EUR 4639 e
Part 4 of 4

COMMISSION OF THE EUROPEAN COMMUNITIES

HFR INFORMATIONS FOR USERS

Survey of high flux facilities in the HFR Petten,
selected for boiling water and
pressurized water reactor (BWR and PWR) materials testing

by

J. MARKGRAF

1972

Joint Nuclear Research Centre
Petten Establishment - Netherlands

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KEYWORD

HFR
IRRADIATION DEVICES
CAPSULES
IRRADIATION PROCEDURES
MATERIALS TESTING
MEASURING METHODS

C.C.R.
Petten Establishment
Irradiation Technology

SURVEY OF HIGH FLUX FACILITIES IN THE HFR PETTEN, SELECTED FOR BOILING WATER AND PRESSURIZED WATER REACTORS (BWR AND PWR) MATERIALS TESTING.

by

J. Markgraf

EUR 4639–4

INTRODUCTION

The present paper intends to give a brief survey on the High Flux Reactor (HFR) of the CCR Petten, its main facilities and corresponding irradiation devices available in view of its utilisation for BWR and PWR materials testing irradiation experiments.

All information is presented in the from of illustrations, tables, diagrams and highlights particular features, restrictions, definitions and subjects related.

A separation into three chapters is made, dealing with the reactor, the irradiation devices and the irradiation projects.

Other papers of this type describing facilities for applications outside BWR and PWR materials testing are also available.

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

The illustrations shown under this heading are:

(a) the reactor vessel, which is placed in the reactor pool. The vessel is sealed and pressurized to 2.6 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 opposit 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 also by the table with horizontal displacement units for adjustment of pool side facility irradiation devices.

(b) 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.

(c) a vertical cross section of the reactor vessel, which shows the main arragements for access to the high flux facilities and some accessory equipment.

(d) a view from the top of the reactor vessel onto the high flux facilities and the different ways of access.

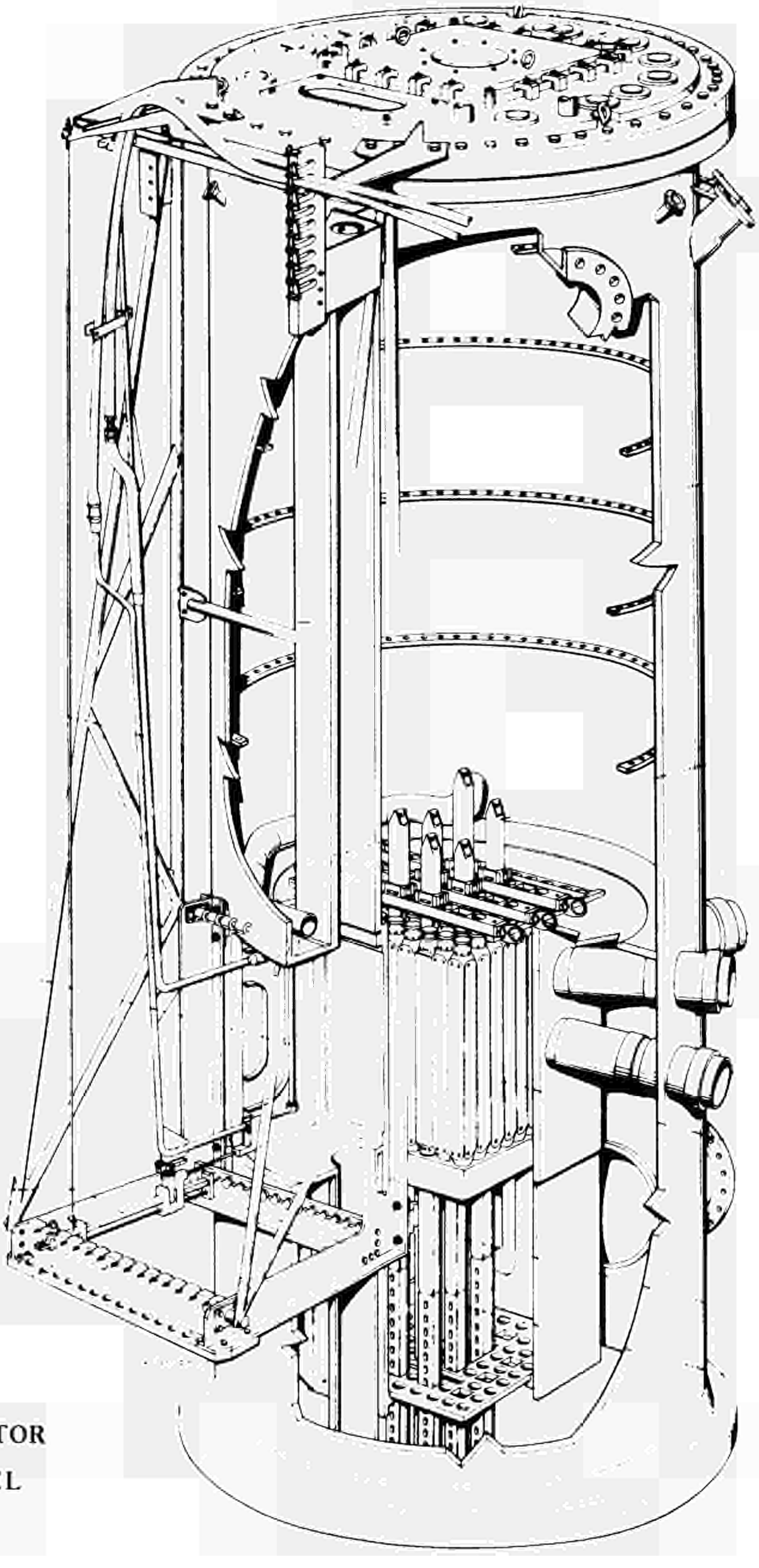
Typical nuclear data are indicated for the different experimental positions on the following two pages. They ar defined as follows: Nuclear heating in W/g induced by nucl radiation on a typical graphite drum; thermal neutron flux density values, reduced to the 2200 m/s energy equivalent according to the Westcott convention; fast neutron flux density is the equivalent fission neutron flux density.

(e) vertical distribution of fast and thermal neutron flux density and nuclear heating density for the experimental positions in the core

(f) vertical distribution of fast and thermal neutron flux density and nuclear heating density for the pool side facility positions, horizontal distribution of fast and thermal neutron flux density in various pool side facility positions and distance to the outside of the core box wall.

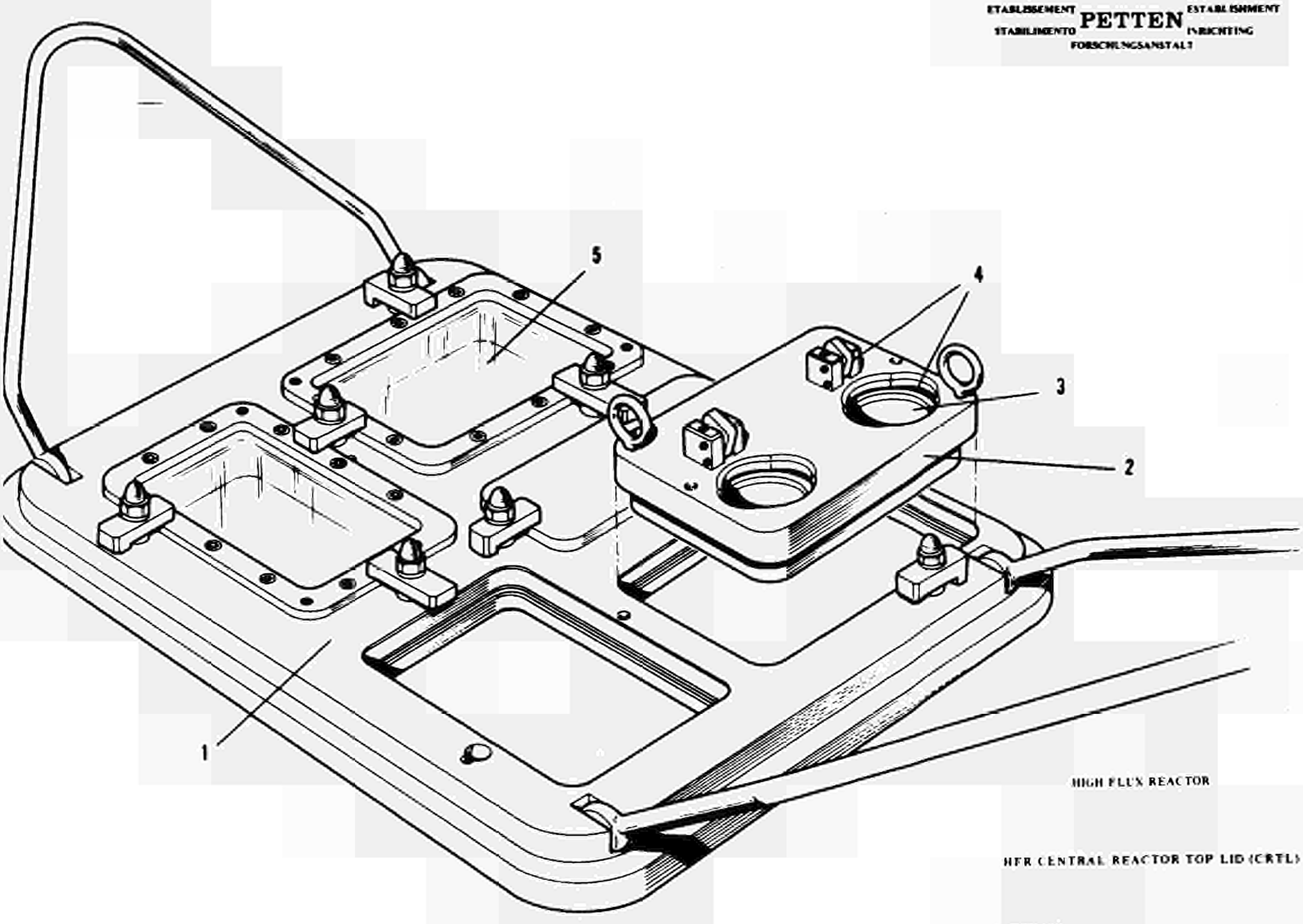
(g) the neutron radiography device, which is placed in the reactor pool near to the pool side facility.
This device serves for neutron radiography examination of irradiated and unirradiated irradiation devices or other devices and materials. The max. dimensions of a device to be examined by neutron radiography may not exceed 75 mm. diameter and 750 mm length. The main applications of neutron radiography are:

- check of integrety of irradiation devices
- check of dimensional changes of fuel pins or other materials
- check for cracks, voids, deformation, burn-up profile in fuel
- check of components made from material with high specific density, which cannot be examined by x-ray.



HIGH FLUX REACTOR
REACTOR VESSEL

ETABLISSEMENT STABILIMENTO **PETTEN** ESTABLISHMENT INRICHTING FORSCHUNGSANSTALT

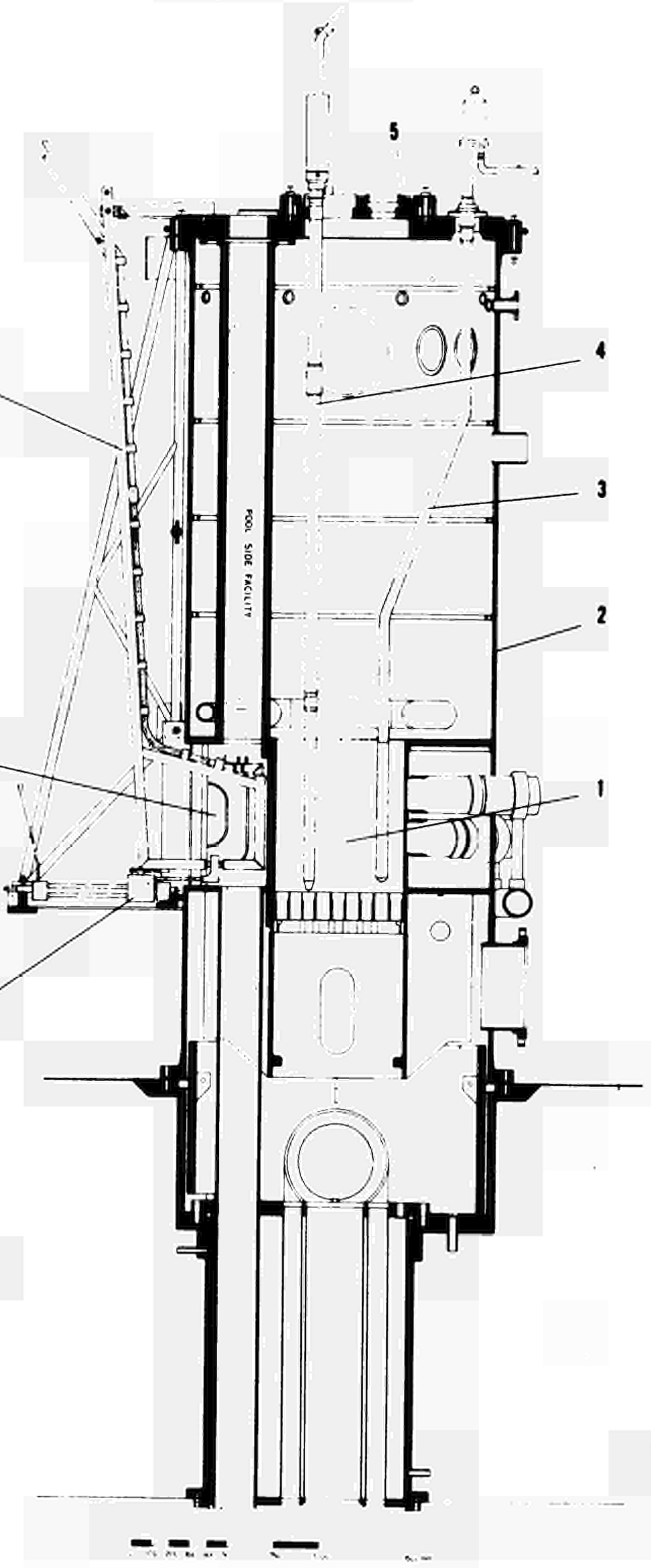


HIGH FLUX REACTOR

HFR CENTRAL REACTOR TOP LID (CRTL)

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

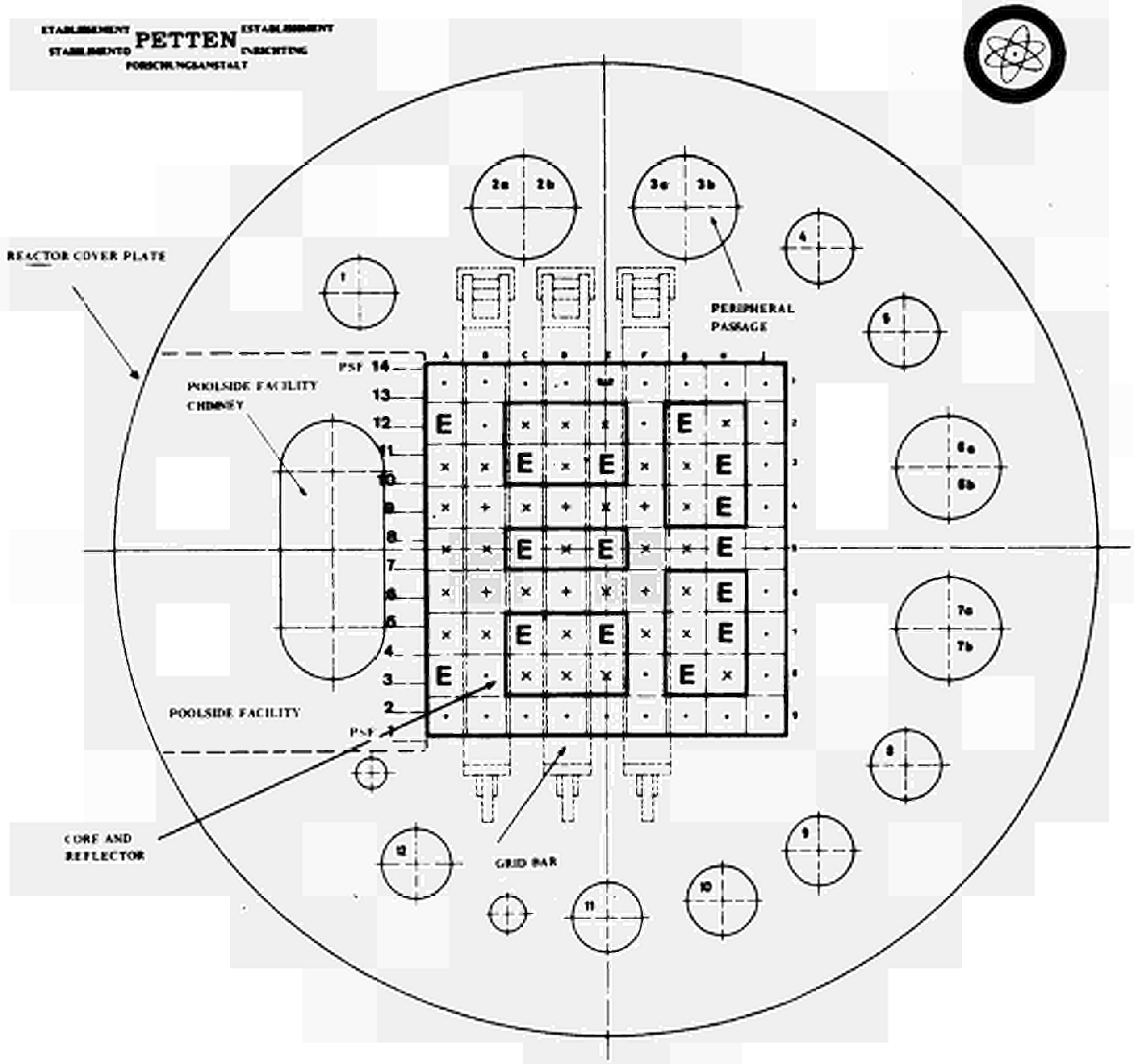
REF FLR
R 1 190



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

REF EUR
R 1202



HIGH FLUX REACTOR

HIGH FLUX IRRADIATION FACILITIES

▭	ACCESS BY CENTRAL REACTOR TOP LID
+	CONTROL ROD
×	FUEL-ELEMENT
•	Be-ELEMENT
E	EXPERIMENT POSITIONS IN HFR-CORE

PSF 1...14 – EXPERIMENT POSITIONS IN POOL SIDE FACILITY.

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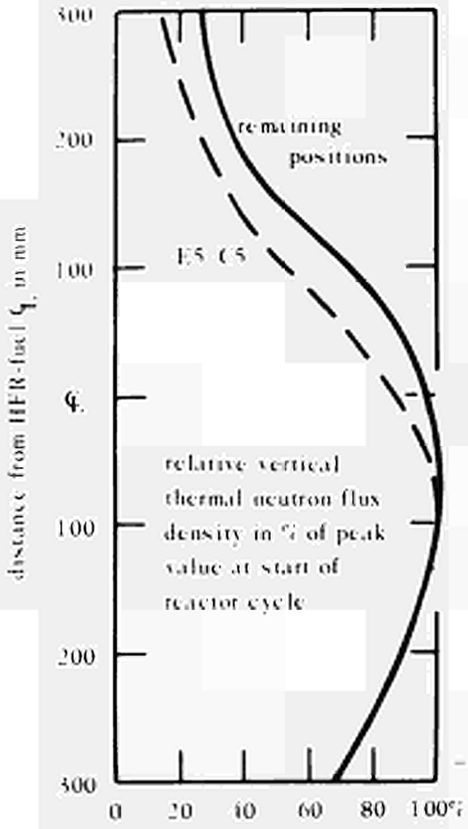
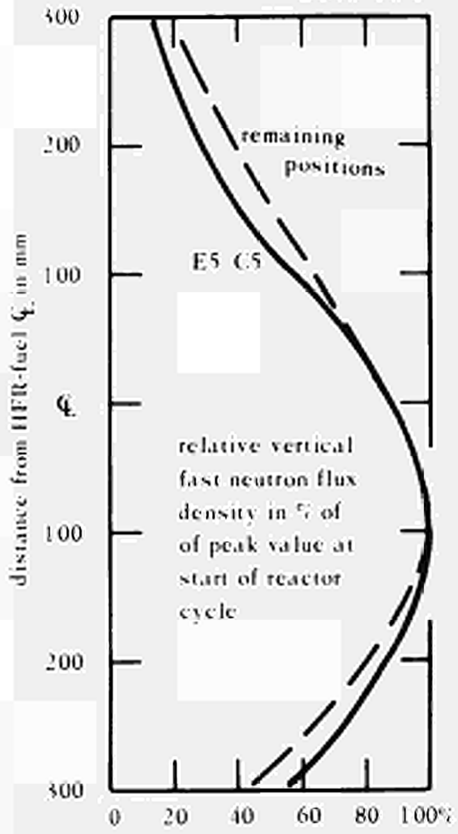
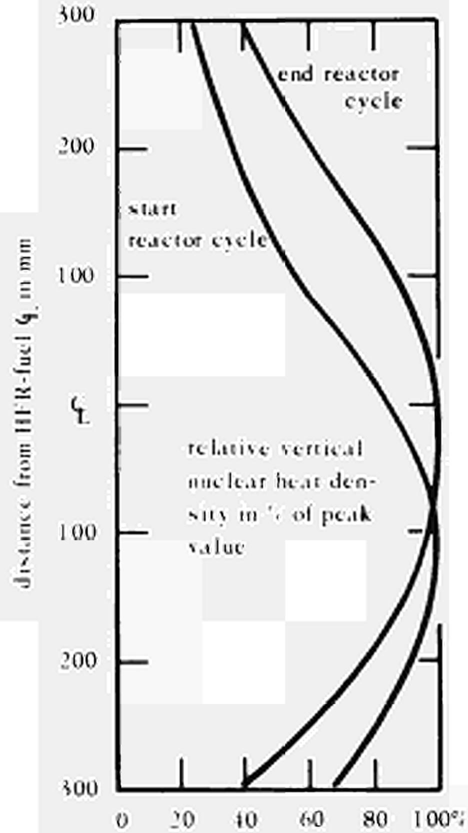




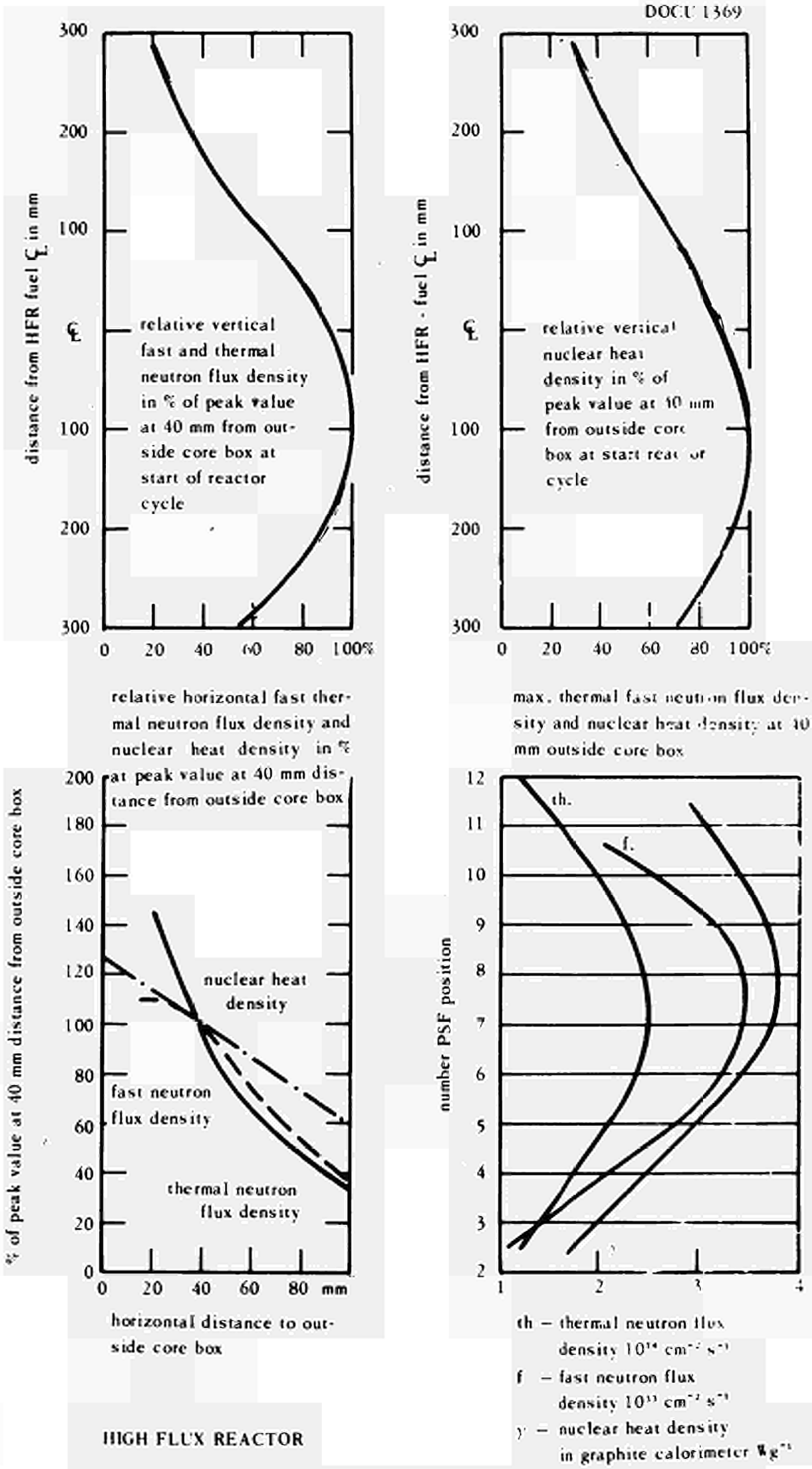


Core position	neutron flux density $.10^{14}\ cm^{-2}\ s^{-1}$ max. thermal	max. fast	nucl. heat* $W.g^{-1}$ graphite max. nucl. heat
A2,A8	1,20	0,7	10
C3,C7	2,10	2,60	11
C5	2,35	2,85	13
E3,E7	2,30	2,85	12
E5	2,60	3,15	14
G2,G8	1,75	1,00	5
H3,H7	1,40	1,05	5
H4,H6	1,45	1,20	5
H5	1,45	1,25	5

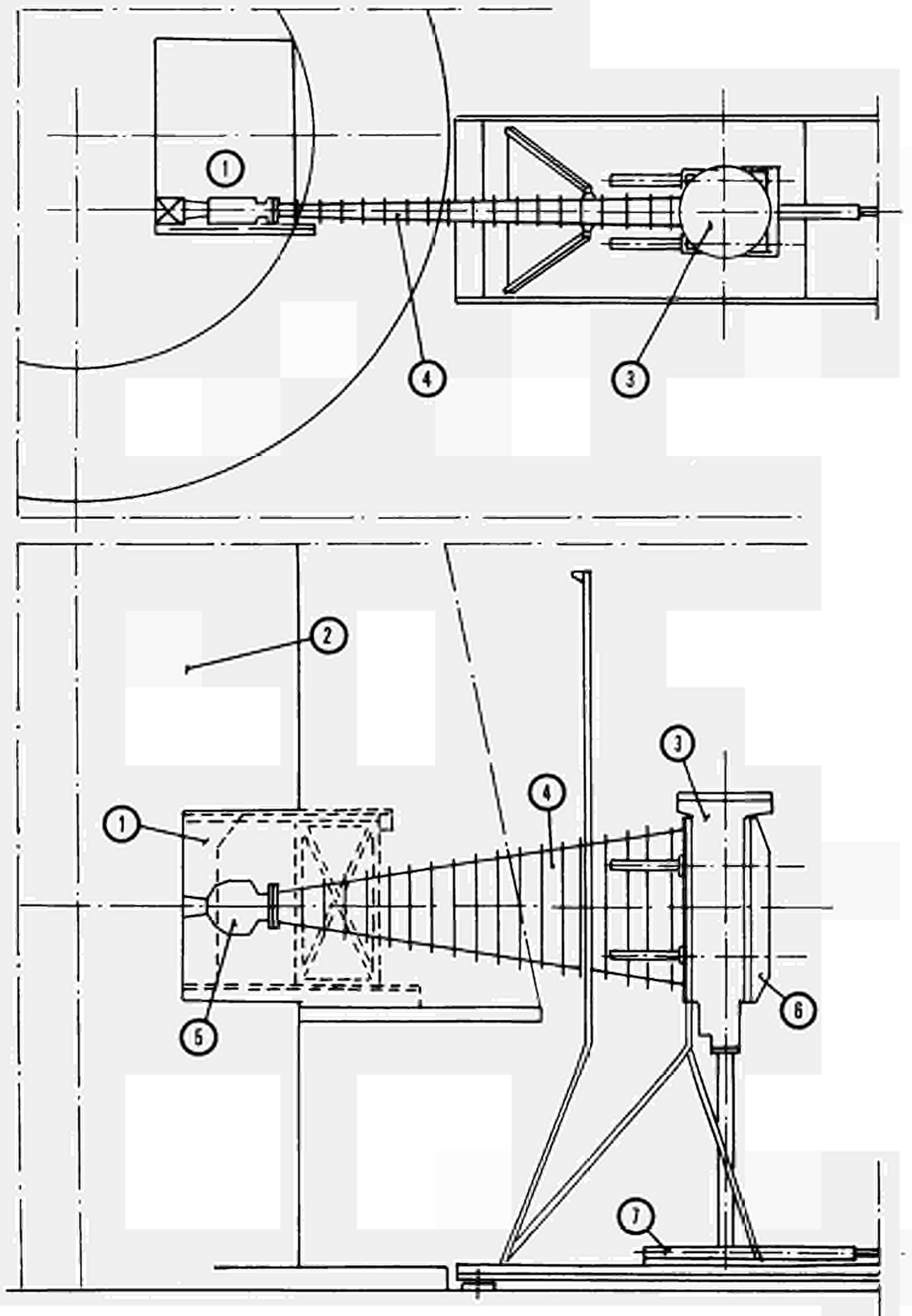
* in typical graphite drum

HIGH FLUX REACTOR

HFR - Petten, typical nuclear data of PSF-positions at 45 MW reactor power.



HFR - Petten, typical nuclear data of PSF-positions at 45 MW reactor power.


1
4
3
2
1
4
3
5
6
7

HIGH FLUX REACTOR

Neutron Radiography Device

1 - Poolside facility
2 - HFR pressure vessel
3 - Object holder
4 - Collimator
5 - Diaphragm
6 - Cassette system
7 - Vertical displacement device and support structure.
8 - Typical photo of neutron radiography at an UO_2 - fuel pin with voids in the center.

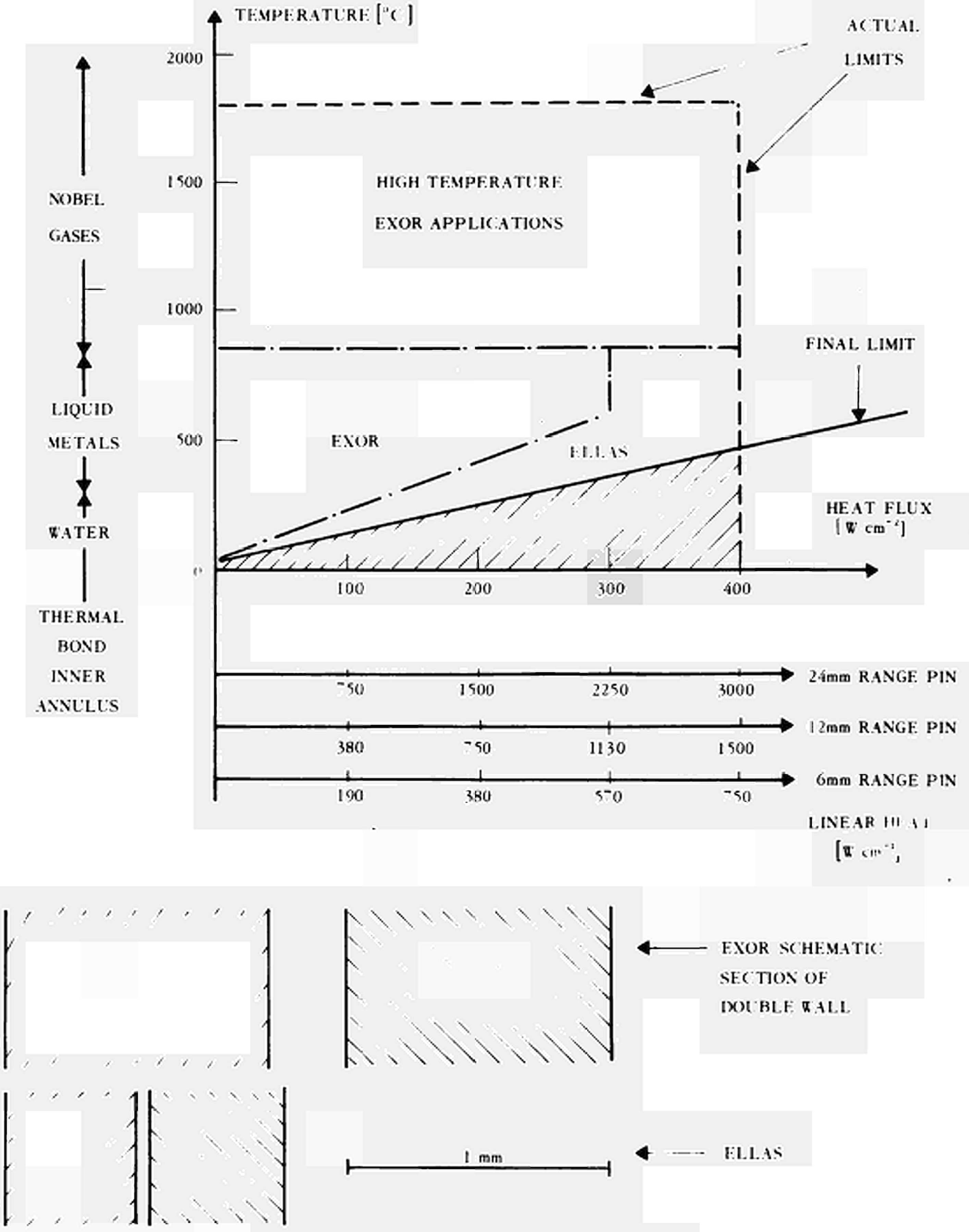
3. SURVEY OF AVAILABLE IRRADIATION DEVICES

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

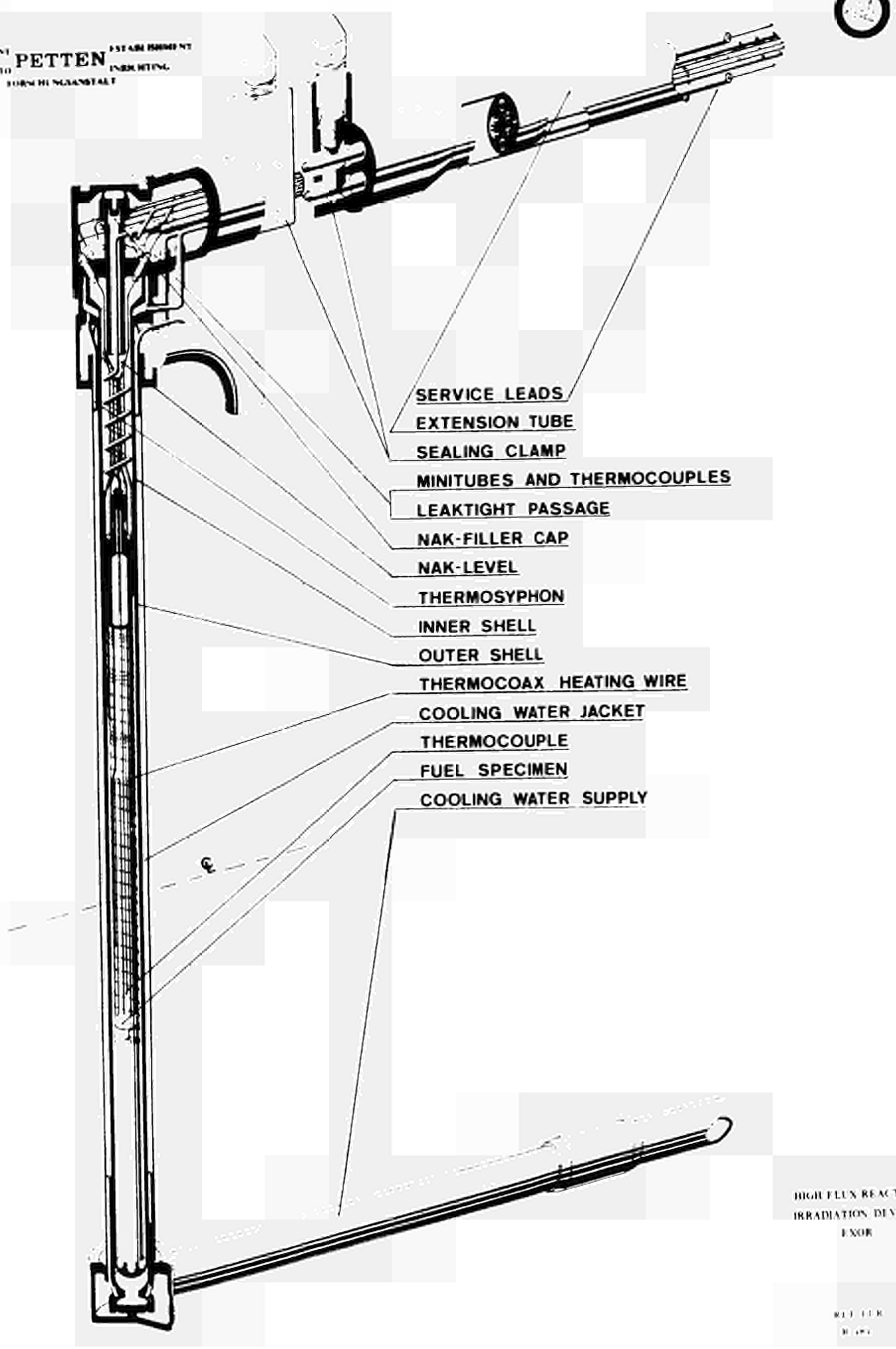
Due to the hazard of contamination by fission products, double containment is normally required for irradiations of fissile material in the HFR. The opposite scheme shows the general operation fields of double wall capsules.

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

ETABLISSEMENT PETTEN ESTABLISHMENT
STABILIMENTO INRICHTING
FORSCHUNGSANSTALT



HIGH FLUX REACTOR
IRRADIATION DEVICES
EXOR

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}	x) in core
Peak flux fast x) :	3.1×10^{14} cm^{-2} 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.

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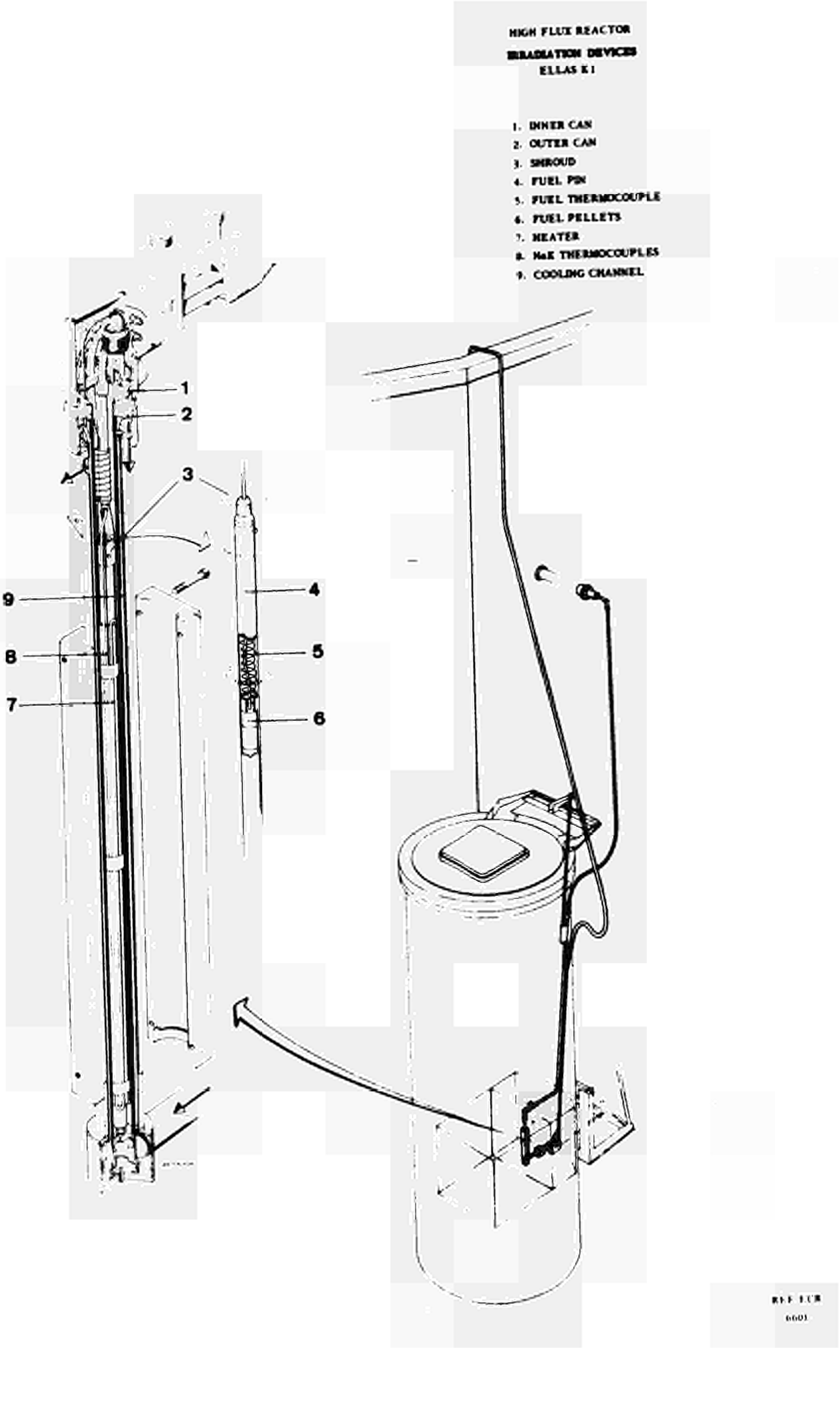
HIGH FLUX REACTOR
IRRADIATION DEVICES
ELLAS K1
1. INNER CAN
2. OUTER CAN
3. SHROUD
4. FUEL PIN
5. FUEL THERMOCOUPLE
6. FUEL PELLETS
7. HEATER
8. NaK THERMOCOUPLES
9. COOLING CHANNEL
1
2
3
4
5
6
7
8
9

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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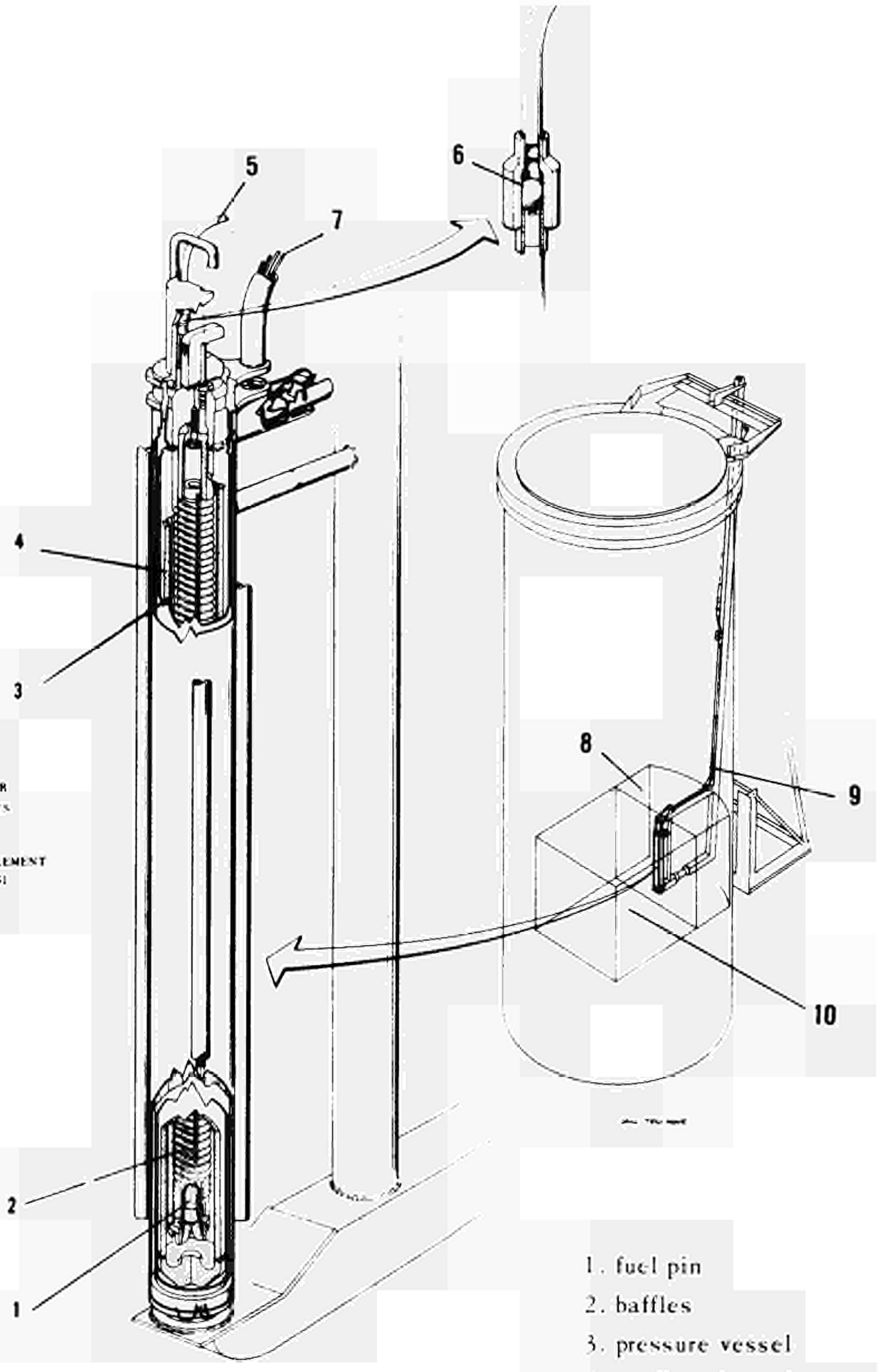
HIGH FLUX REACTOR
IRRADIATION DEVICES

BOILING WATER FUEL ELEMENT
CAPSULE BWFC – 51



1. fuel pin
2. baffles
3. pressure vessel
4. cooling channel
5. primary water monitoring
6. no return valve
7. thermocouples
8. poolside facility
9. standard carrier
10. HFR core

IRRADIATION DEVICE SPECIFICATION SHEET

Designation	: BWFC
Application	: Irradiation of canned fuel
Reactor position	: Pool Side Facility alternatively core or reflector
Basic concept	: Heat removal from specimen by sub-cooled boiling in pressure vessel Primary water sampling + chemistry Open secondary cooling-circuit

Range of utilisation:

Specimen length	: 400 mm	
Specimen diameter	: 10 mm	
Heat dissipation	: 800 W/cm	
Cladding temperature	: 350 °C	
Peak flux thermal x)	: 2.8×10^{14} cm^{-2} s^{-1}	x) in PSF
Peak flux fast x)	: 0.6×10^{14} cm^{-2} s^{-1}	

Special features:

Thermal calibration by thermal balance of coolant
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
Thermal cycling by H.D.U. at constant cladding temperature
Temperature control by variation of primary pressure
Corrosion testing

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BOILING WATER FUEL ELEMENT CAPSULE BWFC.

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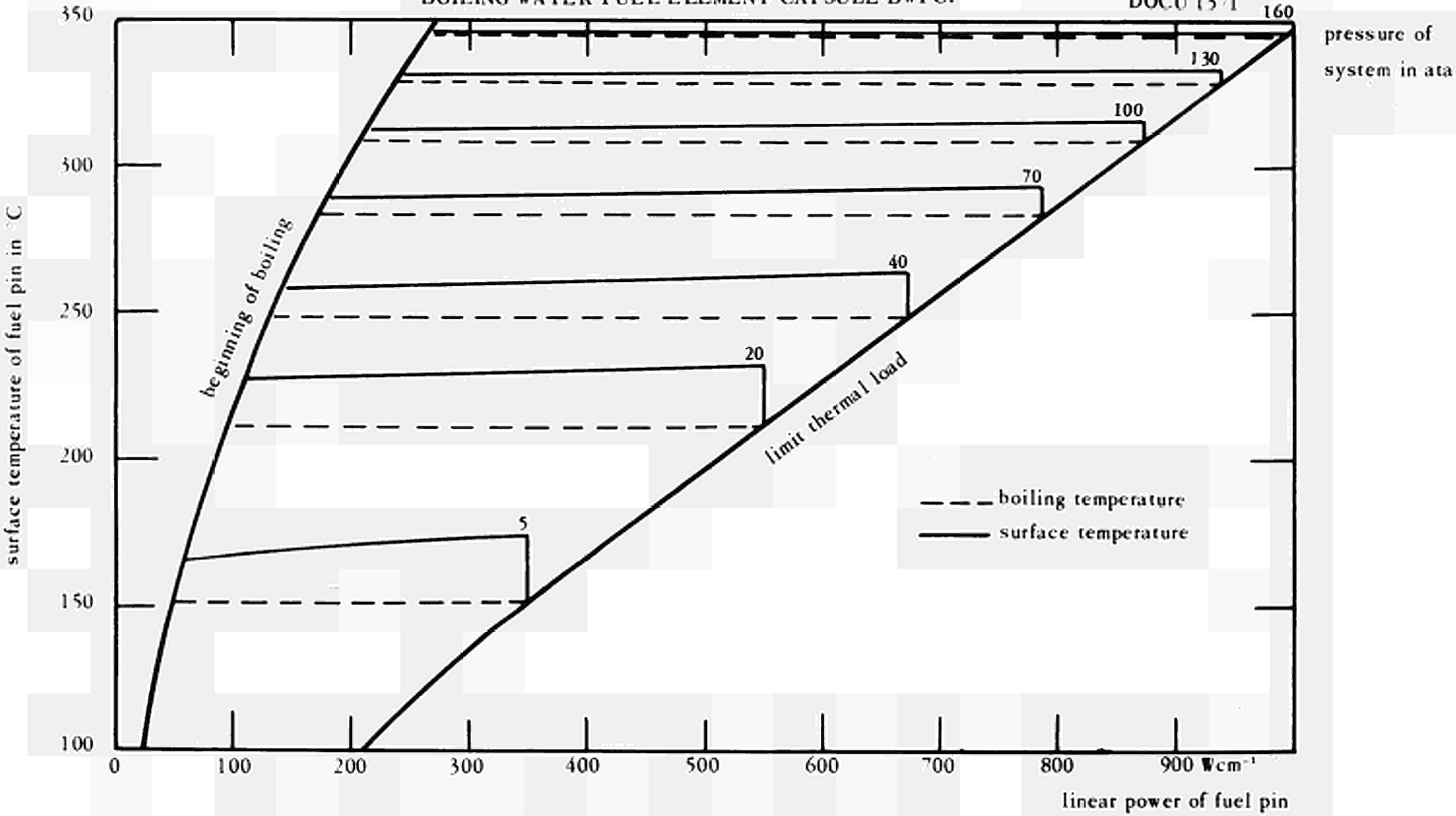
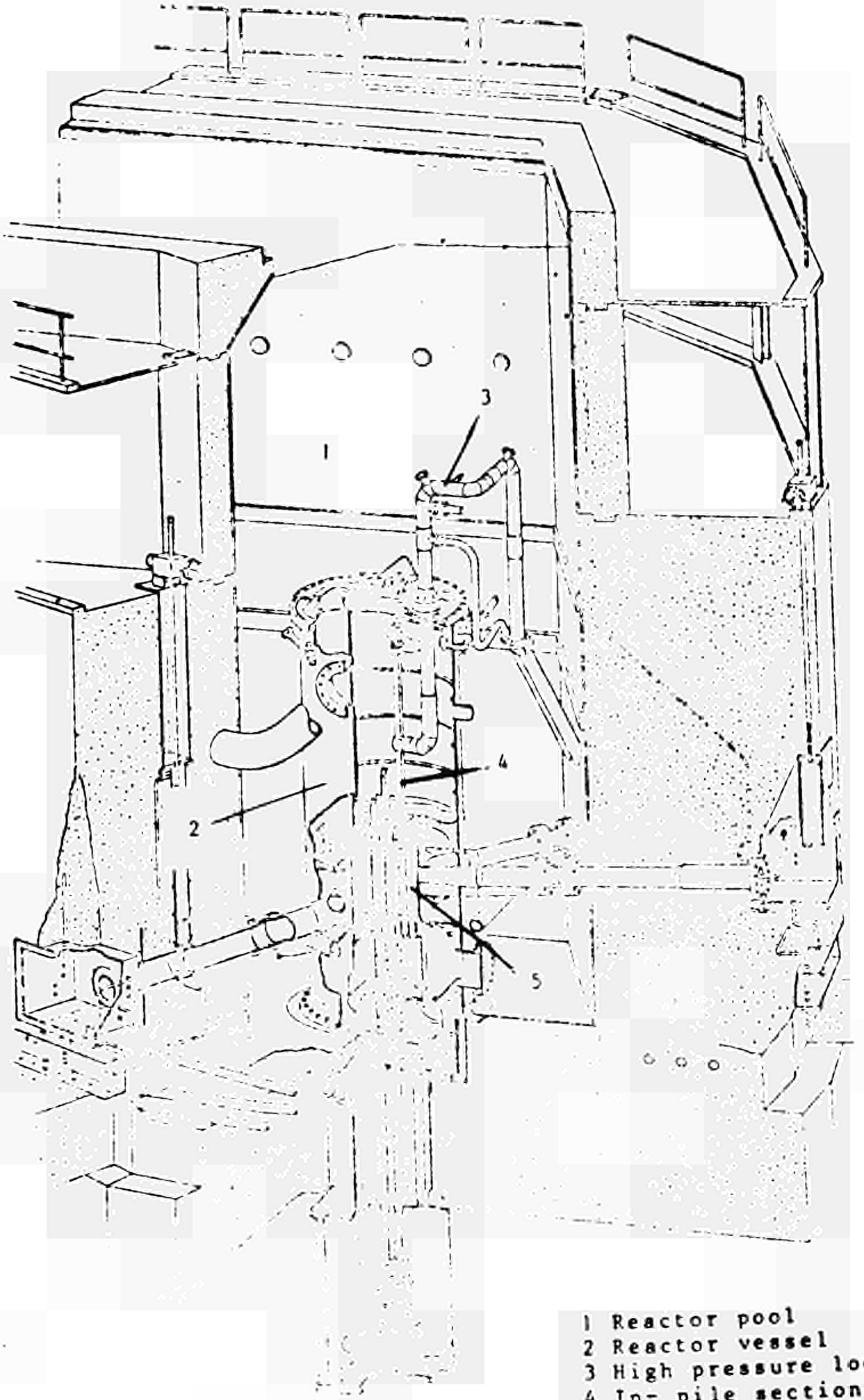


Linear power and surface temperature of a 12 mm diameter fuel pin in function of system pressure at inlet temperature of coolant of 30°C and flow rate of coolant 0,5 kg s⁻¹ boiling water fuel element capsule BWFC.

HIGH FLUX REACTOR
IRRADIATION DEVICES
HIGH PRESSURE LOOP HD



1 Reactor pool
2 Reactor vessel
3 High pressure loop HD
4 In- pile section of HD
5 Core and reflector

IRRADIATION DEVICE SPECIFICATION SHEET.

Designation : High pressure loop, HD-HFR

Application : Irradiation of canned fuel, fuel bundles and structural materials

Reactor positions: H 5 and H 6 in the core

Basic concept : Water loop with U-shaped in-pile section, heat remocal by forced cooling, separate loading of each leg at open reactor vessel.

— Range of utilization.

Useful length : 760 mm in flux zone, 1000 mm above flux zone

Useful diameter : 42 mm (free passage)

Loop pressure : 140 bars

Temperature of coolant: 280°C at inlet of in-pile section

Cooling capacity : 200 kW when both in-pile sections are loaded
140 kW when only one in-pile section is used.

Max. perm.surface heat flux of fuel pin: depending on experimental set up e.g. 700 W cm^{-1} at 280°C inlet temperature of coolant, 12 mm diam. fuel pin and 15 mm^{3} h^{-1} flow; 1200 Wcm^{11} at 200°C inlet temperature of coolant, 12 mm diam. fuel pin and 20 m^3 h^{-1} flow.

Max. coolant flow: 20 m^3 h^{-1}

Max. allowable fuel rating $\int_0^{Te} k\,dt$: > 95 for UO_2 pellets

Water quality : > 8 pH (adjustable by NH3)

Peak flux thermal: $1{,}4.10^{14}$ cm^{-2} s^{-1}

Peak flux fast : $1{,}2.10^{14}$ cm^{-2} s^{-1}

Special features.

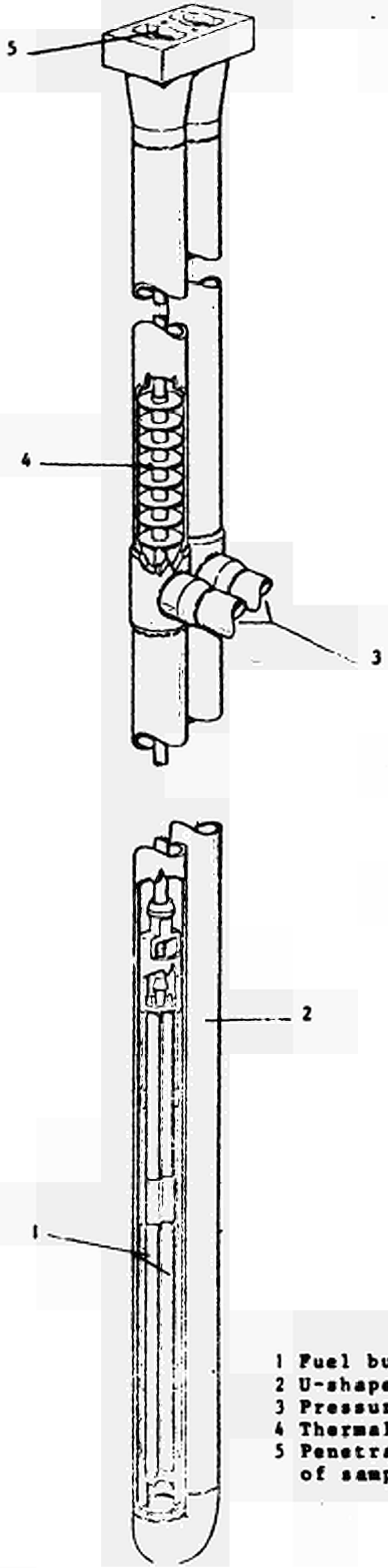
Thermal calibration by thermal balance of coolant

Measurement of bulk water temperature

Corrosion testing

Water chemistry.

HIGH FLUX REACTOR
IRRADIATION DEVICES
IN-PILE SECTION OF
HIGH PRESSURE LOOP HD



1 Fuel bundle (sample holder)
2 U-shaped in-pile section
3 Pressurized water in- and outlet
4 Thermal barrier
5 Penetration for instrumentation of sample holder inserted

Sampling and analysis system(B.A.T.)for high pressure loop (HD-HFR).

In combination with the HD-HFR a special device B.A.T.can be operated as bypass system for corrosion testing purposes and water chemistry.

The B.A.T. consists of:

-a high temperature mechanical filter,
-a high temperature ion exchanger,
-a low temperature mechanical filter,
-two sampling vessels at low temperature,
-low temperature anion-,kation-and mixed bed ion exchangers.

The max.allowable operational temperature in the low temperature section of B.A.T. is 50^{o}C.
Each filter, ion exchanger and vessel can be separated from the system.

Water quality and activity are measured before and after the filters. The flow (about 30 kg h^{-1}) is measured by a flowmeter.

With B.A.T. the following tests can be made:

- With the high temperature mechanical filter: retention of solid particles in stainless steel discs of 3, 20 and 75 microns mesh.

- With the high temperature ion exchanger: exchange of active metal ions and metal oxides to a non-active bed of metal oxide grains as e.g. magnetite.

- With the low temperature mechanical filters: retention of solid particles in stainless steel discs of 3, 20 and 75 microns mesh.

- With the low temperature ion exchangers: selective absorption of ions in anion- or kation exchanger and study on function of resin beds.

- With the sampling vessels: as the two vessels are exchangeable, complete analysis of the water is assured with external equipment available in the center e.g. gas-chromatograph.

Instead of a sampling vessel, special devices or equipment can be installed for special purposes. Adaptation of B.A.T. to special requirements is possible on request.

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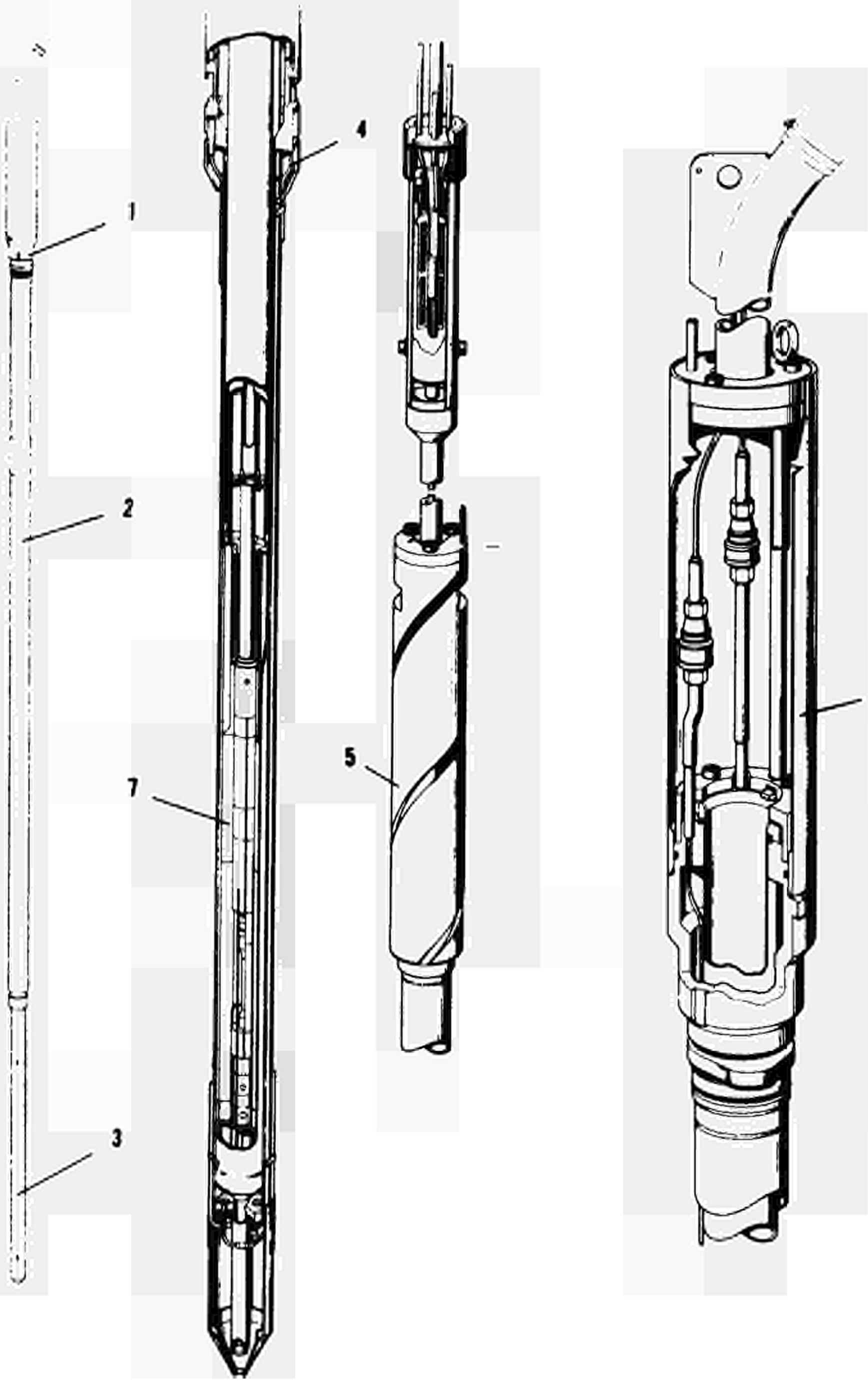
3.2 Irradiation devices for non fissile materials

Under this heading two irradiation devices are presented, they are called REFA and GRIF.
They differ in temperature range, temperature accuracy, useful specimen volume and permissible nuclear heat load limiting their use in in-core positions.
A new device is presently being built, TWIN. This device is based on the REFA design but has two thimbles in-pile with an useful diameter of 29 mm. The TWIN device will be operational in Sept. 1971.
As already mentioned in the previous chapter the high pressure loop, HD-HFR, can be used for non fissile material irradiations in particular for corrosion testing.
At the end of this section a simplified diagramm conveys a general impression on capsule temperature control.

PETTEN



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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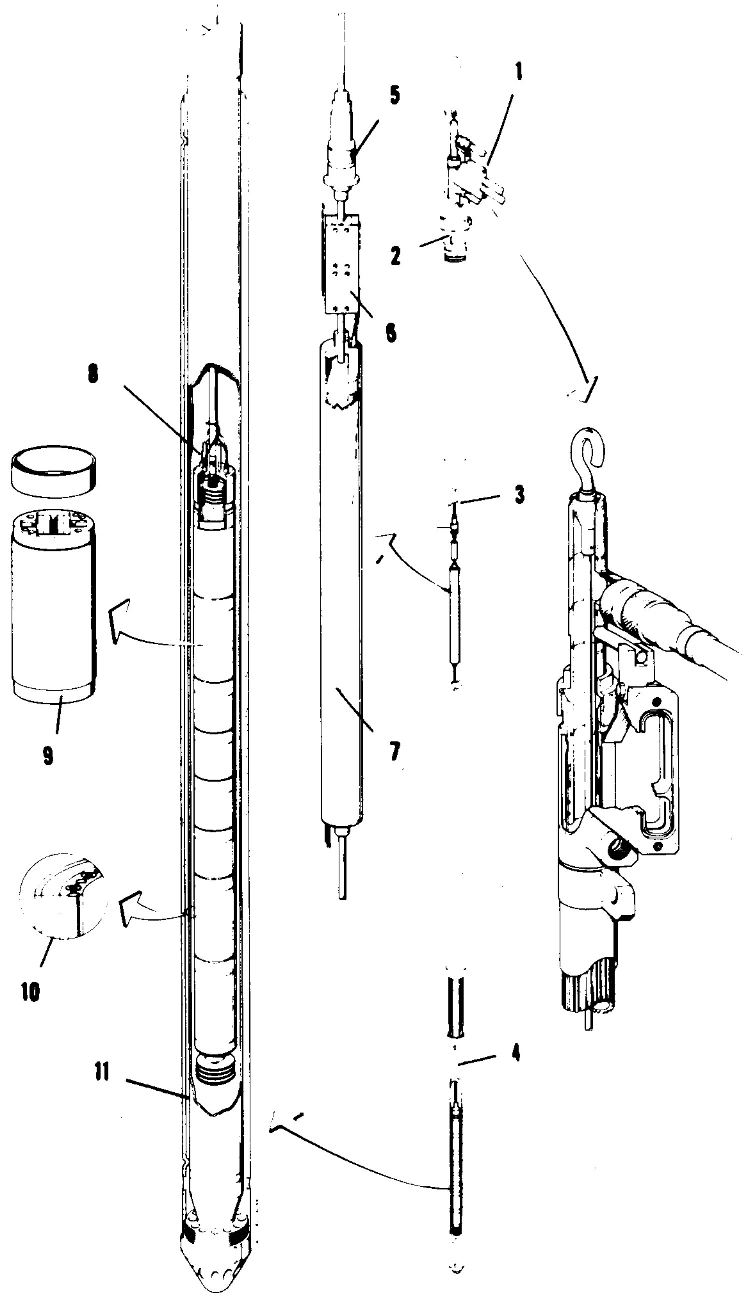
ETABLISSEMENT PETTEN ESTABLISHMENT
STABILIMENTO INRICHTING
FORSCHUNGSANSTALT

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



REF HFR
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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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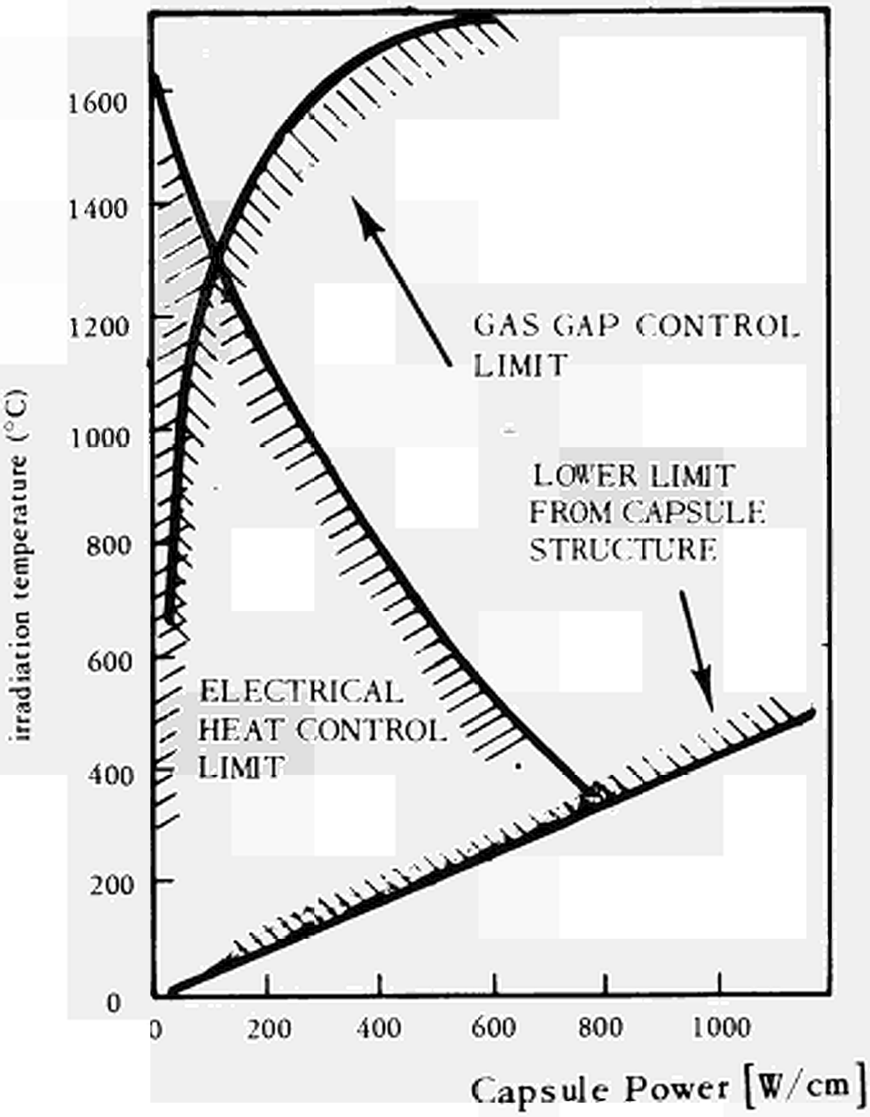
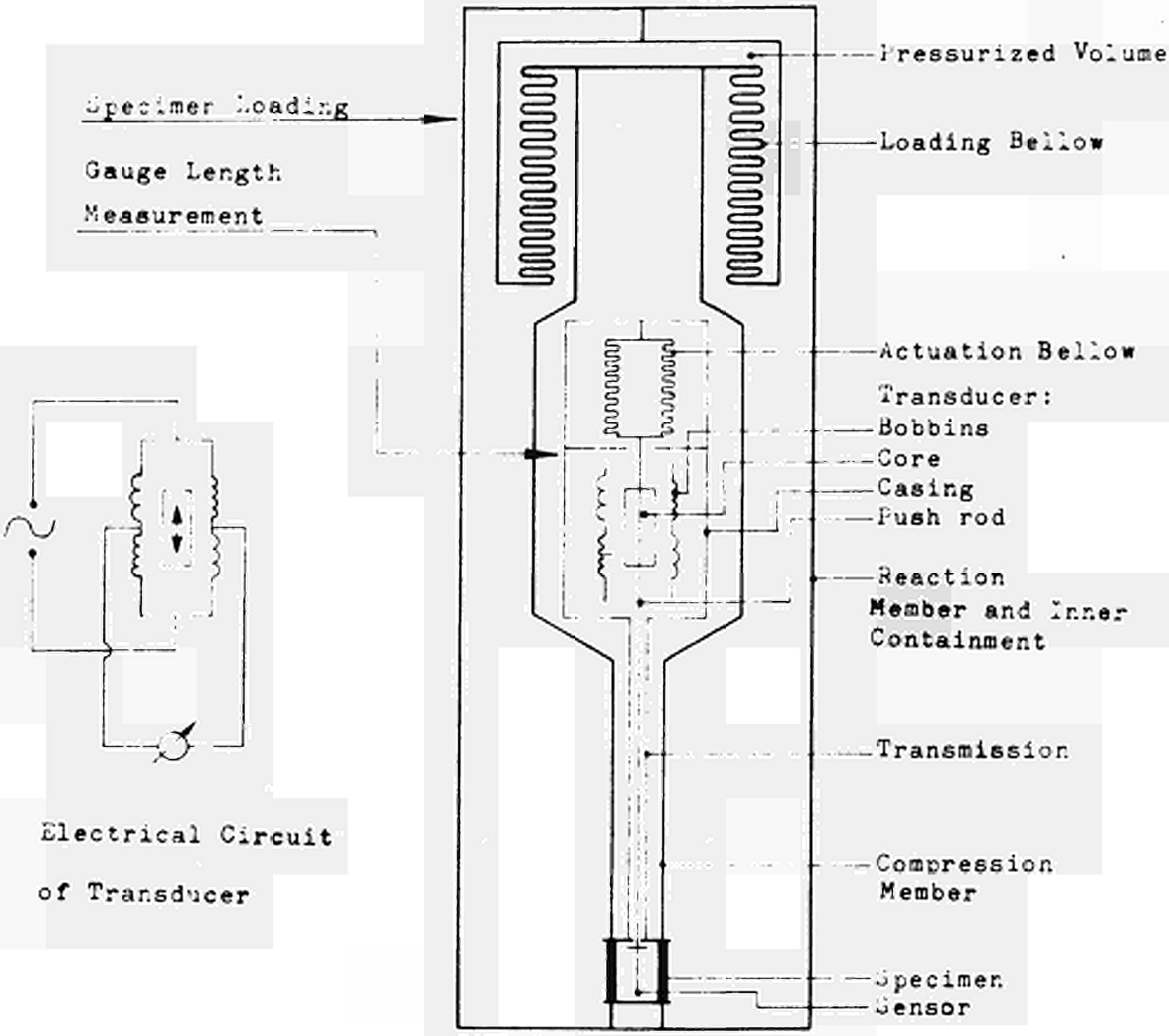


LIMITS OF CAPSULE TEMPERATURE CONTROL.

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 drawn between compressive or tensile testing. From the materials point of view we categorise ceramic fuel, cladding and 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.

The main facilities of these devices are the loading and the measuring systems. 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.



Scheme of Fuel Creep Assembly.

IRRADIATION DEVICE SPECIFICATION SHEET

Designation	:	Fuel Creep Assembly
Application	:	Measurement of elongation of fissile specimen during neutron irradiation under variable loading, fission rate and specimen temperature.
Reactor position	:	pool side facility, alternatively core or reflector.
Basic concept	:	Hollow cylindrical specimen 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; specimen thermal bonding NaK or noble gases.

Range of utilisation:

Total gauge length	:	20 mm
Compressive load	:	0 to 3000 N
Temperature range	:	> 800°C
Transducer coarse	:	± 2.5 mm
Transducer resolution	:	$< 10^{-4}$ mm
Peak flux thermal x)	:	2.8×10^{14}
Peak flux fast x)	:	0.6×10^{14}

x) in PSF

Special features:

Controlled load by pressure line to bellow.

Temperature variation by gas mixture.

Fission rate control by horizontal displacement unit.

Transducer remote from specimen.

Differential gauge length measurement by bellow actuated sensor.

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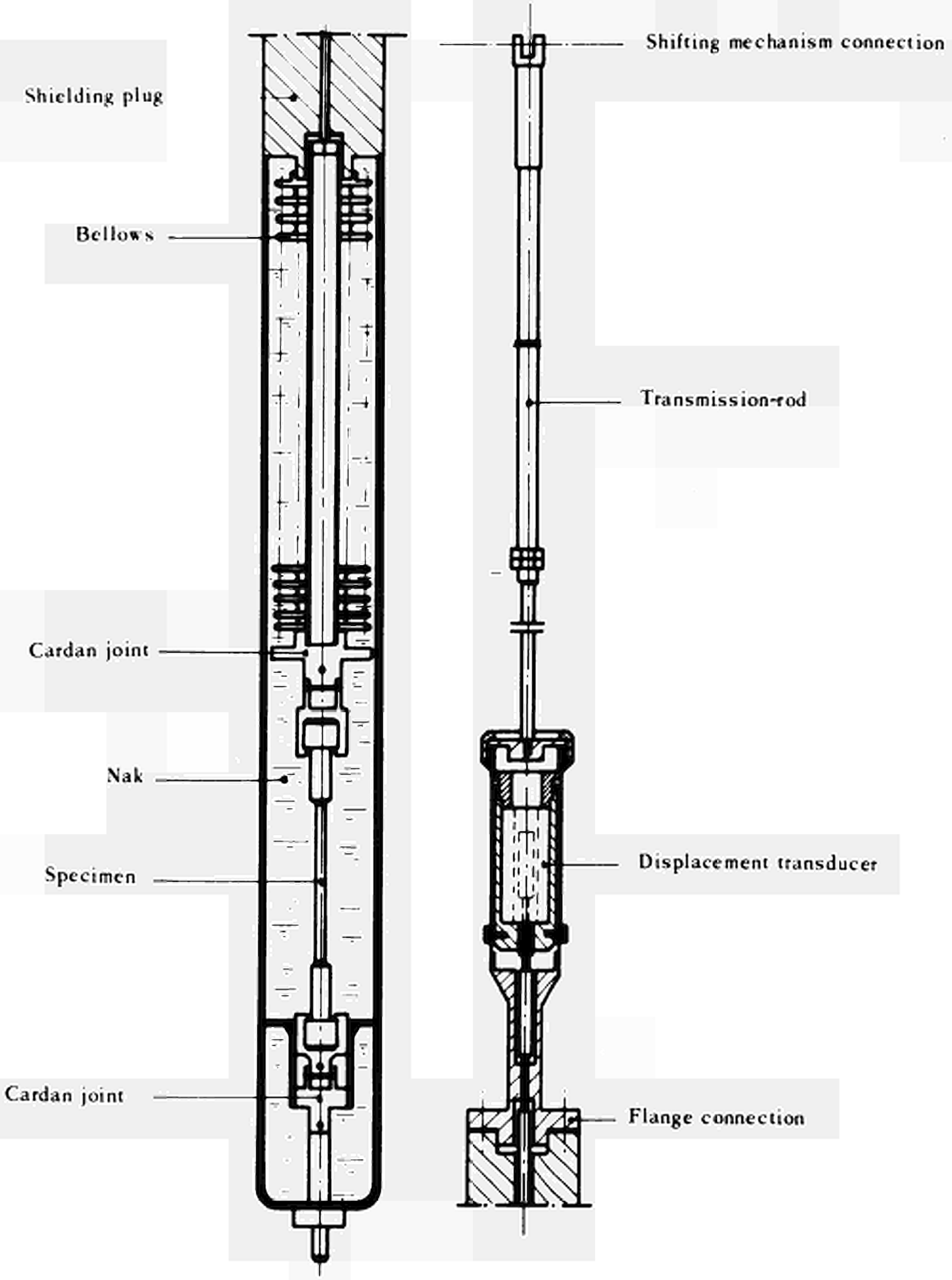

HIGH FLUX REACTOR
IRRADIATION DEVICES
CANNING CREEP ASSEMBLY

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	:	± 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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Alfred Nobel

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