technicatome

cea

IGORR 6 - Session 2

INTERNATIONAL GROUP ON RESEARCH REACTORS

6th MEETING - 29th April - 1st May 1998

"REACTEUR JULES HOROWITZ" (RJH)
A new material testing reactor
Status Report

Authors :

A. BALLAGNY - S. FRACHET - CEA/DRN
31-33 rue de la Fédération 75752 PARIS Cedex 15

C. LEYDIER - J.L. MINGUET - TECHNICATOME
BP 34000 13791 AIX-EN-PROVENCE Cedex 3

Presenting and corresponding author : J.L. MINGUET tel : 33.4.42.60.22.75
fax : 33.4.42.60.20.15
E.mail :Jminguet@Tetacom.fr

technicatome

ABSTRACT

The "REACTEUR JULES HOROWITZ" (RJH) is a new research reactor dedicated to material and nuclear fuel testing. This reactor, which will be erected in the CEA Cadarache nuclear research Center is now at a feasibility study stage.

At the beginning of the next century, at a time when most of existing material testing reactors will have to be shutdown or will be at the end of their lifetime, le RJH will offer outstanding neutron flux levels (twice those of existing french reactors).

This paper deals with the following topics :

- functional specifications of the project,
- safety approach,
- design and construction codes,
- alternative designs under consideration at the feasibility stage.

1. FUNCTIONAL SPECIFICATIONS

The concept of the reactor will have to fulfil the thermal neutron irradiation requirements as well as the fast neutron experimental needs, with a potential versatility for any new irradiation programs.

The reference concept under consideration is a 100 MW light water moderated core located in an open pool. A central loop will allow irradiations of fuels up to severe limits for the purpose of qualification.

2. SAFETY APPROACH

This reactor will satisfy the highest level of safety in full accordance with international safety recommendations and french safety approach for this kind of nuclear facility, thus giving an added safety margin keeping in mind the versatility of research reactors.

3. DESIGN AND CONSTRUCTION CODES

Design and construction specifications exist in France for application to research reactors and have been used for the erection or the refurbishment of research reactors. The RJH project gives the opportunity for the issue of an updated version of these rules, taking advantage of the "R.C.C" approach already set up for the nuclear power reactors.

4. ALTERNATIVE DESIGNS UNDER CONSIDERATION

Within the here above concept, the feasibility studies have been focused on the main following items :

- neutronic and thermalhydraulic studies on alternative core designs, with or without added pressurization,
- assessment of different core surrounding structures in connection with the core studies,
- overall layout of the reactor/auxiliary pools and reactor building.

TABLE OF CONTENTS

REFERENCES

<1> IGORR 5 — The RJH reactor - The CEA future tool for technological irradiation - CEA
S. FRACHET - P. MARTEL - B. MAUGARD - P. RAYMOND - F. MERCHIE

<2> IAEA — Safety Series 35 - S1 - Code on the safety of nuclear research reactors.

<3> IGORR 5 — French research reactors - Design of reactor building in accordance with IAEA recommendations.
TECHNICATOME : J.L. MINGUET - F. ARNOULD - P. ROUSSELLE.

<4> RRFM — Technical Ability of new MTR high density fuel alloys regarding the whole fuel cycle.
CEA/CERCA/COGEMA : B. MAUGARD - J.P. DURAND - A. GAY

technicatome

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

The "REACTEUR JULES HOROWITZ" (RJH) is a new research reactor dedicated to material and nuclear fuel testing. This reactor will be erected in the CEA Cadarache nuclear research centre.

At the beginning of the next century, at a time when most of existing material testing reactors will have to be shutdown or will be at the end of their lifetime, the RJH will offer outstanding neutron flux levels.

CEA and TECHNICATOME are now performing jointly the feasibility studies.

The present paper deals with :

- the functional specifications of the Project,
- the safety approach which is being discussed,
- the design and construction codes to be issued for the project,
- the alternative designs under consideration at this feasibility stage.

2 FONCTIONAL SPECIFICATION OF THE PROJECT

The RJH Project is aiming at satisfying irradiation needs under representative conditions in the frame of R and D programs related to different types of nuclear power plants considered in France.

The required possibilities cover basic research on fuel and materials up to qualification of fuel elements of any type, including testing under severe conditions with possible partial fuel melting.

For this purpose a removable loop will be located at the centre of the core of the reactor. Depending on the supported programs, the reactor will have to be able to host different types of loops such as gas or pressurized or liquid metal cooled test rigs.

Tables 1 and 2 give information on the foreseen irradiation programs.

Having in mind a foreseen lifetime of 40-50 years for the reactor the designer has to select design options leading to high neutron flux levels for a wide range of energy, and allowing flexibility and evolutivity of the facility :

- up to now the basic requirements have been to obtain twice the level of neutron flux existing in OSIRIS, typically :
  - thermal flux > 5 x 10^{14} n/cm^2.s,
  - damage due to fast flux > 10 dpa/year,
- as a consequence of the recent decision to shutdown SUPERPHENIX the need for ongoing R and D programs for fast flux reactors leads to take into account fast flux requirements of an order of magnitude above those existing in OSIRIS, typically 40 to 50 dpa/year and fast flux > 10^5n/cm^2.s.

At the end of 1995 a decision was made to select a water cooled pool type reactor.

A first step of studies has been dedicated to the optimization of an open core concept (see Table 3). LEU fuel is considered in any case.

A power density of 600 KW/l (twice those of OSIRIS) can be reached in such a concept, matching the initial flux requirements however with, as a consequence, a necessary coolant flow rate velocity of 15 m/s and some concerns for the fuel element design. New fast reactor R and D requirements could not be met (Table 4).

The pressurization of the core in a closed vessel (20 to 50 bars) would allow an increase of the power density up to 1000 KW/l with a possible flow rate reduction down to 9 m/s.

To fulfil with the same core the fast reactor R and D requirements, higher power densities are necessary (1000 to 2000 KW/l), however 40 to 50 dpa/year figures could be obtained only for the highest power density (Table 4). In order to enhance the fast flux performances some concepts of irradiation central loops equiped with a neutronic conversion device (such as a belt of U5 pins) have been also investigated ; though the positive effect of the conversion on the fast flux (conversion gain factor of ~ 1,2) a power density significantly higher than 1000 KW/l would still be necessary in that case.

As a conclusion these analysises demonstrate that the design of a unique core giving the required level of flux for both thermal and fast neutron irradiations appears to be a difficult issue.

The existence of too high gamma an thermal neutron fluxes for high quality PWR representative irradiation in a small high power density core (which means also a lack of space for the experiments) on one hand and the necessity to lower the thermal flux in the fast flux experiments on the other hand lead us to choose a nuclear facility concept which could potentially host two separate cores :

- one dedicated to thermal neutron irradiations,

  the open core concept seems to be a good choice for this, however a more detailed comparison with a pressurized solution has to be performed before making a decision, having in mind the wanted versatility of the facility,

- one dedicated to fast neutron needs,

  further analysises are necessary to orientate the design options for this eventual second core.

3 DESIGN AND SAFETY APPROACH

3.1 OVERALL APPROACH

Existing research reactors in France and in Europe are at least 20 years old. The safety approach has progressed a lot during this period. In addition, a large operating experience has been accumulated in the CEA research reactors. With a new concept, the RJH Project is wished to adopt a safety approach as close as possible to the one considered for the reactors of the future.

Safety objectives have been defined and safety options are under considerations, they will be issued within the beginning of 1999.

The safety objectives are aiming at defining the radiation hazards for the environment and the public. In addition similar objectives are identified for the reactor workers.

These objectives take into account, on the basis of the french regulation, the ICRP recommendations.

We take advantage of the research reactor available operating experience when writing the initiating events to be considered. The existence of experimental devices, when having a potential additional effect on the safety, is also taken into account when determining the possible initiating events to be considered and their consequences.

The European utilities requirements (EUR) are not considered as an objective but will be considered as far as possible in the design.

Risks for environment and people will be as low as possible during normal operating conditions and eventual accidental events.

Radiological doses will be as low as possible for reactor workers in full accordance with ICRP and ALARA principle.

When designing the reactor the "defence in depth" principles will be followed, according to the IAEA recommendations (Cf. reference <2> and <3>) leading to :

- multiple levels of protection against the release of radioactive material,
- a coherent and homogeneous combination of inherent safety features, safety systems and engineered safety features achieving a progressivity in the protection, thus avoiding any sudden increase of potential consequences in case of the failure of one "defence line".

3.2 SAFETY ANALYSIS FOR THE DESIGN

- Classification of initiating events

  We are investigating the solution consisting in following a way similar to the one already adopted for the nuclear power plants and hereafter summarized : the combination of a list of selected initiating events with the possible initial situations of the reactor leads to a list of operating conditions to be considered for the design.

  The initiating internal and external events are divided into five categories, in a deterministic way : categories 1 to 4 for the design ($f > 10^{-6}$/year) plus an highly hypothetic event category ($f < 10^{-6}$/year).

  These events are selected according to IAEA recommendations and the french research reactors operating experience.

  In the same way the resulting operating conditions are divided into five categories, taking into account the frequency of the initial situation considered : categories 1 to 4 for the design events plus a beyond design basis accident category ($f < 10^{-6}$/year).

- Risk definition

  Table 5 gives an indication of considered irradiation limits for normal operation and incidental events, and for accidental events. One objective is that there would be no need for population evacuation for any of the above mentioned events.

  In addition significally lower objective values are fixed in accordance with ALARA principle having in mind the EUR.

- Beyond design basis events

  The objectives are to achieve a design for which, in case of identified potential severe events (for instance core melting at low pressure, major criticality event), the consequences for the public and the environment would be limited and would need only protection measures limited in terms of location and duration. ICRP63 will be taken into account.

  One objective is to avoid any need for the population evacuation within 24 hours and for long term restrictions or living conditions.

  In addition situations with a probability of occurrence very close to the design limits are considered under realistic conditions with the limits mentioned here above for the 4^{th} category.

  This will result in an added safety margin having in mind the wanted versatility of RJH reactor.

All the above mentioned objectives will probably lead to separate the reactor operation activities from the others activities (searchers, experimentators) and to locate these two kind of activities in separate dedicated areas.

4 DESIGN AND CONSTRUCTION CODES

A hudge experience of research reactor construction exists in France in the CEA, in TECHNICATOME the french dedicated company for research reactor engineering and in the component manufacturers.

This led to the writing of numerous construction specifications and rules, namely in TECHNICATOME.

Till recently this documentation has been used for refurbishment actions in SILOE, OSIRIS, RHF and ORPHEE reactors.

In connection with the here above mentioned progress on the safety approach, the nuclear power plant (NPP) realisation program created a need for a french coherent system of design and construction codes, with as a result the issue of the french "RCC" (Recueil de Conception et de Construction - ie : design and construction code) for the PWR and then the RCCMR for the FBR.

Recent experiences in refurbishing or designing experimental in pile loops shown that a similar coherent system would be of a great help for the research reactor projects and for any new experimental device to be installed in a research reactor.

For these reasons the CEA made the decision to develop a "RCC-X" design and construction code adapted to the research reactor field. This code will benefit from :

- the existing design and construction experience in research reactors and experimental loops,

- the experience in writing and in using the RCC rules for NPP.

It was decided firstly to start the RCC part related to the mechanical components of research reactors and called RCCMX.

An associated RCCPX (process volume) will have to be written in order to give the key access to the RCCMX in which mechanical components are selected into 4 quality classes.

The particularities of research reactors (ie often no significant pressure and temperature, use of aluminium alloys,...) will be of a great influence when refering to the RCC existing rules.

The RCCMX writing activity has started under the leadership of the CEA/DRN/DER department in Saclay, associating TECHNICATOME as engineering company in charge of the Project and FRAMATOME bringing its own experience on the RCCM (PWR) and RCCMR (FBR).

5 ALTERNATIVE DESIGNS UNDER CONSIDERATION

The RJH feasibility studies started at the middle of 1996. TECHNICATOME has been associated since 1997 to these studies. They are foreseen to be completed within the middle of 1999.

In addition to the work performed on the functional specifications (see chapter 2) the studies have been focused up to now on an overall survey of a wide scope of possible solutions in order to select the concepts worth of further detailed analysises during the second phase of the feasibility studies.

We present hereafter the current status of the ongoing studies on :

- the fuel and core design,

- the core surrounding structures,

- the reactor and auxiliary pools and reactor building.

5.1 FUEL AND CORE DESIGN

Having in mind the required level of performances, twice those existing in an irradiation reactor like OSIRIS, the RJH core will have to reach a specific power density of 600 KW/l at least, with a power of 100 MW.

At this level of performance an upward flow rate is necessary. A core shroud and a chimney need also to be installed to collect the primary coolant flow.

A plate type fuel element has been selected on the basis of the large amount of fabrication and operating experience with LEU (U3Si2) aluminium type fuel (fuel density : 5,8 g/cm^3).

Depending on the level of pressure in the core when operating the reactor, the design may either select a high velocity flow rate, typically 15 m/s or adopt a significant pressurization (some tens bars) needing pressurized vessel and primary loop.

In the first case (open core) standard MTR plate type fuel is not acceptable due to vibration hazards.

Thus, a circular plate concept was selected for the fuel elements as a reference concept for the Project (see figure 1) with six tubular plates in an hexagonal Al-Bore tube (on the basis of the experience on BR2 with similar fuel elements manufactured by CERCA). It was decided to keep free of fuel the centre of each element, thus giving in the core a lot of available locations for irradiation or control rods.

In the second case (pressurization), a lower velocity would allow the use of MTR type plate fuel element.

In conclusion, the following alternative designs are mainly considered at this stage for the fuel elements, having in mind the fabrication and operating costs :

- hexagonal fuel element with circular shaped fuel plates (figure 1),
- "MTR type" smaller plate bundle (5,01 cm) associated by three or four in a fuel assembly (figure 2).

Depending on the fuel element design the core configuration adopts overall common features (see figure 1 and 2 for the two selected concepts) :

- several layers of beryllium reflector elements (3 to 4),
- a grid plate allowing outside core free irradiation locations,
- irradiation locations in the core and in the reflector,

- up to four displacement irradiation boxes (fuel ramp test simulation),

- in core compensation and security absorbers,

- four outer core rotating absorbers for burn-up compensation and regulation (concept selected to avoid axial flux perturbations) or control rods in the first Be layer,

- a possible location in the core of a central penetrating irradiation fuel loop cooled by different possible coolants (gas, water, liquid metal),

- a neutronography equipment.

Further studies need to be performed in connection with the new fast neutron irradiation demand before selecting a core concept, including studies on higher power densities and on a pressurized solution.

5.2 CORE SURROUNDING STRUCTURES

The feasibility studies are under progress. They are aiming at identifying all the constraints related to :

- different core concepts and related required operating pressures (open core or pressurized vessel),

- the size of the core shroud or vessel (immediately around the core or outside the reflector),

- the concept of a central irradiation loop with different possible designs (one-through or "U" type introduced downwards or upwards into the core),

- the location of control rod drive mechanisms.

A decision was made to compare the most representative combinations of options through the studies of a small number of selected sets of options.

Figures 3 to 5 show some of the studied configurations :

- Figure 3 : small vessel concept, with a U type downward central loop. Practically this solution is limited to a first step of pressurized solutions (some bars) due to the core vessel shape at the core level and the necessity to limit the wall thickness (heating of the structure and limitation of the flux perturbation outside the core).

- Figure 4 : large vessel concept including all irradiation devices and reflector with a U type upward central loop.

- Figure 5 : open core, large core shroud with a once through type central loop associated with control rod mechanisms located below the pool (as in OSIRIS). This shows the contraints generated on the building design and on the handling of the central loop, should this combination of options be selected for the reactor.

The aim of the studies within the few next months will be to go further in detail in the analysises, comparing open core and pressurized solutions in order to select a reference design for the second phase of the feasibility studies (June 1998 to May 1999).

An important choice will be the one related to the level of temperature in the primary loop ; should an average hot leg temperature be chosen above the bulk saturation value under the pool static pressure, this would have a high impact on the safety design and related safety systems and features.

5.3 REACTOR AND AUXILIARY POOLS AND REACTOR BUILDING

As for the design of the core surrounding structures of the reactor, a systematic approach has been used for the design of the buildings and pools, in order to study a maximum of possible options. This approach consists in the following work :

- writing firstly, with the future "operator", the functional specifications for the main systems (buildings and pools), in order to characterise the needs, and to make some basic choices such as :
  - Safety features, for example the choice of taking into account a criticality "BORAX" type event,
  - Capacities of the pools and buildings (areas devoted to experimental loops),
  - Different work areas (work on the loops, storage of irradiated experimental materials, storage of irradiated fuel) assigned to separate pools. This feature was chosen on the basis of the CEA operational experience,

- determining a list of alternative options to study, when designing each of the main systems,

- selecting the combinations of alternative options in the different drawings, in such a way that every individual choice will been studied, in one or two investigated combinations,

- analysing the resulting drawings, in accordance to technical and economical criteria. Following criteria are taken into account :
  - Easy reactor operation,
  - Easy operation of experimental loops. (including handling operations),
  - Easy operation in the experimental facilities (hot cells, pools),
  - Risks limitation (handling, mutual aggressions...),
  - Radiological risk limitation during normal operation (ALARA),
  - Realisation costs,
  - Operating costs,
  - Versatility of the plant,
  - Dismantling feasibility.

In existing irradiation research reactors many operations are performed in the reactor building :

- reactor operation,
- fuel handling,
- fuel storage,
- irradiation devices and samples preparation, loading and downloading,
- operations in hot cells and laboratories.

The safety objectives and constraints as well as the ALARA principle may lead to a separation of the operations (and associated workers access) in dedicated areas.

Thus, in an alternative option, it was decided to study a design with a part of the pools and the hot cells and laboratories located outside the reactor building and leading to :

- a medium size reactor building dedicated to the reactor and excluding any permanent scientist or experimentator activities,
- an auxiliary building including fuel storage pool, transport and auxiliary channels, hot cells and laboratories.

This design appeared to have a lot of advantages, as well as for reactor operation as for the experimental facilities, in spite of adding a lock for the irradiated material. After this work it was decided that there would be two separate buildings as described.

The second phase of studies will be focused on a detailed review of this concept.

We are also studying now others alternative choices, for example :

- the general shape of the containment, and technical ways for its realisation,
- the impact of different ways of loading and unloading the central loop in the core (upwards or downwards).

technicatome

TABLE 1

FORESEEN IRRADIATION PROGRAMS - PWR NEEDS

PWR irradiation needs	
Item	Programs
Fuel - burnable poisons - Control rods	– irradiation in loops or capsules of fresh or irradiated samples (up to 60000 MWd/t and for load following improvement and safety) – qualification of UO2 and MOX fuel, – new cladding materials (Zr, ceramics), – fuel with new burnable poisons, – control rods with absorbing cladding.
Materials	– the plant lifetime extension requires important irradiation program on existing or new materials with a dose rate higher than 10 dpa/year.

TABLE 2

FORESEEN IRRADIATION PROGRAMS

FAST NEUTRON REACTORS AND OTHER NEEDS

Fast neutron reactors and other irradiation needs	
Item	Programs
Fast neutron reactor needs	- structures and cladding material irradiation in chemical and thermalhydraulic representative conditions, - selection of fuel for fast reactors, - qualifying the next coming fast reactor fuel with ramp test possibilities.
Other needs (non exhaustive)	- material qualification for fusion programs, - activation analysis, - radioisotope production, - neutronography.

TABLE 3
RJH REFERENCE DESIGN - 600 KW/l

core	type	light water pool
	core structure	open core
	max thermal power	100 MW
	max fissile length	0,80 m
	eq diameter	0,51 m
	volume	166 dm^3
	specific power	600 kW/dm^3 core
	nb of fuel elements	37
	type of fuel elements	STD - CNT - EXP
	reflector	H2O - Be
	coolant flow direction	upwards
	primary flowrate	1,2 m^3. s-1
	average speed	15,8 m.s-1
	max speed	16,3 m.s-1
	outlet core pressure	0,2 MPa
	inlet core temperature	30°C
	core ΔT	26°C
	core ΔP	0,63 MPa
	average thermal flux	154 W.cm-2
Fuel	composition	plates U3Si2Al - Al
	U density	4,8 - 6
	enrichment	19,75 % in mass
	external structure	hexagonal tube Al (Al-B)
	hexagonal size	4,65 cm
	coolant channel	1,84 mm
	plate thickness	1,27 mm
	meat thickness	0,51 mm
	cladding thickness	0,38 mm
Reactor operation	cycle length (reference)	28 efpd
	cycle length mode "B"	21 efpd
	nb of cycles per year	9
	annual availability	252 efpd
	refueling (reference)	1/3
	refueling mode "B"	1/1
Irradiation	nb of simultaneous irradiations	20
(performances)	max thermal flux	> 8 E14 cm-2.s-1
	max fast flux (in core)	> 7 E14 cm-2.s-1
	damage build up on materials	> 13 dpa.year-1
	available irradiation length with flux > 80 % max flux	0,50 m

TABLE 4

IRRADIATION NEEDS AND PERFORMANCES IN ALTERNATIVE RJH CONCEPTS

fast flux performance	OSIRIS* SILOE*	RJH open or pressurized*	RJH pressurized*	RJH pressurized	PHENIX**	SPX**
average core		100 MW - 166 l	100 MW - 100 l	100 MW - 50 l		
		initial version	200 MW - 200 l	200 MW - 100 l		
specific power (kW/l)	~ 300	600	1000	2000	400	280
ϕ1 (E14 cm-2.S-1)	1,7 to 2,1	3,4 to 3,9	5,5 to 6,5	11 to 13	6,6	5,5
(> 0,907 MeV)						
ϕ2 (E14 cm-2.S-1)	2,2 to 2,6	5,6 to 6,4	9 to 11	18 to 21	35,2	34
(5keV to 0,907 MeV)						
ϕ1+2(E14 cm-2.S-1)	3,9 to 4,7	9 to 10,3	14,5 to 17,5	31 to 34	41,8	39,5
(> 5 keV)						
ϕtot (E14 cm-2.S-1)	8	16	27	56	44,2	41,7
dpa/year	4 to 5	11 to 15	18 to 25	36 to 50	35 to 50	30 to 45

* perturbed fluxes in an irradiation device in the core
** non perturbed value in the fuel

TABLE 5

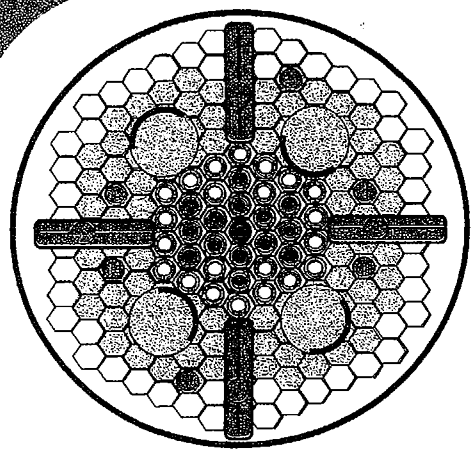
RJH - IRRADIATION DOSE LIMITS AND OBJECTIVES

	Dose limits		ALARA objectives per year	
Conditions	Workers	Others and public	Workers	Others and public
Normal operation and incidental events	< 20 mSv mean value for five years < 50 mSv max	< 1 mSv	< 5 mSv	< 25 µSv
Accidental events of moderate frequency	< 30 mSv *	Other personals < 5 mSv Public < 1 mSv	**	**
Accidental events of low frequency	< 100 mSv *	Other personals < 5 mSv Public < 1 mSv	**	**

* eventualy higher for some workers
** defined in terms of release rate per radioelement

DIRECTION DES REACTEURS NUCLEAIRES

Cylindrical type fuel elements



Standard fuel assembly

Reflector (Be)

Control fuel assembly (Security)

Control fuel assembly (Compensation)

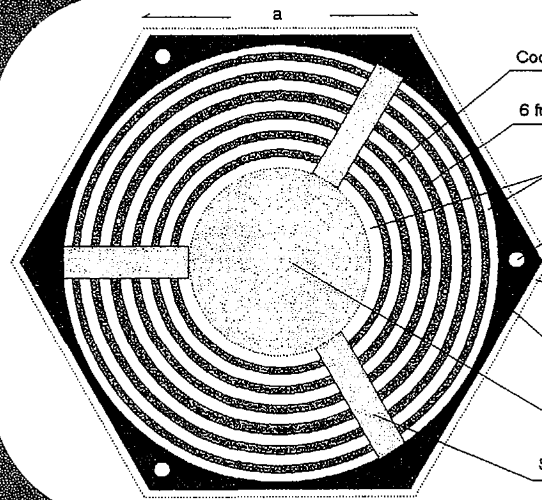
Mobile absorber of compensation-regulation

Experimental location in experimental fuel assembly

Experimental location in reflector

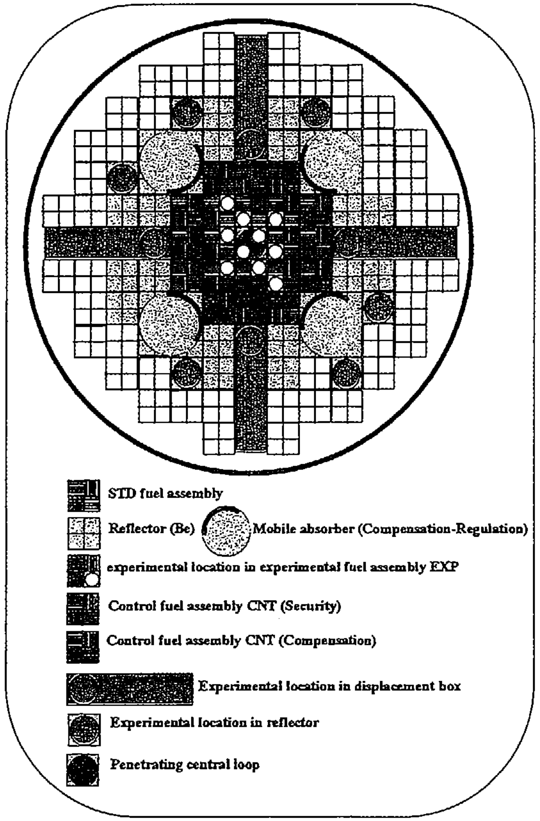
Experimental location in displacement box

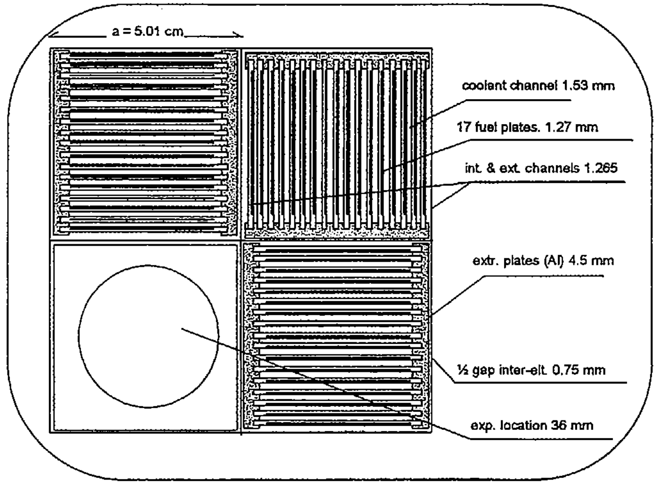
Penetrating central loop



DIRECTION DES REACTEURS NUCLEAIRES

Plate type fuel elements





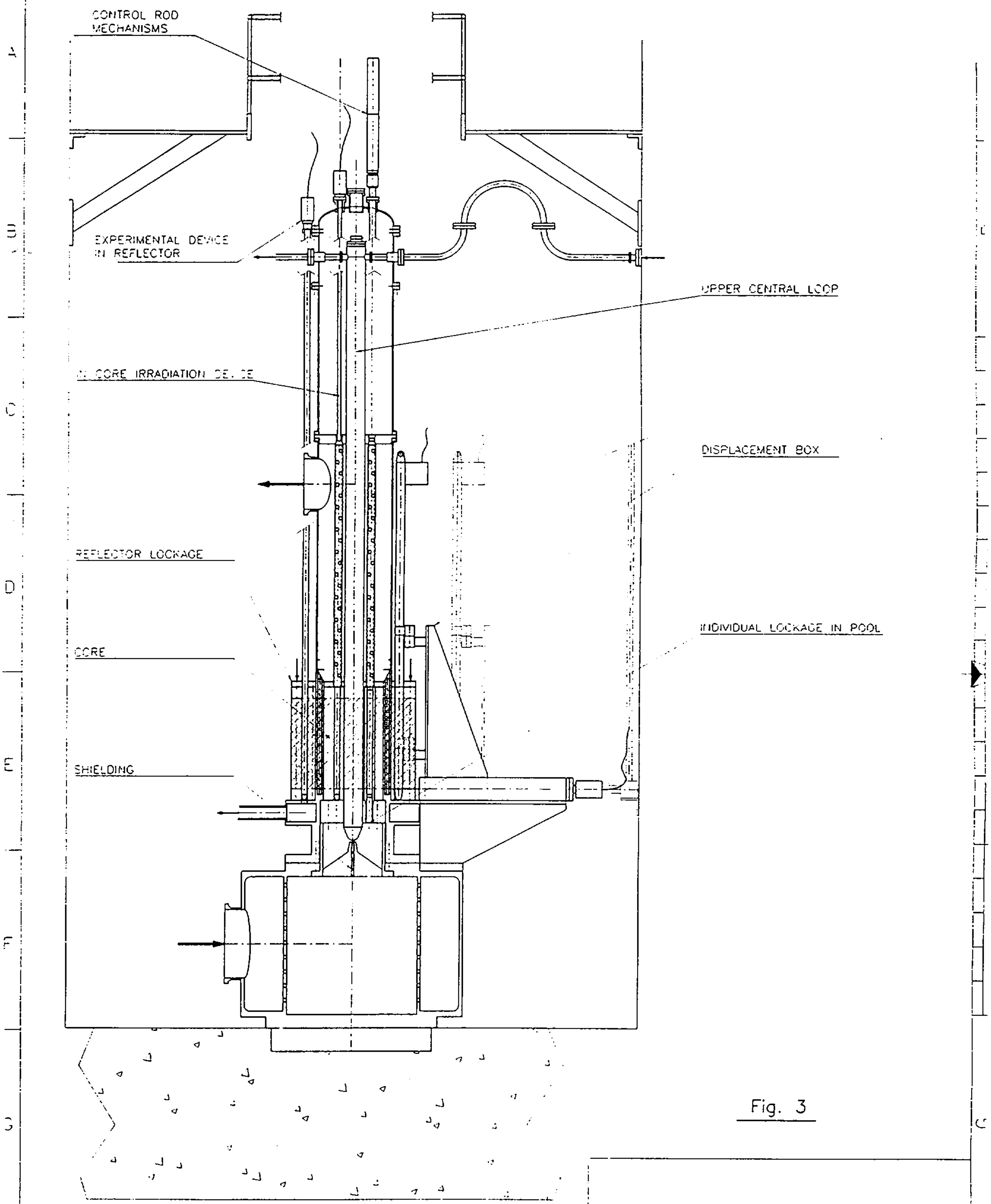


Fig. 3

RJH CORE SURROUNDING STRUCTURES
PRESSURIZED VESSEL – UPWARD FLOW
UPPER CONTROL ROD DRIVE MECHANISMS
UPPER "U" TYPE CENTRAL LOOP

technicatome

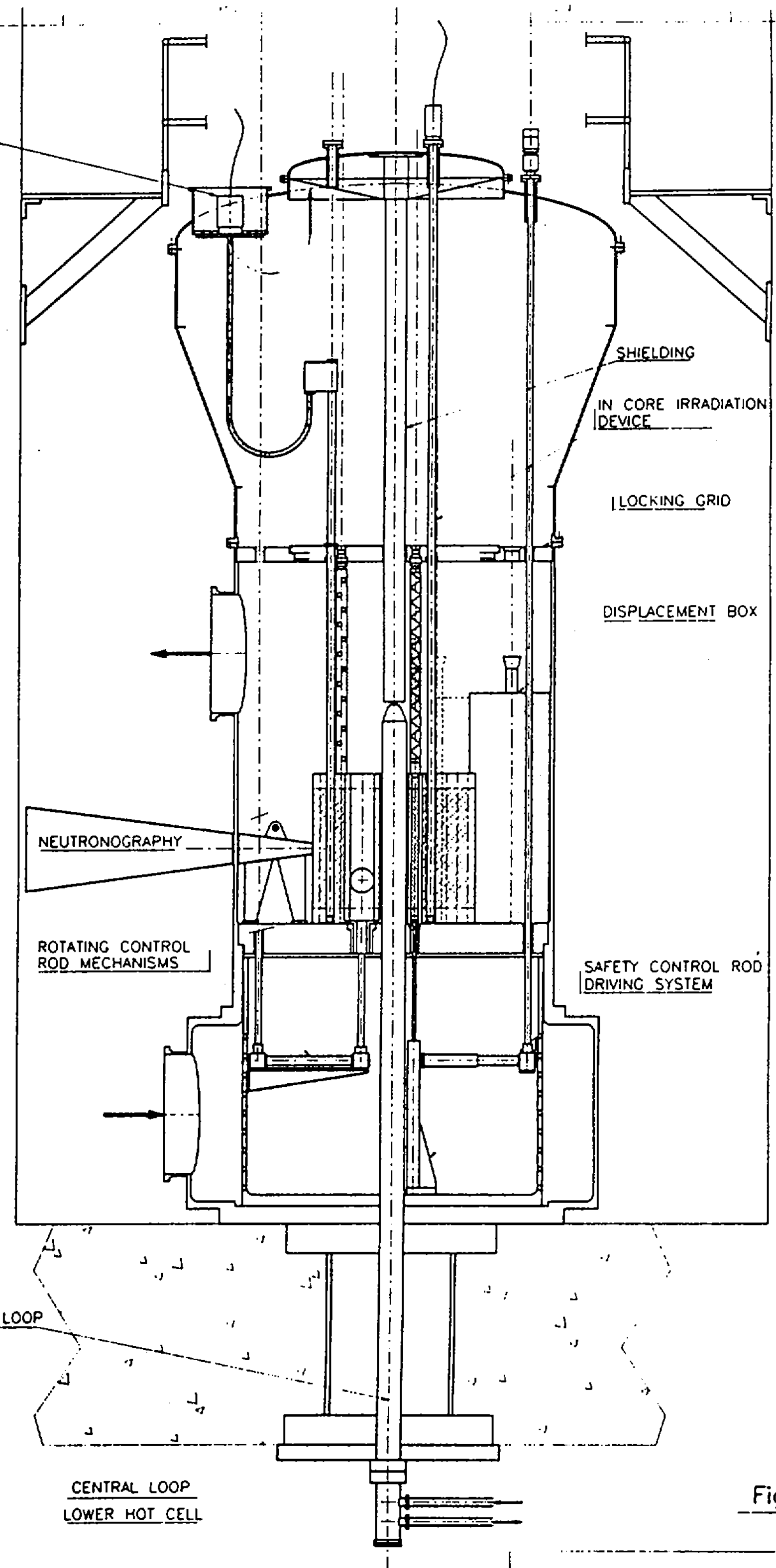


Fig. 4

RJH CORE SURROUNDING STRUCTURES
PRESSURIZED VESSEL – UPWARD FLOW
LATERAL CONTROL ROD DRIVE MECHANISMS
LOWER "U" TYPE CENTRAL LOOP

technicatome

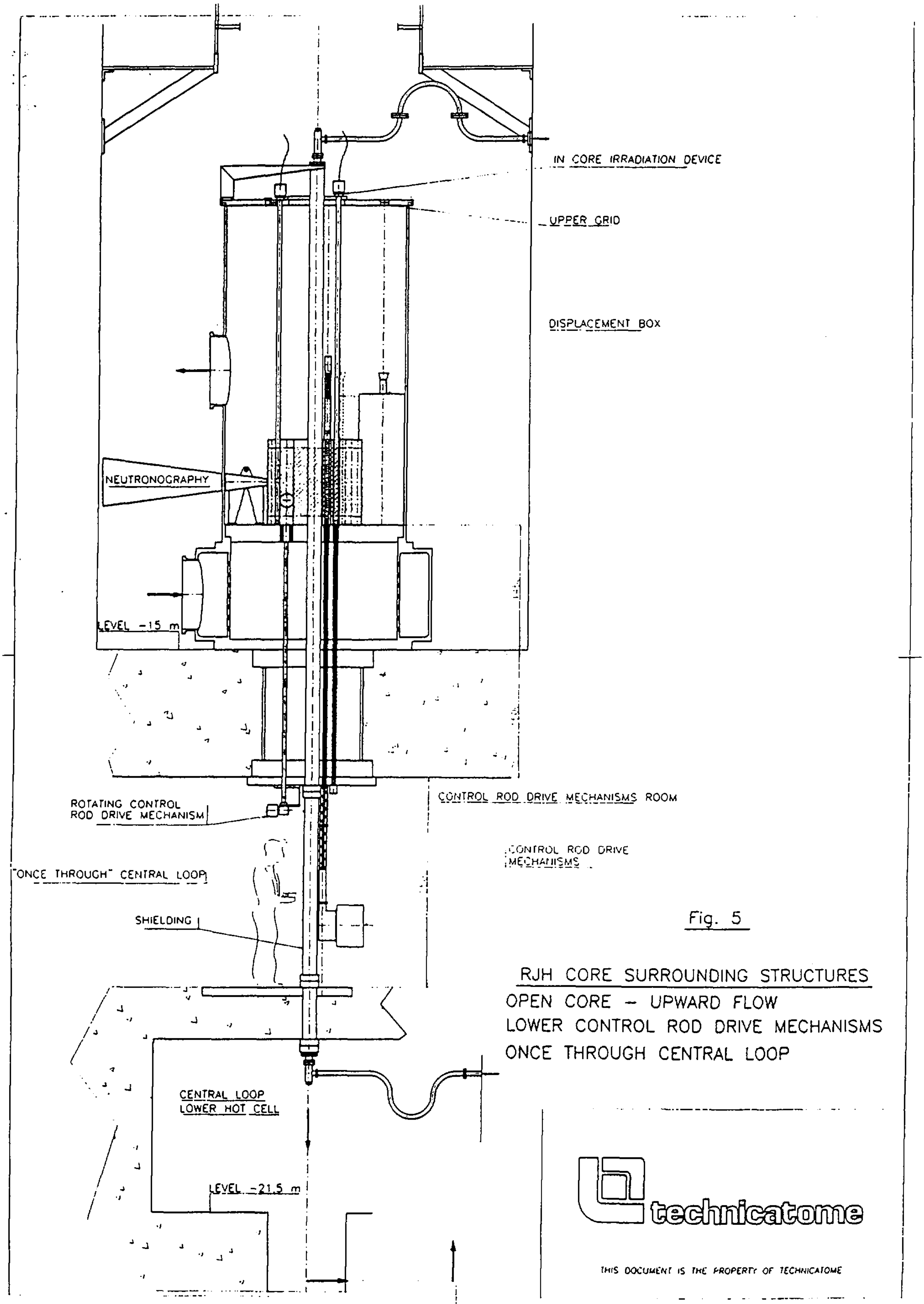


Fig. 5

RJH CORE SURROUNDING STRUCTURES
OPEN CORE – UPWARD FLOW
LOWER CONTROL ROD DRIVE MECHANISMS
ONCE THROUGH CENTRAL LOOP