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POTENTIAL BR2 IRRADIATION TEST FACILITIES FOR GBR FUEL

by

P. von der HARDT

1972

Report prepared at the CEN
Centre d'Etude de l'Energie Nucléaire, Mol - Belgium

Association No. 006-60-5 BRAB

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ABSTRACT

Potential contributions from irradiation testing in BR2 to fuel and materials development for the Gas-Cooled Fast Breeder Reactor can originate from the existing liquid metal cooled devices and high temperature rigs as well as from new designs, mainly in-pile gas loops.

Short descriptions of available and possible BR2 facilities are given, together with their performance figures, with particular reference to GBR parameters.

KEYWORDS

IRRADIATION
BR-2
REACTOR MATERIALS
GAS COOLED REACTORS
FAST REACTORS
BREEDER REACTORS
CAPSULES
IN PILE LOOPS
GAS FLOW
PLANNING
PERFORMANCE

Potential BR2 Irradiation Test Facilities for GBR Fuel.

Tables.

Figures.

Summary.

This report is intended as a guide to BR2 irradiation possibilities but also as a basis of discussions from which suggestions on the development of new facilities should originate.

The Belgian Materials Testing Reactor BR2 (Mol, Belgium) has been used as a test irradiation facility and as a radioisotope production plant since 1963. Its irradiation devices are designed according to the requirements of three main programmes :

- the fuel element R & D work of the sodium-cooled fast breeder reactor,
- the fuel and graphite R & D work of the gas-cooled high temperature reactor,
- the production of radioisotopes, including heavy nuclei beyond plutonium.

The present report summarizes potential contributions to the Research and Development work of the gas-cooled fast breeder reactor (GBR)* which can come forth from existing BR2 irradiation devices and from those to be developed and built, viz. :

- FAFNIR (liquid metal cadmium-screened rig),
- C.P.U.R. (swept coated particle rig),
- He 2 (2 or 20 kW in-pile helium loop),
- He 3 (400 kW transformation of existing CO_2 into He loop).

Hence, both metal-clad fuel pin and coated particle fuel have been considered. Experimental parameters used in this report are derived from recent publications** in the GBR field (Ref. 1, 2, 4, 10, 12, 13, 15, 16). Each irradiation facility is presented by schematic drawings of in-pile section and out-pile equipment, together with its main performance parameters. Estimated figures on availability and cost are given wherever possible.

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*) The abbreviation "GBR" is used, within the scope of the present report, without reference to a particular reactor concept.

**) Some of the references mentioned in paragraph 4 of this report are not available in open literature. Hence, no direct information has been disclosed from them.

1. General.

1.1. Present Status of BR2.

From November 1971, BR2 operates with new primary heat exchangers which will enable the increase of the thermal output from 70 to 100 MW. The increased capacity is utilized to accomodate a large loading of reactor fuel elements which, in turn, is required by the great number of irradiation experiments loaded. The photograph fig. 1 shows gas leads and instrumentation cables in the reactor pool, giving an image of the intensive reactor utilization.

Typical nuclear data of the BR2 core are summarized in table 1 hereafter.

Future increases of the available neutron fluxes are envisaged, taking full profit from the enlarged thermal capacity of the system.

1.2. GBR Irradiation Devices.

As for the gas-cooled fast breeder reactor concepts as such, the development of adequate irradiation devices is founded on experience from both the liquid-metal-cooled fast reactor and the gas-cooled high temperature reactor lines.

Experiments for these two reactor types carried out in BR2 are resumed in tables 2 and 3 hereafter.
Table 2 presents the most important operating facilities for LMFBR fuel. Most of these use NaK or Na as a primary heat transfer medium, but should be directly applicable to certain GBR tasks.
Table 3 contains, in its upper portion, facilities for the HTGR which are no longer in use, the two main operating series of experiments in the central part, and "special" irradiation devices in the lower part.

Finally, table 4 shows some facilities (operating, extrapolated or to be developed) which are assumed to be of certain value to the development of GBR fuel.

Brief presentations of these facilities are then given in the following paragraphs.

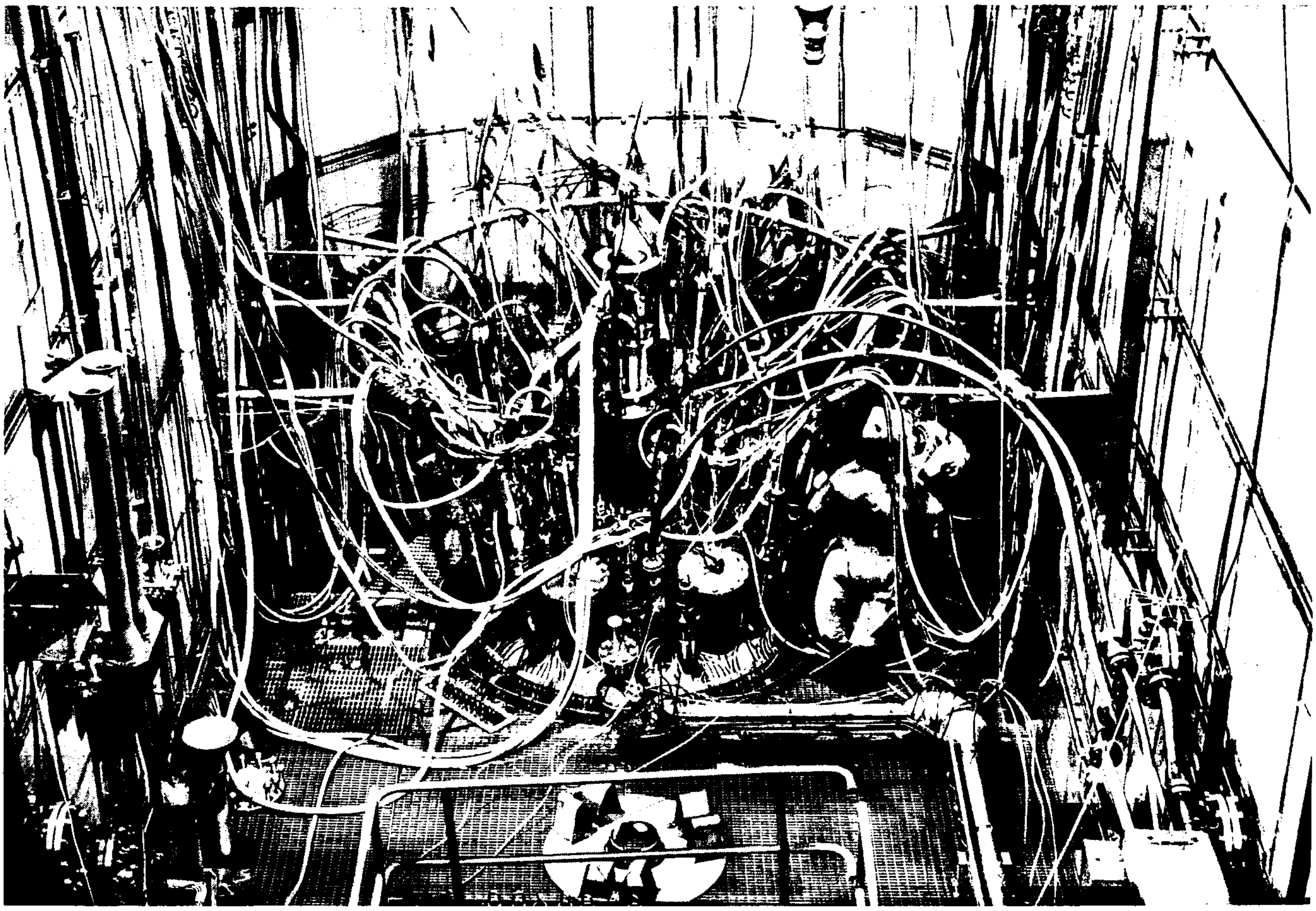


Fig. 1

BR2. View of the Reactor Top Cover showing Gas Leads and Instrumentation Cables of the Irradiation Devices (photograph taken during a reactor shut-down).

TABLE 1.

BR2. Nuclear Data of the Core for Reactor Cycle 10/71 (December, 1971) Maximum, Beginning-of-Cycle Figures at 70 MW Total Reactor Power (Ref. 6).

Channel	Fuel element Type	β %	Ø th. max 10^{14} n/cm^{2}s	Ø>0.1 MeV 10^{14} n/cm^{2}s	H. max. W/gr. Al.
A 30 A330	VIn* VIi*	0 0	2.55	4.63	13.4 13.5
A150 A210	Vn VIn*	0 0	3.76 2.51	4.59 4.55	13.8 13.7
B 0	VIi*	0	2.53	4.59	13.4
B 60 B300	VIn* VIn*	0 0	2.29	4.15	12.1 12.0
B120 B240	VIn* VIi*	0 0	2.39	4.68	14.1 13.7
B180	VIn*	0	2.53	4.59	13.3
C 41 C319	VIi* VIi*	14 14	2.44	4.12	11.0 11.2
C 79 C281	VIn* VIn*	28 34	2.63 2.77	2.47 2.18	9.1 8.5
C101 C259	VIi* Vn*	0 14	2.47 2.83	4.83 4.49	12.8 11.3
C139 C221	Vn Vn	0 0	3.64	4.44	12.7 12.5
D 0	VIn	37	2.75	1.63	7.8
D120 D240	VIn* VIn*	0 20	2.13 2.56	4.34 4.18	12.3 11.2
D180	VIn*	28	2.14	2.25	7.8
E 30 E330	VIn* VIn*	37 35	2.23 2.20	2.90 2.99	8.0 8.2
F 14 F346	VIn* VIn*	0 25	1.56 1.97	2.83 2.25	7.9 7.2
F 46 F314	VIn* VIn*	47 13	2.30 1.75	1.26 2.56	6.1 7.7
F106 F254	VIn* VIn*	26 22	1.99 1.93	2.21 2.34	7.8 7.6
F166 F194	VIn* VIn*	47 32	2.18 1.96	0.76 1.55	4.6 5.3
G120 G240	VIn* VIn*	30 30	1.51	1.37	5.6 5.4
H 23 H337	VIn* VIn*	26 28	1.49 1.53	1.65 1.61	5.4 5.3
H 37 H323	VIn* VIn*	26 36	1.49 1.62	1.65 1.32	5.1 5.0
H 1/0					7.8
H 1/1 à 6	IIIs*	27	2.59		

* Cermet elements.

Legend : β = initial fuel element burn-up   H = nuclear heating

IIIs, Vn, VIn, VIi = indications of number of fuel plates per element, and type.

TABLE 2

Fast Reactor Fuel and Fuel Element Irradiation Programme for the Belgian Materials Testing Reactor BR2. (up-dated from Ref. 9).

Type of irradiation devices	Neutron Spectrum	Target(s)	Hot Spot Irradiation Cond.		Irradiation Period	Remarks.
			Linear Power	Surface Temperature		
			W/cm	°C		
200 kW Na Loop	Epicadmium	3 to 7 oxide or carbide (nitride) fuel pins	600 to 3300	650	from 1965	from 1965 to 1971 : 6 in-pile sections
500 kW Na Loop	Epicadmium	19 oxide fuel pins or 7 carbide fuel pins	600 1500	650 700	from 1972	
"FAFNIR" oxide rigs	Epicadmium	1 oxide fuel pin per rig	600	700	1968-1972	1968 through 1971 : 6 rigs irradiated 12 rigs under irradiation
"FASOLD" carbide rigs	Epicadmium	1 carbide fuel pin	1500	550	1971-1975	Prototype rig under irradiation
Fuel creep rig	Thermal	short fissile specimens	500	700	1970-1972	C.E.A. development
Hollow fuel pellet rig	Thermal	1 oxide fuel pin per rig	1000	500	1970-1972	
Several rig types	Thermal (fission spectrum)	Transuranium isotope pellets			from 1964	
Boiling water capsule	Thermal	1 oxide fuel pin per rig	700	600	from 1965	from 1965 to 1971 : 10 rigs
Several rig types, incl. Creep facil.	(fission spectrum)	cladding material specimens			from 1965	Development by GfK Karlsruhe, C.E.A. etc...
650°C Na filled rig	(fission spectrum)	cladding material specimens		650	1969-1973	6 rigs in 1969-1971

T A B L E 3

BR2 Irradiation Tests for Graphite and HTR Fuel.
(Updated from Ref. 8).

Experiment	Target	Characteristics	Position*	Number of Irradiations	Period
In-Pile Carbon Transfer Loop	Graphite Cylinders	Graphite corrosion 600-900°C, 10 kg/cm^2 3 g He/sec.	FE	9	63-66
Fuel Ball Rig	AVR Fuel Elements	1000°C surface temp. unswept.	refl.	1	66
1250°C Coated Particles Rig	Loose Coated Fuel Particles	1250°C max. fuel temp. unswept.	FE	2	66-67
Graphite Irradiation Rigs	Graphite	150 to 350°C, 500 to 700°C, 750°C, 900°C, 1200°C.	FE	about 50**	63-69
"A" type Coated Particles Sweep Rigs	Loose Coated Fuel Particles	1250°C max. fuel temp. sweep gas loop.	FE	4	67-70
"B" type Coated Particles Sweep Rigs (KFA-Jülich)	Loose Coated Fuel Particles	900 to 1300°C fuel temp. 3 swept capsules per in-pile section	FE	3 finished 2 under irradiation	69-71 71
Coated Particles Unit Rigs CPUR	Loose Particles Compacts, Coupons, etc.	900 to 1500°C fuel temp. Various design possibilities. One sweep circuit per rig.	FE	1 finished 2 under irradiation.	70-71 71
Boiling Water Capsules nr. 8,11	Fuel compacts	900 to 1200°C max. fuel temp. Calorimeter device	refl.	1 finished	70-71
Hydraulic Rabbit Irradiations	Fuel compacts	Short-time irradiation	refl.	6	71
Sodium Loop Appendix (MFBS 6)	Loose Particles and Compacts.	Sealed specimen carrier	refl.	1	70-71

* (FE : fuel element position; fast flux (> 0,1 MeV) up to 6 x 10^{14} n/cm^2 sec
(refl. : reflector position ; fast flux(> 0,1 MeV) up to 1 x 10^{13} n/cm^2 sec.

** Sponsors : CEA, KFA, U.K.A.E.A., etc...

TABLE 4

Potential BR2 Irradiation Test Facilities for GBR Fuel.

Designation	Type	Neutron Spectrum	Fuel: Type	Fuel: Rating (W/cm)	Fuel: Surface Temp. (°C)	Heat Transfer Medium: Nature	Heat Transfer Medium: Pressure (kg/cm^2)	Heat Transfer Medium: Temperature Inlet (°C)	Heat Transfer Medium: Temperature Outlet (°C)	Availability	Cost of one in-pile section (10^3 $)	Remarks
C.P.U.R.	Swept capsule	thermal (fission spectrum)	C.P.	50 to 500	500 to 1500	He-Ne (low flow)	2	virtually same as fuel surface temperature		immediate	15	
FAFNIR	Capsule p.t.	epi-Cd	F.P.	700 max	700-800 max.	NaK	≈ 10			immed.	14	
	HP						70-120			1a	18	
	C.P.		C.P.	80	900-1000	He-Ne	2			0,5a	14	
MFBS 7 (8)	Na loop	epi-Cd	3 carbide F.P.	1250	650	Na	≈ 10	450	580	≈ 2a (end 1973)	90	alternatively 7 oxyde F.P.
"He 2"	He 2kW	epi-Cd	C.P.	≈ 500	800-1000	He	70	300	600	3a	≈ 15	
	Loop 20kW	fission or epi-Cd	F.P. or C.P.		750-900		70				≈ 20	
"He 3" (former SIEMENS CO_2 loop)	400 kW He Loop	epi-Cd	12 F.P.	450	750	He	60	320	580	≈ 2a (end 1973)		Sponsored by KFA Jülich

Legend.

C.P. = coated particles

F.P. = metal-clad fuel pin

HP (FAFNIR) = high pressure version

p.t.(FAFNIR)= pressure transducer version

immediate availability = 3 to 4 months after specimen supply. epi-Cd = irradiation under cadmium screen.

Cost of one in-pile section includes development and manufacturing cost but does not include irradiation and operating expenses (approximate figures).

2. Descriptions, and Development Potential.

2.1. FAFNIR.

2.1.1. General.

The "Fuel Array Fast Neutron Irradiation Rig" (FAFNIR) has been developed for the irradiation of LMFBR fuel pins in a neutron spectrum above the cadmium cut-off (Ref. 9).

2.1.2. Standard Version.

In the standard design, the fuel pin is placed inside a NaK filled specimen carrier which is mounted into the stainless steel clad cadmium screen (fig. 3).

Gas supply to the two separate volumes (rig and rig head) comes from multiple control consoles (fig. 2).

Instrumentation comprises thermocouples placed on the fuel cladding and, for certain rigs, a strain gauge pressure transducer for measurement of the fission gas pressure in the fuel pin.

Further design extrapolations covered central fuel temperature measurement and calorimetric thermocouples in the Cd screen.

The main performance parameters of the standard FAFNIR are :

- Fuel nature	UO_2 - 20% PuO_2 93% U235	
- Fuel pin O.D.	mm	6,0
- Fuel pin overall length	mm	1000
- Hot plane conditions :		
Fission rating	W/cm	600
Clad surface temperature	°C	700 max.
Burn-up	MWd/t	80.000

The available neutron spectrum in the fuel has been calculated by means of multi-group codes (Ref. 3).

The required irradiation time, at an average of 500 W/cm, to reach 80.000 MWd/t_{oxide}, is 300 days net (14 to 15 months gross). The maximum fast fluence (above 0,1 MeV) accumulated is then 0,5 x 10^{22} n/cm^2.

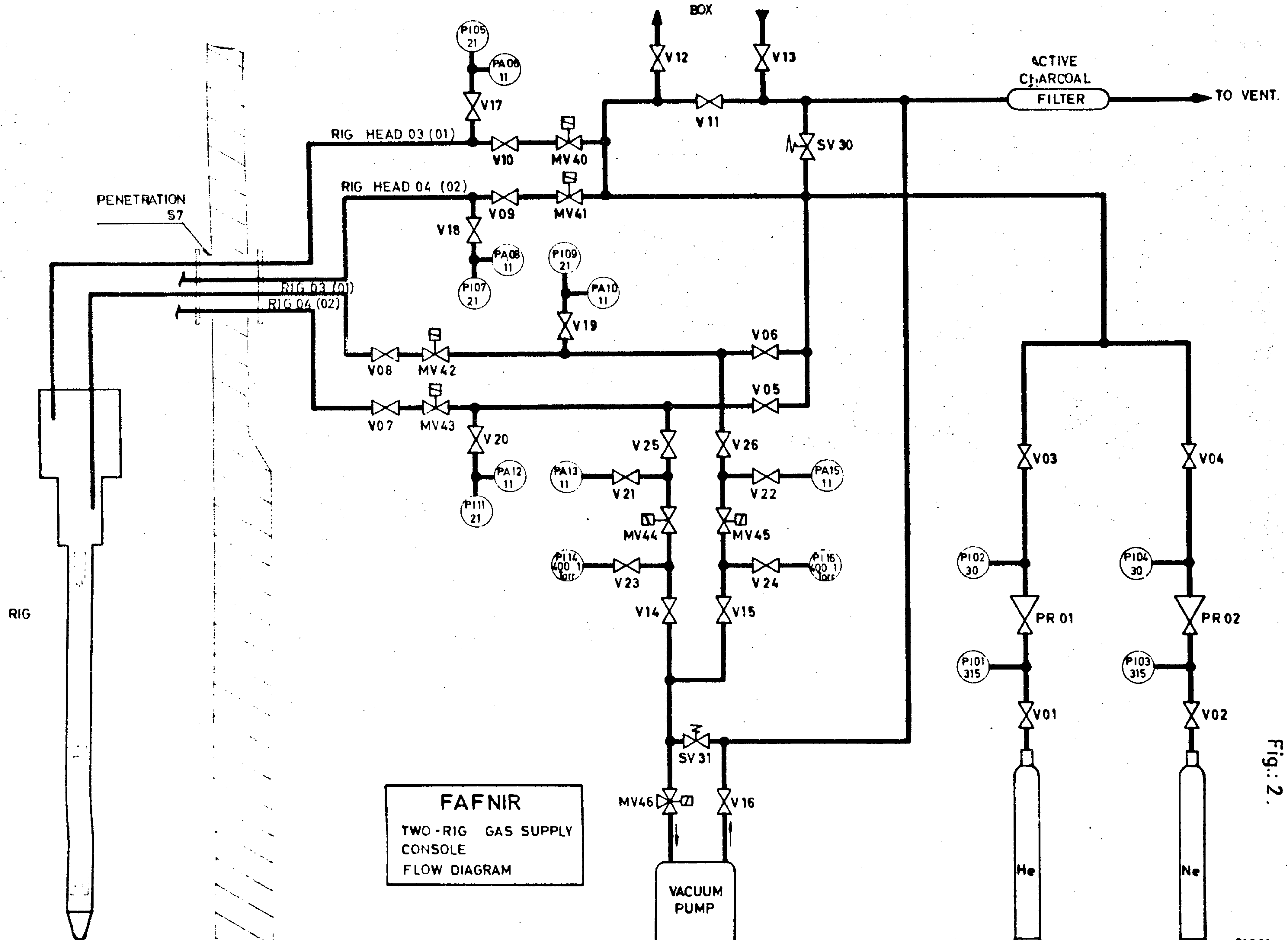
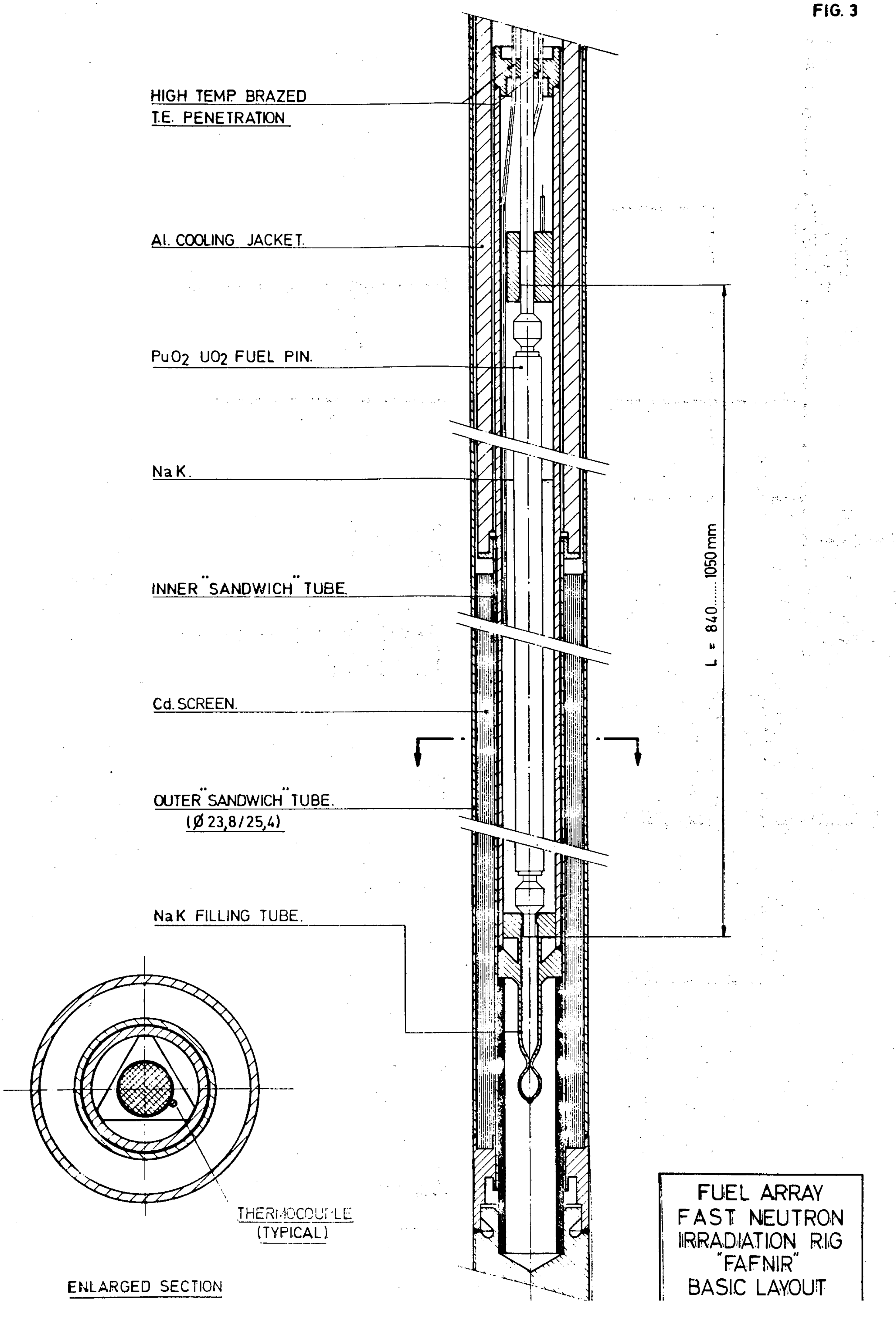

BOX
V12
V13
ACTIVE
CHARCOAL
FILTER
TO VENT.
P105 21
PA06 11
V17
V11
SV 30
RIG HEAD 03 (01)
V10
MV40
RIG HEAD 04 (02)
V09
MV41
PENETRATION
S7
V18
PA08 11
P107 21
P109 21
PA10 11
V19
RIG 03 (01)
RIG 04 (02)
V08
MV42
V06
V05
V07
MV43
V20
PA12 11
P111 21
V25
V26
PA13 11
V21
V22
PA15 11
MV44
MV45
P114 400 1 Torr
V23
V24
P116 400 1 Torr
V14
V15
V03
V04
P102 30
P104 30
PR 01
PR 02
P101 315
P103 315
V01
V02
SV 31
MV46
V16
RIG
FAFNIR
TWO-RIG GAS SUPPLY
CONSOLE
FLOW DIAGRAM
VACUUM
PUMP
He
Ne

Fig.: 2.

FIG. 3



FUEL ARRAY
FAST NEUTRON
IRRADIATION RIG
"FAFNIR"
BASIC LAYOUT

Availability :

In November 1971, six FAFNIR had been irradiated, and 12 rigs (pressure transducer version) are under irradiation with generally satisfactory results. New rigs for the GBR programme could be ready for irradiation in three to four months from supply date of specimens.

2.1.3. High Pressure Version.

The high pressure design is derived from the standard FAFNIR version for the irradiation of fast reactor fuel pins under external pressure. It would be used for testing of unvented GBR fuel.
The pressure is applied through the NaK surrounding the fuel pin, by pressurizing the gas space above the liquid metal from a control console (see fig. 4).

The main performance parameters are identical to those of the standard version (see paragraph 2.1.2.), the maximum possible pressure in the NaK container is 180 kg/cm^2.

Availability :

Detail design and safety analyses for the high pressure FAFNIR have been carried out. A long-term autoclave out-pile test has proven the creep resistance of the specimen carrier tube which confines the high pressure. Low pressure gas consoles, most rig parts and some high pressure components are available, so that the total time required between "freezing" of test specifications and start of the irradiation is about 10 months.

2.1.4. Coated Particle Version.

Principle.

The unfavourable ratio damage flux : burn-up of a thermal test reactor irradiation of coated particle fuel can be largely improved by the utilization of a neutron filter.

The proposed design uses the main components of the FAFNIR for a static irradiation of coated particles under cadmium.

Rig Description.

The structure of the Cd screen assembly corresponds to the standard layout (see fig. 5), including the gas purge tube fitted before final extrusion.

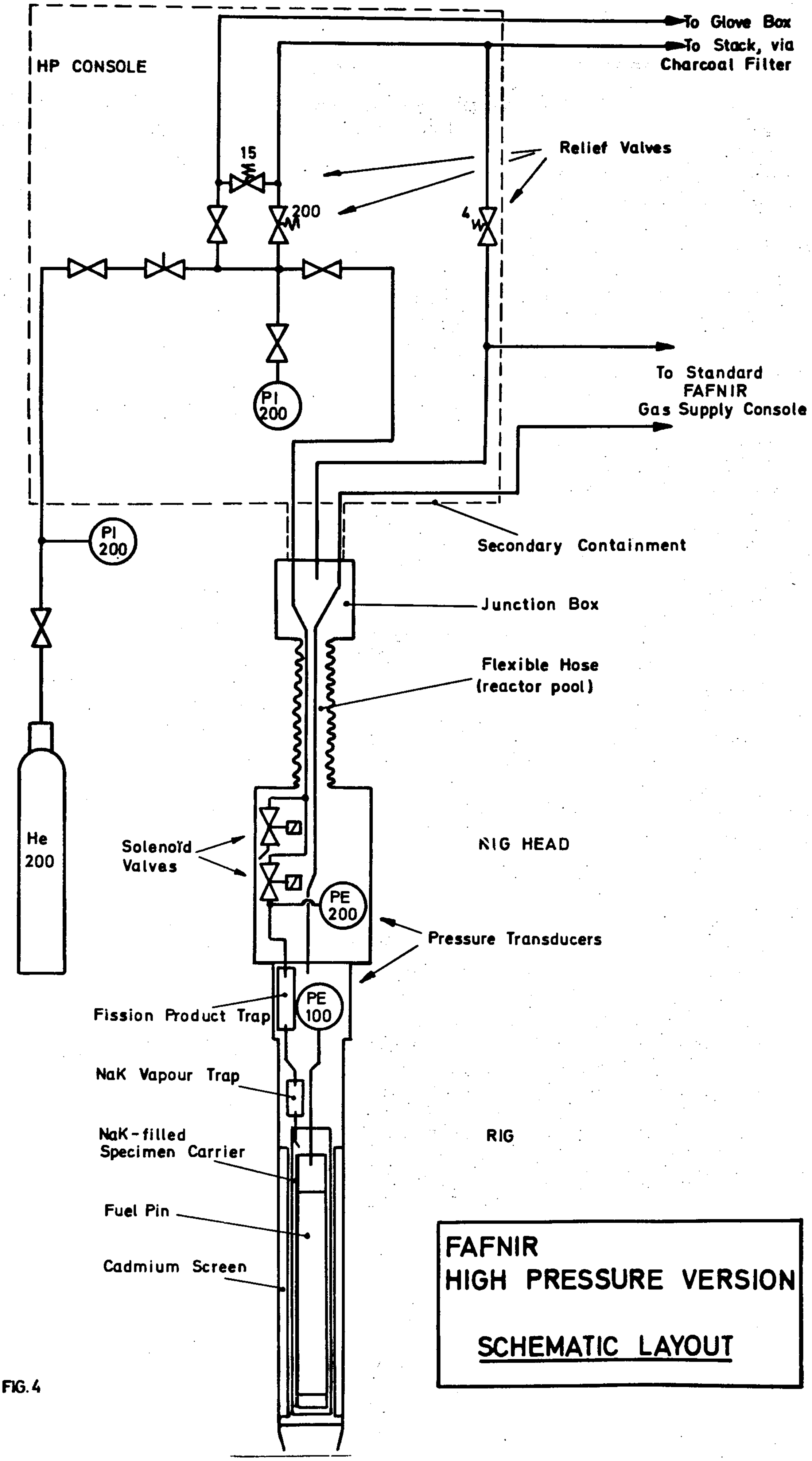
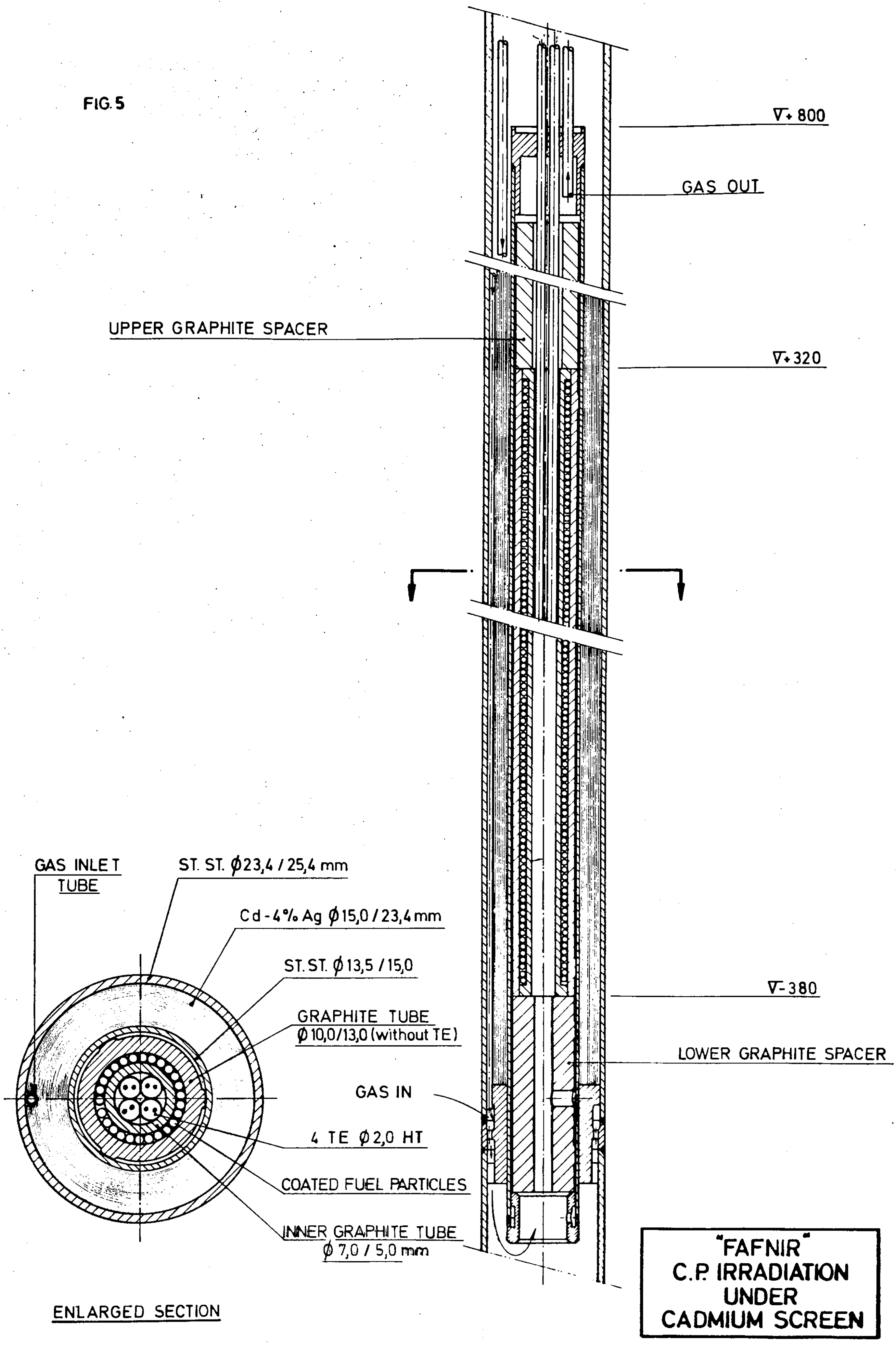

HP CONSOLE
To Glove Box
To Stack, via
Charcoal Filter
15
Relief Valves
200
4
PI
200
To Standard
FAFNIR
Gas Supply Console
Secondary Containment
PI
200
Junction Box
Flexible Hose
(reactor pool)
He
200
Solenoid
Valves
RIG HEAD
PE
200
Pressure Transducers
Fission Product Trap
PE
100
NaK Vapour Trap
NaK-filled
Specimen Carrier
RIG
Fuel Pin
Cadmium Screen
FAFNIR
HIGH PRESSURE VERSION
SCHEMATIC LAYOUT

FIG. 4

FIG. 5


∇+ 800
GAS OUT
UPPER GRAPHITE SPACER
∇+ 320
GAS INLET TUBE
ST. ST. ϕ23,4 / 25,4 mm
Cd - 4% Ag ϕ15,0 / 23,4 mm
ST. ST. ϕ13,5 / 15,0
GRAPHITE TUBE
ϕ10,0/13,0 (without TE)
GAS IN
4 TE ϕ2,0 HT
COATED FUEL PARTICLES
INNER GRAPHITE TUBE
ϕ7,0 / 5,0 mm
ENLARGED SECTION
∇- 380
LOWER GRAPHITE SPACER
"FAFNIR"
C.P. IRRADIATION
UNDER
CADMIUM SCREEN

However, the specimen carrier is replaced by a graphite tube (Ø 13,0/10,0 mm) which confines a coated particle layer of 1,5 mm thickness. The central space is taken by a graphite spine (Ø 7,0/5,0 mm) fitted with four high-temperature thermocouples.

The inner cadmium screen clad tube is thus used as specimen carrier. The rig is connected to a He-Ne sweep loop according to the C.P.U.R. design (fig. 7).
The gas is conducted underneath the specimen column through the purge tube, enters through holes in the bottom of the specimen carrier, and flow upwards acting both for temperature regulation and fission gas sweeping. The gas return line departs from the upper end plug of the specimen carrier.
500 to 700 mm can be occupied by the fuel.

The out-pile equipment (see paragraph 2.2.) provides supply of purified helium-neon set to yield the desired irradiation temperature, permanent control for fission product release, gas sampling facilities and safety features.

<u>Performance</u>.

Studies on the C.P. FAFNIR are based on two main considerations :

1. BR2 positions equivalent to B 120 / B 240 are to be selected for the irradiation due to their high fast flux ($4,5 \times 10^{14}$ n/cm^2 s above 0,1 MeV).

2. The C.P. bed thickness is limited in order to avoid large temperature gradients across the bed.

The following figures have been assumed :

- Fuel nature	UO_2- 20% PuO_2 particles 93% U 235, 1,0 mm O.D.
- Bed density	1 g heavy metal/cm^3
- Irradiation duration	18 months gross 380 days net
- C.P. bed effective thermal conductivity (Ref. 7)	0,021 W/cm°C
- Nominal (unperturbed) nuclear characteristics of the irradiation position B 120/ B 240 (Ref. 6)	
thermal neutron flux	$2,4 \times 10^{14}$ n/cm^2 s
fast neutron flux (> 0,1 MeV)	$4,7 \times 10^{14}$ n/cm^2 s
gamma heating	14 W/g

NB.

The Pu/U ratio can be altered, i.e. more Pu accomodated if necessary, without changing significantly the characteristics of the experiment.

The calculation yields the following approximate results ("hot plane") :

- Fission rating in the fuel bed — 160 W/cm, 400 W/cm^3
- C.P. bed temperatures, outer (pure helium) — 680°C
  inner — 910°C
- Total rig fission power output (assuming 600 mm occupied length) — about 7 kW
- Achieved performance in 1,5 years gross (380 days net) irradiation time :

  burn-up — 75.000 $\frac{MWd}{t}$

  fast neutron dose (>0,1 MeV) $0{,}15 \times 10^{23}$ n/cm^2
- Antireactivity cost in 380 days irradiation time

  0,65 x 380 x 400, approximately $ 100.000.-
- Cost for 1,5 years' utilization of the out-pile equipment approximately $ 22.000.-

Availability.

FAFNIR C.P. devices could be made available for the GBR programme within two to four months from supply date of specimens and graphite holders, allowing for an extra two months design time.

Out-pile equipment (sweep loops) is existing as a BR2 installation hired to experimenters.

2.2. C.P.U.R.

The "Coated Particles Unit Rig" (C.P.U.R.) has been developed for the irradiation of loose or compacted coated fuel particles in the BR2 fission neutron spectrum (Ref. 8).

The rig is made up essentially of two concentric stainless steel tubes and an inner specimen area. Different structures of the specimen area have been used (see fig. 6).

A low flow helium-neon mixture is made up in the out-pile equipment (sweep loop), for temperature regulation and fission product sweeping (fig. 7).
The gas enters through the annulus between the two stainless steel tubes, flow downwards and penetrates into the specimen carrier through an opening in its bottom cover. It flows then upwards collecting volatile fission products, and is conducted via the gas return line brazed into the upper end plug of the specimen carrier.

<u>Performance</u>.

Typical C.P.U.R. figures for 1,5 years gross irradiation time are :

burn-up	180.000 MWd/t_M
fast neutron dose ($>$0,1 MeV)	0,08 x 10^{23} n/cm^2

at

1000...1500°C maximum fuel temperature

and 5...10 kW total rig fission power output.

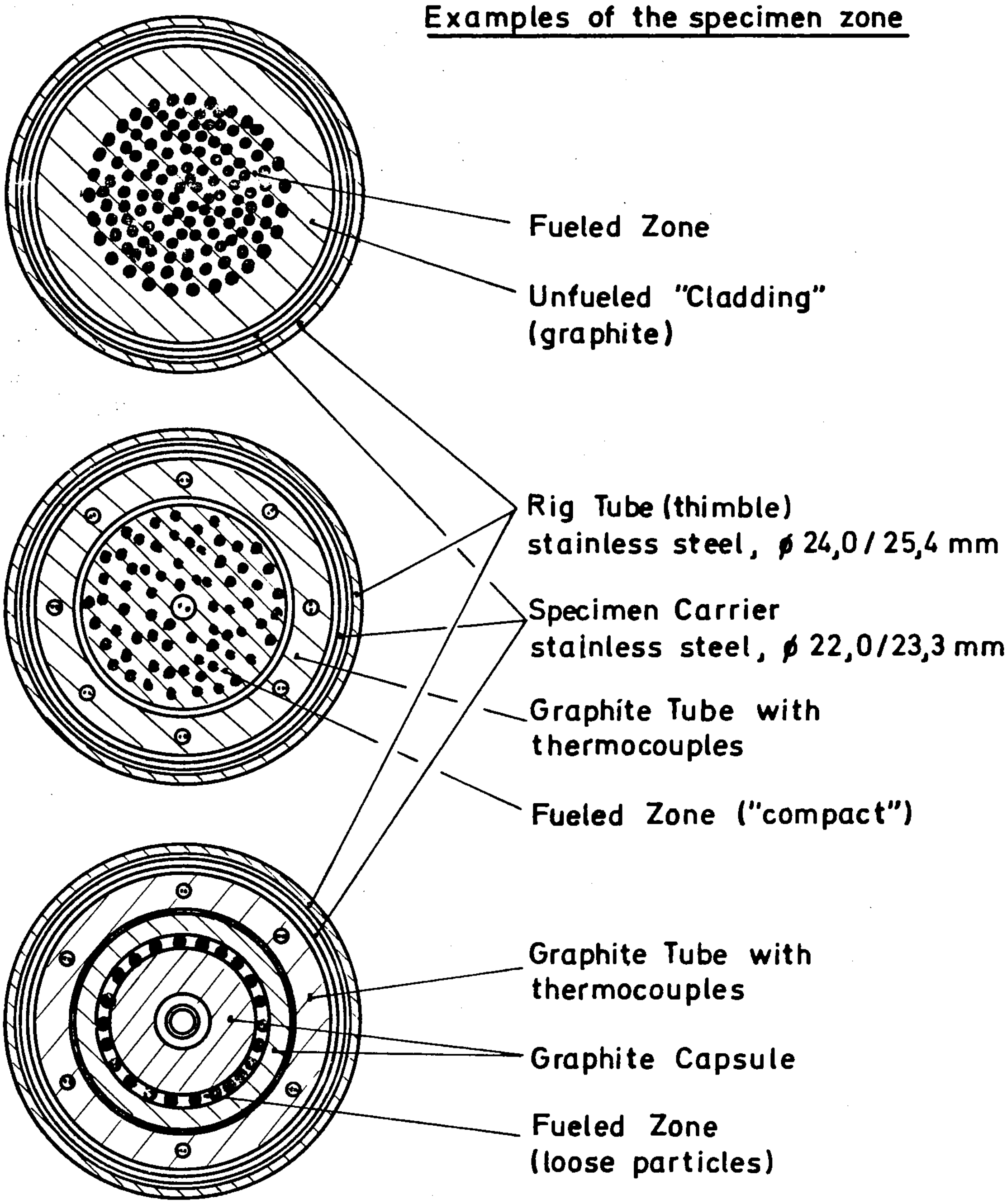
<u>Availability</u>.

C.P.U.R. rigs are current production devices. The time required from specimen supply date to start of irradiation is one to two months.

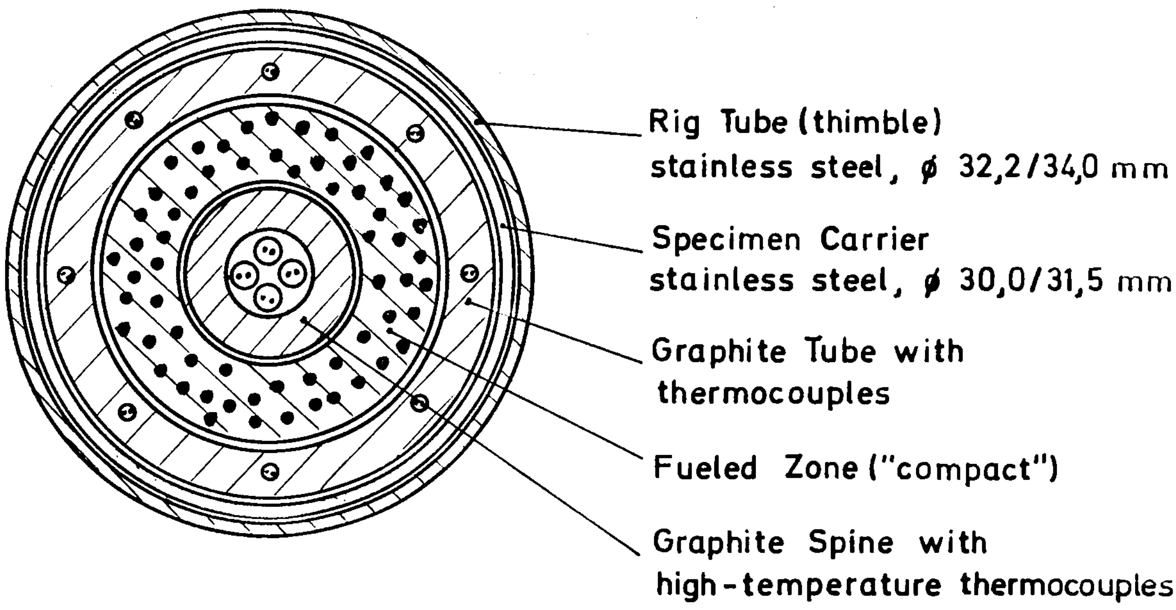
Out-pile equipment (sweep loops) is existing as a BR2 installation hired to experimenters.

Examples of the specimen zone

Type I



Type II



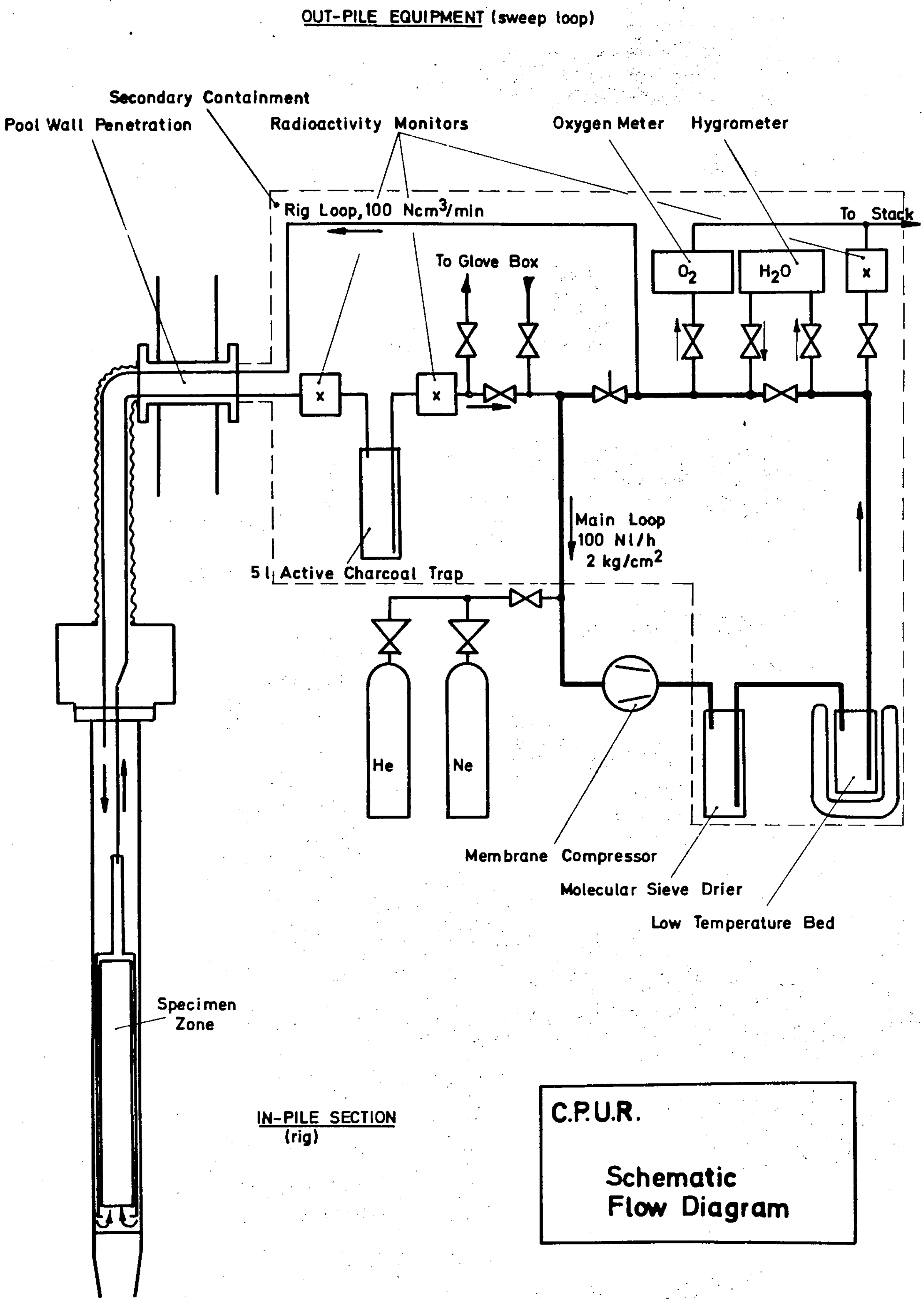

OUT-PILE EQUIPMENT (sweep loop)
Secondary Containment
Pool Wall Penetration
Radioactivity Monitors
Oxygen Meter
Hygrometer
Rig Loop, 100 Ncm³/min
To Stack
To Glove Box
O2
H2O
x
Main Loop
100 Nl/h
2 kg/cm2
5 l Active Charcoal Trap
He
Ne
Membrane Compressor
Molecular Sieve Drier
Low Temperature Bed
Specimen
Zone
IN-PILE SECTION
(rig)
C.P.U.R.
Schematic
Flow Diagram

FIG. 7

2.3. He 2*)

2.3.1. General.

Of all irradiation devices presented in this report, helium loop "He 2" is the most speculative since it exists only as a feasibility study.

He 2 has been considered for two different power levels (2 kW or 20 kW thermal capacity), according to different requirements that might emerge from GBR R & D work. The two proposed solutions are briefly outlined hereafter.

2.3.2. The 2 kW Version.

The short-comings of a coated particle irradiation in a capsule-type device as described in paragraphs 2.1. and 2.2. above are, obviously, a large temperature gradient in the C.P. bed due to the conductive heat transfer mechanism, and the lack of corrosion study possibilities.

Therefore, thought has been given to a small gas loop capable of direct cooling of a C.P. bed under irradiation (Ref. 11). A simplified loop flow diagram is given on fig. 8. Full flow purification is provided for safety (fission product adsorption) and corrosion study accuracy. Membrane compressors are proposed rather than centrifugal circulators in order to avoid excessive engine r.p.m. and to facilitate flow rate regulation.

In-pile temperatures, in-pile pressure drop, and sweep gas gamma activity are continuously monitored and recorded.

Fig. 9 shows a simplified layout of the in-pile section with a small coated particle bed, to be irradiated under an incorporated cadmium screen in the upper rig portion, the heat from the targets is entirely dissipated towards the reactor primary circuit, and a strong heat exchange between gas inlet and outlet is provided. Means of temperature regulation are :

- flow rate,
- input to the electrical gas pre-heater,
- composition of the thimble gas filling.

A design pressure of 70 kg/cm^2 has been adopted, in order to assure satisfactory local heat transfer in the target.

./.

*) The designation "He 2" is an internal working title and subjet to changes as the project procedes.

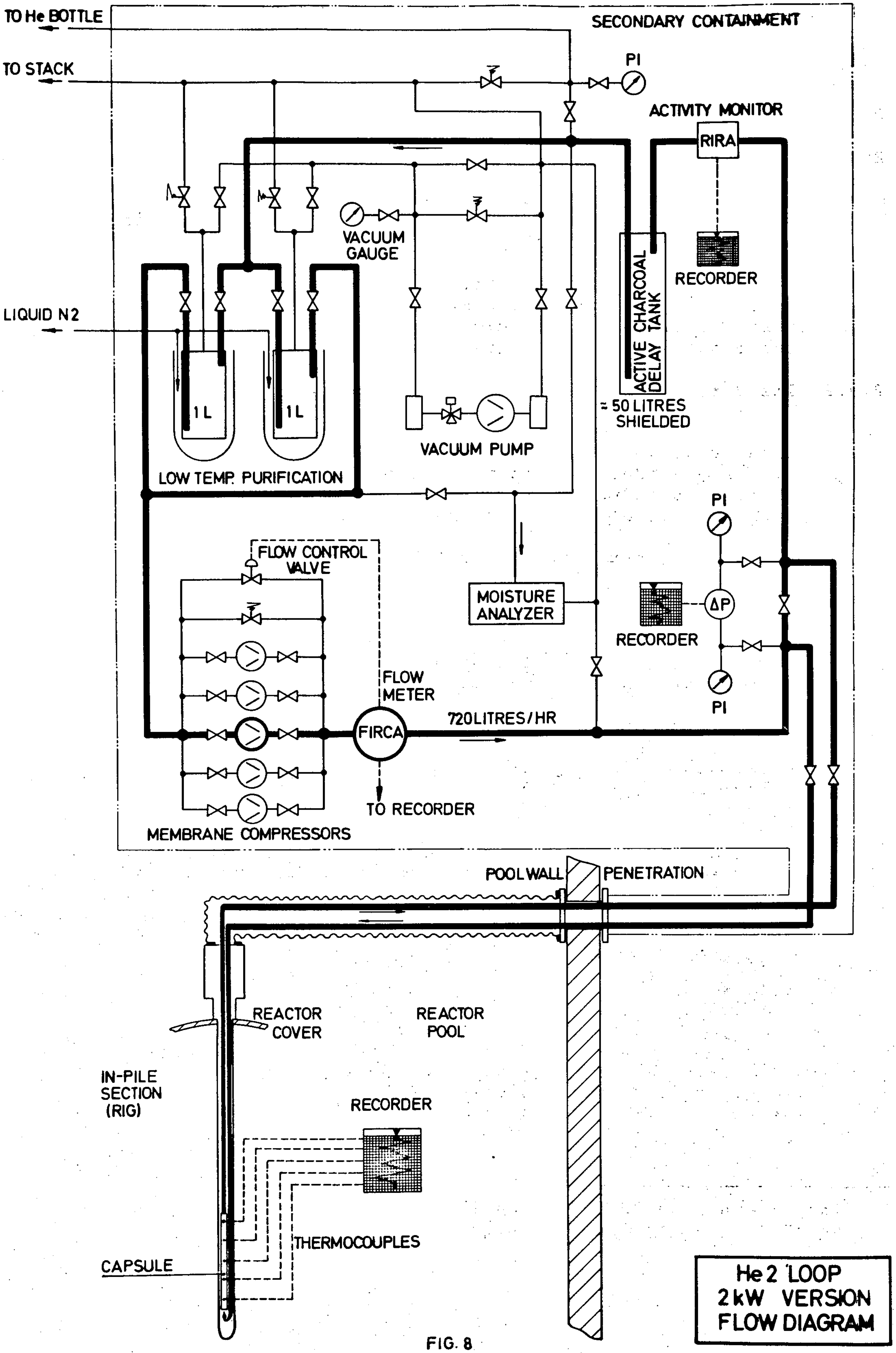
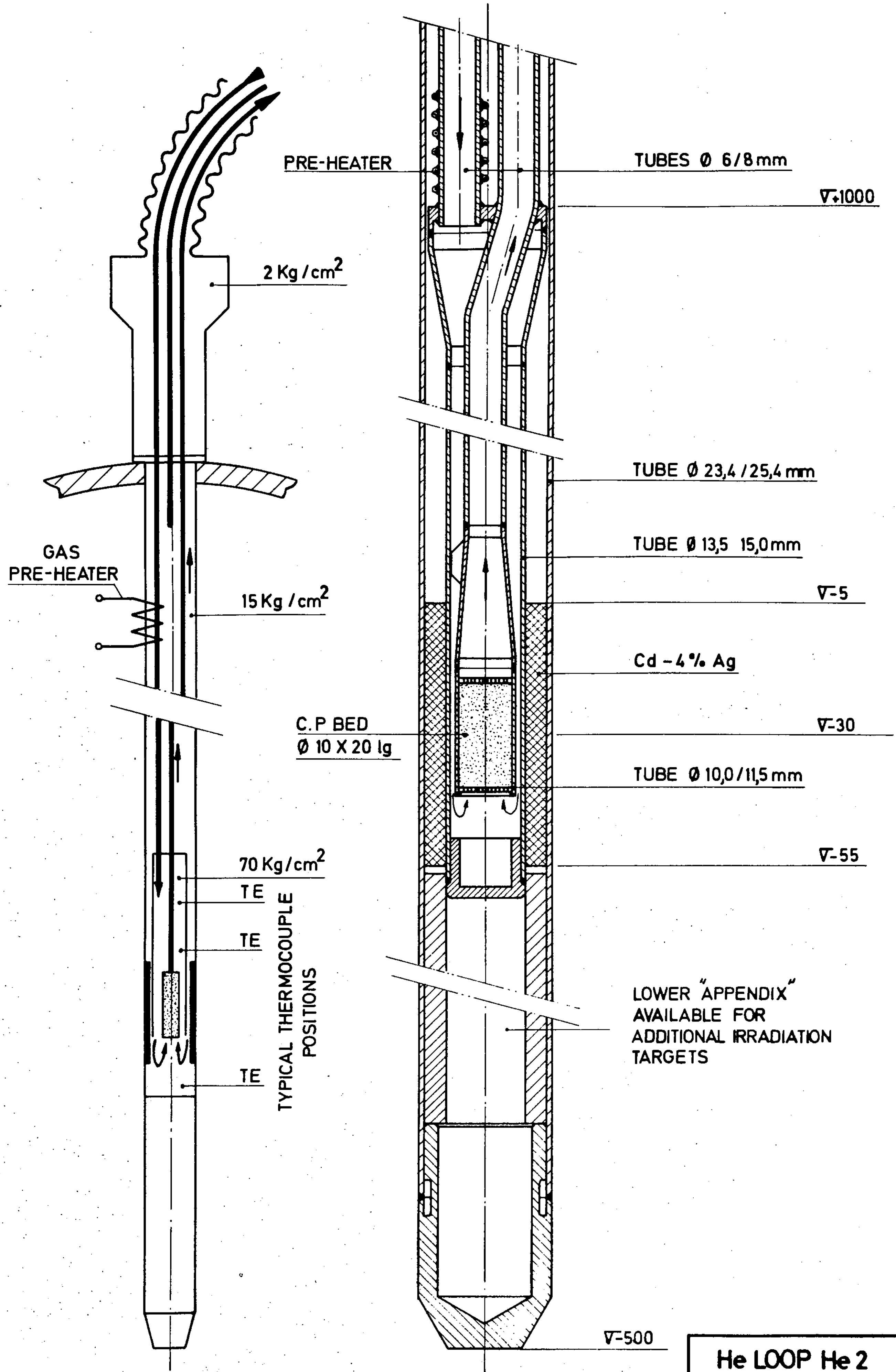

TO He BOTTLE
TO STACK
SECONDARY CONTAINMENT
PI
ACTIVITY MONITOR
RIRA
VACUUM GAUGE
RECORDER
ACTIVE CHARCOAL DELAY TANK
LIQUID N2
1 L
1 L
≈ 50 LITRES SHIELDED
VACUUM PUMP
LOW TEMP. PURIFICATION
PI
FLOW CONTROL VALVE
MOISTURE ANALYZER
ΔP
RECORDER
FLOW METER
PI
720 LITRES / HR
FIRCA
TO RECORDER
MEMBRANE COMPRESSORS
POOL WALL
PENETRATION
REACTOR COVER
REACTOR POOL
IN-PILE SECTION (RIG)
RECORDER
THERMOCOUPLES
CAPSULE
He 2 LOOP
2 kW VERSION
FLOW DIAGRAM

FIG. 8

FIG. 9



He LOOP He 2
2 kW VERSION
IN-PILE SECTION

Main parameters of the 2 kW He 2 loop are :

- Fluid	-	Helium (with trace impurities)
- Pressure	kg/cm^2	70
- Total thermal capacity	kW	2,2
- Flow rate	Litres/h	720
	g/s	0,94
- Gas temperature in pile,		
at inlet to specimen bed	°C	300
at outlet from specimen bed	°C	750.

Parameter Variation.

a. 120 kg/cm^2.

Uprating of the operating pressure to 120 kg/cm^2 is, in principle, possible.

b. CO_2.

Replacing helium by carbon dioxyde requires changes to the purification traps, using 800°C Ti-Zr sponge furnaces rather than low temperature traps, in order to avoid CO_2 condensation.
The membrane compressors, however, remain unchanged.

Availability.

The total development and construction time required is estimated to 3 years.

Cost.

Cost studies are not available at present, but the following order-of-magnitude figures can be noted :

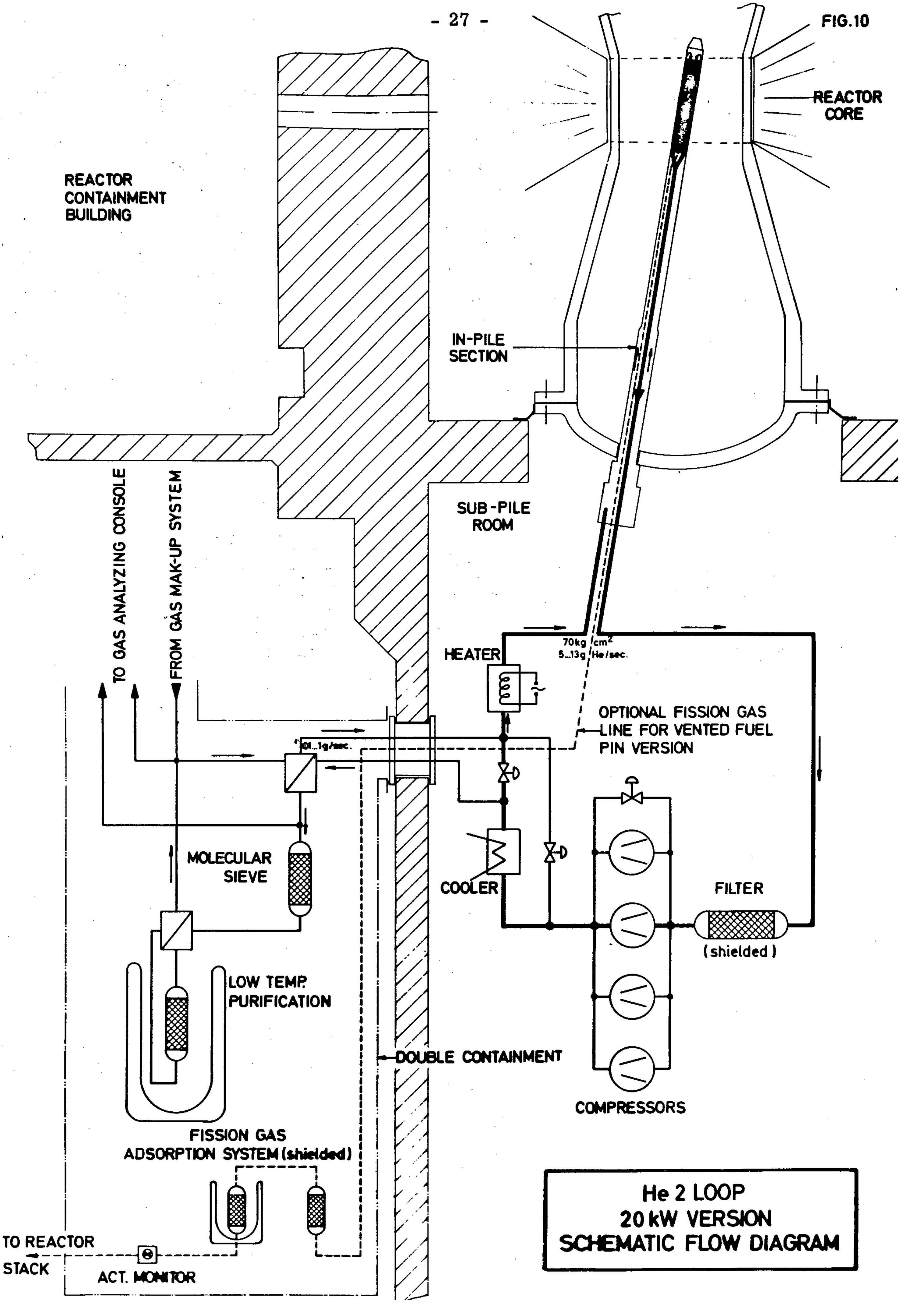
- Price of the out-pile equipment	\$ 200.000.-
- Price per in-pile section	\$ 15.000.-
- Monthly irradiation and operating cost (loop hired)	\$ 10.000.-

2.3.3. The 20 kW Version.

The loop thermal capacity has to be increased considerably if "full length" pin type or coated particle fuel elements are to be irradiated (full length meaning 500 mm fissile column).

The proposed installation (fig. 10) features an in-pile section with inlet and outlet connections on the lower reactor vessel cover, and the main loop components mounted in the sub-pile room. The advantage of this solution consists in a substantial economy of specific loop component shielding.

FIG.10



He 2 LOOP
20 kW VERSION
SCHEMATIC FLOW DIAGRAM

Again, large reciprocating compressors are proposed rather than blowers, protected by a full-flow shielded filter.

All auxiliary circuits, including a 2 to 5% flow purification, are mounted in accessible areas in the reactor building.

The main loop parameters are resumed as follows :

- Thermal capacity (from the target)	kW	20
- Fluid nature	-	He
- Pressure	kg/cm^2	70
- Flow rate	g/sec	13 max.
- Gas inlet temperature to target area	°C	300
- Gas outlet temperature from target area	°C	600
- Nominal pipe diameter	mm	20.

Figure 11 represents the layout of an in-pile section with an unvented metal-clad fuel pin of 1,0 m total length. Helium enters through the external annulus between rig pressure tube and the flow divider, it flows down the inner annulus cooling the fuel pin.
Strong internal heat exchange between the two gas streams is provided, as well as heat dissipation towards the reactor primary circuit.

The rig is to be irradiated either in a Vn type BR2 fuel element (fission spectrum) or in a IVn type element (with Cd screen, epicadmium spectrum). Instrumentation comprises thermocouples for the measurement of helium temperatures at various points (not represented).

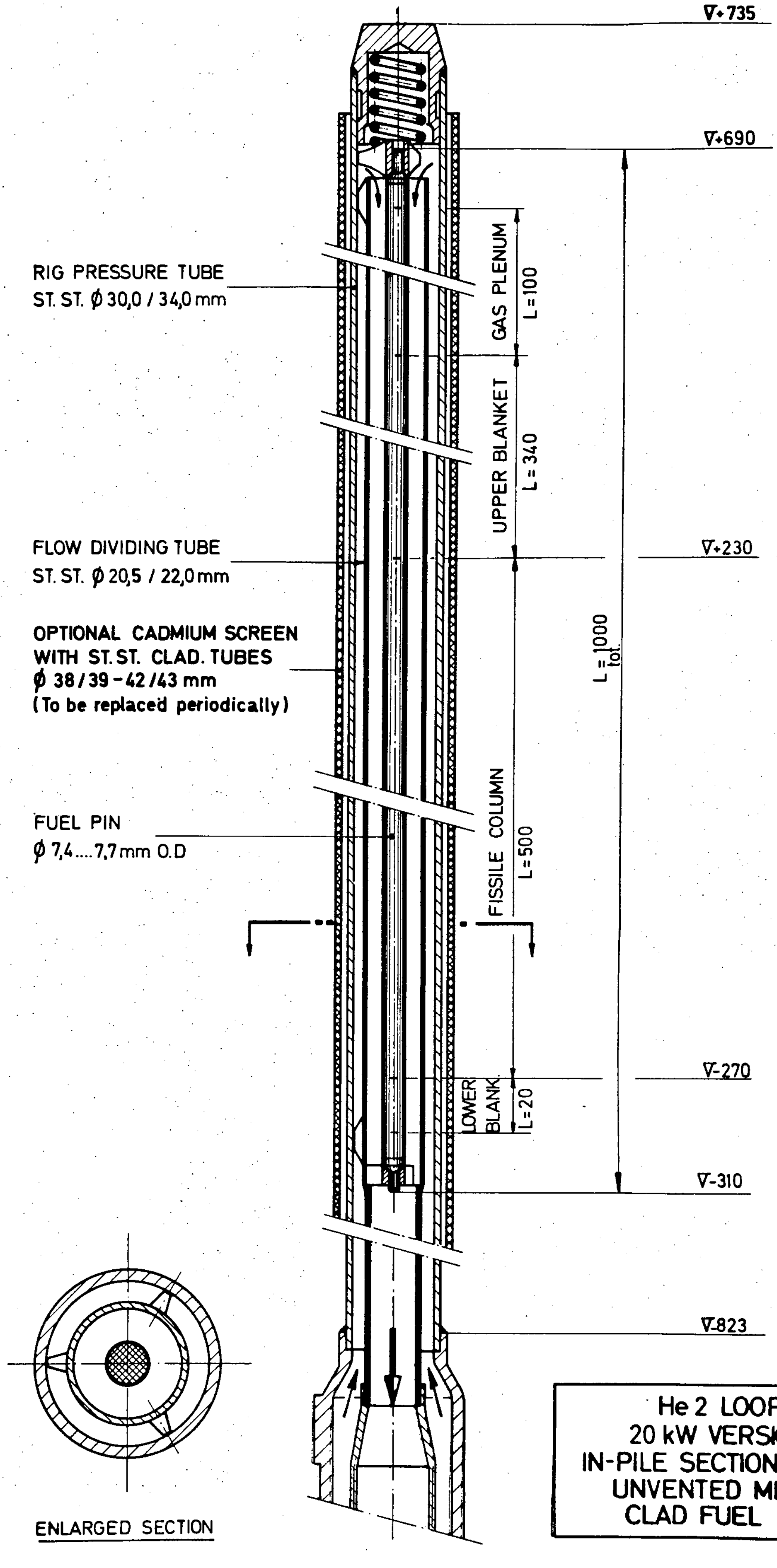
Figure 12 proposes a 20 kW in-pile section containing a long, tapered coated particle fuel element enclosed between two porous tubes. The remainder of the rig is similar to the fuel pin version. Proposals on nature and design of the porous "clad" tubes are not included (refer to Ref. 16, pp. 7-13/23).

<u>Parameter Variation</u>.

a. 120 kg/cm^2.

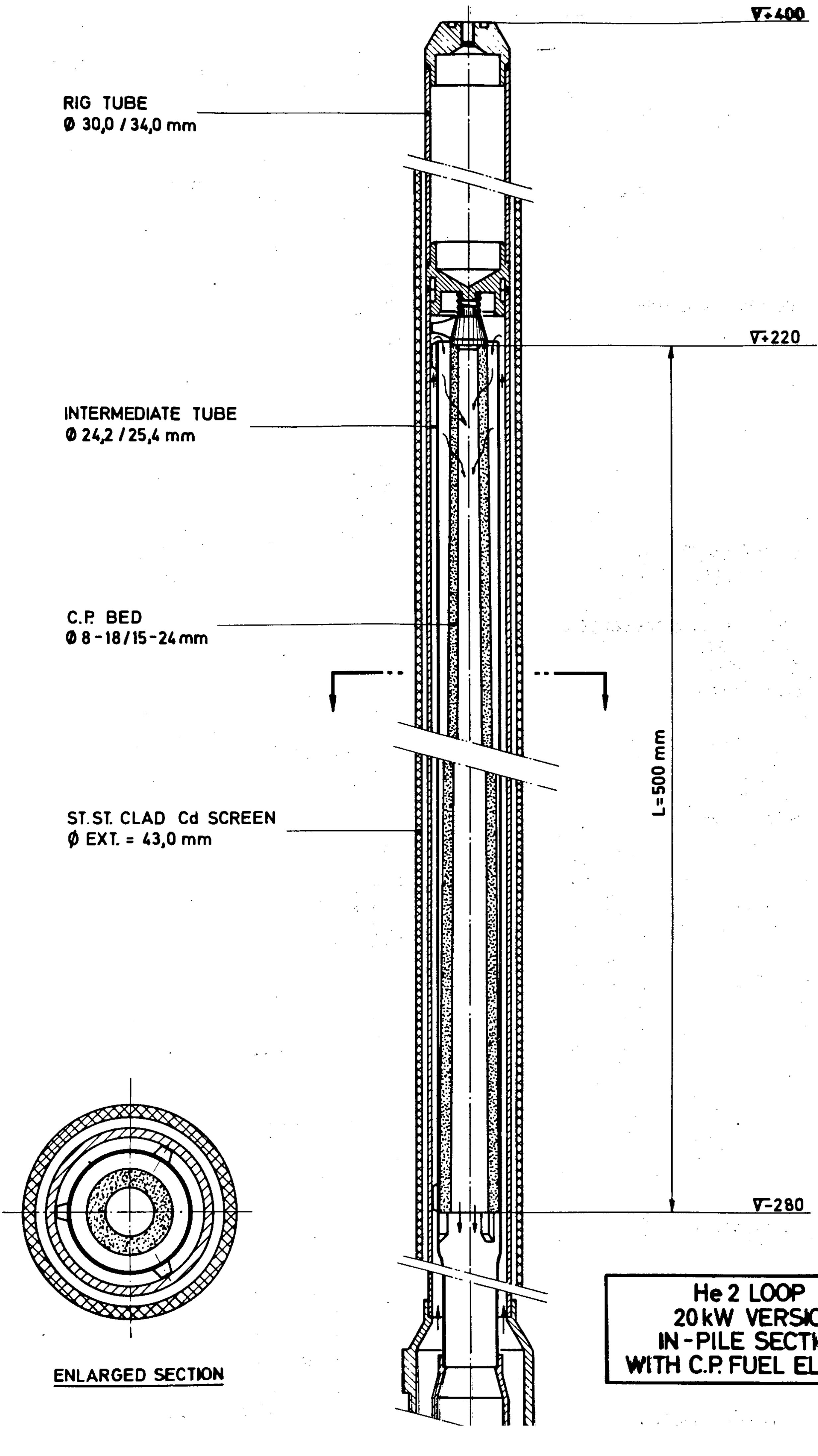
Uprating of the operating pressure to 120 kg/cm^2 is, in principle, possible. A considerable increase of loop component cost is anticipated.

FIG. 11



He 2 LOOP
20 kW VERSION
IN-PILE SECTION WITH
UNVENTED METAL-
CLAD FUEL PIN

FIG. 12



He 2 LOOP
20 kW VERSION
IN-PILE SECTION
WITH C.P. FUEL ELEMENT

b. CO_2.

Replacing helium by carbon dioxyde requires changes to the purification circuit (Ref. 16, pp. A-37/41) since CO_2 condenses more easily than most of its impurities. The solution would consist in leaving the activated charcoal fission product delay trap and molecular sieve drier vessels in the main loop (full flow purification), whereas a 10% by-pass flow is cooled to condensate the CO_2, removing the remaining gas phase by release for the stack. A small make-up compressor than pushes the purified CO_2 back into the main loop. The Ti-Zr furnace solution proposed for "He 2" (paragraph 2.3.2.) could be used as an alternative.

Availability.

The total development and construction time required is estimated to 3-4 years.

Cost.

Cost studies are not available at present, but the following order-of-magnitude figures can be noted :

- Price of the out-pile equipment ($70\ kg/cm^2$ version)	$ 300.000.-
- Price per in-pile section	$ 20.000.-
- Monthly irradiation and operating cost (loop hired)	$ 14.000.-

Emergency Cooling.

For all gas loops considered, the following provisions are made for the event of a cooling flow reduction (compressor deficiency, flow blockage, large leak) :

a. a fast reactor trip is wired to relevant variations of parameters like pressure, differential pressure, flow rate, temperatures,...

b. a high pressure gas storage tank will provide a post-accident purge carrying away the decay heat during a short time (not represented on fig. 10 and 13).

2.4. He 3*)

2.4.1. General.

A CO_2 loop had been operated in BR2 (Ref. 14) for the irradiation of fuel pin bundles in a thermal neutron flux. Studies are being carried out at present under sponsorship of KFA Jülich (Germany), in view of transformation of the existing equipment into a fast neutron helium loop.

2.4.2. Layout.

A schematic flow diagram of the new loop is represented on figure 13, as connected to a "through-loop" in-pile section. The main parameters of the installation are (Ref. 5) :

- Thermal capacity (from the targets)	kW	300
- Fluid nature	-	He
- Pressure	kg/cm^2	60
- Flow rate	g/sec	300
- Gas inlet temperature to target area	°C	320
- Gas outlet temperature from target area	°C	580
- Number of fuel pins	-	12
- "Active" fuel pin length	mm	600
- Hot plane fission rating	W/cm	450
- Hot spot cladding surface temperature	°C	750.

The equipment is installed in the reactor building, inside a shielded and vented cubicle. The gas circulators are high-speed centrifugal blowers.

An overall schematic of the in-pile section in its reactor channel is given on figure 14, for a re-entrant version (coolant inlet and outlet on one side).

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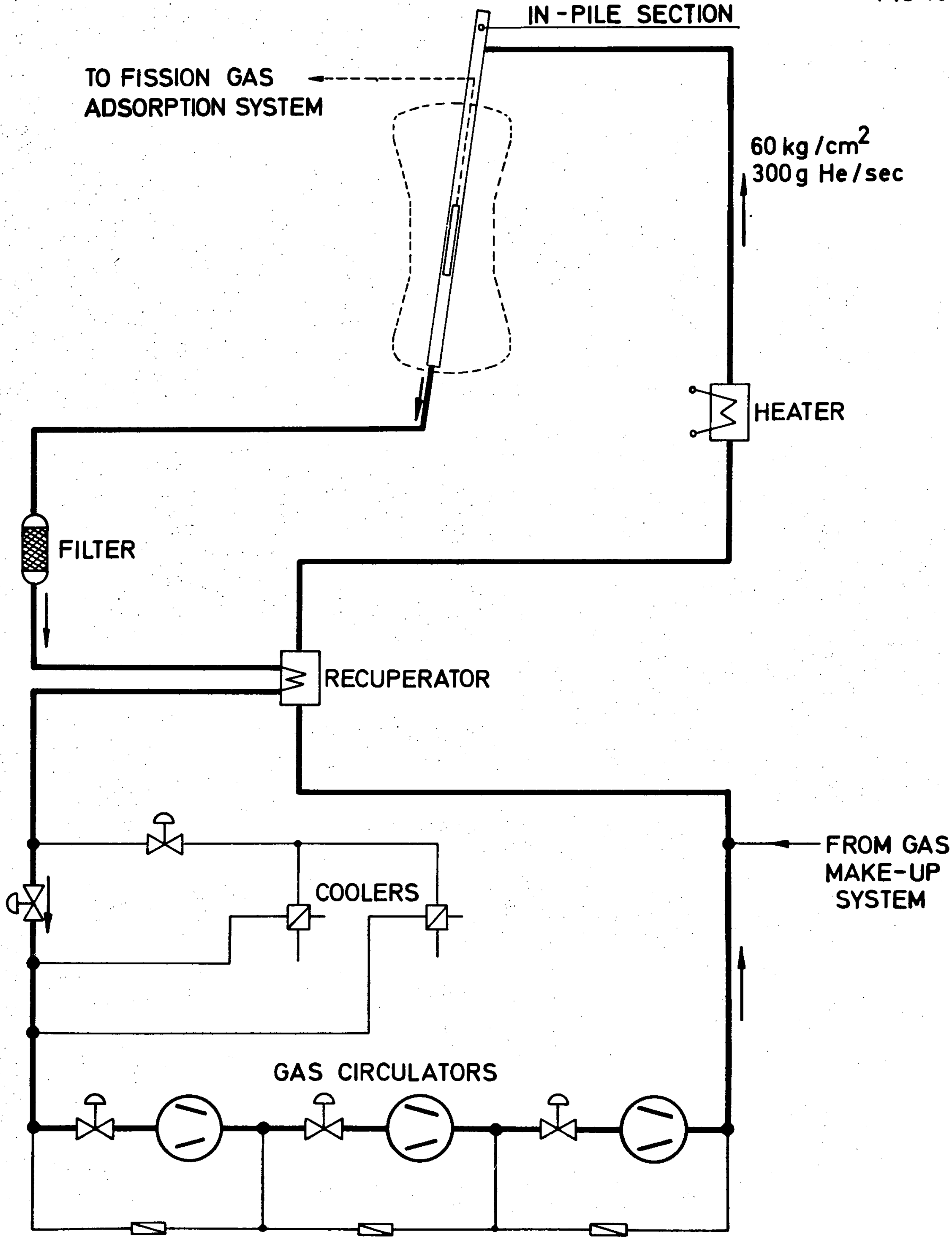
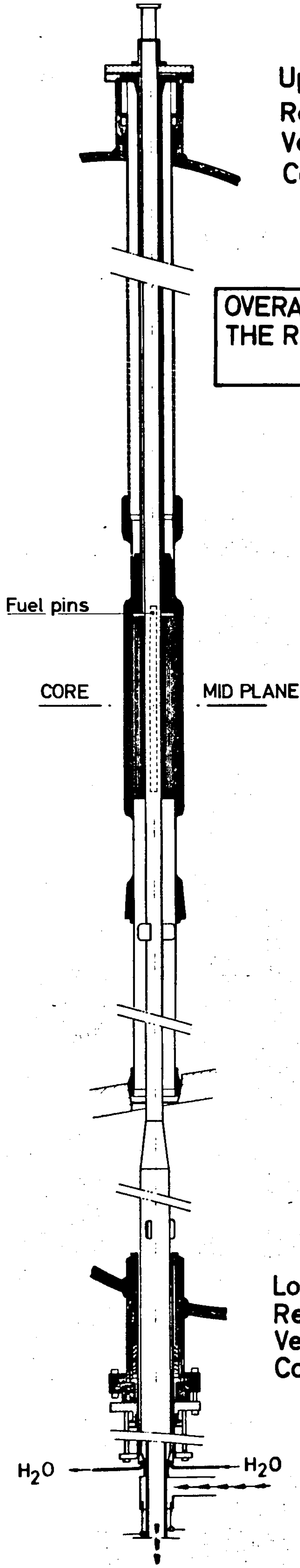
*) The designation "He 3" is an internal working title and subject to changes as the project procedes.

FIG. 13



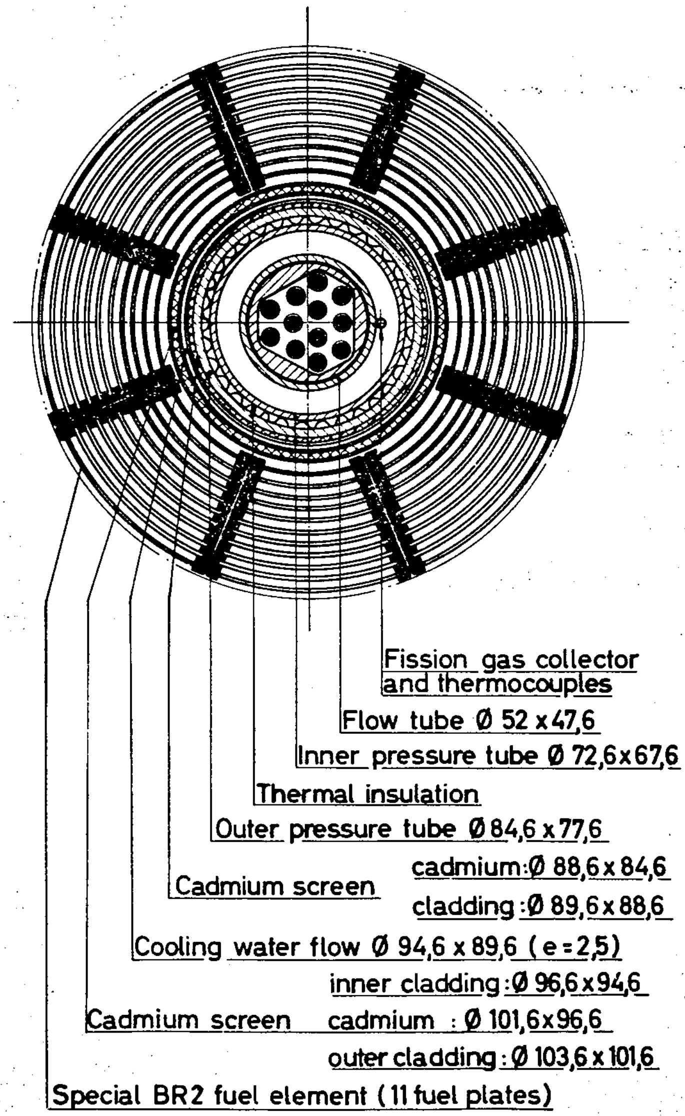
He 3 (400kW) SCHEMATIC FLOW DIAGRAM

FIG: 14



OVERALL SCHEMATIC OF THE REACTOR CHANNEL ASSEMBLY

SECTION AT CORE MID PLANE



He 3 (400 kW)
GENERAL LAYOUT
OF THE IN-PILE SECTION

The section through core mid-plane shows the pressure tube with incorporated Cd screen and thermal insulation, placed inside a removable Cd screen, and surrounded by a special 11-plate BR2 fuel element.

Due to the permanent occupation of the central 200 mm channel by sodium loop in-pile sections, the 400 kW assembly will be irradiated in a periphery position. This brings about two main difficulties :

- the mechanical problem of loading and unloading the heavy and fragile assembly in an inclined position,
- the neutron physics problem of achieving the specified fission rating at the periphery of the reactor core.

The latter consideration might lead to an overall power and flux increase in BR2.

Parameter Variation.

a. 120 kg/cm^2.

Operating of the loop operating pressure is not feasible without major changes to the design of loop components and in-pile section.

b. CO_2.

The installation in its original state is a CO_2 loop (see paragraph 2.4.1. above).

Availability.

The actual time schedule results in a start-up date towards the end of 1973.

Cost.

No cost estimation is available at present within the scope of this report.

3. Conclusions.

A number of BR2 irradiation facilities have been presented which are or will be available for the in-pile testing of fuel pin or coated particle fissile assemblies of gas-cooled fast breeder reactors. Further discussions on the subject are expected from which modifications and additions to the present review should emanate.

The author wishes to acknowledge the valuable help from all the S.C.K./C.E.N. and EURATOM colleagues who have collaborated in this paper.

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