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CHARACTERISTICS AND DESIGN OF A FACILITY FOR K-inf MEASUREMENTS ON D_2O LATTICES IN THE RB-1 REACTOR

by

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(*) CNEN
(**) EURATOM

1967

ORGEL Program

Report prepared by CNEN
Comitato Nazionale per l'Energia Nucleare
Centro di Calcolo, Bologna - Italy

Euratom Contract No. 284-66-5 ORGI

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Brussels, June 1967

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Brussels, June 1967 - 32 pages - 14 figures - FB 50

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Part I describes neutronic design criteria of the facility, with particular reference to the errors introduced in the measurements by neutronic flux non-flatness and spectrum mismatch in the test cell.

Part II illustrates the design of the facility according to the experimental requirements, with special regards to some characteristic components.

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SUMMARY

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CHARACTERISTICS AND DESIGN OF A FACILITY FOR K-inf MEASUREMENTS ON D_2O LATTICES IN THE RB-1 REACTOR[+]

Introduction

In the frame of the cooperation between Euratom and CNEN a D_2O facility has been installed in the RB-1 pile of Bologna [1]. The criticality of the RB-1 pile with this in pile facility was reached on October 21, 1965.

This will permit the execution of k-inf measurements, according to the PCTR technique, on heavy water lattices, thus extending the usefulness of the RB-1 pile which was until now used for the investigation on graphite lattices.

The experimental program will deal first with the measurements on ORGEL-type fuel elements [2] (until the end of 1966) and it will continue with the analysis of lattices in the framework of the CIRENE project. The k-inf experiments will be completed by a series of detailed parameter measurements such as initial conversion ratio, fast fission ratio, etc., by the activation technique.

The ORGEL experiments will be carried out with three types of fuel elements:

1) a 19-rod, natural uranium metal cluster (UM-19), cooled by an organic liquid (diphyl, eutectic mixture $C_{12}H_{10}$ - $C_{12}H_{10}O$)
2) the same as 1) with a slight enrichment in plutonium
3) a 7-rod, natural uranium carbide cluster (UC-7), cooled by diphyl.

Several square lattice pitches will be investigated, ranging from 19 to 27 cm.

It must be noted that the UM-19 and UC-7 fuel elements have been or are being tested on the Euratom exponential and critical facility, EXPO and ECO, installed at Ispra.
In EXPO the material buckling of the ORGEL lattices is evaluated by measuring the relaxation length of the assembly by the activation technique.

In ECO the material buckling is determined for the UM-19 lattices by flux mapping and for the UC-7 lattices by the progressive substitution technique [3].

[+] manuscript received on October 6th, 1966

In all the above mentioned measurements on RB-1, ECO and EXPO, the same fuel elements will be used, so that a quite clean cross checking of the different experimental methods of obtaining the overall lattice neutron balance of a typical heavy water reactor will be possible.

In particular, the k-inf measurements on RB-1 will allow in combination with the ECO and EXPO experiments a test of the theoretical models for the evaluation of the neutron leakage in an ORGEL-type reactor.

A detailed illustration of the PCTR technique is found in references [5], [1].

Here only a brief analysis of the method is presented as an introduction to the design analysis of the facility.

The k-inf of a multiplying medium can be obtained from the measurement of the amount of thermal absorber to be added to the medium for reducing its k-inf to 1.

In the ideal case of an infinite critical homogeneous reactor (k-inf = 1), no reactivity changement occurs when vacuum is substituted to a portion of the medium.

In a finite heterogeneous lattice it is necessary to obtain in the test cell the same asymptotic spectrum and flux distribution as exists in the infinite critical reactor. The amount of thermal poison necessary to obtain a null reactivity signal when the test cell is substituted by vacuum is determined. k-inf is evaluated from the amount of such thermal absorber and from the thermal neutron density distribution across the cell.

In a facility designed for k-inf measurements by such a technique, three regions are generally found:

a) an external feeding zone, loaded with enriched uranium;

b) a "buffer zone", i.e. some cells similar to the test lattice, designed to yield the asymptotic spectrum in the test central cell;

c) the test cell to be poisoned and substituted by vacuum in reactivity measurement and allowing thermal utilization factor measurement.

In the RB-1 ORGEL facility, the feeding zone is the same as that of the RB-1 pile and it is constituted by some rings of enriched uranium fuel elements in a graphite moderator. The central cavity of the pile (1 m diameter) is filled with the "buffer" zone: a special vessel has been designed for containing the ORGEL lattice. The vessel, the D_2O and nitrogen loops and the central special fuel elements, have been designed and constructed at CCR Euratom Ispra.

A description of the criteria used for the neutronic design of the ORGEL tank region is given in Part I. The mechanical design of the D_2O system will be described in Part II together with a general description of the overall facility.

Part I

Neutronic design criteria

1. Checking the feasibility of flux matching and flattening

The main design problem, from the neutronic point of view, was to obtain criticality while respecting the infinite medium conditions in the central test cell.

In fact from a first calculation it appeared that the amount of enriched uranium pellets available to feed the graphite driver zone was not enough to permit criticality when the ORGEL tank was installed. This made it necessary to increase the U-235 mass of the feeding zone by putting in the periphery of the D_2O tank region a certain number of highly enriched plates, thus reducing in practice the size of the buffer zone.
As a consequence it was necessary to check if, in such conditions, the spectrum could be matched and how many thimbles in the buffer region would be necessary in order to get the flattening of the flux distribution in the test cell.
This check has been carried out by a series of calculations in conditions which simulated the experimental procedure.
The actual geometry of the RB-1 reactor with the D_2O in-pile facility in the center was represented as closely as possible by means of a schematization in an r-z geometry as shown in fig. 1 a,b. In the D_2O tank there are inserted 13 ECO reference elements, the central one containing the test cell of 60 cm length and a radius of 10.6 cm which corresponds to the square pitch of 18.8 cm of the ECO lattice. The ECO reference elements are surrounded by 16 standard driver elements (see part II), with 20 % enriched fuel which are inserted into the D_2O tank.

The "correct Cu-mass", that is the Cu-mass which corresponds to the theoretical k-inf value at this pitch k-inf = 1.07851 (calculated by the code CAROLINA, ref. [4]) is

$$\mu^{\circ}_{Cu} = 7.41 \text{ g/cm}$$

or in the case of a 60 cm long test cell a total mass of $M_{cu}^{(o)}$ = 445 g Cu. By replacing the test cell by void the reactivity change of the reactor is calculated with the two dimensional two-group-code EQUIPOISE 3 for different copper masses finding in such a way the "experimental Cu-mass", M_{cu}^{exp} , that corresponds to a zero reactivity change of the assembly. This calculation has been performed for three different degrees of flux flattening which were obtained by inserting into the thimbles at a radius of 35 cm fuel elements with different active length ℓ (see fig.1a) at top and bottom. By changing ℓ the axial flux distribution can be influenced to a considerable degree when 20 % enriched fuel pellets are used in these leveller elements. Figures 2, 3 show the axial flux distribution in the three different cases. (This flux distribution refers to the case where only the test cell has been poisoned and where the surrounding ECO region is unpoisoned.)

From each value of the copper mass corresponding to a zero-reactivity of the pile, the "experimental k-inf" can be derived. The difference between "k-inf^{exp}" and "k-inf^{th}" as a function of the flux flatness over the test cell is plotted in curve I of fig.6. The flux flatness has been characterized by a quantity called m_f^2 which is related, as explained in section 2, to the axial and radial flux flattening of the pile.

It is seen that the error increases linearly with the non-flatness and that in the case of an unpoisoned ECO buffer (curve I) and a perfectly flat flux (m_f^2 = 0) the mismatch error is about 0.4 % in k-inf. In the case of a poisoned buffer however the spectrum matching is good and the non-flatness is the only source of error.

In fig. 4 the ratio of fast to thermal flux is plotted axially along the test cell, for the case in which the buffer cells are not poisoned. This ratio is about 3 % higher in the poisoned test cell than in the surrounding medium due to the increased thermal absorption in the test cell. This corresponds to about the same relative difference in the Cd-ratio of a gold detector. For the case of a poisoned buffer region the ratio of fast to thermal flux in the test cell was found

$$\left(\phi_1/\phi_2\right)_{\text{pois. ECO}} = 0.944$$

which is very near to the theoretical value that is given by

$$\left(\phi_1/\phi_2\right)_{\infty} = 0.946$$

In fig. 5 the radial flux distribution in the whole pile is shown for the case with unpoisoned and poisoned test cell and unpoisoned buffer.

2. Approximate relations for spectrum matching and flattening evaluation

In order to have quick methods to check the spectrum matching and flattening, simplified expressions may be derived, in the frame of two-group perturbation theory.

- Spectrum effects

It has been shown (ref. [5]) that the error on k-inf due to a spectrum mismatching can be evaluated by the formula:

$$\rho^{sp} = \left(\frac{k_\infty - 1}{k_\infty}\right)^{sp} = \frac{\left(\frac{\phi_1}{\phi_2} - \frac{\phi_{1\infty}}{\phi_{2\infty}}\right)\left(\frac{\phi_1^+}{\phi_2^+} - \frac{\phi_{1\infty}^+}{\phi_{2\infty}^+}\right)}{k_\infty \cdot \frac{\phi_{1\infty}}{\phi_{2\infty}} \cdot \frac{\phi_{1\infty}^+}{\phi_{2\infty}^+}} \qquad (1)$$

where

ϕ and ϕ^+ are respectively the flux and the adjoint flux

1 and 2 refer to the fast and thermal energy group

ϕ_∞ refers to the values for an infinite medium.

- Flattening effects

The effect of non flattening on k-inf can be expressed by a simple approximation of the flux distribution over the test cell:

$$\rho^{nonfl.} = \left(\frac{k_\infty - 1}{k_\infty}\right)^{nonfl.} = -\frac{2}{R^2}\left(\tau\alpha_{r1}^2 + L^2\alpha_{r2}^2\right) - \frac{16}{3H^2}\left(\tau\alpha_{z1}^2 + L^2\alpha_{z2}^2\right) \qquad (2)$$

where R and H are the radius and height of the test cell, τ and L^2 are the Fermi-age and the thermal diffusion length in the medium and α_{ri} and α_{zi} are the non-flatness parameter defined by

$$1 + \alpha_{ri} = \frac{\text{flux at the center of the cell in group } i}{\text{flux at the cell boundary in radial direction in group } i} \qquad (3)$$

$$1 + \alpha_{zi} = \frac{\text{flux at the center of the cell in group } i}{\text{flux at the cell boundary in axial direction in group } i} \qquad (4)$$

In order to check the validity of these two simplified formulae, they have been used to evaluate the errors in k-inf due to spectral mismatch and non flatness of the flux for the case of fig. 1.

Curve III of fig.6 gives the difference Δ k-inf = k-inf^{exp} - k-infth, as evaluated by formulae (1) and (2).

From the curve III, as compared to curve I, it can be seen that

- the spectrum effect is underevaluated by the simplified formula (0.1 % in k-inf instead of 0.4 % for $m_f^2 = 0$)
- the flattening effect is also too low. In fact from the EQUIPOISE calculations (curve I) it is found, for the axial flattening effect, that

$$\frac{\Delta k_\infty}{\Delta \alpha_{z2}^{2}} = -\,1.0 \cdot 10^{-4}$$

The corresponding values, derived from (2), is

$$\frac{\Delta K_\infty}{\Delta \alpha_{z2}^{2}} = -\,\frac{16\,L^2}{3\,H^2} \cdot 10^{-4} = -\,0.13 \cdot 10^{-4}$$

It is interesting to note that the EQUIPOISE result is confirmed by the experiments performed in PLATR (Pawling Lattice Test Rig) by Brooks et al. [6] where the following relationship has been found between the error in k-inf and the non-flatness of the axial thermal flux:

$$\frac{\Delta k_\infty}{\Delta \alpha_{z2}^{2}} = -\,2.0 \cdot 10^{-4}$$

It must be noted however, that in the PLATR experiments the length of the test cell is 70 cm instead of 60 cm as in the RB-1 measurements.

3. Effects connected with the shape of the test cell

For practical reasons, it has been found convenient to use, as test cell, instead of the true square central lattice cell the equivalent cylindrical cell determined according to the Wigner-Seitz presciption.

It can be demonstrated that this induces an error on the k-inf which, in a two group formalism, is given by Ref. [7]

$$S^{shape} = \left(\frac{K_\infty - 1}{K_\infty}\right)^{shape} = \frac{\int_{(V)} df \left(\phi^{+}_{1\infty} D_1 \frac{\partial \phi_{1\infty}}{\partial n} + \phi^{+}_{2\infty} D_2 \frac{\partial \phi_{2\infty}}{\partial n}\right)}{\int_{V} dv \left(\phi^{+}_{1\infty} \nu \Sigma_{f1} \phi_{1\infty} + \phi^{+}_{1\infty} \nu \Sigma_{f2} \phi_{2\infty}\right)}$$

where

D_i is the diffusion coefficient in group i and

$\partial \phi / \partial n$ signifies the normal derivative on the surface of the cell.

A calculation of this error has been carried out for our case and it has been found to be less of $0.1 \cdot 10^{-3}$, i.e. practically negligible.

4. Conclusions of the neutronic evaluations

The preceding analysis leads to the following conclusions concerning the design of the D_2O lattices region:

1. The introduction of U-235 enriched plates at the boundary of the heavy water tank does not prevent the spectrum matching in the test cell. Nevertheless for a good matching it has been found necessary to poison not only the test cell but also the surrounding buffer cells (otherwise an error of 0.4 % in k-inf and 3 % in the ratio of the fast to thermal flux is introduced).

2. The flattening of the axial flux in the test cell can be obtained by adding thermal poison (copper) or enriched pellets in the buffer region through tubes which are fixed inside the D_2O tank.
In pratice it appeared that 41 tubes, distributed at four radial positions, were necessary to satisfy the requirements of points 1 and 2 above mentioned. Details on the tubes used, as well as on their position are given in part II.

3. The use of simplified formulae to calculate the effect of the spectrum mismatch and the flattening of the flux on k-inf must not be encouraged because they can underestimate these effects by a factor 5 - 10.

4. The use of cylindrical void cells does not introduce appreciable errors in the measurements at the k-inf.

Part II

Experimental requirements and mechanical and hydraulic design of the facility

1. Main experimental requirements

The D_2O facility mounted in RB-1 had to fulfil the following physical and technical requirements:

a) To allow the insertion of 13 ORGEL fuel elements (buffer zone) in an aluminium tank having a diameter and a height defined by the RB-1 central cavity in order to adjust the spectrum in the test cell as specified in the introduction and in part I.

b) To allow an accurate adjustment of the lattice pitch of D_2O lattices between 180 mm and 270 mm.

c) To allow the frequent extraction of the special central element for the necessary manipulations inside the test cell (poisoning of the test cell; substitution by vacuum, fine structure measurements, etc.)

d) To allow the introduction of enriched fuel elements and copper rods in the D_2O vessel in order to adjust the axial flux distributions and to change the spectral condition in the central test cell.

e) To allow an easy charge and discharge of D_2O from the containers, a fine regulation of the D_2O level in the main vessel and a continous D_2O purification; moreover a nitrogen loop had to be foreseen for D_2O portection.

On the basis of these requirements, the facility consists of the following components:

1) the D_2O vessel placed in the RB-1 central cavity with the ORGEL elements and thimbles necessary to fulfil the requirements of point d);
2) the D_2O hydraulic loop;
3) the N_2 loop;
4) a special ORGEL fuel element for reactivity measurements and fine structure measurements;
5) auxiliary devices.

2. RB-1 description

The RB-1 reactor is installed at the Nuclear Laboratory of Montecuccolino (Bologna); its maximum power is 10 W, corresponding to a thermal flux of 10^8 n/cm^2 sec.

Figures 7 and 8 show a general view of RB-1 [1] with installed D_2O facility.

The reactor is contained inside a metallic vessel (8 mm thickness, 531 cm height and 340 cm internal diameter) to allow underpressure operation. The vessel is surrounded by a 60 cm thick concrete shielding. The top of the vessel is sealed off with an O-ring seal. The inside pressure is adjustable between 30 mmHg and the atmospheric pressure. It can be maintained at a constant value and can exactly be reproduced during reactivity measurements. The feeding zone is constituted by a graphite matrix housing the enriched fuel elements; the matrix has the form of a cylindrical shell with an internal diameter of 100 cm and an external diameter of 183 cm.

Enriched fuel elements are arranged in three rings with a radius of 61,7 cm, 80,8 cm and 91 cm.

The reactor core is surrounded by an axial and radial graphite reflector of 50 cm thickness.

All fuel elements of the feeding zone have a length of 2500 mm and consist of:

a) fuel pellets
b) graphite pellets
c)canning.

The fuel pellets (UO_2) are of two types:
type 1: diameter 7 mm, height 13.2 mm (U-235 enrichment 20 %)
type 2: diameter 7 mm, height 15 mm (U-235 enrichment 4 %).

The graphite is in form of pellets with different heights. As fuel canning are used anticorodal pipes with 8 mm, and 10 mm inner and outer diameter closed by plugs on both ends. Each standard fuel element is divided into three sections. Each section can be filled with 20 % or 4 % enriched uranium. 30 special elements are utilized as safety fuel elements. Their bottom fuel plugs are fixed to the canning by a paraffin layer which melts in the case of an accidental power increase.

From preliminary critical mass evaluation it appeared advisable to introduce in the assembly some enriched fuel plates in the vicinity of D_2O tank, in order to have a reactivity reserve for neutron spectrum adjustment and flux flattening.
Therefore no. 50 "Rospo" [8] plates (90 % enriched uranium) corresponding to a total amount of 2 kg·U-235, were inserted between graphite and D_2O vessel in such a way to facilitate also the axial flux flattening.

3. D_2O vessel (Fig. 9 and 10)

This vessel is a cylindrical Al tank of 972 mm inner diameter, a total height of 4000 mm with a wall thickness of 6 mm, and a flat bottom of 27 mm. It is designed for an inside overpressure of 50 g/cm^2 and outside underpressure of 400 mmHg.
The vessel is made up in two parts, a bottom section of 3000 mm height and a top section of 100 mm height, in order to allow its mounting inside the RB-1 central cavity. Both parts are leaktightly flanged together. The tank top is closed by a stainless steel cover of 1100 mm diameter and 20 mm thickness. A leaktight closeable central hole of 330 mm diameter is provided for the handling of the central fuel element. 4 closeable holes of 125 mm diameter at a radius of 375 mm are used for the insertion of 4 buffer fuel elements at fixed positons. 40 holes closeable by flanges are arranged on 3 different radia, 8 at a radius of 235 mm, 16 et a radius of 350 mm and 16 at a radius of 445 mm.
A special hole is at a radius of 195 mm.
All these holes have a diameter of 16.5 mm.
They are used for the insertion of reentrant tubes which are kept in their proper position by a bottom and an intermediate grid plate. These thimbles are foreseen to house enriched RB-1 fuel elements for flux flattening and spectrum adjustment experiments, or neutron detectors and copper rods for poisoning the buffer (see part I).

The top section houses the support for maximum 13 ORGEL type fuel elements. 4 fuel elements rest in a fixed position at the radius of 37.5 mm, 8 fuel elements hang on carriages which can be adjusted from outside by an endless screw drive mechanisme (fig. 11) in the pitch range 187 mm = d = = 270 mm. The special central element hangs on a plate which rests on the fuel element support.

The D_2O level in the vessel is measured with a pyrex pipe water gauge with a precision of ± 0.25 mm. The level meter is connected by two stainless steel valves to the vessel. A safety device is forseen for closing automatically the valves in case of pyrex pipe rupture.

4. ORGEL fuel element (Fig.12)

The D_2O vessel is loaded with ECO reference type fuel elements (ref. [3]). The element consists of a 19 rod ring cluster with natural uranium cylindrical metal rods.

The cluster is enclosed by a mock up pressure tube and a calandria tube. The pressure tube is filled with diphyl liquid.

The mechanical data of the fuel elements are:

rod diameter	12 mm
cladding	1 mm Al
distance between two cladded rods	1,2 mm
distance between cladded rods and pressure tube	2 mm
pressure tube thickness	1,5 mm Al
calandria tube thickness	1,5 mm Al
length of U rod	2900 mm
weight per rod in U nat	6231,5 gr
volume of organic at 20°C	5001,5 cm^3
uranium volume per unit length of element	21,48 cm^3/cm
volume of organic per unit length of element	17,668 cm^3/cm

The fuel element hangs on a cardanic suspension on the fuel element support.

5. Special central fuel element (Fig.13)

Reactivity change measurements are executed between the following two states:

state 1: central test cell voided

state 2: central test cell of ORGEL type poisoned at different degrees.

These experimental requirements defined the mechanical design of the central test element. The fuel element consists of 3 sections:

The central test section, a bottom and a top section. All 3 sections are inside the calandria tube.

The lower section rests on the calandria tube bottom and supports the test section; the top section hangs on the calandria tube head. Two flanges are fixed on the calandria tube and are used to seal off the vacuum boxed containing the test cell moderator.

State 1 is simulated by filling the box with Helium and by removing the central fuel element section.

The diameter of the vacuum box depends on the pitch under investigation. The length of the box of 500 mm was chosen as a compromise between effects favouring a long test section (big reactivity differences between the two states, small influence of the end caps of the fuel element test section) and effects favouring a short test section (flux flattening and spectrum adjustment).

A substitution of the central part of the fuel element is possible with a special fine structure fuel element section designed for microscopic parameter measurements (ε , f and p) and having the fuel in form of pellets for introduction of neutron detectors.

6. The D_2O loop

The D_2O loop (fig.8) is foreseen for the following operations:

1. filling and emptying of the D_2O vessel at the beginning and the end of the experiments;
2. circulation of D_2O through a purification system;
3. D_2O level fine adjustment in the vessel before any reactivity measurement.

The hydraulic loop is supported by a suitable mechanical structure. The D_2O (and N_2) pipes enters the reactor through a tight flange with cone-sphere connections. The D_2O pipes positioning inside the RB-1 vessel was accurately studies in order to avoid any difficulty during the fuel element loading of the feeding zone. The hydraulic loop consists mainly of (see fig.14):

a) the D_2O vessel (19)
b) the storage tank (9)
c) the purification system, including:
  c-1) a pump (10)
  c-2) a flow-rate meter (12)
  c-3) two filters (13)
  c-4) an ion exchanger (14)
  c-5) a conductivity meter (15-16).

In the vessel and storage tank a device is provided allowing the D_2O level measurement (18).
The D_2O introduction into the tank is obtained by gravity from the storage tank (9), step by step, opening valves 19 and 20 (two valves are inserted for safety reasons).
The pump is used also for emptying the main vessel at the experiments accomplishement.
The pump has an immersed rotor and incorporates a filter to purify the cooling and lubricating liquid (D_2O). The parts in contact with D_2O are of CR-Ni-Mo steel.

The pump characteristics are:
- flow rate: 0.48 ÷ 1.44 m^3/h
- head: 12 m (at 1 m^3/h flow rate)
- power: 1,1 HP.

Flow rate regulation is obtained by using a by-pass.

The storage tank is of stainless steel and has a capacity of about 300 liters. The storage tank is used for receiving the D_2O from the containers, and for small D_2O displacements for level regulation in the ORGEL vessel.

The ion-exchanger consits of a stainless steel column filled with amberlite resin Xe-150. At the input and output a deflector and a filter are installed.

The flow rate meter is of floating type and has a 3-30 lt/min range.

The conductivity meter has a conductivity cell with Pt electrodes connected to an a.c. Wheatstone bridge.

The filters consist of a stainless steel tank (Ø = 7 mm), and height - 250 mm) filled with stainless steel sintered powder.

A D_2O sampling device is provided for periodic title control: D_2O samples are extracted from valve 3.

7. Nitrogen loop

Purpose of the nitrogen loop is:

a) drying the D_2O loop before D_2O introduction

b) keeping of a nitrogen overpressure (50 gr/cm^2) with a low content of H_2O on free D_2O surfaces, in order to reduce to a minimum its contamination.

The N_2 loop consists of (fig. 8):

a) nitrogen supply (1);
b) pressure reducer (2);
c) 2 Mobil Sobead containers (3);
d) 2 molecular filters containers (4);
e) 2 indicators constituted by chromatic molecular Sifters (8);
f) a 4 KW heater (25);
g) a 1,5 KW heater (5);
h) two compressors (7);
i) two thermostates (6) (28);
l) a manometer (21);
m) a safety valve (20).

The drying circuit is intended for the following operations:

1) drying of nitrogen coming from the supply;
2) drying of nitrogen coming from the main vessel (closed loop);
3) drying of air;
4) regeneration of the molecular sifters and of a silicagel.

In operations 1), 2), 3) the thermostate (6) is set at 80° C and the 1,5 KW heater is switched on. Operation 4) can be performed simultaneously with each of the described operations. The normal N_2 pressure is read on a manometer placed on the operational panel; a minimum and a maximum pressure signal is given by a manometer (21).
The threshold pressure value of the safety valve (20) can be varied in the range 20 + 500 gr/cm^2.

8. Auxiliary equipment

For the fuel element handling some auxiliary devices were installed. One working bridge for the assembling of the ORGEL elements was mounted above a cavity in the reactor hall. A fuel element storage is provided for 15 ready mounted elements. For the fuel element loading and unloading an auxiliary manual crane was installed allowing a more accurate positioning of the ORGEL type elements.

9. Cost of the facility

The D_2O facility was constructed at the general work shop of the C.C.R. Euratom - Ispra and mounted at the reactor RB-1 - Bologna. The cost of D_2O loop, all mechanical component included, is of about 30.000 \$ (fuel elements and D_2O excluded).

The D_2O inventory is of about 2 to.

The small D_2O inventory and the small number of ORGEL fuel elements necessary for the buffer zone (8 or exceptionally 12 elements) is an important advantage of k-inf measurements in a RB-1 type reactor where lattices having liquid or solid moderator can be tested. Such a measurement is a useful complement to buckling measurements by substitution technique in a critical facility (ECO) where the D_2O and fuel element investment is much higher 3 while the expected precision of the two methods is of the same order of magnitude.

Acknowledgements

Many thanks are due to Mr. P. Bassi, E. Clementel, V. Raievski, A. Kind, W. Kley for their interest and encouragement in this work, and to Mr. R. Leroy, G. Maracci, J. Quequin, C. Tahir for their collaboration.

References

[1] P. Aiello et al.: "Il reattore sperimentale RB-1: Tarature e misure di k di reticoli a uranio naturale moderati a grafite", Congress on Reactor Physics held at Milano-Pavia, Dec. 1963, Consiglio Nazionale delle Ricerche, Roma 1966,p.341

[2] Euratom Scientific Activities - ORGEL Program, EUR 1830.e (1964)

[3] G. Blässer, P. Bonnaure, G. Casini, R. Cenerini, V. Raievski, F. Toselli: "Expérience critique pour l'étude de la filière ORGEL", EUR 130.f (1962)

[4] G. Casini et al.: "CAROLINE I - A calculation method for non irradiated organic liquid heavy water lattices", EUR 134.e (1962)

[5] D.J.Donadue et al.: "Determination of k-inf from critical experiments with the PCTR", NSE 4 , 1958, p.297-321

[6] W.L.Brooks: Pawling-Lattice Test Rig - Test Report No. 1 PLATR-PCTR Comparison, NDA 2131-40, 1961

[7] W. Humbach, W. Oldekop: "Zur Theorie des Reaktivitätsbeitrages von Hohlräumen und eines Verfahrens zur Bestimmung von k-inf" Nukleonik 1, 1959, p. 265

[8] G. Bitelli et al.: "ROSPO organic moderated critical facility" in Symposium on exponential and critical experiments, Amsterdam 1963

Fig. 1 : RB1-ECO Loading Used for Flux Mismatch Calculations

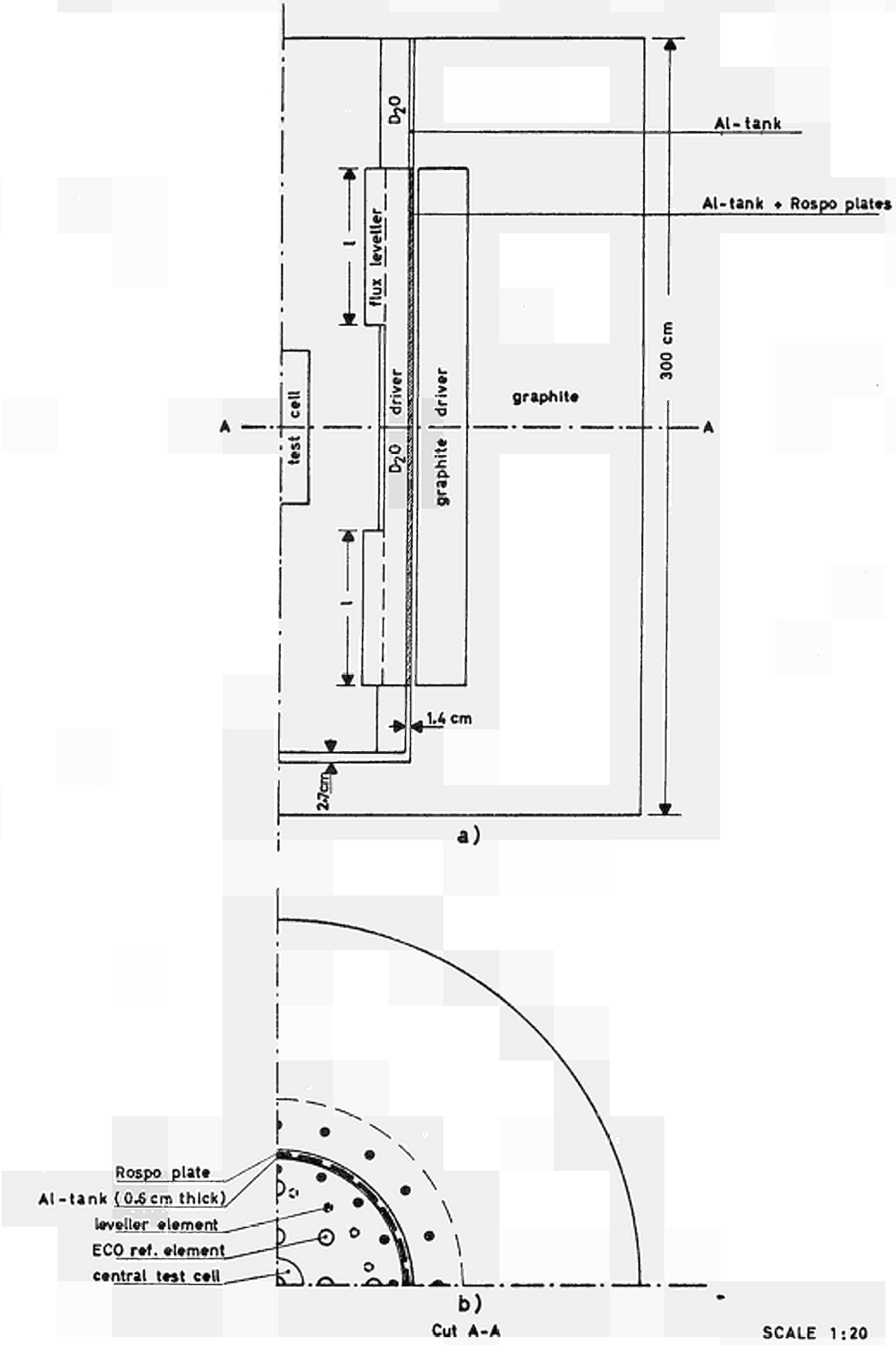


Fig. 2 : Axial Distribution of Fast Flux over the Test Cell

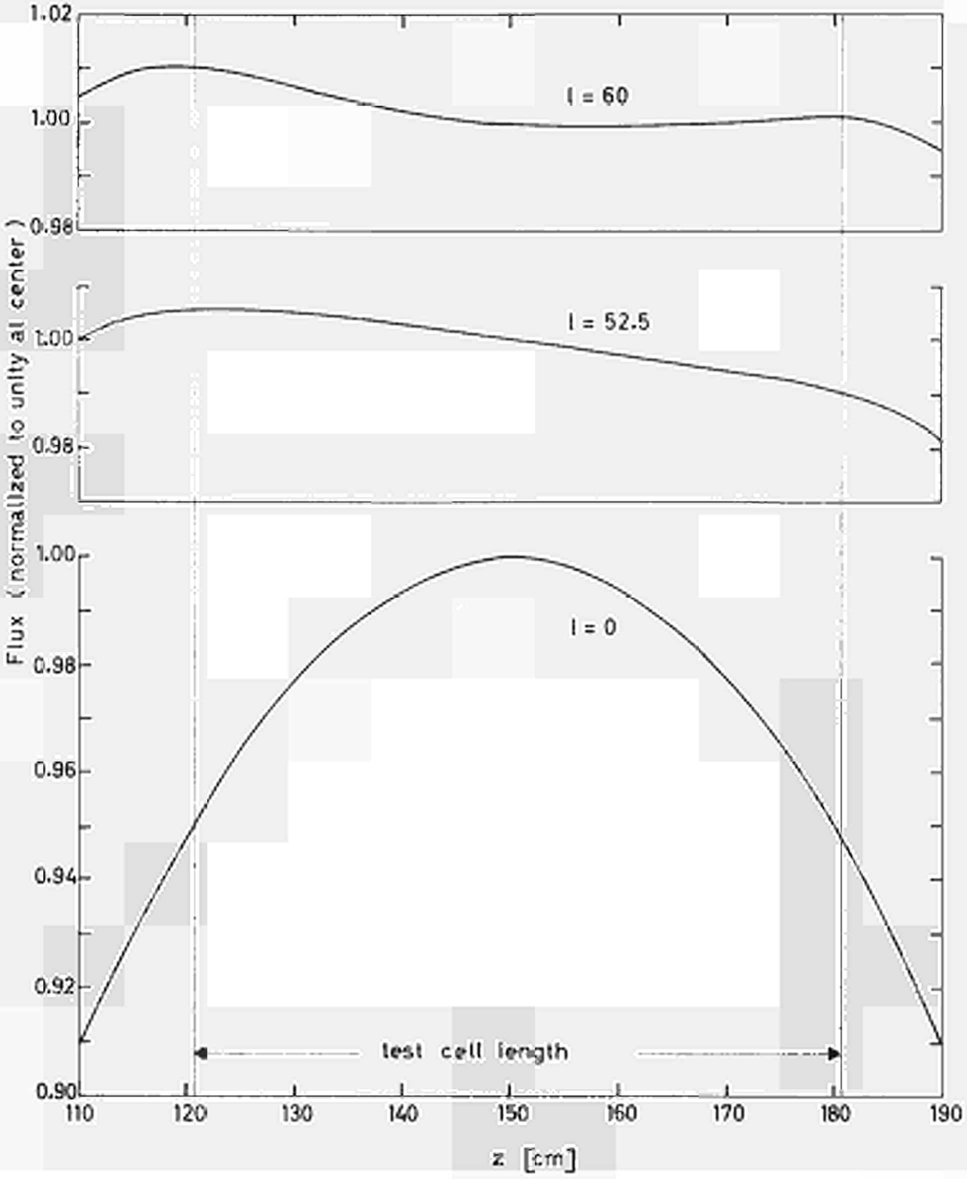


Fig. 3 : Axial Distribution of Thermal Flux over the Test Cell

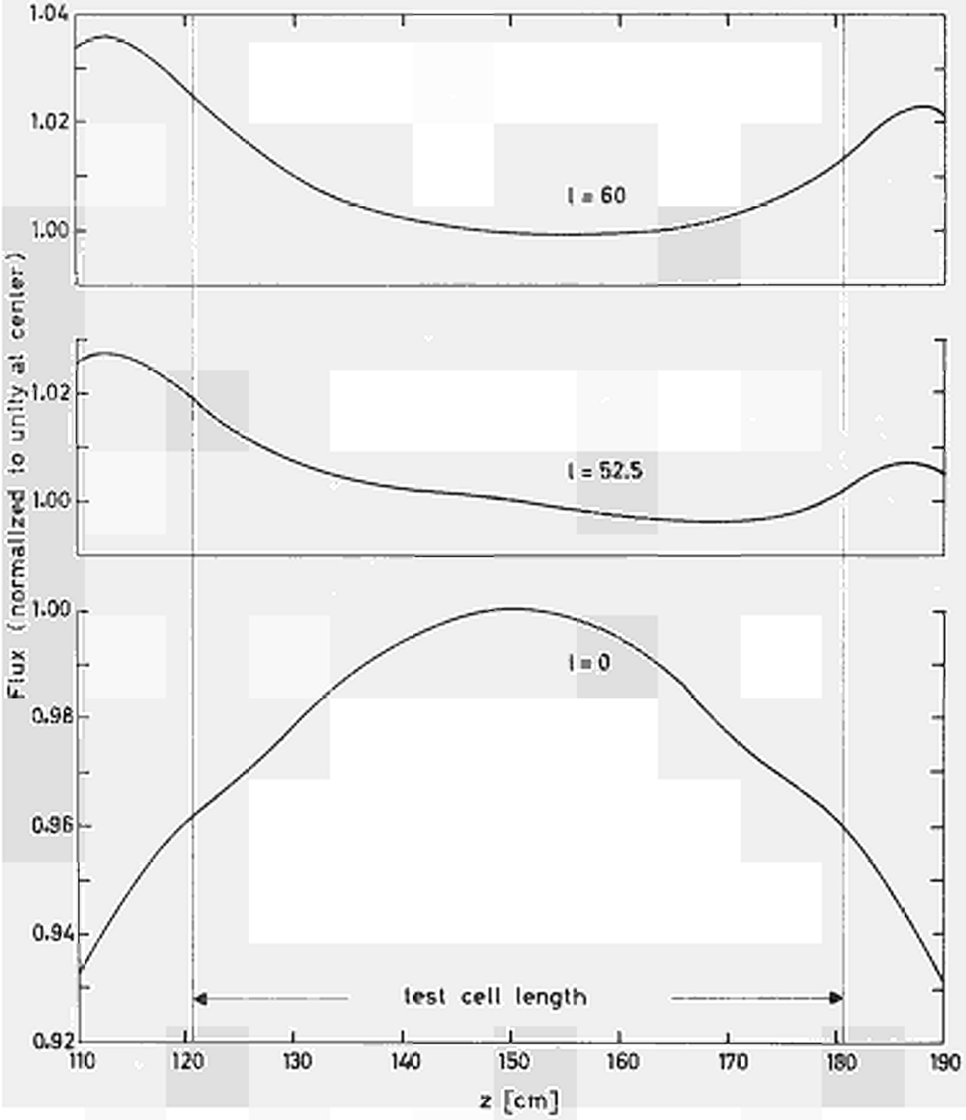


Fig. 4 : Ratio of Fast to Thermal Flux in Axial Direction in the Test Cell (only Test Cell Poisoned)

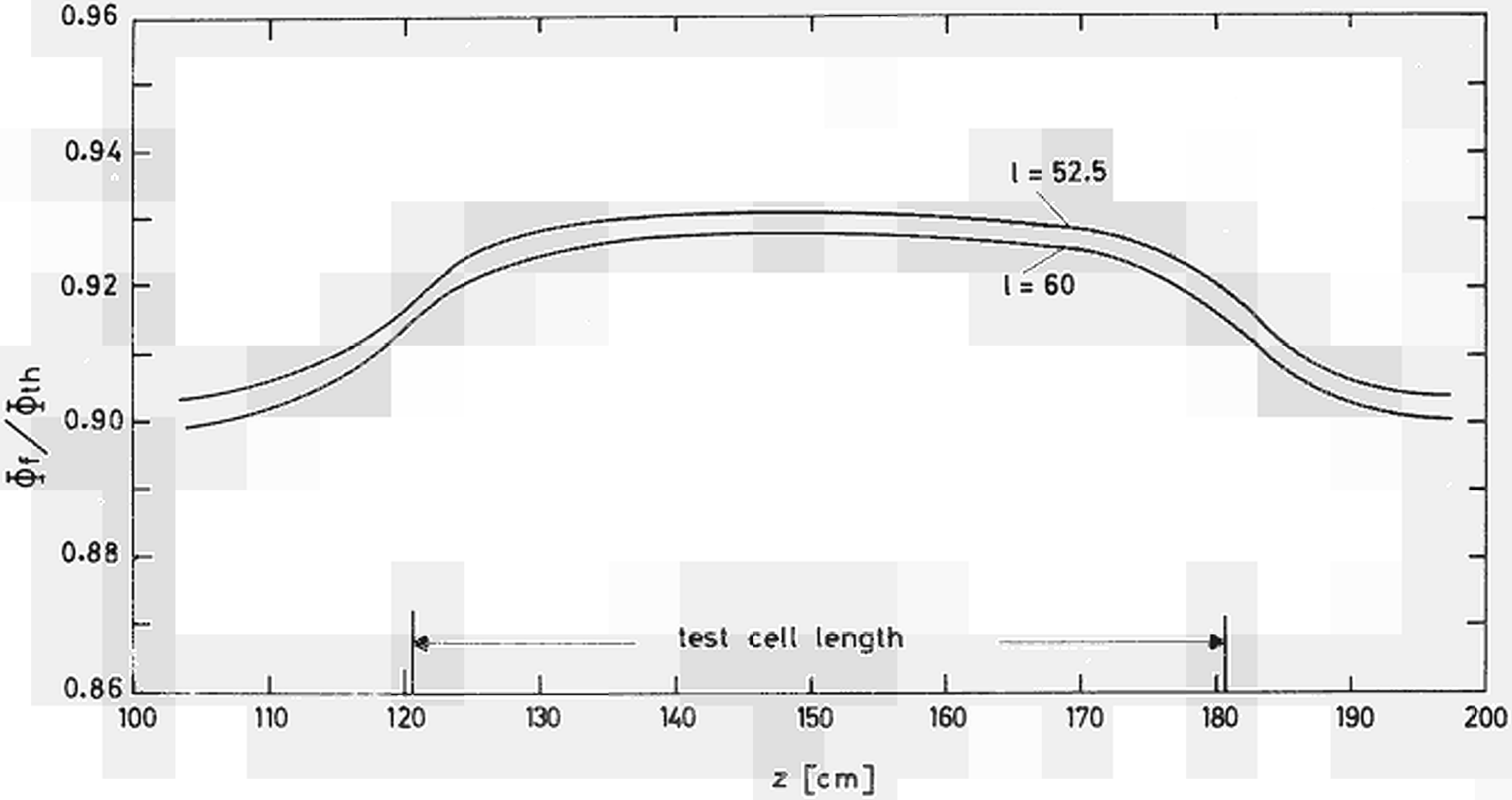


Fig. 5 : Radial Flux Distribution in RB1 - ECO 18.9 cm.

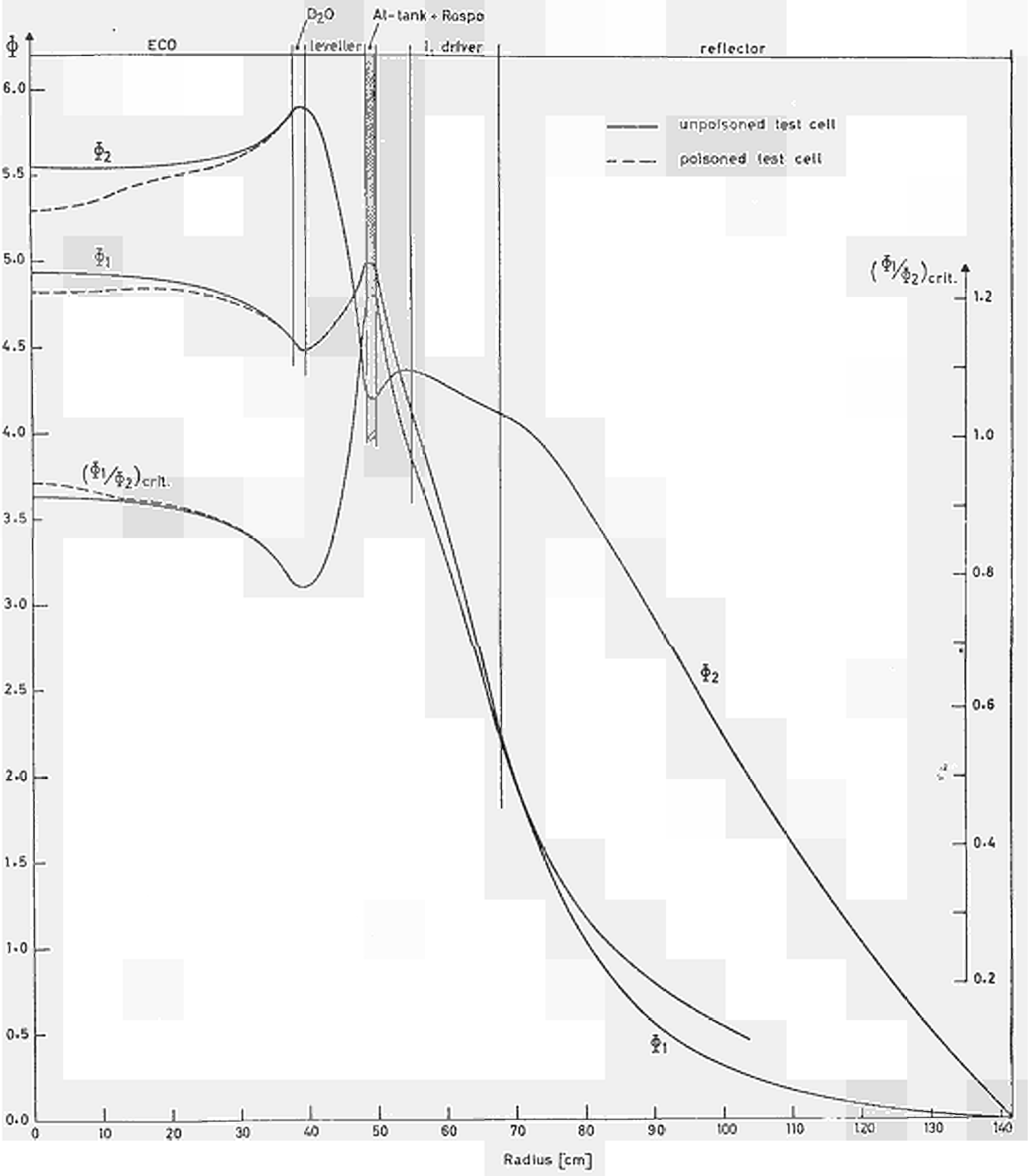
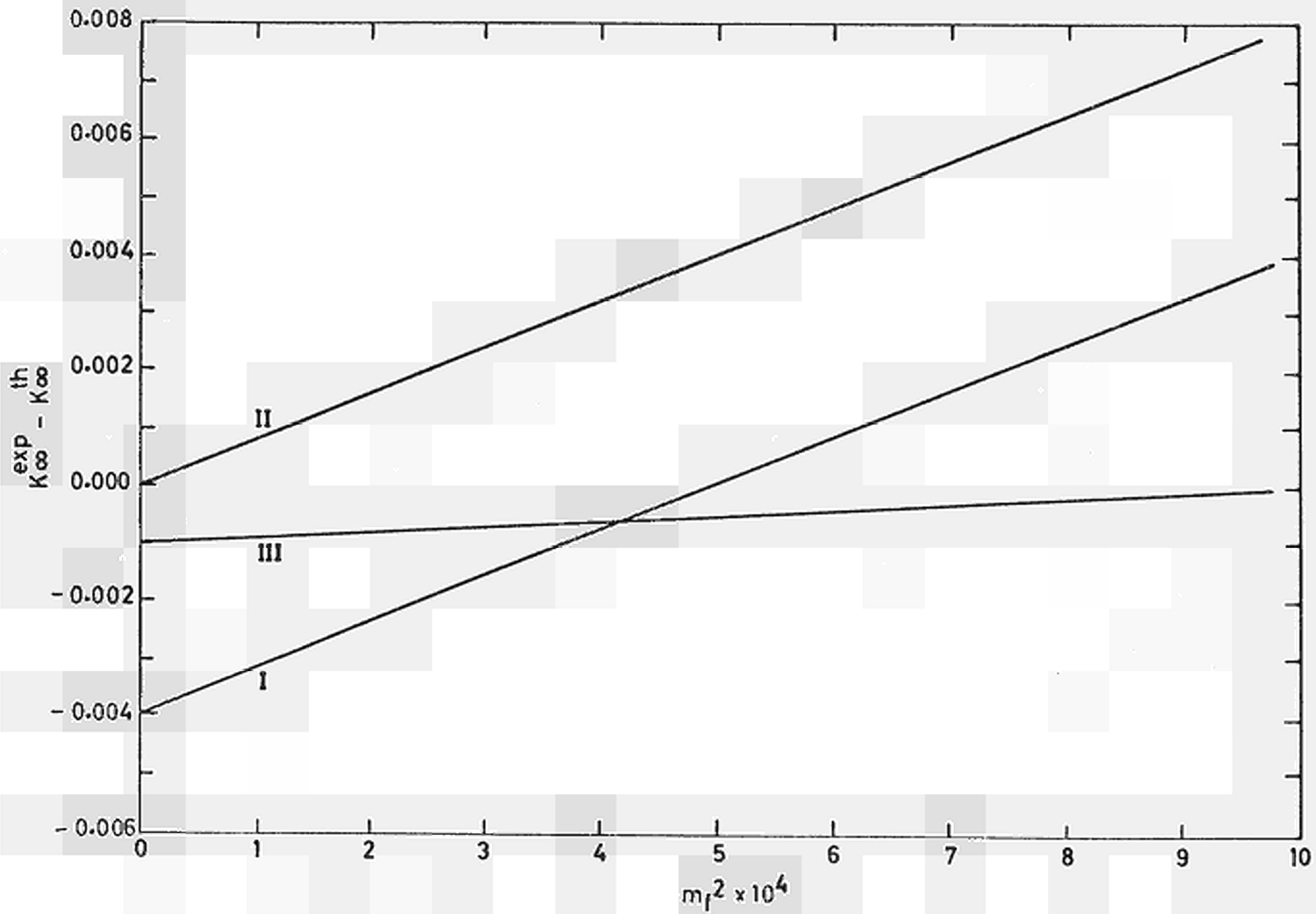


Fig. 6 : Error in K∞ Due to Spectral Mismatch and Non-uniformity of Flux



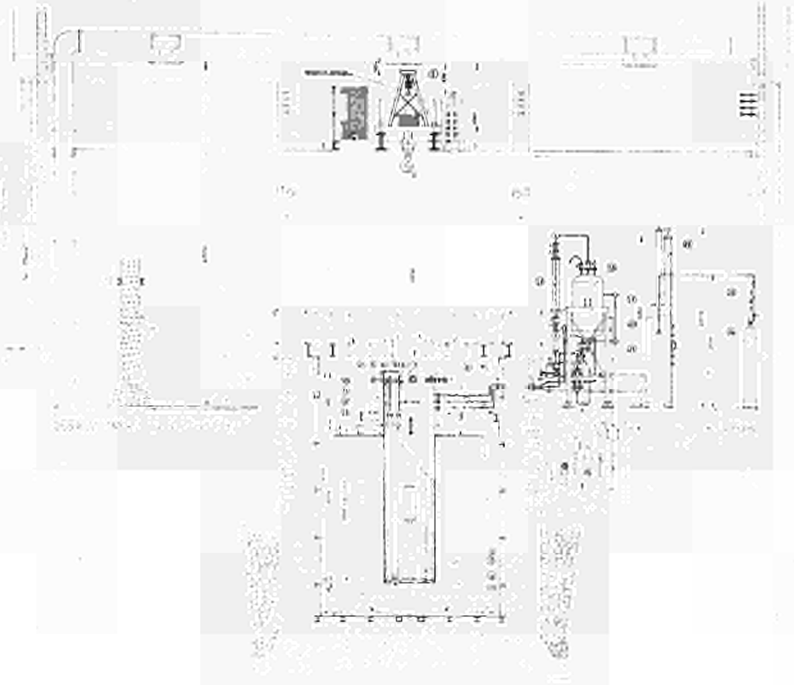


Fig. 7 - Vertical cross section of RB-1 reactor with installed D_2O facility

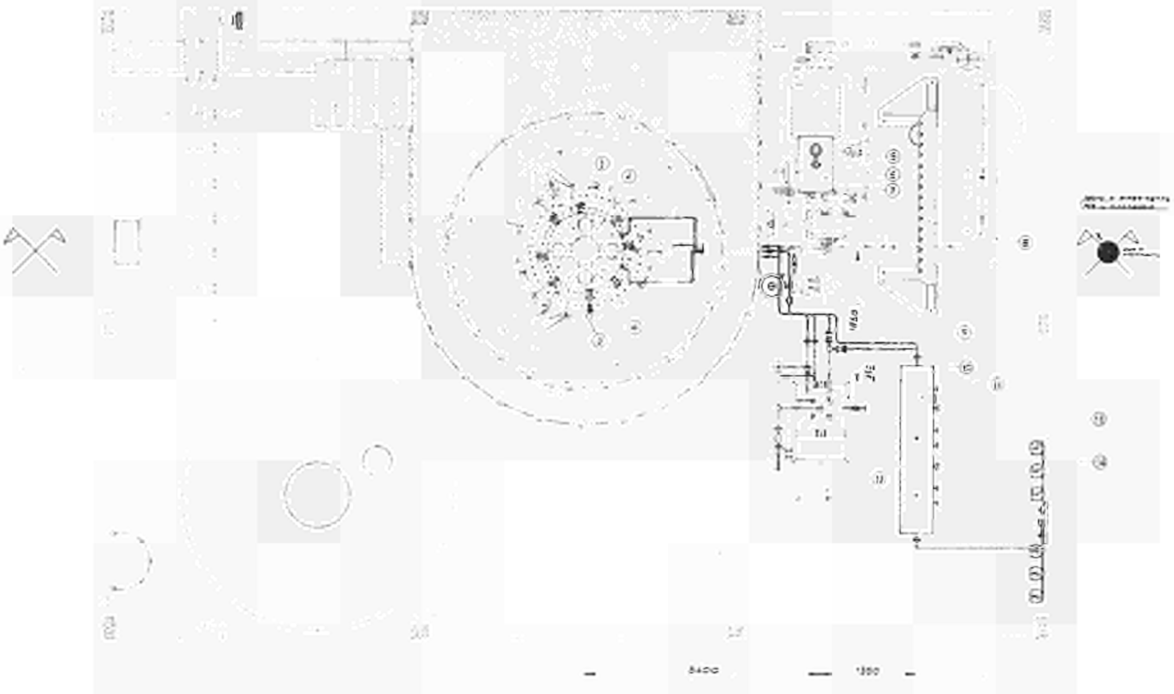


Fig. 8 - Horizontal cross section of RB-1 reactor with installed D_2O facility

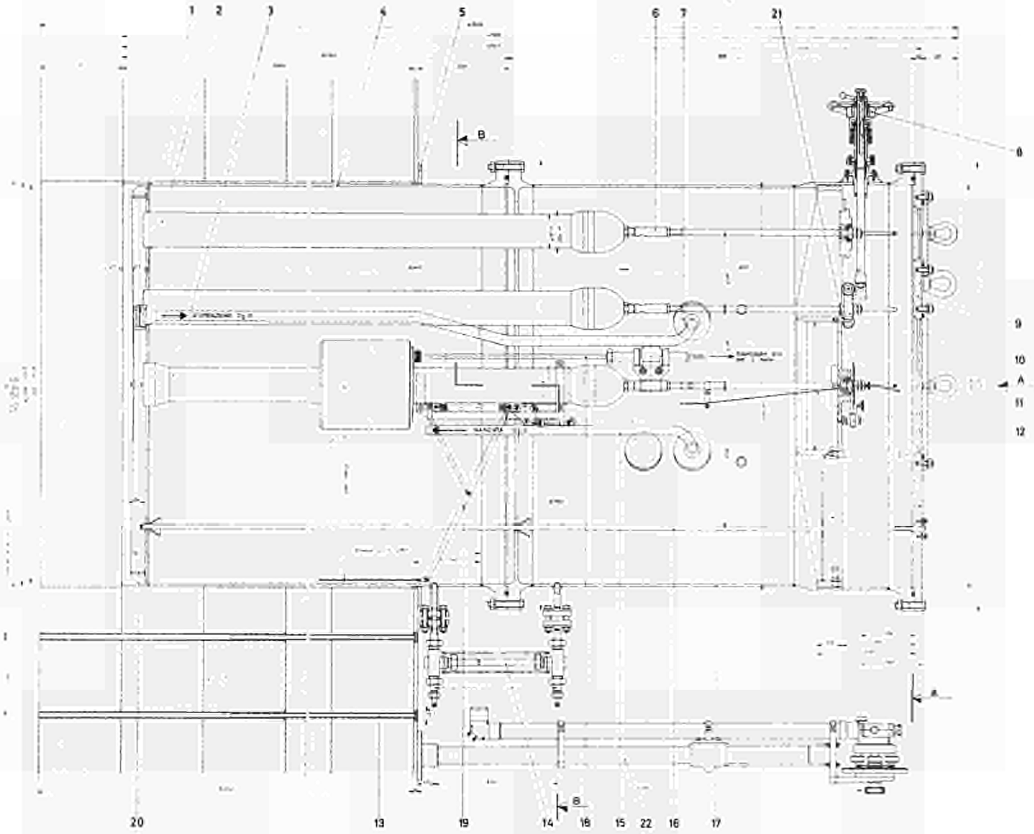
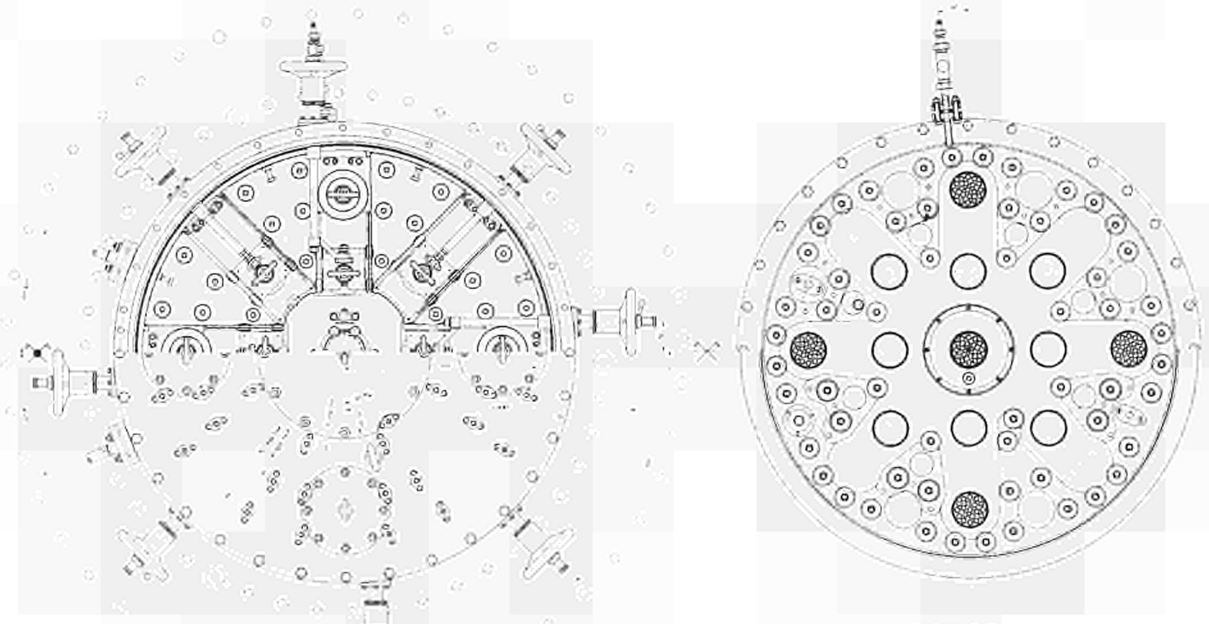


Fig. 9 - Cross section of D_2O vessel



Sezione A-A

Fig. 10 - Top view and section of D_2O tank

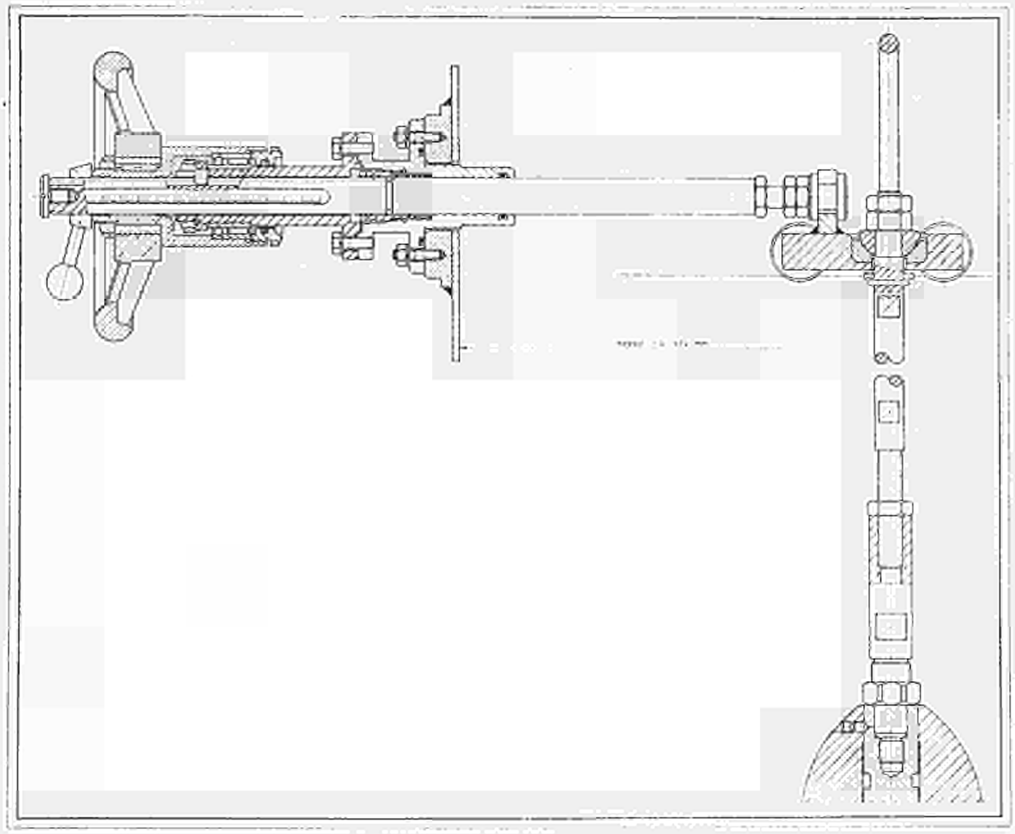


Fig. 11 - Fuel element drive mechanism

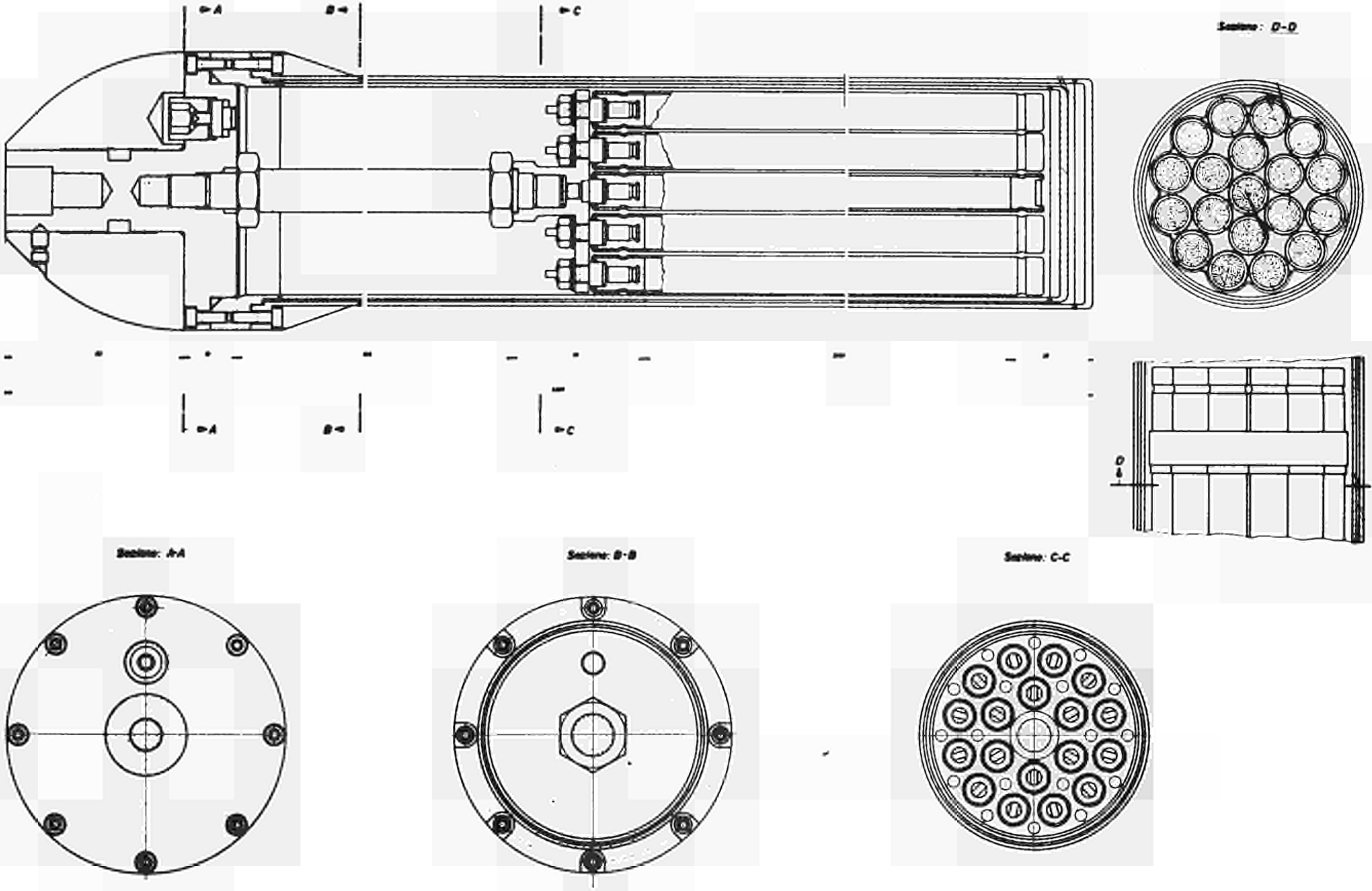


Fig. 12 : The fuel element investigated

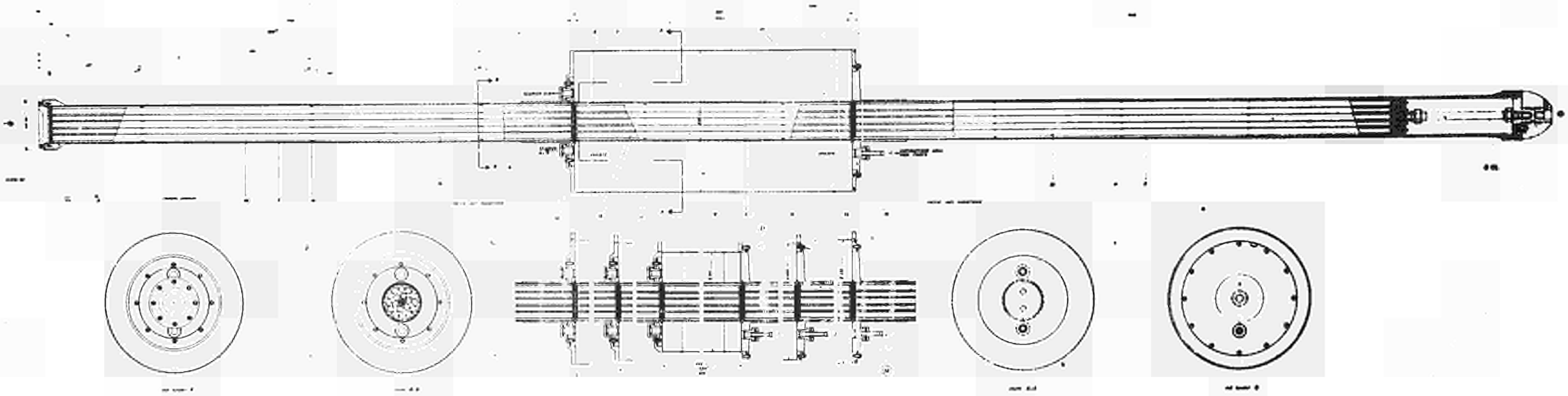


Fig 13 : The special fuel element with the test cell

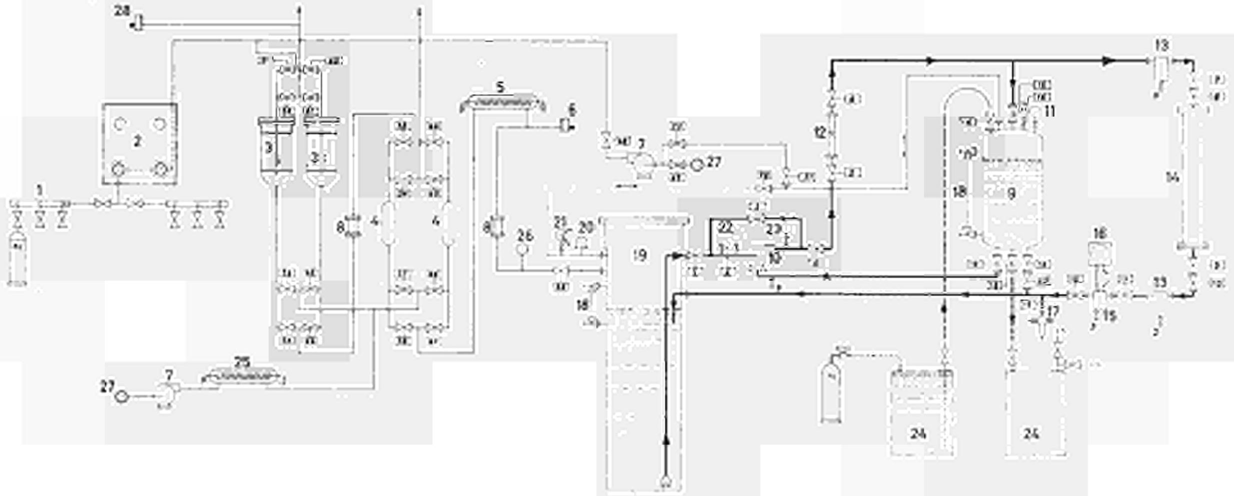


Fig. 14 - Flow sheet of D_2O and N_2 loops

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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