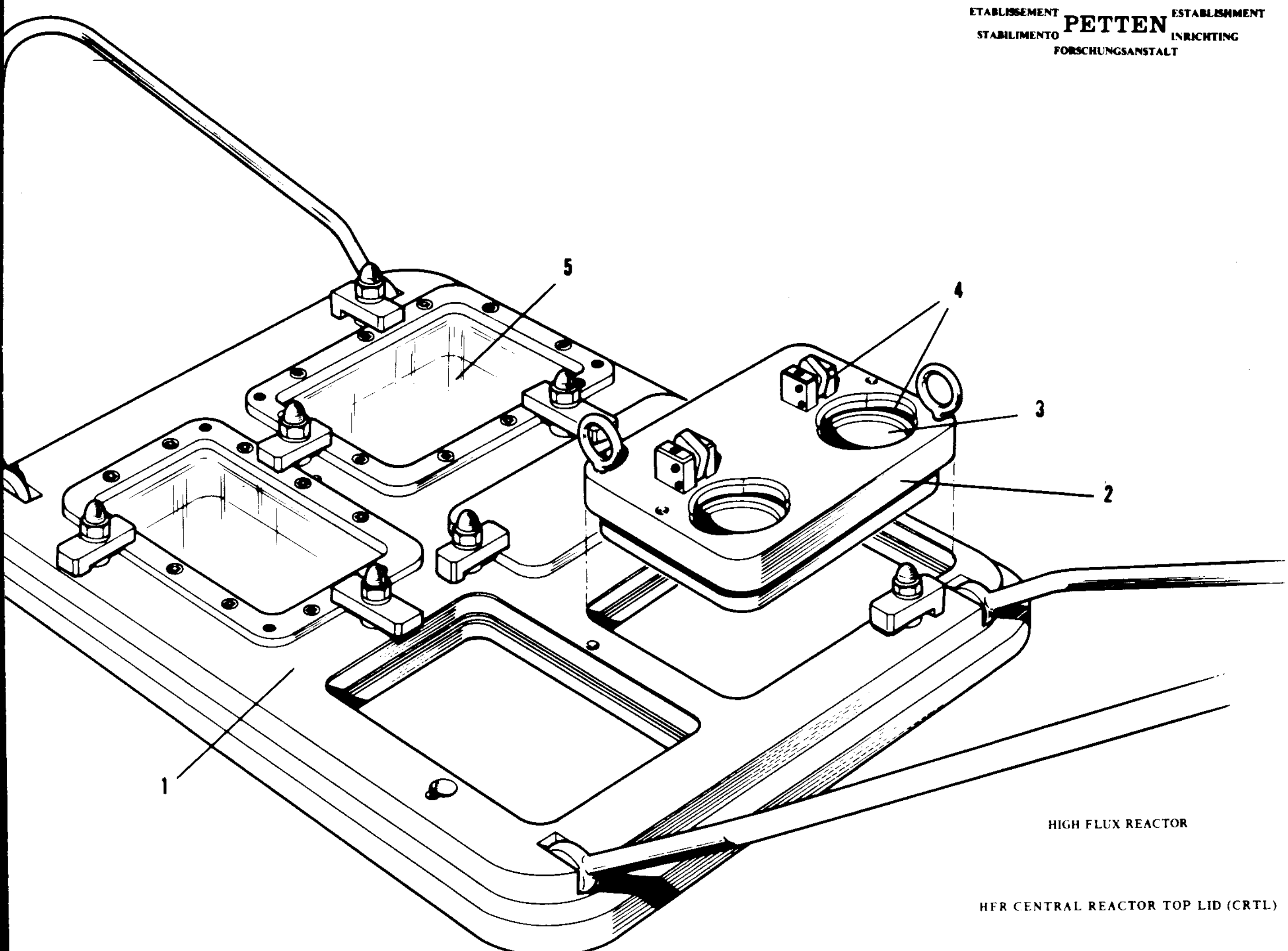
2. PARTICULAR FEATURES OF THE HIGH FLUX REACTOR AT THE JRC PETTEN

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 kg/cm^2.81 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.

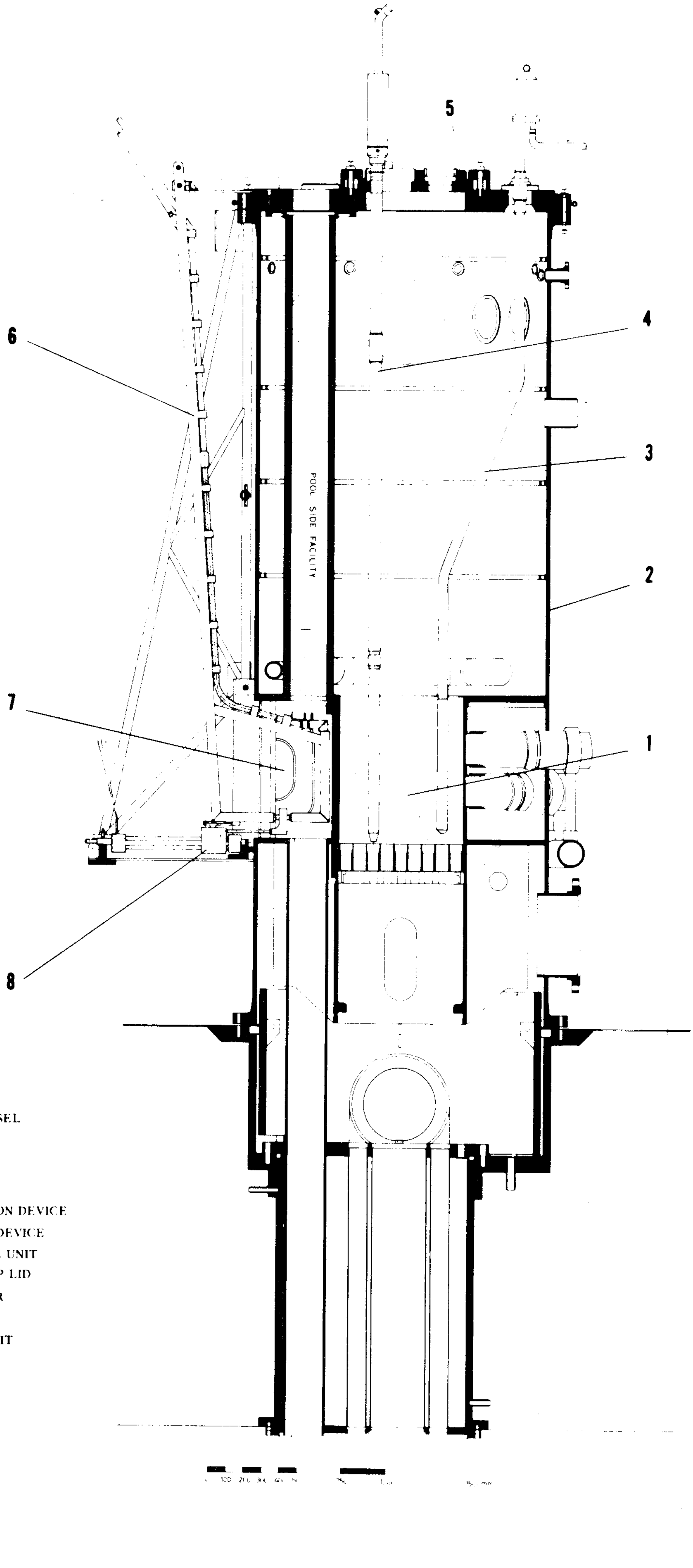




HIGH FLUX REACTOR

HFR CENTRAL REACTOR TOP LID (CRTL)

1. TOP LID
2. PLUG
3. PASSAGE FOR EXPERIMENTS
4. BAJONET - 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

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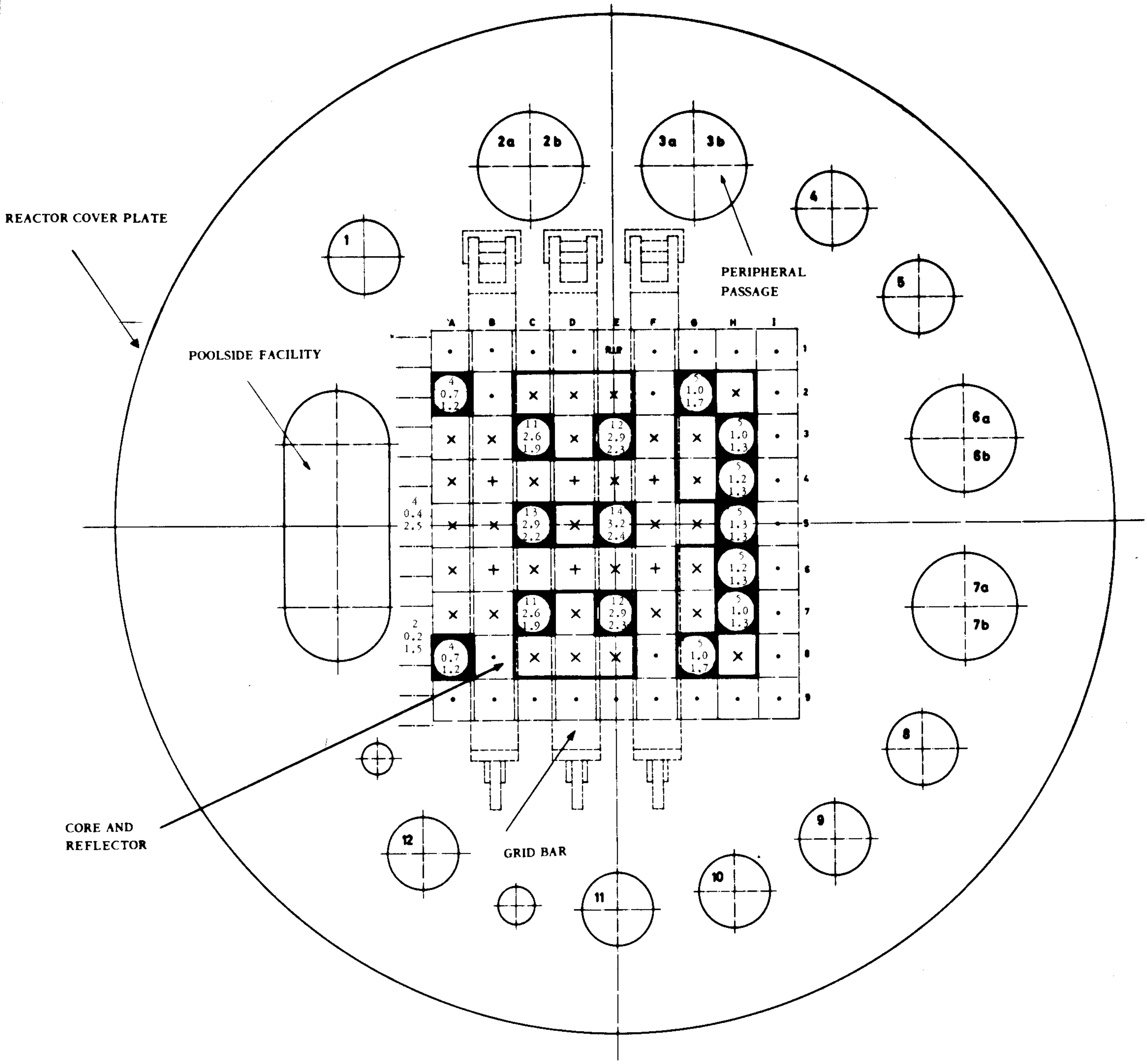


HIGH FLUX REACTOR

HIGH FLUX
IRRADIATION
FACILITIES

▭ ACCESS BY CENTRAL REACTOR TOP LID

\+ CONTROL ROD

● Be-ELEMENT

× FUEL-ELEMENT

EXPERIMENT POSITIONS

5 — NUCLEAR HEATING (W/g GRAPHITE)
1.2 — FAST FLUX DENSITY $\times 10^{14}$ ($n.cm^{-2} sec^{-1}$)
1.3 — THERMAL FLUX DENSITY $\times 10^{14}$ ($n.cm^{-2} sec^{-1}$)

} PEAK VALUES

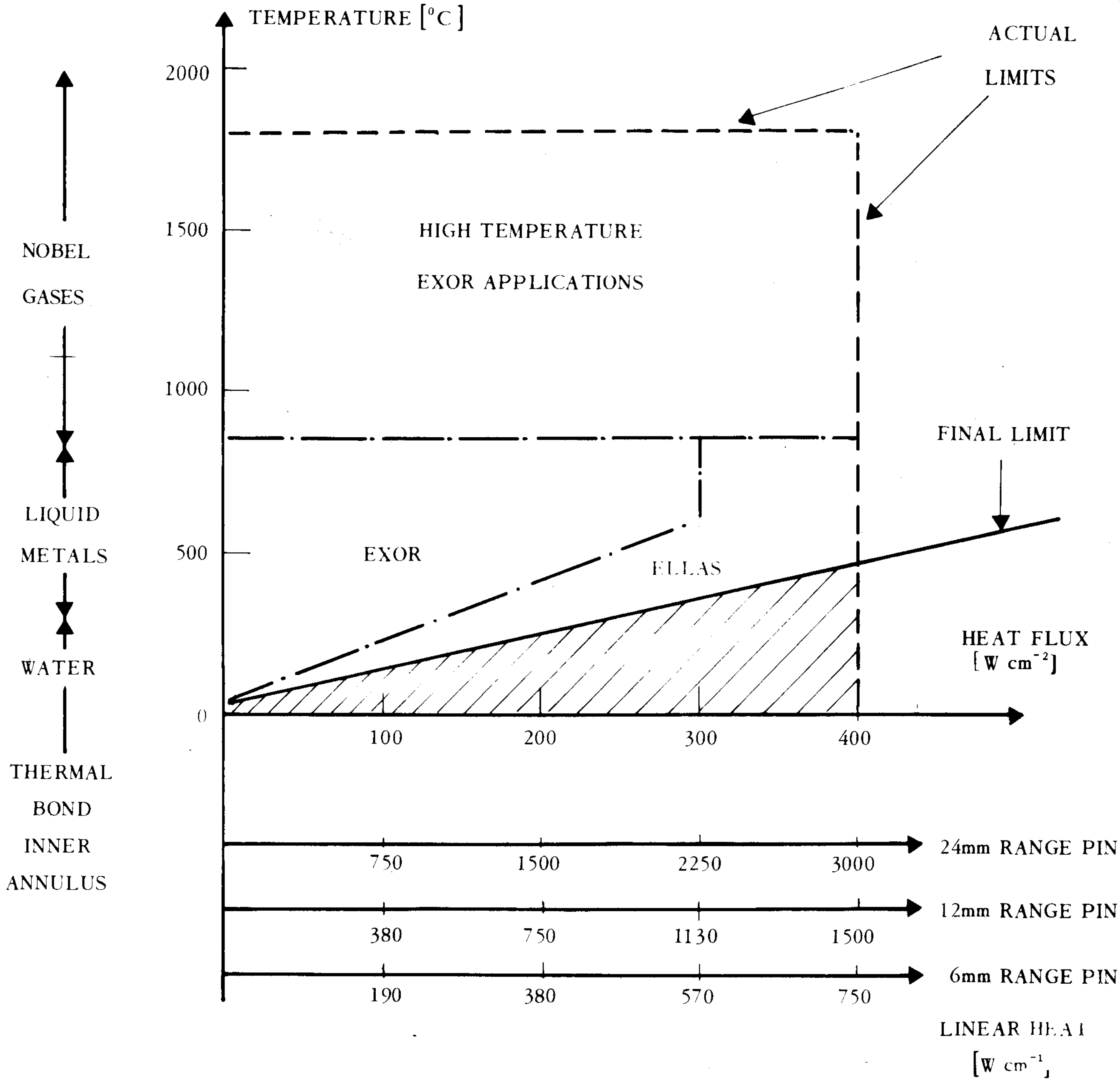
3. SURVEY OF AVAILABLE IRRADIATION DEVICES

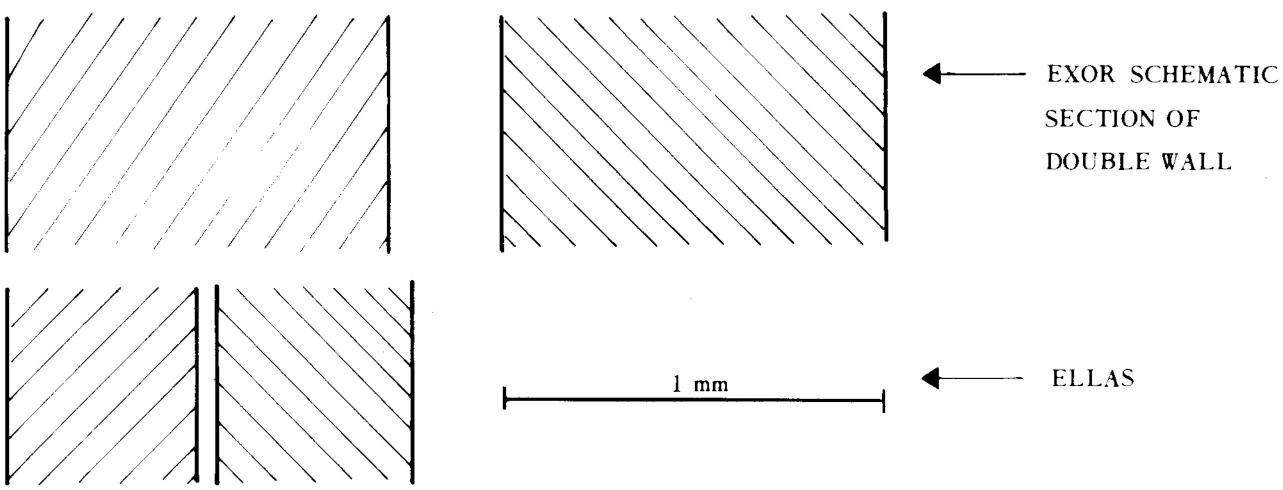
This chapter is divided into three sections, displaying devices, which are mainly used for irradiation testing of fissile materials, non fissile or structural materials, and for in-pile measurement of mechanical properties of various nuclear materials. The chapters are preceeded by explanatory notes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

3.1 Irradiation devices for fissile materials

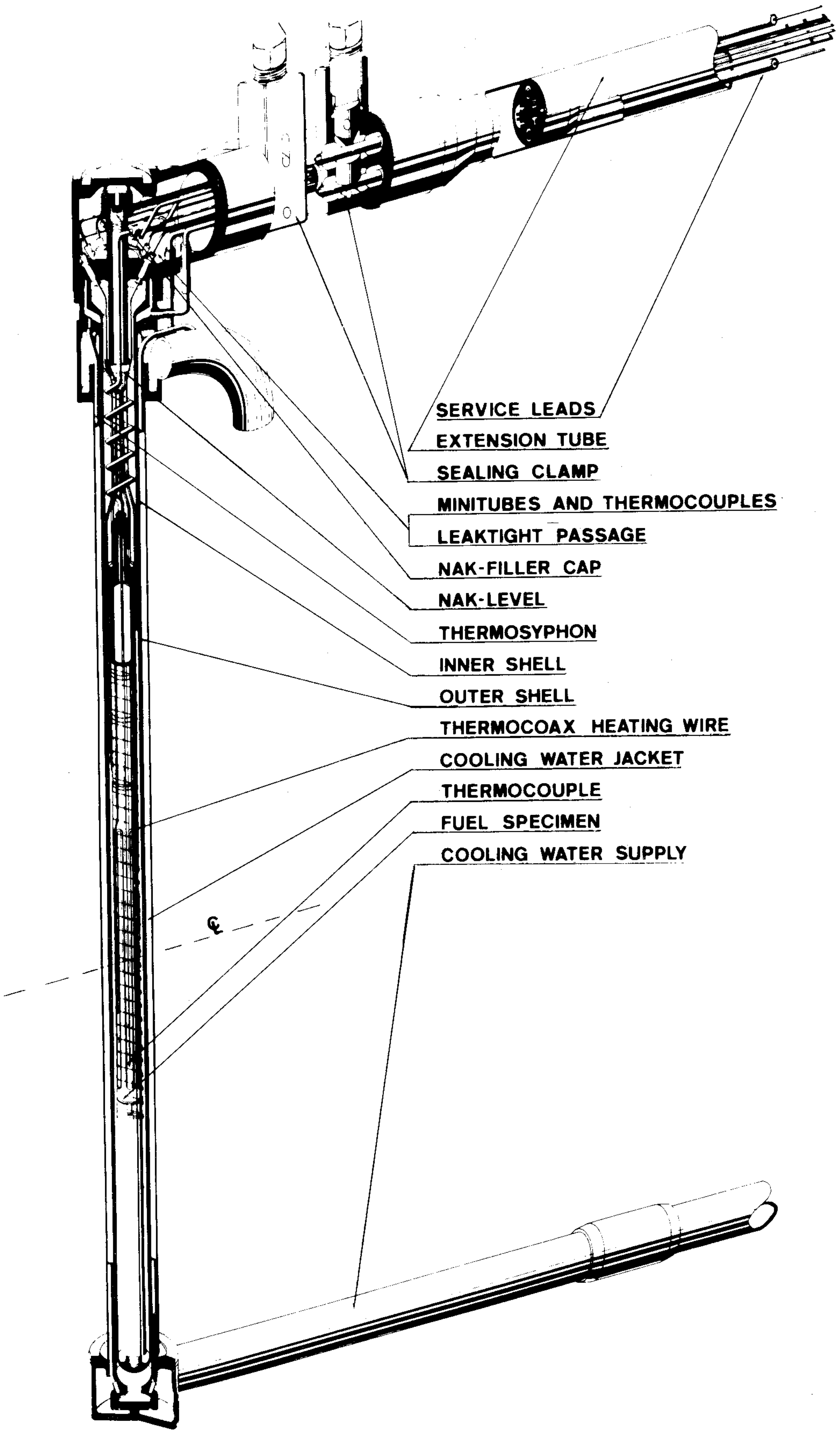
Due to the hazard of contamination by fission products, double containment is normally required for irradiations of fissile material in the HFR. The opposite scheme shows the general operation fields of double wall capsules.

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.





DOUBLE WALL CAPSULES OPERATION FIELDS



HIGH FLUX REACTOR
IRRADIATION DEVICES
EXOR

REF EUR

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 x) :	2.6×10^{14} cm^{-2} s^{-1}
Peak flux fast x) :	3.1×10^{14} cm^{-2} 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.

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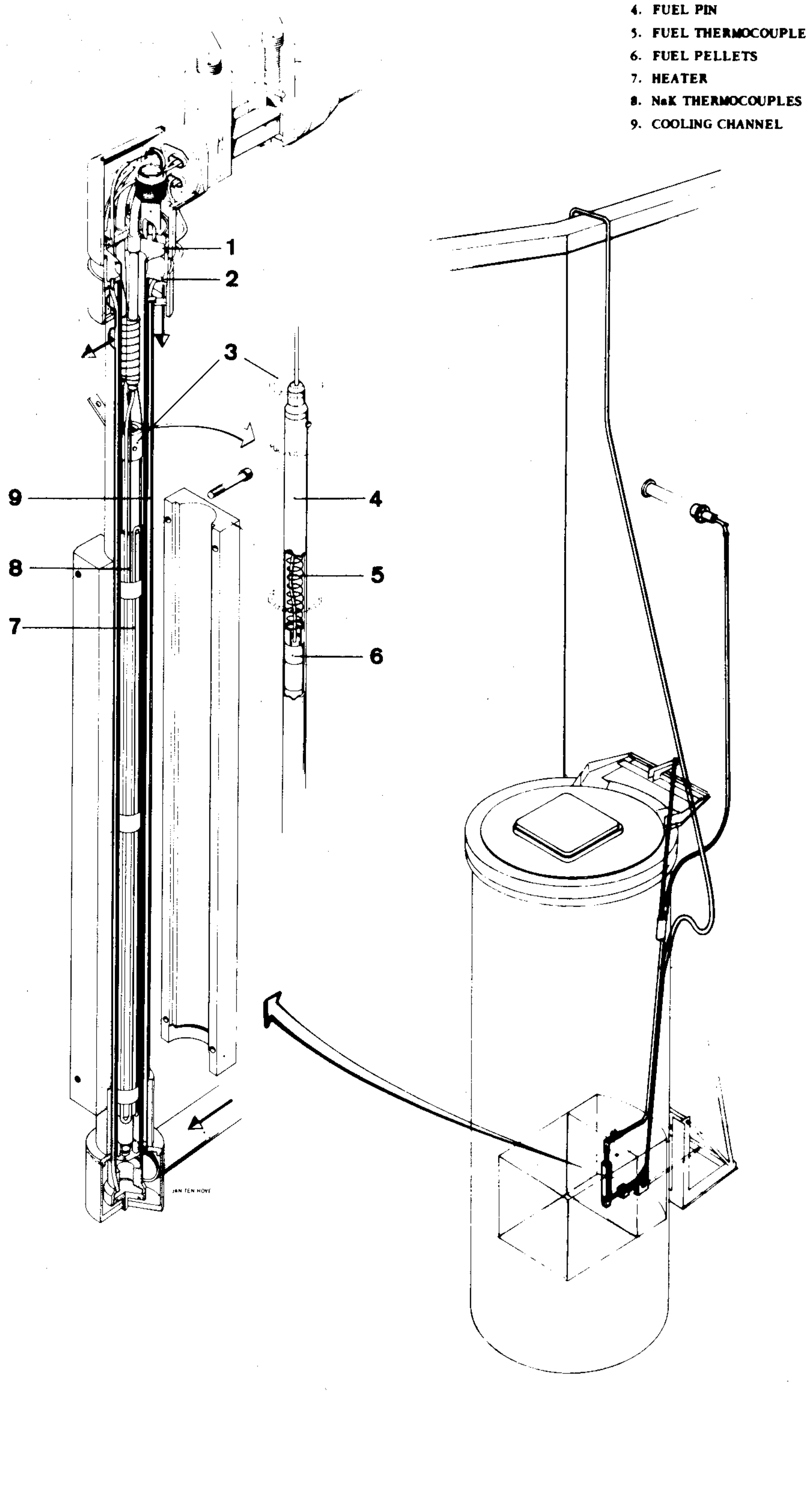
HIGH FLUX REACTOR
IRRADIATION DEVICES
ELLAS K 1

1. INNER CAN
2. OUTER CAN
3. SHROUD
4. FUEL PIN
5. FUEL THERMOCOUPLE
6. FUEL PELLETS
7. HEATER
8. NaK 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	:	$>300^{o}C$
Peak flux thermal x)	:	2.6×10^{14} cm^{-2} s^{-1}
Peak flux fast x)	:	3.1×10^{14} cm^{-2} 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.

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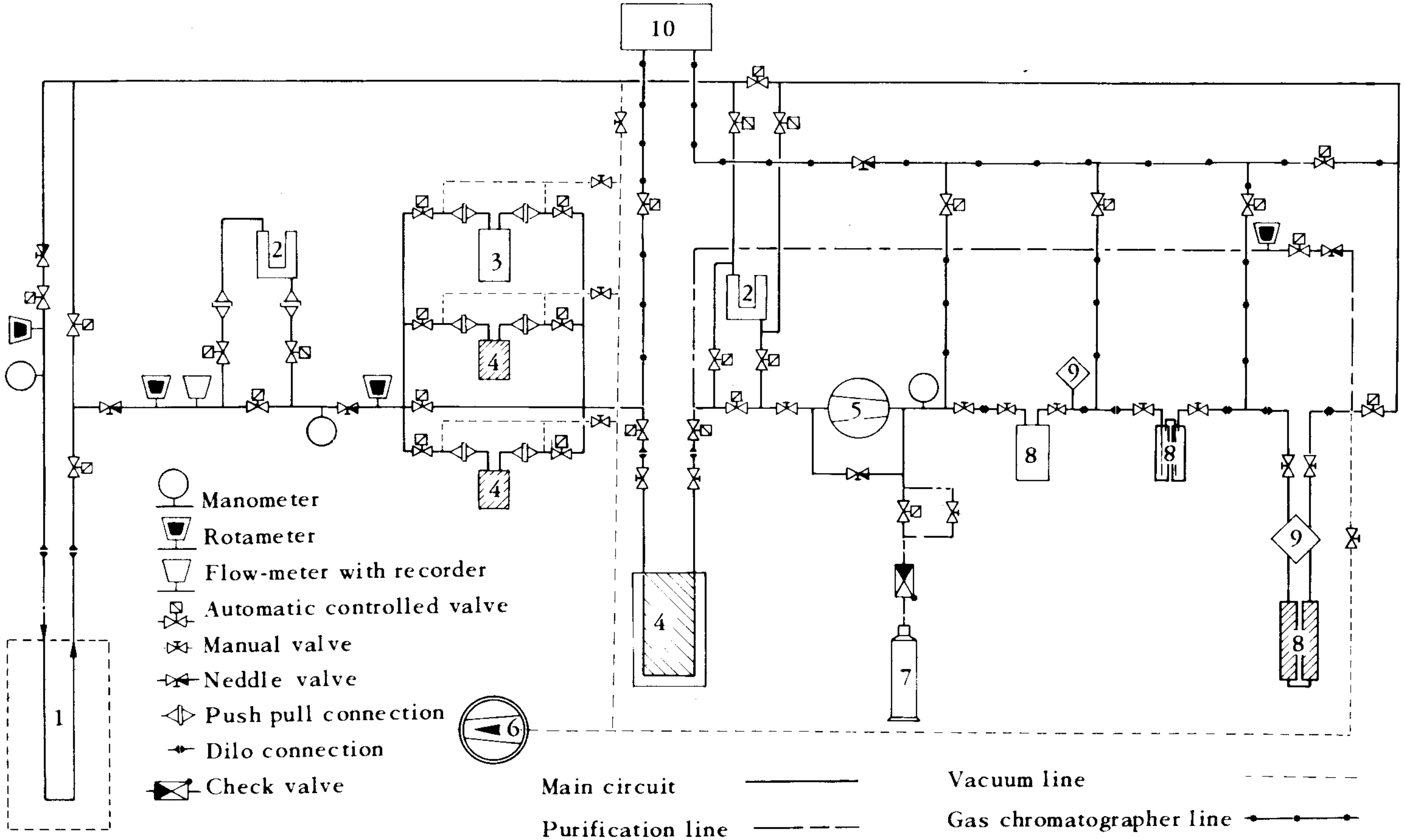


1 – Irradiation rig 2 – Counting chambers 3 – Volumetric gas sampling 4 – Charcoal traps 5 – Diaphragm pump 6 – Vacuum pump (connected to H.F.R. exhaust) 7 – He bottle 8 – Purification system traps 9 – Heat exchangers 10 – Gas chromatographer.

Fission gas release loop – recovering and measuring circuits.

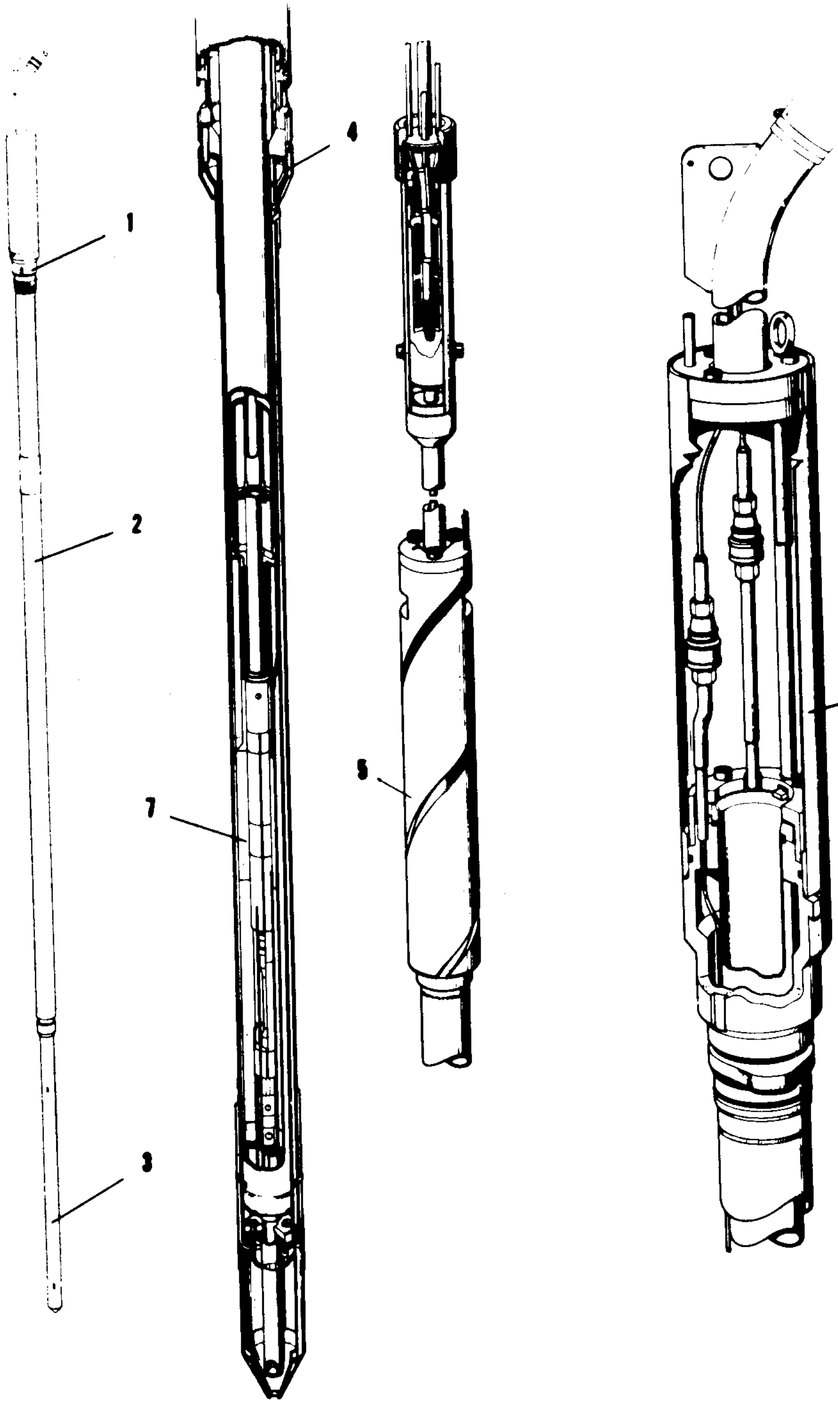
3.2 Irradiation devices for non fissile materials

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 achiève 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.

ETABLISSEMENT PETTEN ESTABLISHMENT
STABILIMENTO INRICHTING
FORSCHUNGSANSTALT



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 (ME04

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	2.6×10^{14}
Peak flux fast :	3.1×10^{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)

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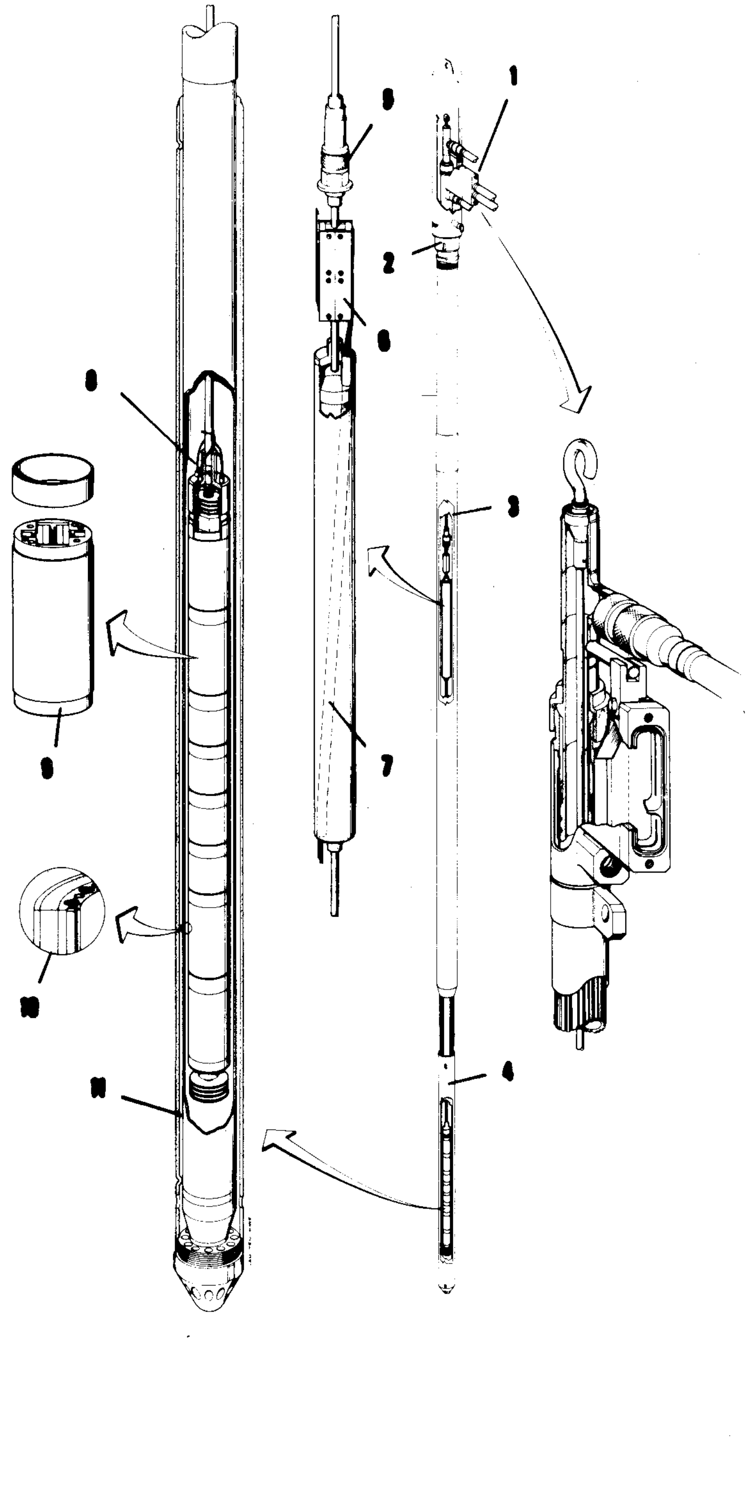
ETABLISSEMENT PETTEN ESTABLISHMENT
STABILIMENTO INRICHTING
FORSCHUNGSANSTALT

HIGH FLUX REACTOR
IRRADIATION DEVICES

RELOADABLE FURNACE GRIF

1. RIG 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.

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

Range of utilisation:

Useful length	:	415 mm
Useful diameter	:	30 mm
Heat dissipation	:	150 W/cm^3
Temperature range	:	200 ÷ 900°C
Peak flux thermal	:	2.6×10^{14} cm^{-2} s^{-1}
Peak flux fast	:	3.1×10^{14} cm^{-2} s^{-1}

Special features:

Multi purpose rig

Temperature control by variation of gas mixture and electrical heating to ± 3°C in space and time

Electric heater power 500 W/cm

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

Double containment.

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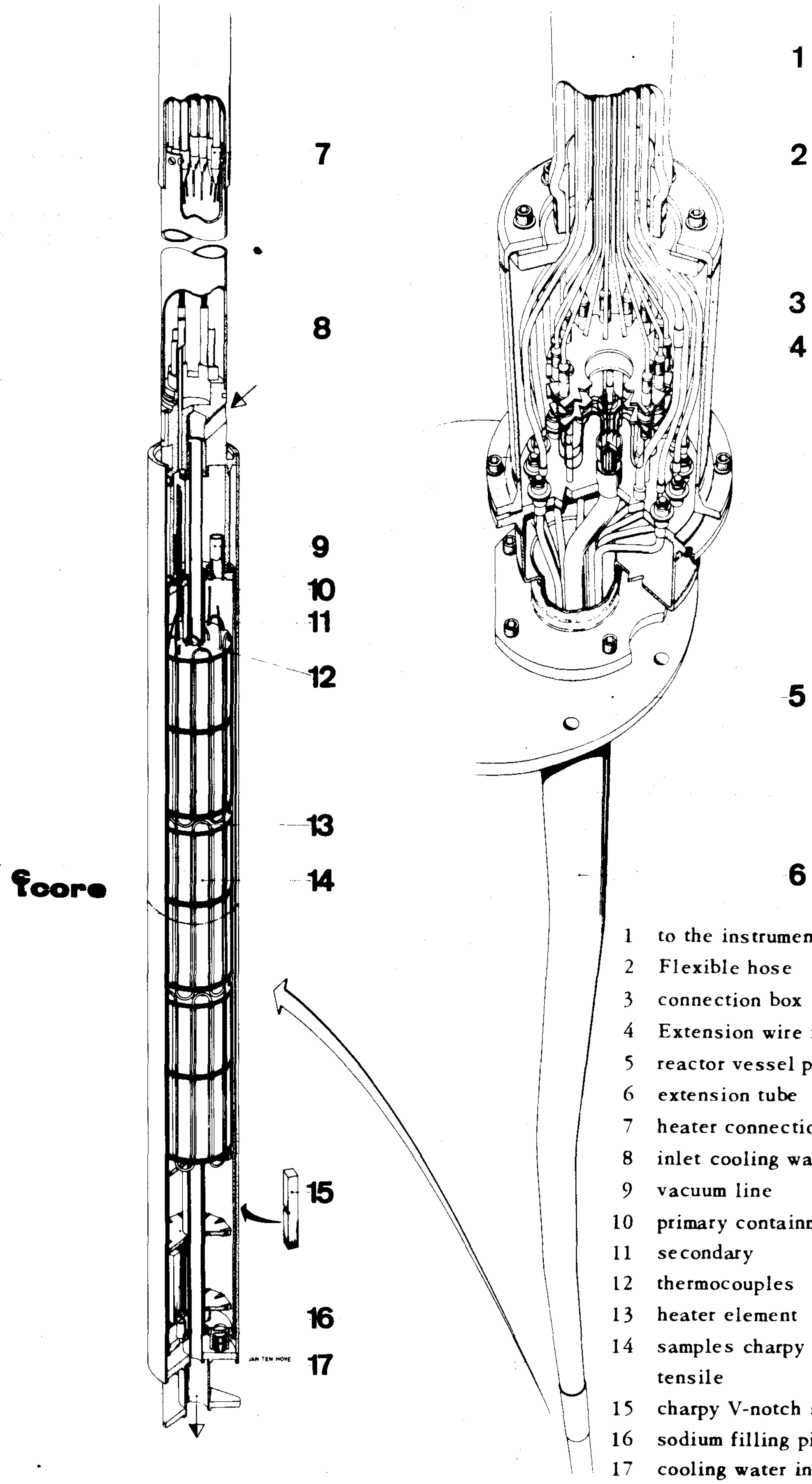
Steel irradiation rig



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

IRRADIATION DEVICE SPECIFICATION SHEET

Designation	:	Steel Irradiation Rig
Application	:	Irradiation of non fissile high density materials
Reactor position	:	Core of reflector, access by peripheral passage
Basic concept	:	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.

Range of utilisation:

Useful length	:	330 mm
Useful diameter	:	about 60 mm
Heat dissipation	:	50 W/cm^3 (carrier average)
Temperature range	:	400 to 700^oC
Peak flux thermal	:	2.3×10^{14} cm^{-2} sec^{-1}
Peak flux fast	:	2.8×10^{14} cm^{-2} sec^{-1}

Special features:

Large useful volume.

Accurate temperature control.

Sodium bonding

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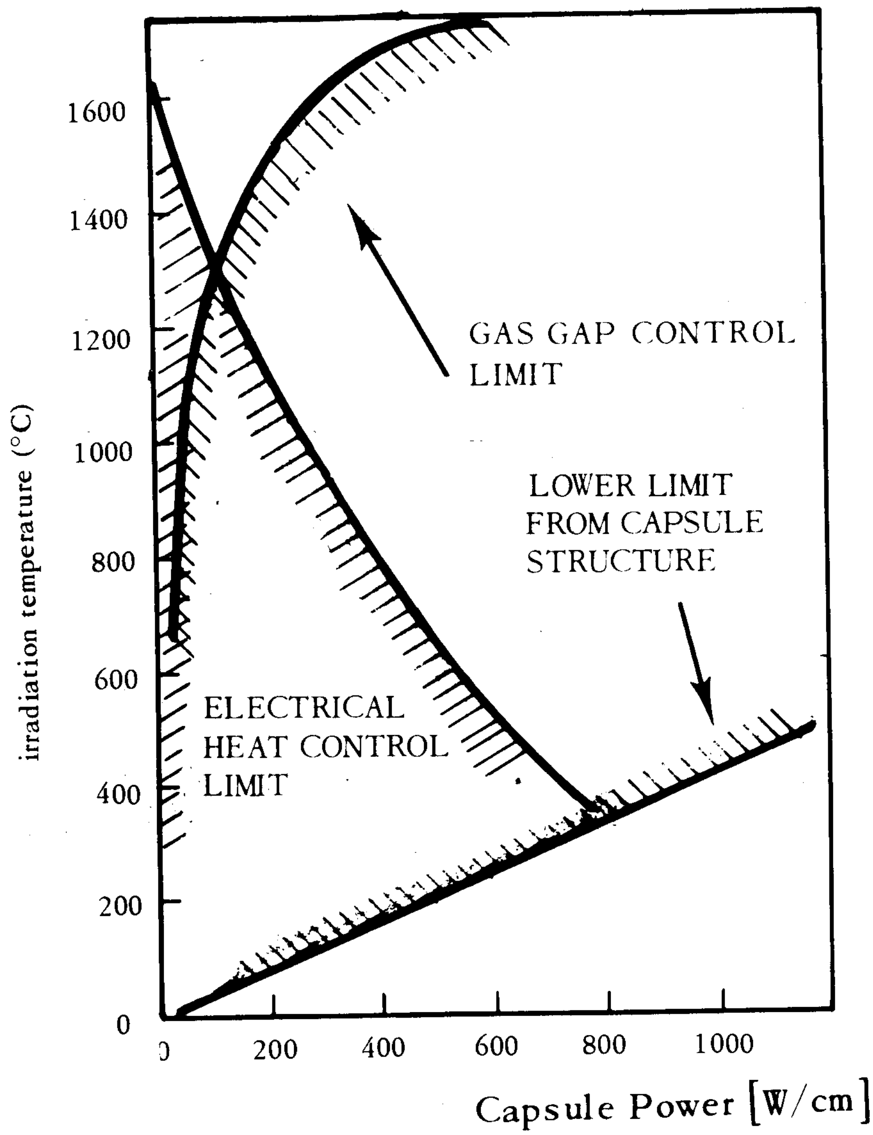


LIMITS OF CAPSULE TEMPERATURE CONTROL.

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.

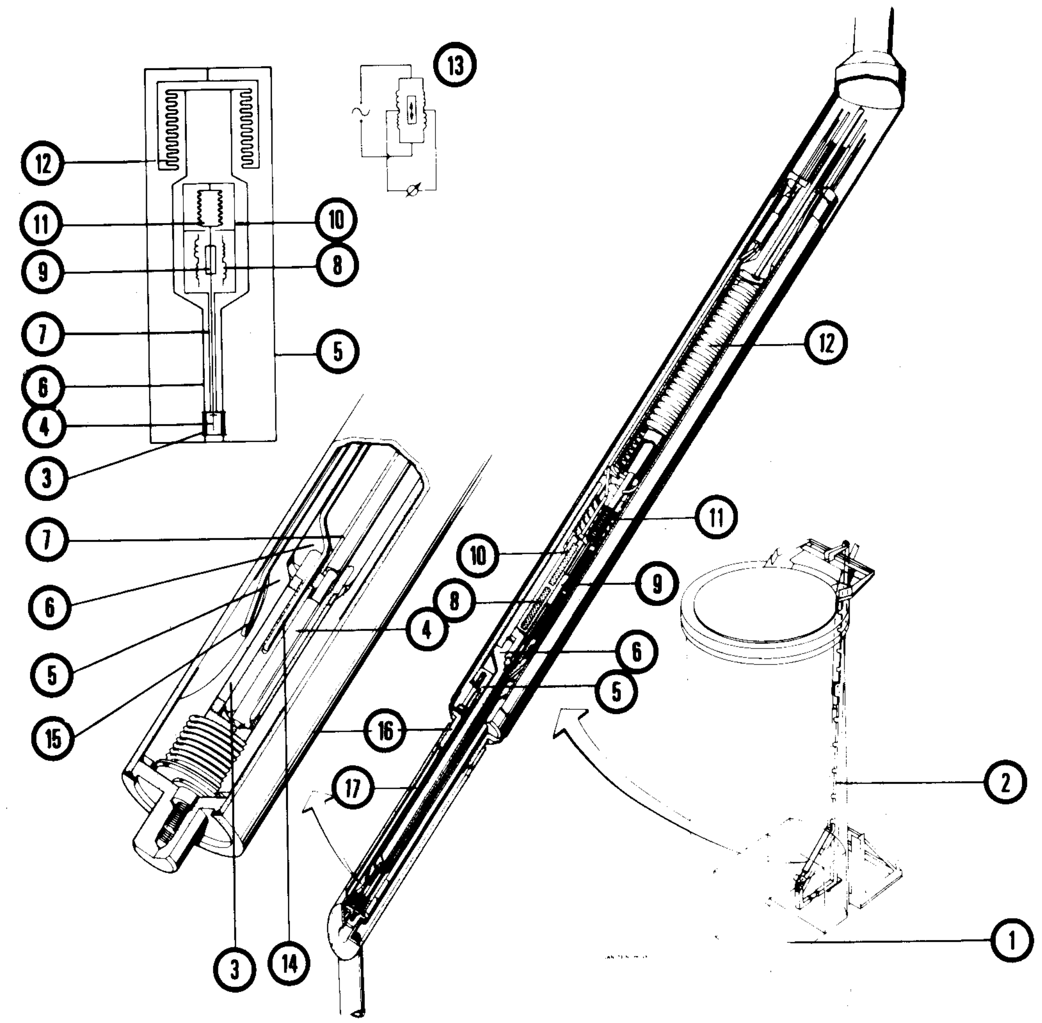
Actually the graphite creep assembly is operational, a fuel creep assembly is being built, and a creep assembly for cladding materials is in the predesign stage.

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 BELLOWS
12. LOADING BELLOW
13. SIMP. SCHEME TRANSDUCER
14. INNER THERMOCOUPLES
15. OUTER THERMOCOUPLES
16. OUTER CONTAINMENT
17. COOLING CHANNEL



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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	:	2.6×10^{14} cm^{-2} s^{-1}
Peak flux fast	:	3.1×10^{14} cm^{-2} 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.

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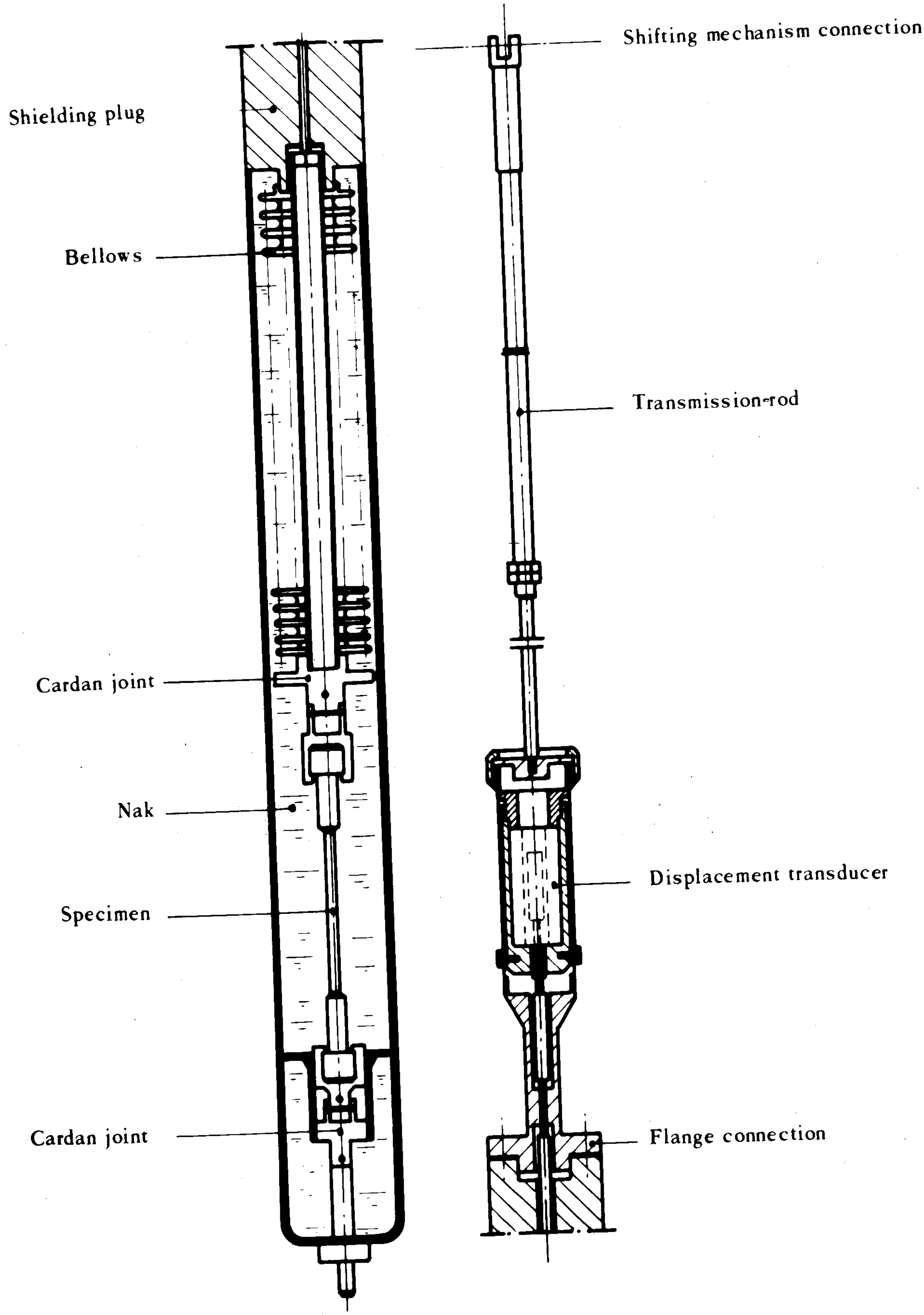

HIGH FLUX REACTOR
IRRADIATION DEVICES

CANNING CREEP ASSEMBLY

IRRADIATION DEVICE SPECIFICATION SHEET.

Designation	:	Canning Creep Assembly
Application	:	Tensile Creep measurements on canning material specimen under irradiation
Reactor positions	:	core or reflector, using Refa thimble
Basic concept	:	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.

Range of utilisation:

Total gauge length	:	100 mm
Tensile load	:	0 to 2000 N
Temperature range	:	250 to 700°C
Transducer coarse	:	$\pm$ 2.5 mm
Transducer resolution	:	$< 10^{-4}$ mm
Peak flux thermal	:	2.6×10^{14} cm^{-2} s^{-1}
Peak flux fast	:	3.1×10^{14} cm^{-2} s^{-1}

Special features:

Controlled load by pressure line to bellow

Temperature variation by gas mixture

Temperature adjustment by Vertical Displacement Unit.

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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 negociations 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

EURATOM PETTEN IRRADIATION TECHNOLOGY

ACTION	EXPL. NOTES
Project Development	Observation of trends in reactor development and irradiation testing, information for potential users.
Irradiation Techniques	Development and application of new techniques of analysis, measurement and fabrication.
Reactor Utilisation	Optimisation and improvement of irradiation facilities and reactor occupation. Allocation of irradiation positions.
Project Handling	Project is initiated by a user's request (letter of intent)
— Preproject	for preliminary negociations
— Proposal	set up by project leader
— Contract	negociated with Contracts Div. after approval of proposal by user and direction
— Design, Analysis	of all necessary experimental equipment
— Safety Report	for approval by the local reactor safeguards committee to operate the equipment
— Manufacture	supply of equipment,subcontractors
— Assembly	line-up components and functional testing
— Testing	reliability and functional testing of assembled equipment,pre-pile operation
— Irradiation	in-pile installation and operation, dosimetry, cycle reports
— Dismantling	P.I.operation,recovery of samples
— P.I. Analysis	alternatively transport of samples to user's laboratories
— Final Report	chronological evaluation of events and presentation of results.

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To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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