

**EURIOI.e**

EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

# ORGEL PROGRAM

1963



**Text presented at the Congress  
of the European Atomic Energy Society on**

**The fundamental problems of nuclear power plants  
likely to be built in the next ten years**

**(Cannes, October 8-12, 1962)**

## LEGAL NOTICE

This document was prepared under the sponsorship of the Commission of the European Atomic Energy Community (EURATOM).

Neither the EURATOM Commission, its contractors nor any person acting on their behalf :

- 1° — Make any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this document, or that the use of any information, apparatus, method, or process disclosed in this document may not infringe privately owned rights; or
- 2° — Assume any liability with respect to the use of, or for damages resulting from the use of any information, apparatus, method or process disclosed in this document.

This report can be obtained, at the price of Belgian Francs 300—,  
from : PRESSES ACADEMIQUES EUROPEENNES —  
98, chaussée de Charleroi — Brussels 6.

Please remit payments :

- to BANQUE DE LA SOCIETE GENERALE (Agence  
Ma Campagne) - Brussels - account No. 964.558,
- to BELGIAN AMERICAN BANK AND TRUST  
COMPANY - New York - account No. 121.86,
- to LLOYDS BANK (Foreign) Ltd. - 10, Moorgate -  
London E.C.2,

giving the reference : "E U R 1 0 1 . e - ORGEL Program".

Printed by E. Guyot,  
Brussels, May 1963.

## **EUR 101.e**

### **ORGEL PROGRAM**

European Atomic Energy Community - EURATOM.

Text presented at the Congress of the European Atomic Energy Society on the Fundamental problems of nuclear power plants likely to be built in the next ten years (Cannes, October 8-19, 1962).

Brussels, May 1963 - pages 251.

This report gives a general view of the present development stage of the ORGEL Program.

The objectives and the basic features of the ORGEL Program are outlined in the first chapter. One chapter deals with the optimization studies being carried out at Brussels. The studies main at finding a set of operational parameters for an ORGEL Power Plant which will yield the lowest cost of the KWh sent out.

Another chapter describes the ESSOR reactor, a test reactor specially assigned to the ORGEL Program.

The other chapters deal with the activities of the various divisions or departments in Ispra, directly involved in the development of the ORGEL reactor : Reactor Physics, Technology, Metallurgy, Heat Transfer, Chemistry and Physical Chemics.

---

## **EUR 101.e**

### **ORGEL PROGRAM**

European Atomic Energy Community - EURATOM.

Text presented at the Congress of the European Atomic Energy Society on the Fundamental problems of nuclear power plants likely to be built in the next ten years (Cannes, October 8-19, 1962).

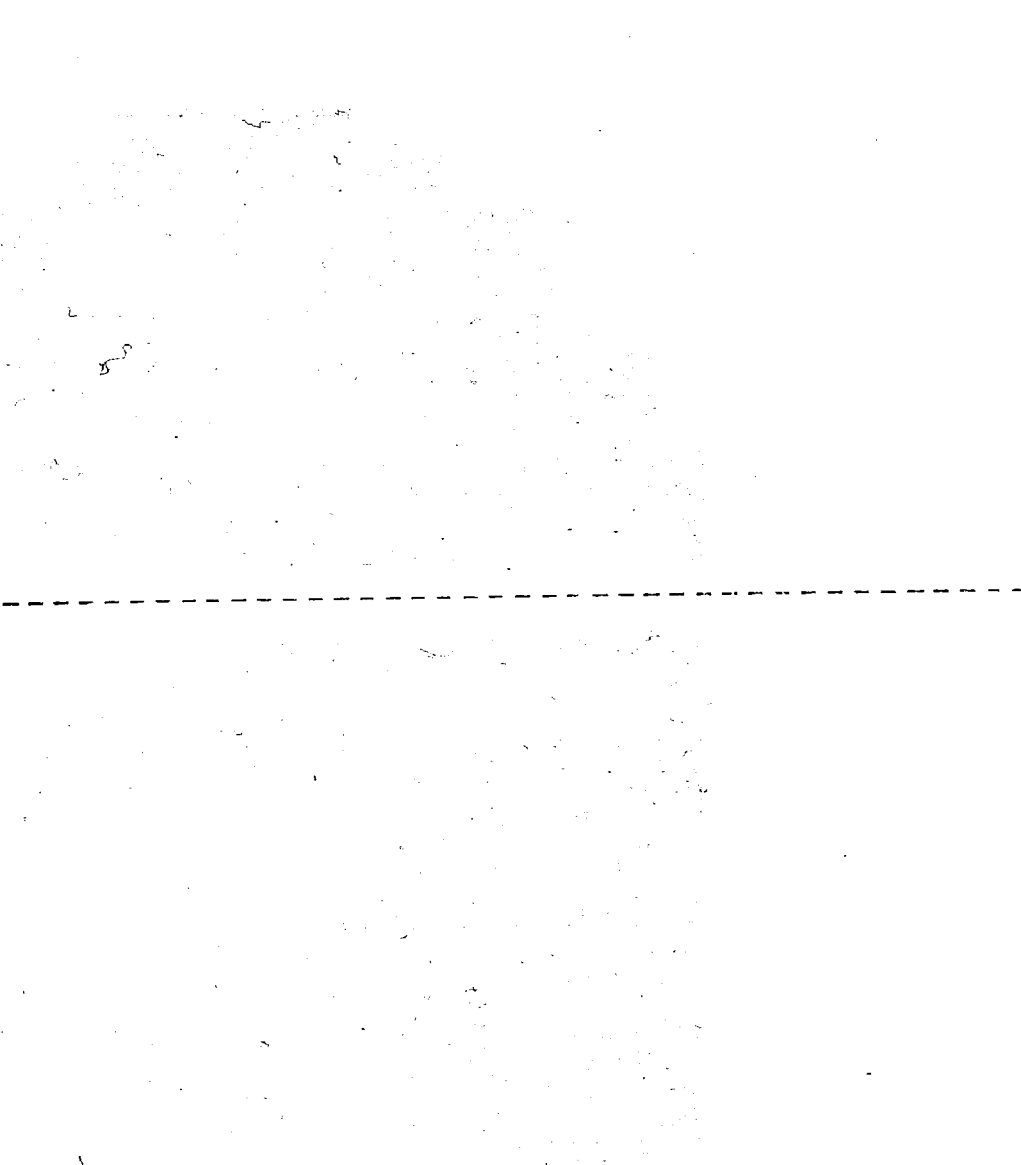
Brussels, May 1963 - pages 251.

This report gives a general view of the present development stage of the ORGEL Program.

The objectives and the basic features of the ORGEL Program are outlined in the first chapter. One chapter deals with the optimization studies being carried out at Brussels. The studies main at finding a set of operational parameters for an ORGEL Power Plant which will yield the lowest cost of the KWh sent out.

Another chapter describes the ESSOR reactor, a test reactor specially assigned to the ORGEL Program.

The other chapters deal with the activities of the various divisions or departments in Ispra, directly involved in the development of the ORGEL reactor : Reactor Physics, Technology, Metallurgy, Heat Transfer, Chemistry and Physical Chemics.



# EURIOI.e

EUROPEAN ATOMIC ENERGY COMMUNITY - EURATOM

## ORGEL PROGRAM

1963



Text presented at the Congress  
of the European Atomic Energy Society on

The fundamental problems of nuclear power plants  
likely to be built in the next ten years

(Cannes, October 8-12, 1962)



## TABLE OF CONTENTS

	Page
<b>CHAPTER I — GENERAL REMARKS</b>	
1 — Objectives . . . . .	7
2 — Basic features of the Reactor System . . . . .	7
3 — Organisation of the project . . . . .	8
<b>CHAPTER II — OPTIMIZATION</b>	
1 — Introduction. . . . .	9
2 — Technological & Economic outline of the plant . . . . .	9
3 — Optimization methods . . . . .	11
4 — Optimization codes . . . . .	13
5 — Results . . . . .	15
<b>CHAPTER III — ESSOR</b>	
1 — General observations . . . . .	33
2 — Assembly . . . . .	33
3 — Core characteristics . . . . .	35
4 — Reactor . . . . .	36
5 — Cooling circuits . . . . .	37
6 — Handling of irradiated elements . . . . .	39
7 — Regulation & control . . . . .	39
8 — Conclusions . . . . .	40
<b>CHAPTER IV — REACTOR PHYSICS</b>	
1 — ORGEL Physics calculation methods . . . . .	57
2 — ORGEL Dynamics . . . . .	59
3 — AQUILON II, Critical experiments . . . . .	61
4 — ORGEL experimental physics program . . . . .	63
5 — ORGEL critical experiment (ECO) . . . . .	63
6 — ESSOR physics calculations . . . . .	65
<b>CHAPTER V — TECHNOLOGY</b>	
1 — Introduction. . . . .	77
2 — Channel Connections . . . . .	77
3 — Thermal Insulation of the Channel . . . . .	79

4 — Thermo-mechanical Stability of Fuel Clusters . . . . .	82
5 — Experimental Stress Analysis on Fuel Element cage by Application of Photostress & Strain Cages Techniques . . . . .	83
6 — Friction & Wear . . . . .	83
7 — Channel Rupture in the Reactor Core . . . . .	84
8 — Conclusions . . . . .	84
 <b>CHAPTER VI — CHEMISTRY OF ORGANIC COOLANTS</b>	
1 — Fundamental Research . . . . .	109
2 — Synthesis of pure standards . . . . .	111
3 — Organic & inorganic analysis . . . . .	112
4 — Ideal organic coolants . . . . .	115
5 — Technology of organic coolants . . . . .	117
6 — Miscellaneous . . . . .	117
 <b>CHAPTER VII — PHYSICAL CHEMISTRY</b>	
Introduction . . . . .	165
1 — Corrosion & Compatibility . . . . .	165
2 — Fouling . . . . .	167
3 — Structure Properties of UC . . . . .	168
4 — Re-entry of Fission Gases . . . . .	168
5 — Contact Conductance & UC Conductivity . . . . .	168
6 — SAP Structure . . . . .	169
 <b>CHAPTER VIII — HEAT TRANSFER</b>	
1 — Introduction . . . . .	195
2 — Actual Status . . . . .	198
 <b>CHAPTER IX — DEVELOPMENT OF FUEL &amp; CLADDING MATERIALS</b>	
Introduction . . . . .	207
1 — Development of Uranium Carbide . . . . .	207
2 — Development of Sintered Aluminium Materials . . . . .	209
3 — Irradiation Program . . . . .	213
4 — Conclusions . . . . .	215
 <b>ANNEX I — CHARACTERISTICS OF GROSS 250 MWe ORGEL-TYPE POWER PLANT . . . . .</b>	
	247
 <b>ANNEX II — SUMMARY OF ESSOR DATA . . . . .</b>	
	249



## ORGEL PROGRAM

### SUMMARY

This report gives a general view of the present development stage of the ORGEL Program.

The objectives and the basic features of the ORGEL Program are outlined in the first chapter. One chapter deals with the optimization studies being carried out at Brussels. These studies main at finding a set of operational parameters for an ORGEL Power Plant which will yield the lowest cost of the KWh sent out.

Another chapter describes the ESSOR reactor, a test reactor specially assigned to the ORGEL Program.

The other chapters deal with the activities of the various divisions or departments in Ispra, directly involved in the development of the ORGEL reactor : Reactor Physics, Technology, Metallurgy, Heat Transfer, Chemistry and Physical Chemics.



## CHAPTER I — GENERAL REMARKS

### 1 — Objectives

The project is aimed at the development of a European power reactor system, i.e. :

- 1) which can be operated in Europe without any outside help; the need for enrichment, if it is not ruled out in every case, is however not necessary (it is not a "sine qua non" condition). As regards heavy water, a certain production capacity could be rapidly built up in Europe if necessary.
- 2) which would utilize the united resources of the six Community countries. The problem here is not only of creating a spirit of personal cooperation, but also — which is more difficult — of inducing commercial firms to work in collaboration.

We have, however, already had some success in two major projects :

- a) the ESSOR (ESSai ORgel) reactor design study being carried out by a Franco-German group made up of the firms Groupement Atomique Alsacienne Atlantique (G.A.A.A.), France and Internationale Atomreaktorbau G.m.b.H. (Interatom), Germany.
- b) the study for the ORGEL reference project, aimed at the complete design of a 250 MWe plant, on which an economic evaluation of the project could be based (determination of cost functions, etc.), is now being carried out by a group consisting of the firms Belgo-Nucléaire (Belgium), Indatom (France) and Siemens (Germany).

However, we do not intend to stop there. Quite apart from the other EURATOM activities, where the same policy is being pursued as far as possible, the aim of the ORGEL project is to enable European industry itself to construct reactors of this type with the aid of the research and development infrastructure set up by EURATOM in its Joint Research Centre or by means of contracts with the Community's public or private laboratories.

- 3) which could be incorporated in the various national programs as harmoniously as possible, at the same time avoiding useless duplication of effort.

In this way the heavy-water lattice study supplements the projects undertaken in Germany and France, thus providing for advantages to be derived by both sides.

The organic coolant studies will make a marked contribution to the organic programs now in progress in Italy and Germany. These programs will likewise benefit from the research being carried out on a fuel (uranium carbide or uranium metal) and a structural material (SAP).

### 2 — Basic features of the Reactor System

- 1) Exploitation of the favorable neutron economy permitted by the use of heavy water.
- 2) Utilization of a fuel cycle which is at the same time inexpensive and free of the uncertainties of reprocessing, an attempt being made to burn as much plutonium as possible in situ. With

this aim in view, slight initial enrichment might be regarded as being of economic value in order to bring technological and neutron burn-ups closer into line in the event of a fuel such as uranium carbide being used; if, on the other hand, the use of slightly alloyed uranium metal is found to be feasible, there is unlikely to be any justification for enrichment.

At all events, two conditions remain fixed :

- the reactor must operate on natural uranium under suitable conditions;
- the fuel can never be reprocessed at the end of a cycle.

- 3) Utilization of the low vapor pressure of polyphenyls for use in a low-pressure range.
- 4) Utilization of the limited corrosive properties possessed by polyphenyls to permit the use of lower-grade materials.

The last two points should result in a low investment cost.

### 3 — Organisation of the project

The Project can be divided in two parts.

- a) The project coordination, carried out at Euratom Headquarters at Brussels and by contract, includes a.o. the optimisation studies and the construction of the specific test reactor (Essor).
- b) The Research and Development Program, carried out at the Research Centre in Ispra (Italy) and by contract.

The following chapters give an overall idea of the various objects of the project.

## CHAPTER II — OPTIMIZATION

### 1 — Introduction

The first approach studies of the natural uranium-organic coolant-heavy water (ORGEL) concept started at EURATOM early in 1960. About a year later, certain basic options regarding the fuel element and the reactor were temporarily adopted and calculation codes were developed in certain specific fields (reactor physics).

It was then possible, on these bases, to undertake optimization studies, comprising :

- the obtention of more detailed technological and economic data of the power plant : mainly through work carried out under contract by certain industrial groups in the Community and of the ISPRA JRC;
- the development of methods of calculating the plant's performances and costs and the study of its optimization.

Thus it has been necessary to deal with this aspect in two distinct parts, namely the nuclear part and the conventional part;

- the machine (IBM 7090) programming and the working-out of the OREE and ORION I optimization codes from the plant mathematical model thus obtained, in order to avoid slow and wearisome calculation by hand and to determine accurately the many divergent and frequently unimportant effects which always occur in optimization research.

I propose to deal rapidly with these three points before setting out the main elements of the results yielded by the relative operations.

### 2 — Technological and economic outline of the plant

#### 2.1 — The Technological Aspect

Rough and ready calculations or optimization studies call for the choice of a number of technological features, such as structural materials, geometries, layout, etc., which remain constant in the course of the study. Such calculations relate to the quantitative aspect of the choice only.

The main parts of this "Skeleton" are as follows (see annex) :

*Reactor* : The reactor is a vertical cylindrical assembly made up of a stainless steel vessel stiffened by zircaloy calandria tubes; sintered aluminium pressure tubes, co-axial with the calandria tubes and insulated from them by a layer of gas, form the channels containing the fuel elements. Here the organic coolant circulates from top to bottom. The vessel is entirely filled with slightly pressurized heavy water.

*Fuel Element* : The element consists of a cluster of 7 natural uranium carbide rods clad with sintered aluminium (see Fig. 1); the spacing between rods is obtained by means of special helicoidal fins.

*Organic Coolant* : The reference coolant is a mixture of triphenyls (O : 11 % - M : 56 % - P : 3 %) containing 30 % high boiler residue.

Its physical properties resulting from recent experiments are shown by Fig. 2 and 3.

#### *Primary Circuit and Heat Exchangers*

The circuit, which is entirely of mild steel, ensures the passage of the organic coolant from the reactor core to the heat exchangers.

At each end of the reactor, coolant feeding is effected by 2 semi-toric headers on which are fixed individual feeding tubes ( $\varnothing = 57$  mm) for each fuel channel; the main primary circuit, which consists of 6 independent loops, is linked to the semi-toric headers through a spherical collector.

Each loop comprises a heat exchanger made up of an economizer, a vaporizer and a superheater in the same container. The organic circulation pump is located at the reactor inlet.

#### *Conventional Part of the Plant*

The 250 MW turbine is of the action type, with a horizontal shaft, being directly connected to a three-phase alternator. It has a divided HP body and two BP bodies with three exhausts each; there are three steam extraction points, one HP and two BP; one or two wheels have special grooved blades which enable the real moisture in the turbine exhaust to be limited to 12 %.

The condenser is of the single-pass type, with an absolute pressure of 44 g/cm<sup>2</sup>.

The condensate is pumped out of the condenser through two BP feed-heaters, one feed-heater with a degassing tank and finally two feed-heaters before being fed into the economizer.

## **2.2 — The Economic Aspect**

The economic model of the power plant has been determined on the basis of an economic study taking into account the various items of the plant.

The direct investments have been estimated from information obtained under contract. The estimates were made in respect of a plant equipped with a single reactor and may be considered as valid at the present time; the development costs are not included, although certain constructors are already taking it into account in their prices for certain pieces of equipment.

These estimates will be revised and supplemented at the end of 1962 in the light of the results of price function studies carried out under contract among the industries of the Community.

The indirect investments have been estimated on the basis of the conventional uncertainty coefficients, an overall escalation rate of 8 %, a reactor construction period of 4 years and a rate of interest of 6 %.

The study and site costs are estimated at 14 million dollars for a 250 MWe power plant.

These investments can be divided into a constant fraction and a variable one.

So far, the only price functions to have been adopted are those relating to the most important items, namely :

for the reactor :

- channels, junctions, end fittings and related instruments
- heavy water (\$ 62/kg)
- fuel (\$ 100/kg)

for the conventional part :

- heat exchanger
- turbo-alternator, pumps and condenser.

The fixed costs derive from the amortization of the capital cost (overall annuity of 10 %, amortization period of 20 years) and payment of the fixed fuel costs (rate of interest 6 %).

The organic consumption costs are calculated on the basis of the radiolytic and pyrolytic decomposition. The price of OM2 organic is \$ 0.6/kg.

### 3 — Optimization methods

#### 3.1 — Optimization of Conventional Plant

The conventional plant study must be a particularly thorough one for a nuclear power plant of the ORGEL type : the temperature region of the proposed organic coolant, namely :

$$\begin{aligned} 350^{\circ} \text{C} < t_1 < 425^{\circ} \text{C} \\ 80^{\circ} \text{C} < t_1 - t_0 < 150^{\circ} \text{C} \end{aligned}$$

appears from a thermodynamic standpoint to be a transition region rich in possibilities; the steam cycles usually chosen for other reactor types may, a priori, still be worth attention, as is shown by Fig. 4.

The study of these cycles and the selection of the plant have been carried out with the overall aim of obtaining the minimum price of 1 kWh supplied by the complete ORGEL power plant. The problem has been simplified by making a partial optimization in connection with the conventional plant, only along the following lines :

In the equation giving the net price C of a kWh supplied to the network, the contribution of the conventional part of the plant is represented by a term  $y_1$ , related to the investment and by the efficiency R.

$$C = A + \frac{X}{R} + \frac{y_1 + y_2}{R}$$

A : constant

X : term relating to reactor, heavy water, fuel, etc.

$y_1$  : term relating to conventional power plant

$y_2$  : term relating to heat exchangers

where y and R depend only on *two variables of a general character*, the temperatures  $t_0$  and  $t_1$  at the inlet and outlet of the reactor; however, it is necessary to introduce into the study heat ex-

changers characterized by an additional variable, the difference  $d_1$  between the organic and water temperatures at the inlet to the boiler section of the steam generators (\*).

Partial optimization is then effected without difficulty in accordance with the above formula, in which A is a constant and X,  $y_1$ ,  $y_2$  and R are functions of  $t_0$ ,  $t_1$  and  $d_1$ ; this last additional variable can, moreover, be eliminated after a certain amount of scanning.

#### a) *Single Pressure Steam Cycle*

The main study was conducted by contract (Allgemeine Elektrizitätsgesellschaft, Alsthom Société Générale de Constructions Electriques et Mécaniques. Ansaldo spt. et Société d'Etude et de Construction Evence Coppée) into the usual single pressure steam cycle, which is considered as the reference cycle; it showed that the variations in the price of the conventional plant, not including exchangers, as a function of the operating parameters were low and of the same order of magnitude as those due to the differences in the turbine prices due to the various technologies and labor costs in the different countries of the Community.

The net electrical efficiency of the conventional plant may attain values of around 0.35.

The single pressure cycle comes up against the problems raised by the excessive moisture encountered at the end of the expansion, if relatively high turbine admission pressures are to be reached.

#### b) *Single pressure cycle with Re-heating*

*Re-heating* has been studied only for some chosen numerical values of the thermodynamical parameters. From the point of view of optimization, it has hitherto been considered as an addition, characterized by the terms  $\Delta R$ ,  $\Delta y_1$ ,  $\Delta y_2$  relating to the operating point selected in the single pressure cycle with no re-heating.

Re-heating by the organic liquid in the heat-exchanger has proved, from both the technical and the economic standpoints, to be preferable to re-heating carried out in a separate re-heater located in the vicinity of the turbine by bleeding off live steam during the expansion.

### 3.2 - Optimization of Nuclear Power Plant

#### a) *The fuel element*

Some work has been performed on the design of the fuel element (bundles of 4, 7, 19, 22, 32 rods, mechanical assembly of the rods, stiffeners, matrices, shrouds and fillers; various cladding and structural materials, etc.). This work is of a highly qualitative character because of the technological choices which it necessitates and the difficulty of assessing the degree of security in the solutions envisaged; it is thus still being continued, paralleled by the development of the experimental research.

---

(\*) In the first approximation, it is also necessary for the difference  $d_0$  to be introduced at the superheater inlet; in the studies carried out,  $d_0$  was taken as being equal to 10°C.



Each fuel element model adopted is subjected to preliminary optimization of its quantitative parameters; in the case of the element shown here (Fig. 1), the most noteworthy range of variation of these parameters is:

Fuel cross section (Cm <sup>2</sup> )	25	30	35
Clearance between rod (mm)	1	1,2	1,4
Finning ratio	1,5	1,7	1,9

#### b) Reactor

The optimization of the reactor has been undertaken within the frame of a 250 electric MW power plant study; the fission power is adjusted to the gross electrical power of the plant. In consequence, the main variables acting on the size of the reactor may be listed as follows:

- coolant outlet temperature  $t_1$ , velocity  $v$  and high-polymer content  $p$
- height of the reactor  $H$
- lattice pitch  $z$
- degree of flux-flattening  $x$
- thickness of radial reflector  $d_r$ .

The influence of the variables on the characteristic quantities of the reactor, such as the number of channels, the weight of the heavy water, the weight of the fuel and the consumption of fuel and organic, has been the subject of various studies with the OREE and ORION I Codes described below.

The most important conclusion from these studies is that the price function to be minimized may, in the first approximation, be represented by a quadratic function of the four independent variables  $H$ ,  $z$ ,  $x$ ,  $d_r$ . The optimization relative to these variables is an easy matter; the extremum conditions in this case are reduced to a system of four linear equations with four unknowns, provided that the existence of an extremum within the region under consideration can be proved. Such an optimization routine is included in the ORION I Code. The studies now in progress will make it possible to ascertain whether this optimization technique is also applicable to the other independent variables ( $t_1$ ,  $v$ ,  $p$ ,...). If this will be the case, the ORION I Code will be modified in order to obtain an automatic optimization as a function of the main variables governing the size of the reactor.

## 4 — Optimization codes

As has been said, the first economic and technological mathematical model of an ORGEL power plant was set up during 1961. Every effort was made to obtain the maximum simplicity and flexibility, the obvious aim here being to bring out as soon as possible the main characteristics of such a plant. The first parametric calculations, which were done by hand, were carried out early in 1961 and from these the pre-eminence of certain parameters was able to be discerned. However, in every optimization study it is necessary to determine with a high degree of accuracy a great many effects which are divergent and frequently of little importance. It was thus considered desirable to devise a series of codes — Fac For, OREE I, OREE II and ORION I — in order to eliminate manual calculations to an increasing extent. This process of elimination was carried out progressively. FAC FOR is purely geometrical code for calculating radial form factors and criticality conditions; OREE I and OREE II are codes for determining the dimensions of the reactor core; and ORION I is the first general optimization code for an ORGEL power plant.

## **Orion I** (Fig. 5)

On the basis of the geometrical data relating to the channel, the fuel element characteristics and coolant properties, the infinite lattice neutron characteristics and its long-term evolution, and finally the values of 5 independent variables, i. e. :

- coolant velocity
- reactor outlet temperature of the coolant
- high-polymer content in the coolant
- maximum cladding temperature
- heat exchanger pinch point

The Code calculates the optimum plant in relation to the following variables :

- height of core
- lattice pitch
- degree of flattening
- thickness of radial reflector

The criticality conditions and the geometry factors are given by the FAC FOR Code.

Xenon anti-reactivity is determined from the maximum neutron flux and the statistical weight factors as shown in Report EUR/C/315/62 f. Preliminary studies, with the aid of OREE II, having shown that in a first approximation the price of the energy produced by the plant is a quadratic function of the 4 variables to be optimized, the optimization routine embodied in the Code does not involve the use of a gradient method but of the extremum conditions of a function of the second degree and with several variables (the minimum is always included in the region).

### **Input Data**

- geometrical data relating to channel
- basic characteristics of fuel elements and coolant
- values of five independent variables not yet optimized

### **Output Data**

- thermal characteristics of reactor core
- thermodynamic characteristics of power plant
- geometry of reactor
- burn-up of fuel
- fixed costs
- fuel and organic consumption costs in the optimum plant.

## Future Developments

During 1962 it is intended to make various improvements in the Codes hitherto developed.

The economic model of the plant will have to be revised; this will be done on the basis of the results of studies under contract.

Determination of the size of the core will be based on the two-group theory and no longer on the one-and-a-half-group theory; if necessary, the long-term evolution calculation will be revised so as to take more account of the radial distribution of the flux.

Finally, the optimization routine will be extended to a greater number of variables; the optimization technique may have to be transferred from the quadratic to the cubic field.

## 5 — Results (\*)

Before setting out the main results obtained from the optimization studies described above, it would appear to be worth while defining roughly ORGEL's field of economic interest and the importance of the optimizable items.

The cost of energy of nuclear origin may be defined as the sum of the following three terms :

- 1) the fixed charges, independent of the amount of power supplied annually, representing the recovery of the capital invested;
- 2) the fuel-cycle charges;
- 3) the operating and maintenance charges (insurance, salaries of staff, basic maintenance and, in the case of ORGEL, organic make-up costs).

It is highly desirable that this cost should at most be equal to that of conventional energy. Thus in graphic (6) a straight line is drawn which separates the regions of competitive and uncompetitive energy costs; the cost of conventional energy has been fixed at 6.5 mills/kWh; item (3) above is not taken in the consideration because of the excessive uncertainty of its determination.

A detailed study of the breakdown of the energy cost of an ORGEL-type nuclear power plant reveals the complementary character of certain items which almost balance each other :

An example is provided by the heavy water tonnage and the fuel consumption. By increasing the distance between channels, the heavy-water investment and therefore the fixed charges are also increased, but the lattice neutron characteristics are improved and in this way the fuel consumption expenditure is reduced.

On the other hand, items such as the alternator and the power transformer are insensitive to the different independent variables.

One is thus led to the conclusion that certain investments are well able to be optimized and that others are in a lesser degree.

The part of the investment which can be optimized amounts approximately to \$ 110/kW; the non optimizable part ranges between \$ 170 to \$ 190/kW.

---

(\*) The results relate to the 250 gross MWe power plant shown in annex I.

The straight line  $y = 2.5$  mills/kWh thus represents approximately the non-optimizable fixed costs. The same method can be used to define the optimizable fuel consumption costs. This amounts to approximately 1 mills/kWh.

It will therefore be seen that the optimization studies cover a wide field and that the items in respect of which both qualitative and quantitative optimizations hold out promises, account for nearly 50 % of the cost of the energy produced.

But three variables fixed for the previous evaluation have a direct influence on the total cost of the energy. These are the efficiency, the plant's load factor and the plant's power rate.

It is therefore necessary to try to make due allowance for the gains resulting from :

- a) the values assigned to these three variables
- b) the exact determination of the plant's technical characteristics by mathematical optimization based on numerical values generally obtained from experiments
- c) various technological choices of a more or less advanced character.

Finally, the influence of uncertainty of the industrial prices of materials to be developed must not be overlooked.

The results are as follows; the numerical values are rough estimations and are given essentially to allow comparisons.

a) — The addition of re-heating by the organic to the usual steam cycle involves a gain of approximately 0.17 mills/kWh; the reduction of the condenser pressure from 52 to 39 g/cm<sup>2</sup> means a gain of approximately 0.05 mills/kWh.

— An increase of 50 MWe in the plant's power brings about a saving, through the effect of the reactor's size alone, of approximately 0.10 mills/kWh.

— By raising the load factor from 7 000 to 7 500 h/year, a gain of 0,3 mills/kWh, all other things being equal, is achieved.

*These gains are, roughly speaking, in the range of 1 or tenths of mills/kWh.*

b) — If a comparison is made between these gains and the differences in cost due to the variations in the parameters relative to the reactor (within the scope of the mathematical optimization) (Fig. 7), it is seen that these differences are of the order of 0.01 to 0.02 mills/kWh (dR, H, V<sub>m</sub>/V<sub>u</sub>) except in the case of the degree of flattening; the same applies to a variation from 380° to 400 °C in the reactor-outlet temperature of the organic coolant.

These *very slight variations* certainly show that the optimization had its effect, but also that the minima are very flat.

— The flux flattening is something of a problem apart; the gain in the price of energy is estimated at 0,4 mills/kWh when passing from a non-flattened flux reactor to a flattened flux reactor and using the same fuel elements. This seems, indeed, to be considerable.

c) The possible gains due to variations in the parameters linked to the channel are believed to be 0.1 mills/kWh when the maximum cladding temperature is increased from 430° to 440 °C and 0.13 mills/kWh when the clearance between the fuel rod is reduced from 1.4 to 1 mm.

It must, however, be pointed out, that these last modifications already have a *pronounced technological aspect* : the raising of the cladding temperature depends on the creep characteristics which can be obtained from the sintered aluminium powder cladding; the minimum admissible

clearance depends on the irradiation behaviour of the uranium carbide, the fuel element thermal cycling, the any burn-out and fouling due to the coolant.

It is extremely difficult, as has already been stressed, to make a quantitative comparison — e.g. by the criterion of the minimum cost of 1 kWh — between different technological choices. The plant "skeleton" is modified, the differences in degree of safety cannot be worked out, and frequently there is a lack of substantial data (especially economic) if the solution is an advanced one.

If, by way of simplification, every gain in reactivity due to an improvement in the barrier assembly separating the heavy-water moderator from the organic coolant in the channel is related to the burn-up (8 000 MWD/T), it is found that 500 pcm corresponds to *0.15 mills/kWh*.

The improvement in the mechanical characteristics and in the creep technology of the sintered aluminium pressure tubes would result in a gain of 0.12 mills/kWh for a reduction of 0.5 mm in the wall thickness, etc.

*All these variations are in the range of 1 or tenths of mills/kWh.*

- d) — The maximum uncertainties in the prices relate to the basic materials of the concept :
- a 50 % fall in the price of the organic coolant quoted at \$ 0,6/kg would bring about a gain of 0.1 mills/kWh;
  - the same fall in the price of the UC fuel element quoted at \$ 100/kg would bring about a gain of 0.95 mills/kWh.

If such a reduction in the fuel price cannot be realized, a less spectacular reduction may still lead to interesting gains.

The possible substantial gains therefore derive mainly from :

- technological choices from the point of view of the channel and fuel element as well as from that of the reactor; it seems, however, that the former, which constitute the keystone of the entire concept and are marked by their effect on the reactivity balance (including coolant), may produce more differences than the latter;
- certain fundamental technical choices directly connected with the energy cost, i. e. choice of steam cycle (efficiency), choice of method and degree of flux flattening, choice of power rating of the projected plant;
- industrial production at a reasonable price of the fuel and, subsidiarily, of the coolant.

The ORGEL Power Plant as presented here has been deliberately given conservative characteristics from many points of view. It would therefore seem to be not unreasonable to hope that the barrier to competition with conventional energy will be crossed and that the plant will prove well worth while from an economic standpoint (Fig. 6).



Fig. 1

N7R

Calandria tube

Stress tube

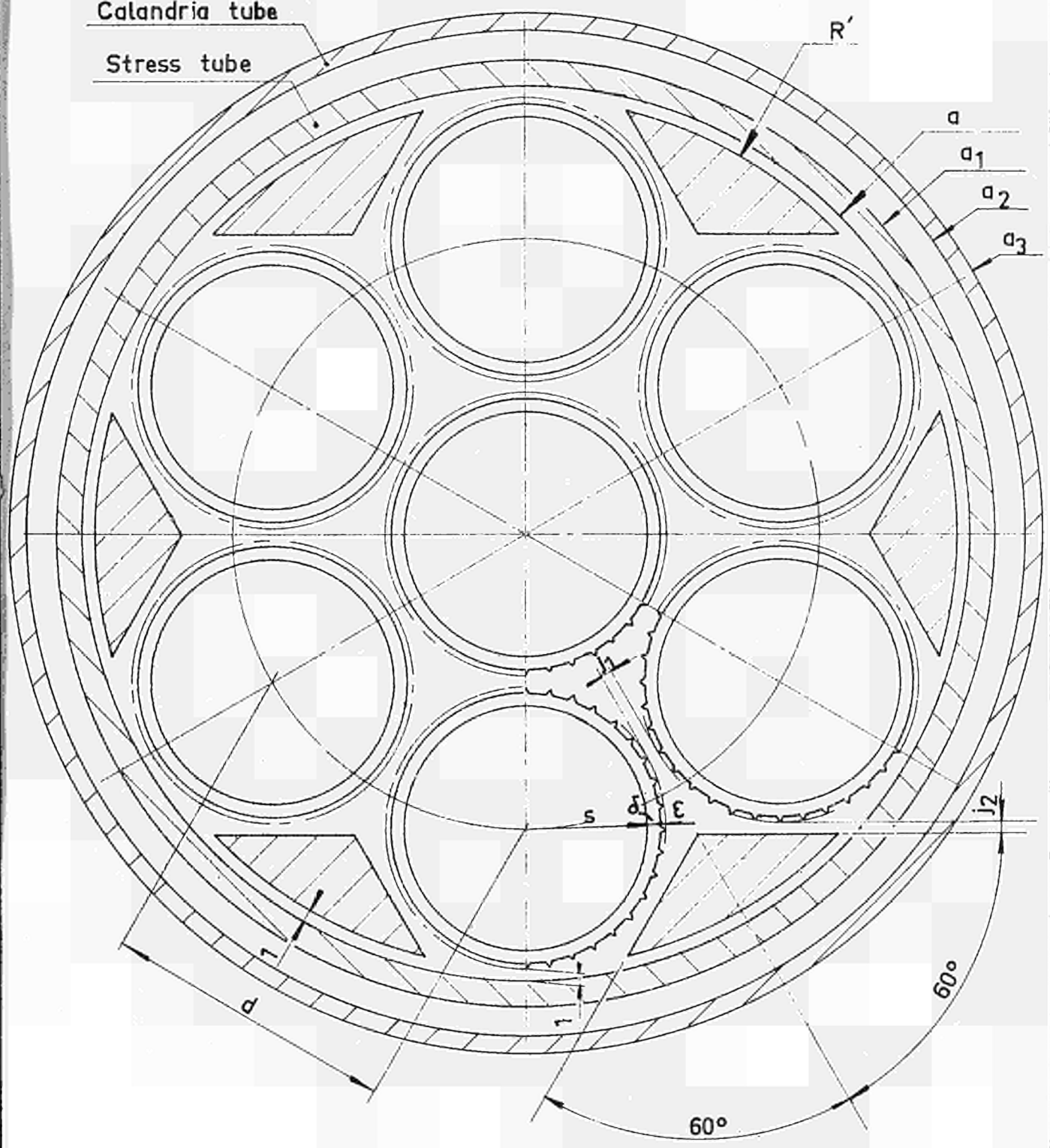
R'

a

a<sub>1</sub>

a<sub>2</sub>

a<sub>3</sub>



Unit : mm  
Scale : 2





$\rho$  (g/cm<sup>3</sup>)

$C_p$  (J/g°C)

$\lambda$  (W/cm°C)

Density  $\rho \equiv \rho(x,t)$

Specific heat  $C_p \equiv C_p(x,t)$

Thermal conductivity  $\lambda \equiv \lambda(x,t)$

x: % HBR

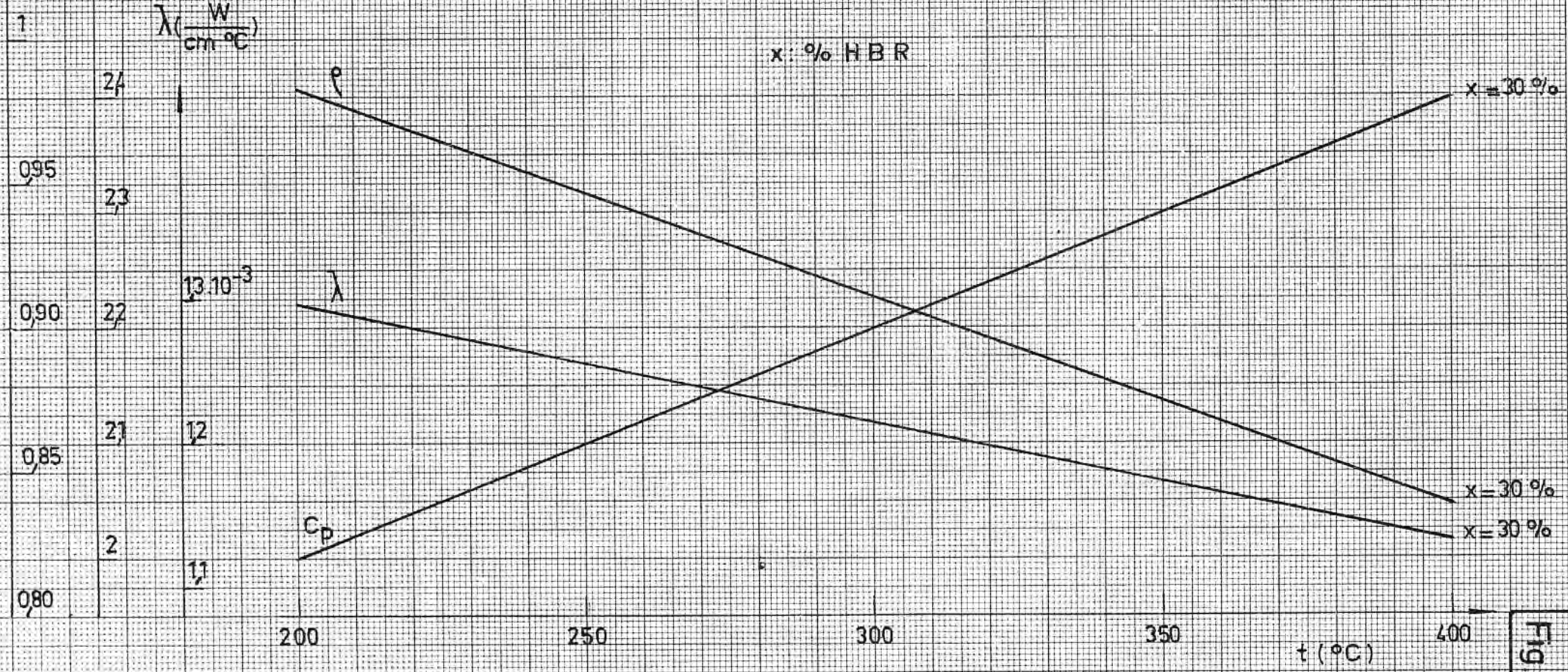


FIG 2



Fig. 3

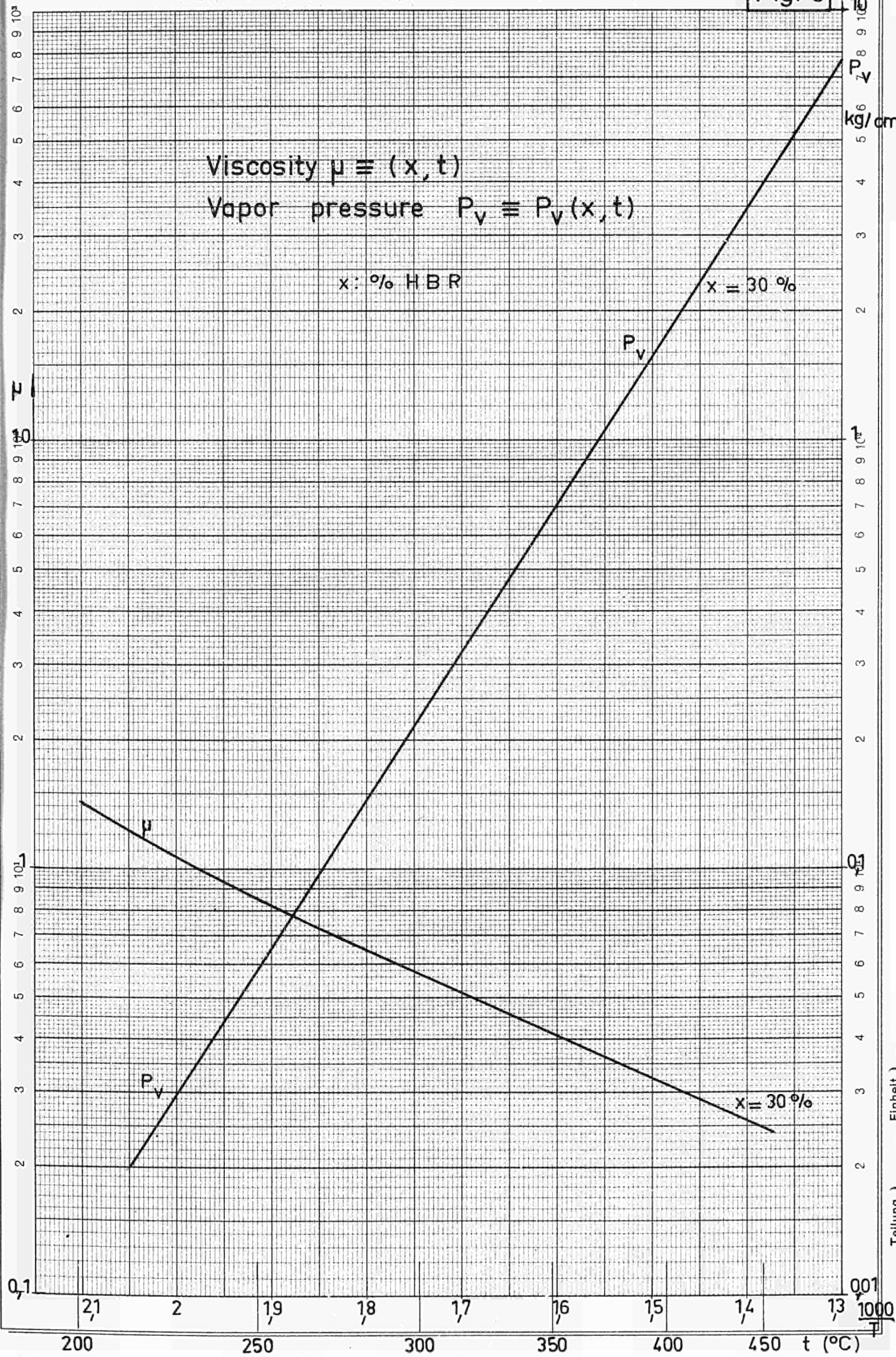
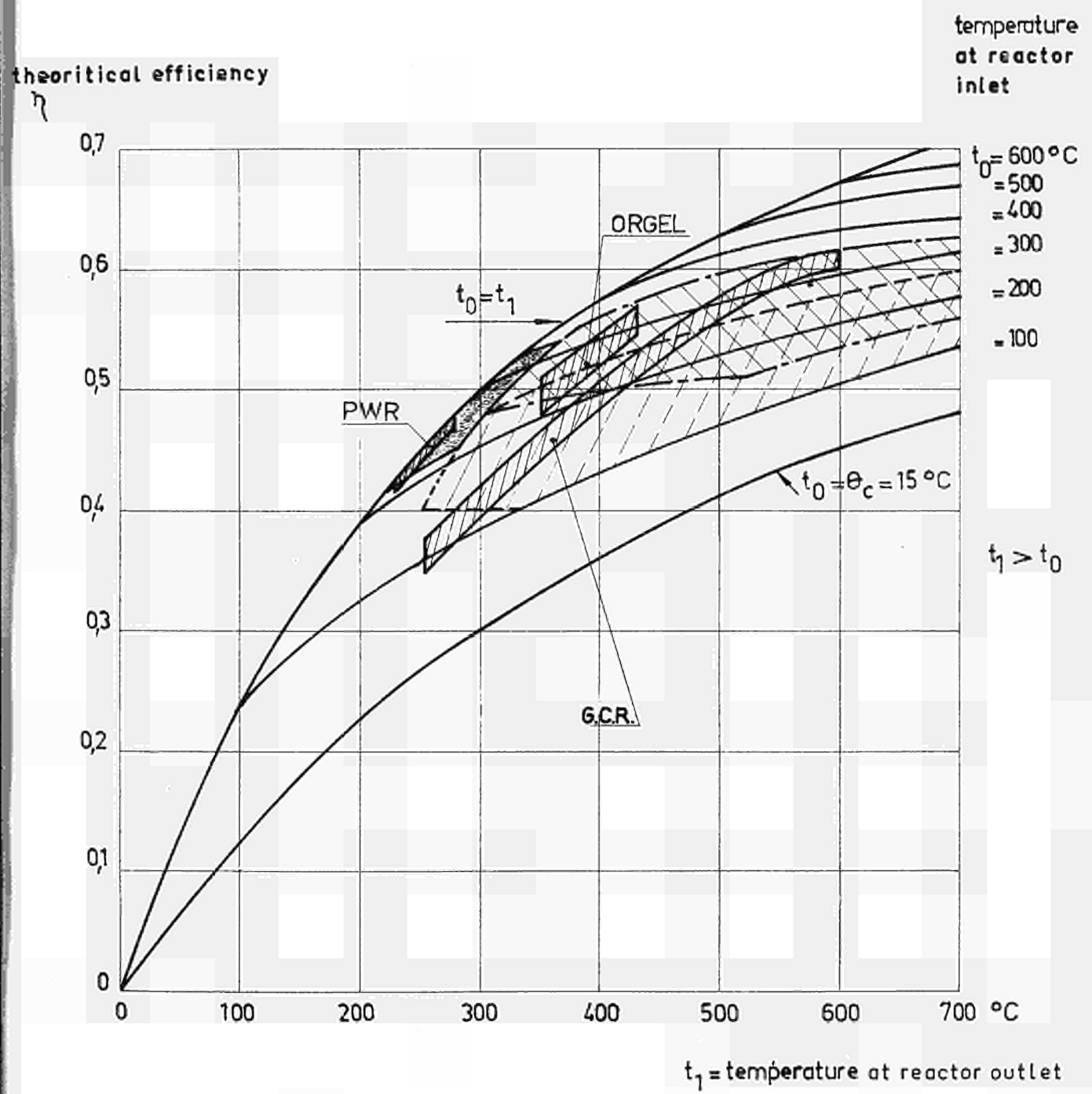







Fig. 4



-  Wet steam cycles
-  Single pressure cycle with reheat
-  Dual pressure cycle



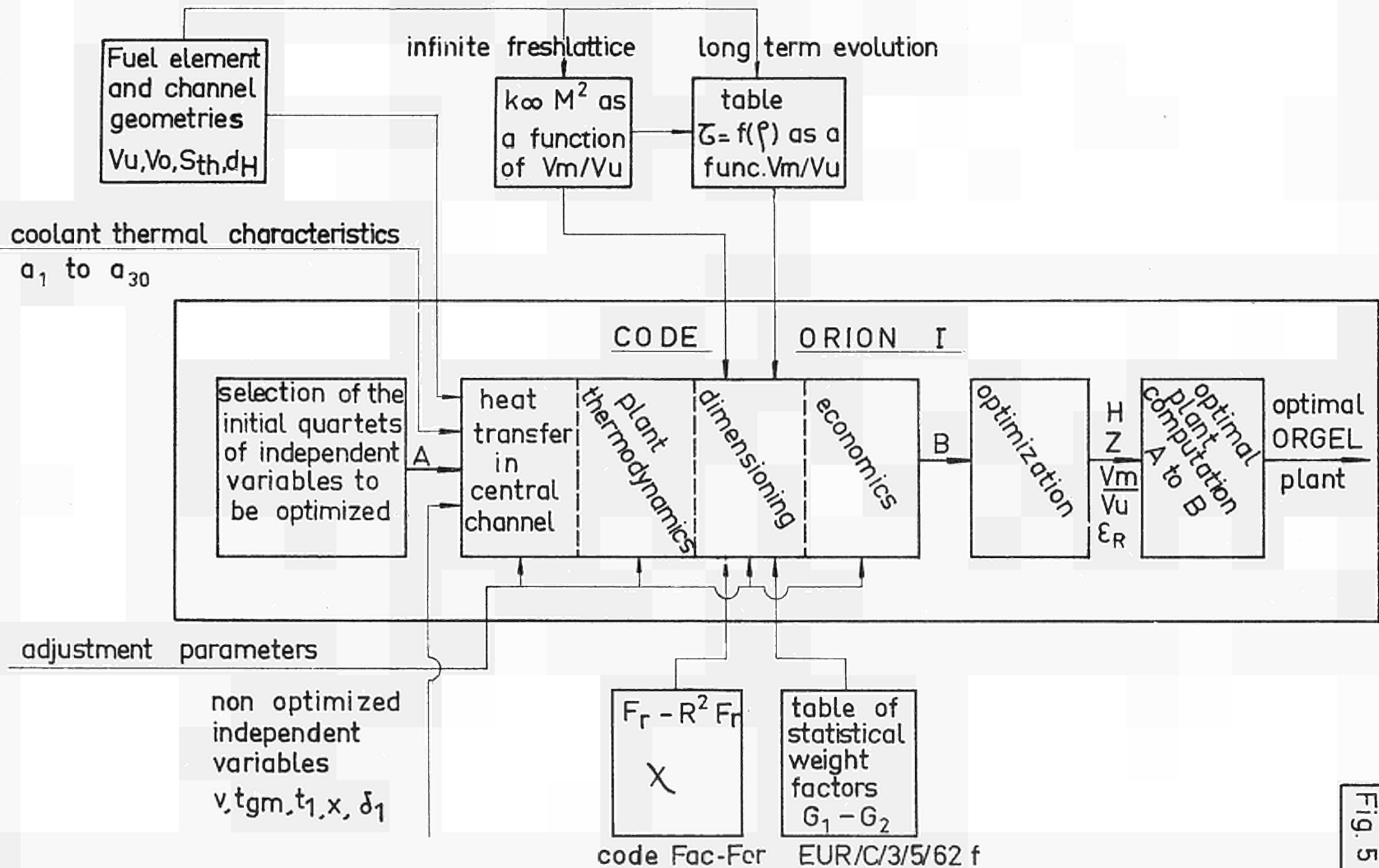
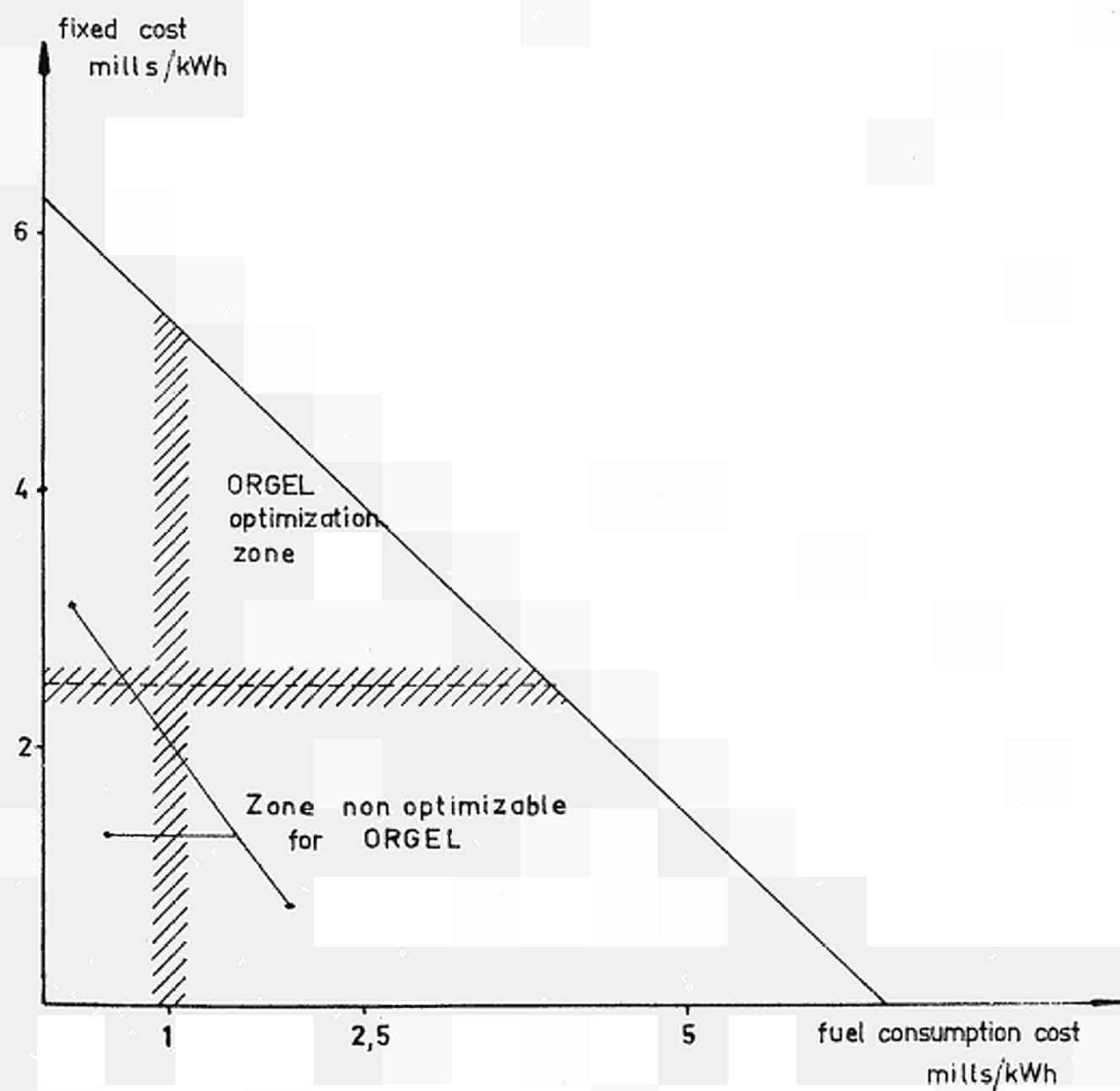


Fig. 5





Fig. 6





# Sensitivity of energy cost to independent variables

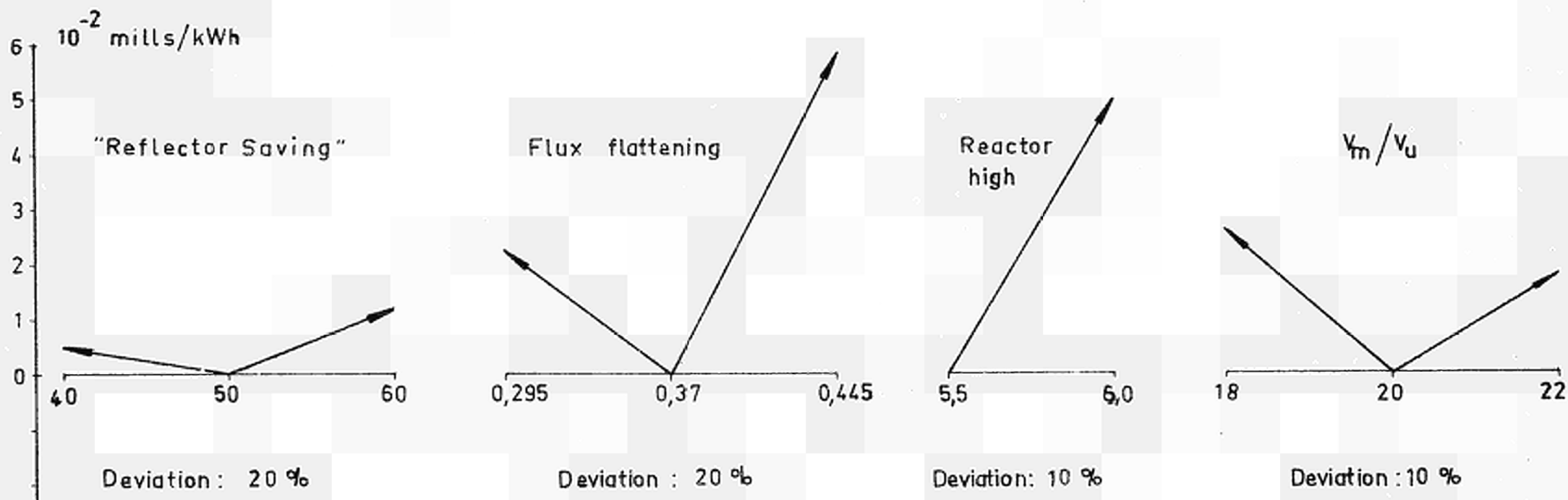


Fig. 7



## CHAPTER III — ESSOR

### 1 — General observations

The ORGEL Program is aimed at the development of the organic liquid cooled, heavy water moderated reactor type.

Apart from individual out of pile and in pile experiments on particular problems such as the behaviour of materials (fuel, cladding, cooling liquid, etc.) or of sub-assemblies (fuel cluster, pressure tube, etc.), experiments had to be carried out making it possible to operate in power reactor conditions, at the same time having carefully defined the parameters for each case.

These experiments will be carried out in a test reactor specially assigned to the ORGEL Program, namely the ESSOR (ESSais ORgel) Reactor, which, by extension, may also be considered as a test reactor specifically connected with the heavy water moderated reactor type containing pressure tubes.

The ESSOR Reactor was fundamentally designed to make possible the testing of a group of an ORGEL type channels, which may be, of very different designs, arranged in the heavy water moderator according to the lattice pitch.

Reactor operation is made as independent of the design of the ORGEL channels as possible by isolating a neutron flux producing zone from the ORGEL zone.

The assembly has been designed to permit accurate simultaneous experimentation in the organic liquid circuits, on the behaviour of the coolant and on the loading-unloading equipment.

These studies have been carried out jointly by the Groupement Atomique Alsacienne Atlantique (France) and Interatom (Germany).

The adjusting tests have been carried out by both companies together with the Centre d'Etude de l'Energie Nucléaire, Mol (Belgium).

### 2 — Assembly

#### 2.1 — Definition of Reactor

Because of the desirability of obtaining, for the purpose of developing the ORGEL channel, an instrument endowed with a high degree of flexibility and which enables individual or group tests to be carried out, the experimental channels have been grouped in the central zone and ringed with a peripheral ring known as the "feeding zone".

In the central zone, some channels are especially designed for carrying out more or less advanced experiments which will relate, for example, to metallurgy, technology, heat exchange, chemistry, etc. and will purposely be carried out separately.

The other channels are grouped in the form which they will assume in the power reactor, i.e. involving all the reciprocal effects to be anticipated. The operating conditions in these channels

will be very similar to those in a power reactor and, in certain circumstances, may be able to furnish information statistical data.

At a later stage, all the positions of the experimental zone will be able to be equipped with ORGEL channels operating simultaneously and in conditions laid down for a power reactor.

Highly enriched fuel elements are used for the feeding zone.

## 2.2 — Description

The central zone contains 12 positions for ORGEL channels (fig. 1). Four of these (peripheral) are intended to accommodate channels for special tests, each being hooked up to an independent cooling circuit. The eight others, which are for group tests, will be linked to a common cooling circuit.

The feeding zone comprises 16 cylindrical elements of the BR-2 type, the cooling of which is effected by forced heavy water circulation independent of that of the ORGEL moderator.

The assembly is contained in a stainless steel vessel resting on the lower end shield, with the upper end shield serving as a leaktight closure. These shielding blocks make it possible to have access in reactor to the two large upper and lower chambers, when the reactor is shut down and the circuits are uncontaminated. (Fig. 2)

The ORGEL channels pass right through the vessel and the two end shields, and thus their connections to the vessel extensions, the leaktight closure and the various feeding or control devices are extended into the shielded rooms and are thus accessible during reactor shutdown.

The feeding sites are also accessible from the upper surface of the shielding, the coolant circulation being of re-entrant type.

The upper chamber is sealed off by a shielding block called "dummy shield", the upper surface of which is on the operating floor on which the loading-unloading machines are running.

A thermal shield (iron and water) surrounds the vessel and safeguards the concrete of the biological shielding from radiation effects. The assembly consisting of the vessel, end shields, chambers and thermal and biological shields forming the reactor block — forms an integral part of the civil work of the various shielded rooms surrounding the reactor and housing the primary heavy water or organic liquid circuits and their auxiliaries, as well as the various storage, observation or clean-up points served by the fuel handling casks. These casks move along the east-west diameter on which the various loading unloading accessory points are arranged. This diameter divides the buildings inside the containment into two parts, one to the south, in which the organic liquid primary circuits are each arranged in a sector, and the other to the north, which mainly houses the heavy water circuits. (Fig. 3)

The containment building, which is in cylindrical form, only permits access to either of these parts through controlled locks.

The buildings intended for operational purposes are set in a rational manner around the containment.

The irradiated fuel elements are extracted through the swimming-pool, the nose of which projects into the containment. The fuel-examination cells are close to the swimming, as also is the new element installation workshop.

The ORGEL channels (not including fuel element) outside the containment, are extracted from the side diametrically opposed to that used for the fuel elements and have their own workshop.

The control room and the data-processing room are situated outside the containment, on the same level as the operating floor, whereas the individual experiment monitoring points are arranged close to each of the organic liquid loop operating sectors.

The other buildings house the electrical and mechanical workshops, the stores, the ventilation, the diesels, the power supply and some offices.

### 3 — Core characteristics

#### 3.1

The core was designed to make it possible to test a channel in conditions representative of those of a power reactor. The values of certain parameters such as specific power, thermal gradients, flux form, use of natural uranium in the ORGEL zone, must therefore be observed. These conditions have entailed a certain number of conditions. For example, a relatively high thermal neutron flux results in a rapid rate of feeding fuel consumption and considerable flux variations in the course of a cycle; a rather compact arrangement of the lattice was also necessary to obtain a satisfactory flux distribution without reaching excessive total powers.

The difficulties were aggravated by certain characteristics of ESSOR such as :

- The physical and geometrical heterogeneity, due on the one hand to the wide difference in the nuclear parameters of the various core regions and on the other to the absence of revolution symmetry.
- The limitations imposed on parameter variation by the minimum amount of congestion of the constituents (vessels, piping passages, cells, etc.).
- The technological limitations allowed for the uranium content of the feeding zone element plates and for the burn-up rate of this fuel.
- The necessity of ensuring the control of strong reactivity excesses.

#### 3.2 — Lattice Arrangement

To take these basic elements into account, several possible lattice arrangements were designed : peripheral feeding zone, central feeding zone, combination of both zones. Extensive research has led us to choose the lattice arrangement as represented on figure 1.

The heavy water level in the vessel is 2 300 m. With a minimum reflector of 30 cm, the active level may be 1.70 m. The development and application of a heterogeneous 3-dimensional calculation method has shown that there was no noteworthy advantage in using an ORGEL zone higher than the feeding zone.

In the central zone the single loop channels form, together with the 8 multiple loop channels, a square-mesh lattice of 256 mm/pitch. Four channels are arranged on a 18.1 cm radius ring and the other eight on a 40.5 cm ring.

The 16 cells of the feeding zone are arranged irregularly along a diameter of 1 180 mm in order to allow the passage of the ORGEL channels' organic liquid feed piping.

The control elements are arranged along a diameter of 1 480 mm., where 16 positions are available and a heavy water reflector increases the vessel's diameter to 2 380 m.

With this lattice arrangement, it is possible to obtain in the experimental zone a relatively uniform flux, whose variations from channel to channel may be estimated at approximately  $\pm 5\%$  and, on the periphery of the cell channel, approximately  $\pm 3\%$  (between peripheral rodlets of one and the same cluster).

The burn-up expected for the feeding zone elements is 40 %. The loading will be carried out in fractions. Unloading of about 4 elements monthly or 8 elements after six weeks in the reactor, for example.

Reactor control is ensured by 4 grey rods for long term compensation (steel - total power 40 MK), 6 black rods for short term compensation (cadmium, total power 80 MK) and 2 fine control rods (total power : about 12 MK).

Scram is ensured by 4 safety rods, the total power of which being 35 MK in less than 0.5 sec.

The other lattice characteristics are shown in the annex to this document.

## 4 — Reactor

The ESSOR Reactor is especially designed for the development of the ORGEL channels. By channel is meant the tubes containing the pressure, the thermal insulation between the hot coolant and the cold heavy water, the various connecting or hook-up devices, the fuel and its method of attachment into the channel.

With this object in view, the 12 ORGEL positions will make it possible to adapt channels whose internal diameter may reach 100 mm and on which certain connections within the reactor may have a diameter of 150 mm. The feeding zone elements, on the other hand, are introduced into the tubes ensuring the independent circulation of the heavy water coolant.

### 4.1 — ORGEL Zone

The channels are linked to the vessel by means of "cuffs" fixed to the external surfaces of the end shields in relation to the vessel. The cuffs now envisaged have been designed so as to permit the installation of channels having the dimensions shown above and a length (according to the type of insulation used) of around 7 m. The channel is fixed at the upper part and expands freely towards the lower part, where its extensions are compensated by the moving of organic liquid piping, by bellows on the heavy water side and by sliding joints on the less important fluids, such as the gaseous insulator. (Fig. 4)

The fuel element may be either suspended at the upper part or rested on an independent support of the pressure tube. Other effects, such as axial stress compensation or pressure drop variation, may be reproduced on this channel in order to simulate the operating conditions of any one of the channels of a power reactor.

The tube is cooled by annular heavy water circulation across the end shields. The complete channel is normally withdrawn after the draining-off of the heavy water. Consideration has been given to the possibility of withdrawing tubes and fuel without draining off the water in the event of a serious accident to the fuel.

Figure 4 gives a schematic section of a channel equipped with a suspended fuel element and gas insulated pressure tube.



The design of the channels of the single loops and the multiple loop is the same. However, in order to obviate the need for reactor shut-down during a change of experiment on a single loop channel, a device for withdrawing the fuel from the core during reactor operation has been fitted to two of the single loop channels. This screw-bolt system brings up the fuel to the upper shielding, from where the fuel element and transfer mechanism group is withdrawn after a certain decay time.

#### 4.2 — Peripheral Zone

The feeding zone is made up of BR2 type plate fuel elements. The fuel plates are arcs of concentric circles supported by a rigid three-arm central structure. The heavy water circulates from top to bottom outside the fuel element and from bottom to top inside it. The water circulation tube and the element itself extend to the floor of the upper shielding, from where the fuel is extracted. (Fig. 5)

This type of fuel element is better suited from the pressure standpoint and enables the cooling circuit to be slightly pressurized. ( $3 \text{ kg/cm}^2$ )

The shim and control rods are operated by a rack and pinion system and their drive mechanism is located in the outside corridor next to the upper chamber for the sake of accessibility.

The safety rods are inserted in the core, after the electro-magnet is switched off, by the expansion of a gas behind the piston terminating the control shaft.

#### 4.3 — Vessel and Thermal Shielding

The vessel is made of 12 mm-thick stainless steel and is designed to withstand an internal pressure of  $8 \text{ kg/cm}^2$ . In the event of a pressure-tube rupture, the hot organic liquid can spill over into the heavy water, causing it to vaporize rapidly. Evacuation pipes for the helium and the heavy-water steam are provided in the upper shielding in an attempt to reduce pressure in the vessel. The steam is then collected and condensed in an appropriate condenser located within the leaktight containment.

The thermal shielding consists of successive iron and water screens, the water circulation providing the cooling.

### 5 — Cooling circuits

The moderator or heavy water circuits serving to cool the feeding cells are of conventional design and constructed of equipment well-proven in practice. On the other hand, the 5 organic liquid circuits (1 for the multiple loop and 4 for the 4 single loops) are designed in such a way as to facilitate study of the coolant behaviour as well as the attachment of the various experimental devices.

#### 5.1 — Organic Liquid Circuits

The organic liquid circuits are installed in 5 shielded rooms in the form of contiguous sectors, insulated from each other and protected. The building is designed in such a way that the protective walls separating the rooms are not self-supporting and could be removed in the event of a complete change in the arrangement of the rooms. (Fig. 3 and 7)

The terphenyl of the primary circuits is cooled by a secondary liquid circulating at 200° C and which is itself air-cooled.

The primary circuits and the pumps and tanks of the secondary circuits are located inside the organic rooms, the secondary heat exchangers being situated at a distance from the main building and cooled by forced ventilation.

#### *Single Loop Circuits*

Each single loop circuit permits the extraction of 2 MW for an organic temperature ranging from 300 to 425 °C. The primary liquid circulation is carried out by 3 pumps, capacity of each being 50 % of full flow.

The 4 single loop circuits are provided with a discontinuous distillation system and pump pressurization which can be relayed through the gaseous cover of the surge tank. However, they differ in the following manner :

One of them, made of ordinary steel, is linked to a channel equipped with a device which permits extraction during reactor operation, and is intended for use in studies on fuel clusters or channels.

The second, made of stainless steel, incorporates a stepped-up capacity distillation circuit, and is connected to the second channel, which is equipped with a device permitting extraction during reactor operation and will be used in particular for cladding rupture studies or for destructive tests.

Of the two other circuits, made of ordinary steel, one comprises a continuous distillation device, the other a gas pressurization system for which various gases can be used (H<sub>2</sub>, CH<sub>4</sub>, etc.).

In each of these circuits sufficient positions have been provided to allow for the use of other purification, degasing or filtration devices.

#### *Multiple Loop Circuit*

The multiple loop circuit differs from the single loop circuits in that it has a greater degree of safety. The primary and secondary circuits are duplicated. These circuits are made of ordinary steel and are provided with discontinuous distillation devices and pump pressurization.

The maximum thermal power which can be extracted for organic temperatures ranging from 300 and 425° C is about 1.5 MW per channel, i.e. 12 MW.

The 5 circuits each have their auxiliaries such as fusion station, dosage or storage tank, auxiliary cooling plant. Only the final storage tank, which is installed outside the leaktight containment, is common to all 5 circuits, being fed by the various storage tanks for each loop.

### **5.2 --- Heavy water circuit**

The cooling circuit for the feeding zone fuel elements is pressurized at about 3 kg/cm<sup>2</sup> at the outlet from the elements. The power to be extracted is about 15 MW and the circuit is designed for 18 MW, which are extracted by 3 heat-exchangers, the capacity of each being 33 % of full power. Total flow is 1 200 m<sup>3</sup>/h. The secondary liquid is light water cooled by atmospheric coolants. The assembly is installed in 3 independent casemates. (Fig. 6)

The moderator circuit is made up of 2 exchangers and 3 pumps, each having a capacity of 50 % of full power. The maximum power which can be extracted is about 3.6 MW for a flow of 400 m<sup>3</sup>/h. The assembly is installed in an independent room.

The other sections contain the recombination and purification devices, cold traps, etc.

## 6 — Handling of irradiated elements

The handling of irradiated elements is carried out by means of 2 casks circulating on the operational floor along the east-west diameter of the leaktight containment.

The carriage track is 5.70 m wide and the casks can move transversely on the carriage cask. When a cask is not on the carriage, it is located at its storage point, where decontamination and maintenance can be carried out.

The 2 fuel handling casks operate in nitrogen atmosphere at atmospheric pressure or an overpressure of several atmospheres, and are designed in such a way as to prevent any contact between the outside air and the heavy water or the organic liquid.

The handling cask for the fuel elements also permits the withdrawal of a complete ORGEL channel either with the fuel or without it. It is about 17.50 m high and weighs approximately 150 tons.

The handling cask for the feeding elements is about 9 m high and weighs approximately 60 tons.

In the event of an accident during the withdrawal of the fuel, the two casks can be flooded with the appropriate liquid (organic liquid or heavy water).

The fuel elements are unloaded from the east side, where the swimming-pool is also located. (Fig. 8). On this side of the carriage path and served by the fuel handling casks, are located the observation, washing and storage cells before the fuel is put into containers. After being placed in a container enclosing an organic liquid, the elements are stored in the decay pool, from where they can be withdrawn and passed through the observation, metrological and dismantling cells. Certain rodlets which require particular examination are placed in a container and taken to a hot laboratory for detailed examination.

The ORGEL channels (not including the fuel element) are unloaded on the west side via a vertical lock leading to the irradiated-channel processing workshop, where they are subjected to various examinations and sectioning processes. Along the fuel handling cask track and on this side of it are located various storage points in addition to a working cell to be used in the event of a fuel element having to be withdrawn at the same time as the pressure tube due to an accident. The assembly would be sectioned at the ends of the fuel element and then placed in a container.

The feeding zone fuel elements are stored directly in the swimming-pool water and then withdrawn in order to be sent in containers to an irradiated-fuel reprocessing centre.

## 7 — Regulation and control

The equipment coming under the heading of regulation and control must enable the control, regulation and measuring to be carried out for the operation of the reactor and its allied facilities, and also of the various experiments which may be going on at the same time.

This control assembly has been broken down in the following manner :

- The control, measuring and signalling devices which are directly concerned with the operation and safety of the reactor are located in the control room and are supervised by a single operator.
- The auxiliary control, measuring and signalling devices are located in the auxiliary premises inside the leaktight containment and are reproduced only in outline in the control room.
- Experimental staff have at their disposal auxiliary premises within the leaktight containment above each of the organic liquid circuits and also an automatic data processing room alongside the control room.

The automatic measurement-processing system enables experiments to be carried out on the 5 circuits simultaneously. The experimental measurements can, for example, be programmed beforehand and extracted and recorded as required; the programme can be modified if the course of the experiment warrants it; the data can be filed or passed through an analog output or placed in the archives. The rate of measurement is about 50 per second.

The reactor can be regulated by means of the thermal power, but this method requires the use of the neutron flux value, since the thermal time constants of the circuits may be high.

Automatic reactor start-up has been provided for.

## 8 — Conclusions

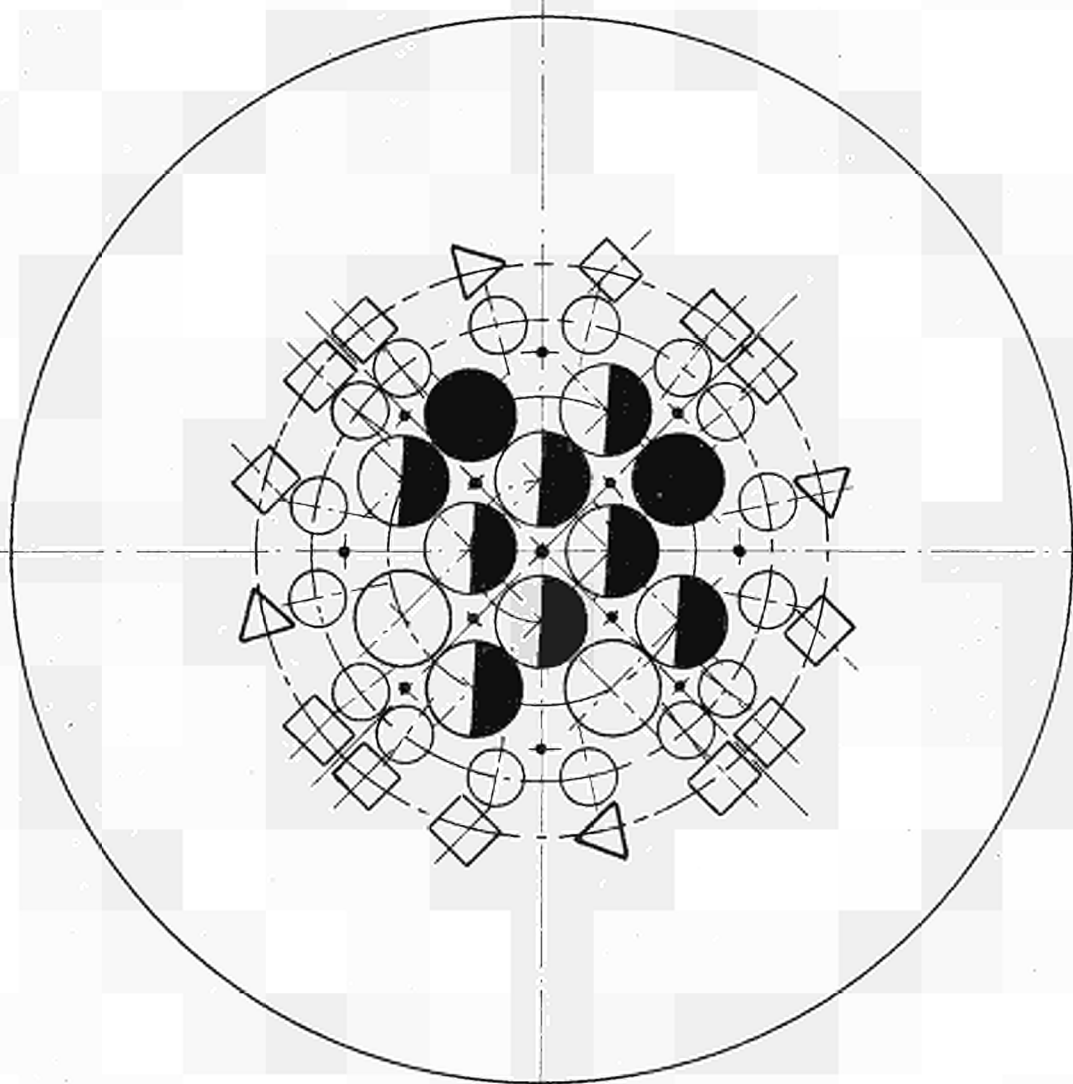
Of the factors having an influence on the quality of the results which we are likely to obtain from the ESSOR experiment, special mention should be made of the following :

- The ease with which various experiments can be carried out, which at the same time allows the fundamental parameters to be accurately determined in each case.
- Knowledge and monitoring of the operational parameters during an experiment.
- The possibility of making maximum use of the information obtained and particularly that concerned with irradiation.

The ESSOR Reactor, as it is briefly described above, complies with these three requirements by virtue of :

- The highly flexible arrangement of the reactor and its different circuits.
- Its appropriate control and measurement-processing system.
- An assembly of devices particularly developed for the handling and observation of irradiated elements.

The very nature of its design should enable it to help in the successful completion of the studies relating to the ORGEL Program, and then, in a later stage, to contribute towards the development of heavy water moderated reactors and in which the coolant circulates in pressure tubes.

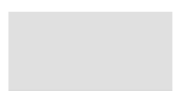


- 2 BS type D
- 2 BS type E
- ◐ 8 BM type E
- 16 Nourrices
- 12 Barres de contrôle
- ▽ 4 Barres de sécurité
- 13 Mesures de flux

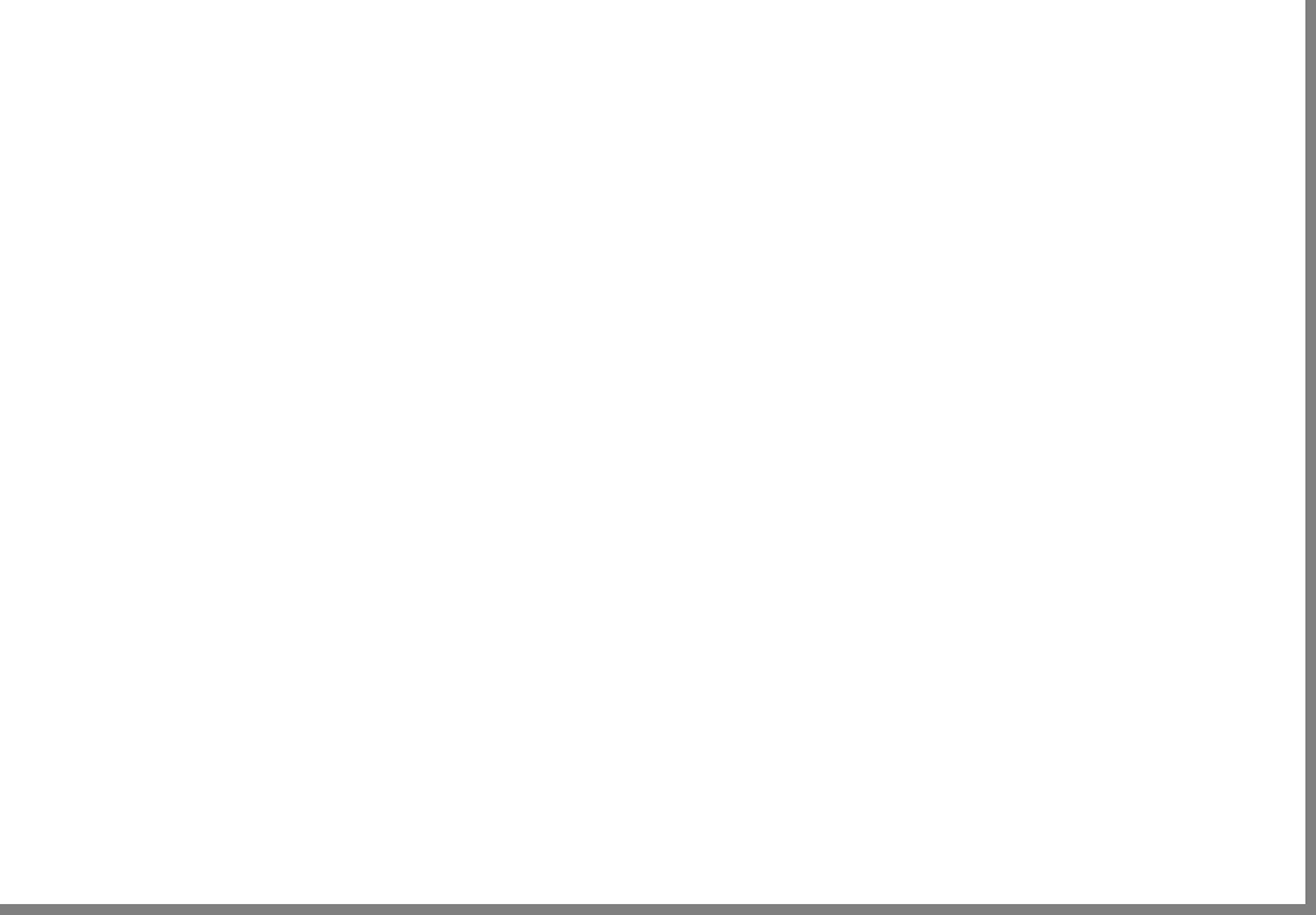
FIG 1

ECH : 1/20

REACTOR SCHEMATICAL  
CROSS-SECTION

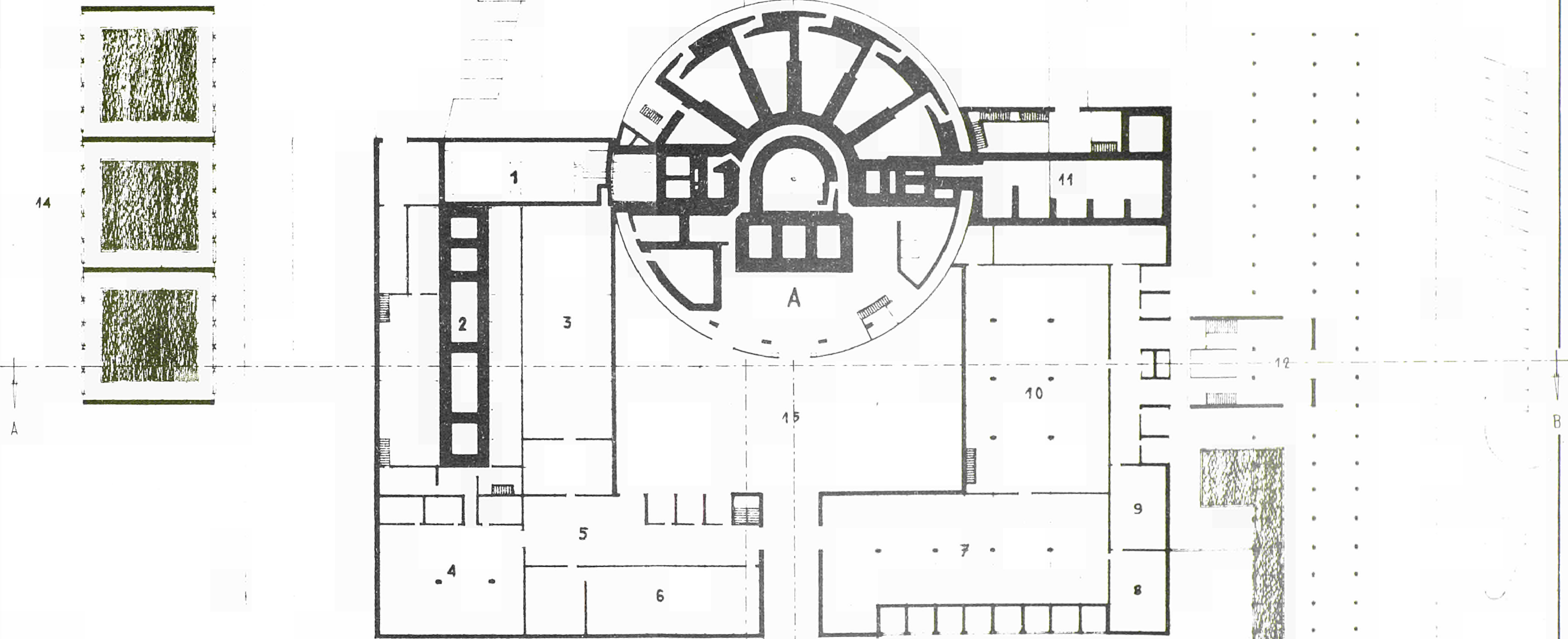








D ← → E



LEGENDE

- A BLOC PILE
- 1 PISCINE
- 2 DEMANTELEMENT DU COMBUST
- 3 MONTAGE DES BARRES MEUVES
- 4 MAGASIN
- 5 AIRE DE STOCKAGE
- 6 ATELIER MECANIQUE
- 7 EQUIPEMENTS ELECTRIQUES
- 8 BATTERIES
- 9 GROUPE SYNCHRONES
- 10 SALLE DE REPARTITION
- 11 DEMANTELEMENT DES TUBES DE FORCE
- 12 ENTREE PRINCIP: RENSEIGN: CONTROLE
- 13 REFRIGERANTS ORGANIQUES
- 14 REFRIGERANTS ATMOSPHERIQUES
- 15 COURS DE SERVICE
- 16 DIESELS
- 17 BASSINS INCENDIE

ECH 1/500

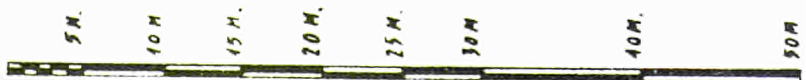
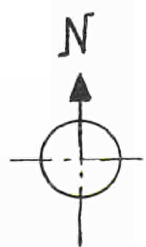


FIG: 3 ECH: 1/500

GENERAL VIEW  
OF BUILDING



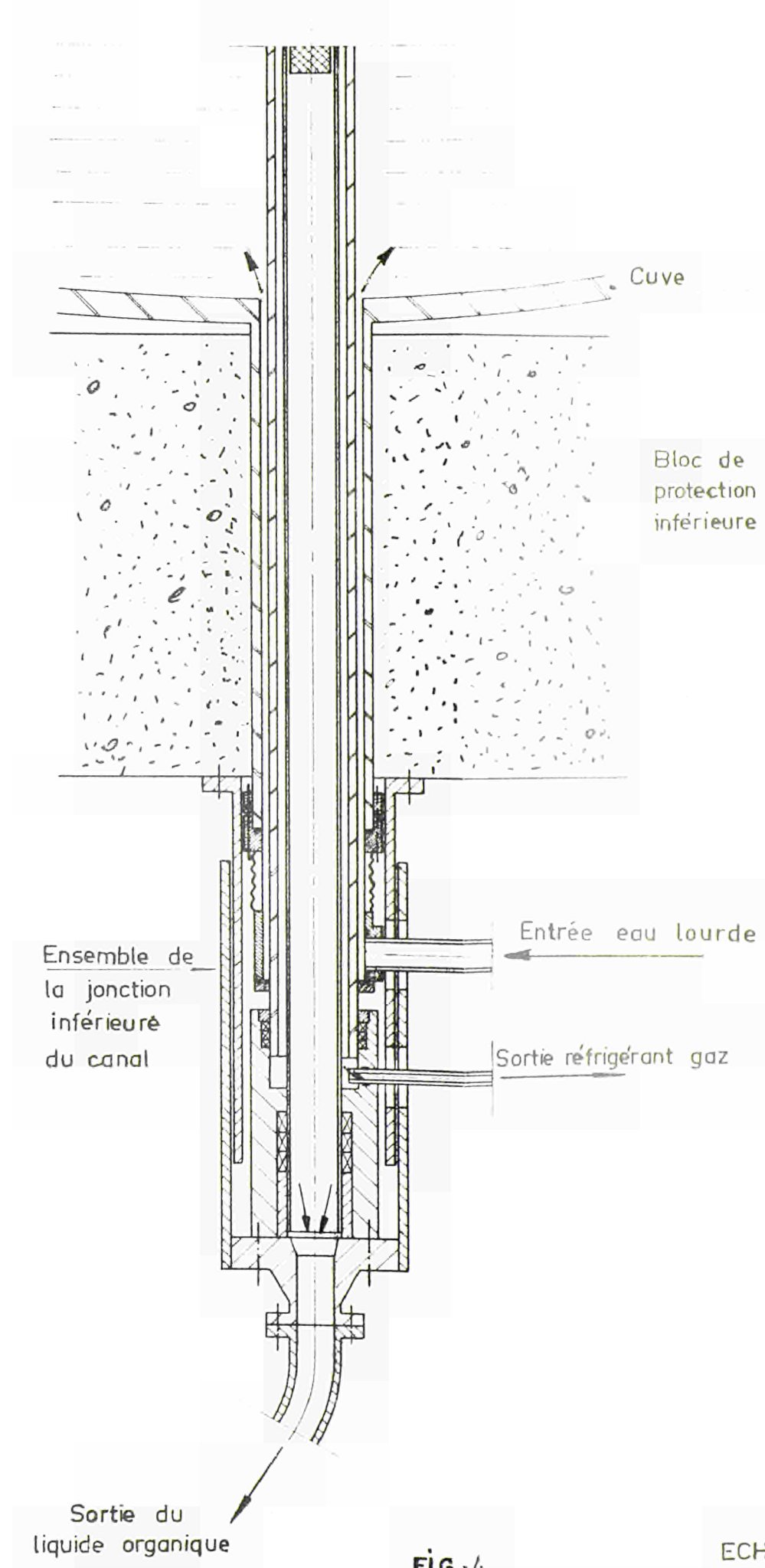
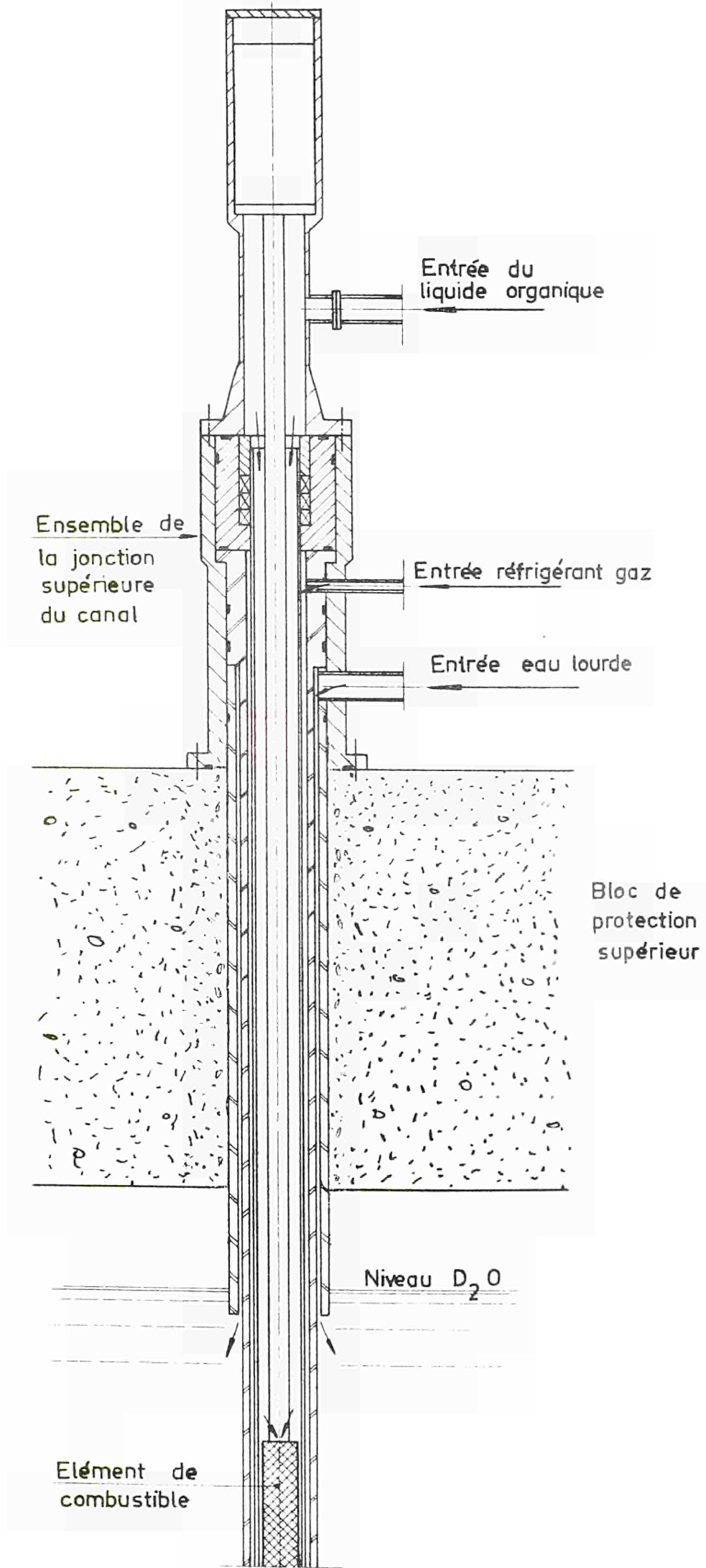
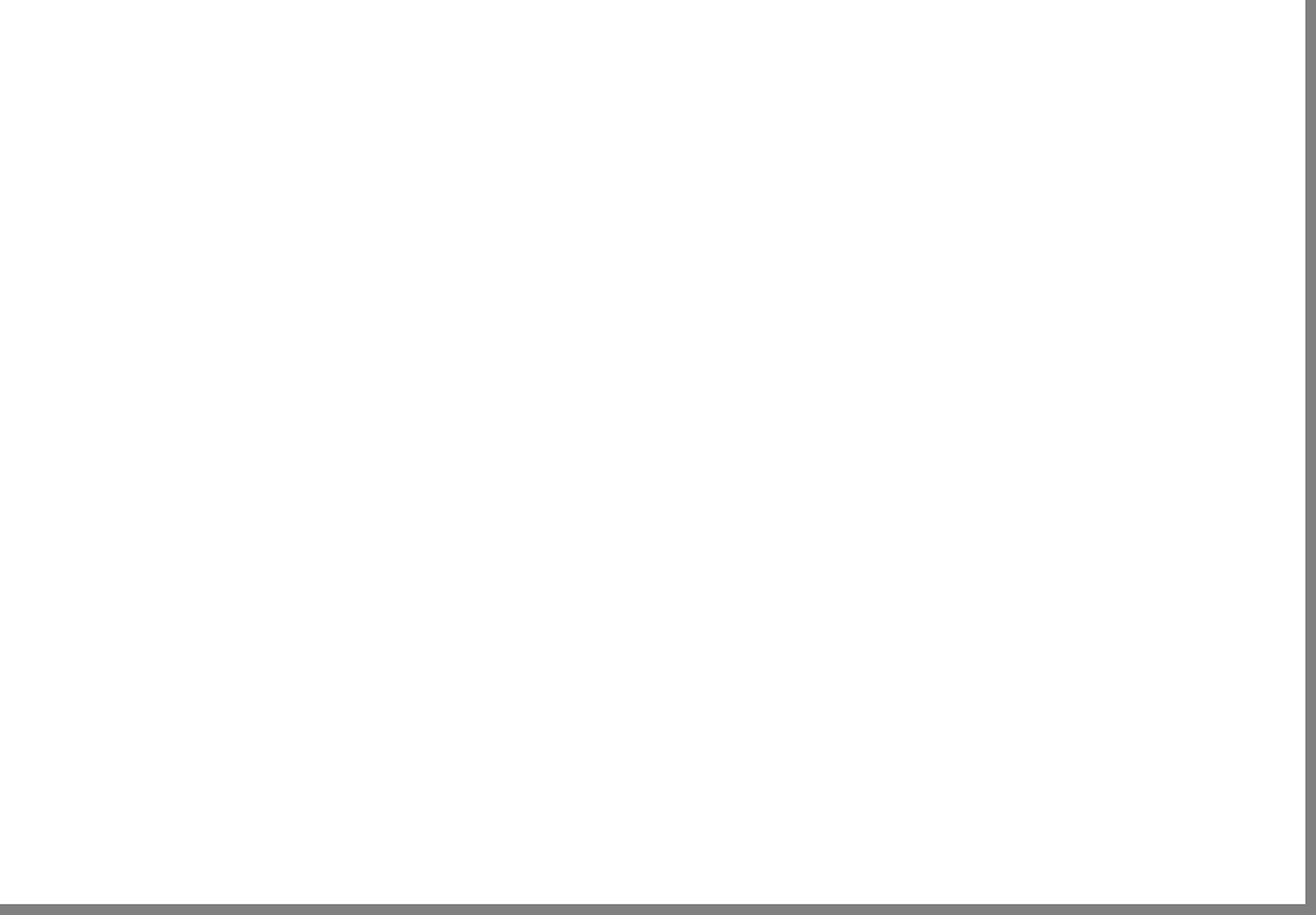


FIG:4 ECH 1/10

SCHMATIC OF FUEL CHANNEL



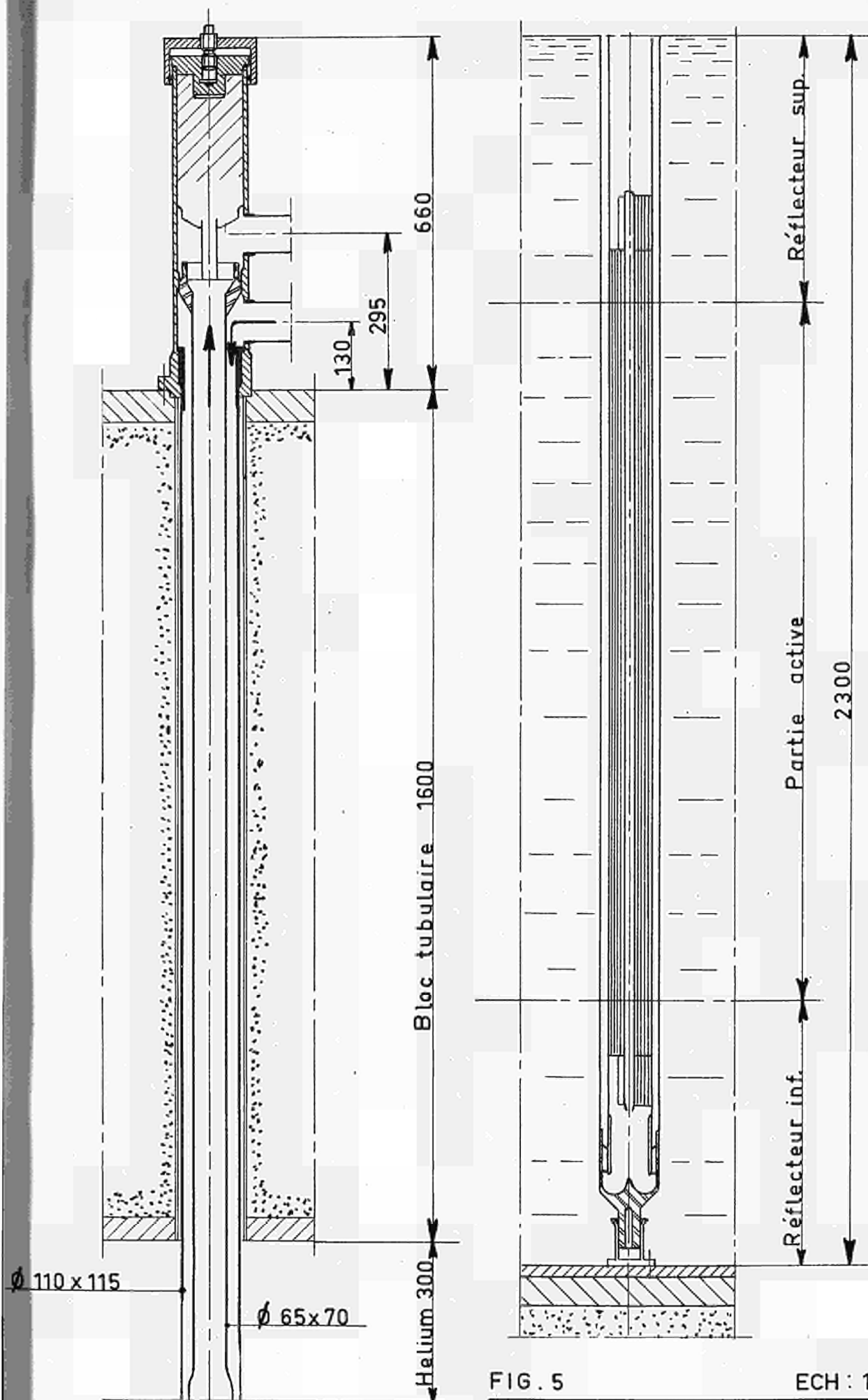


FIG. 5

ECH : 1/10

SCHMATIC OF FEEDING  
ZONE FUEL ELEMENT



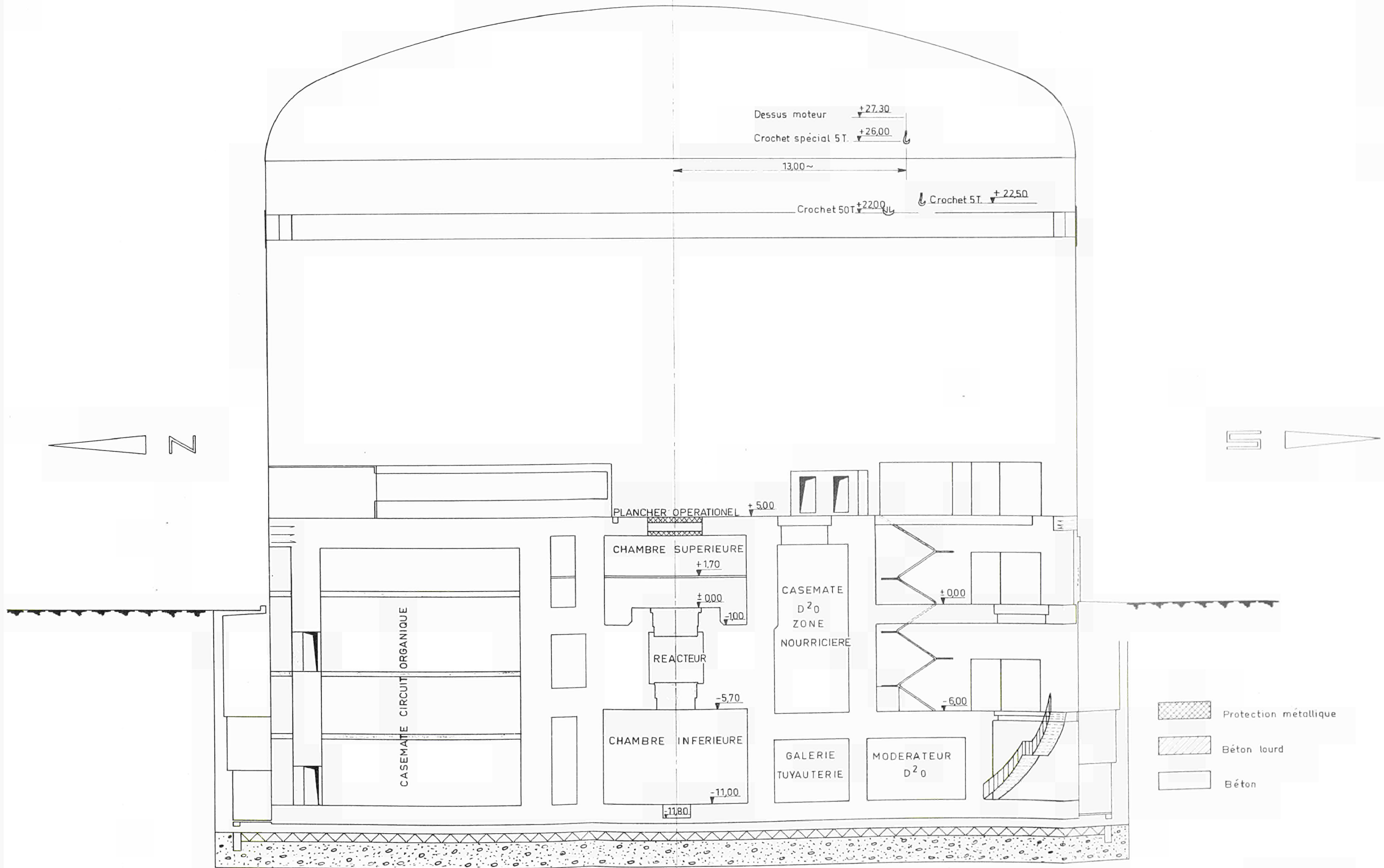
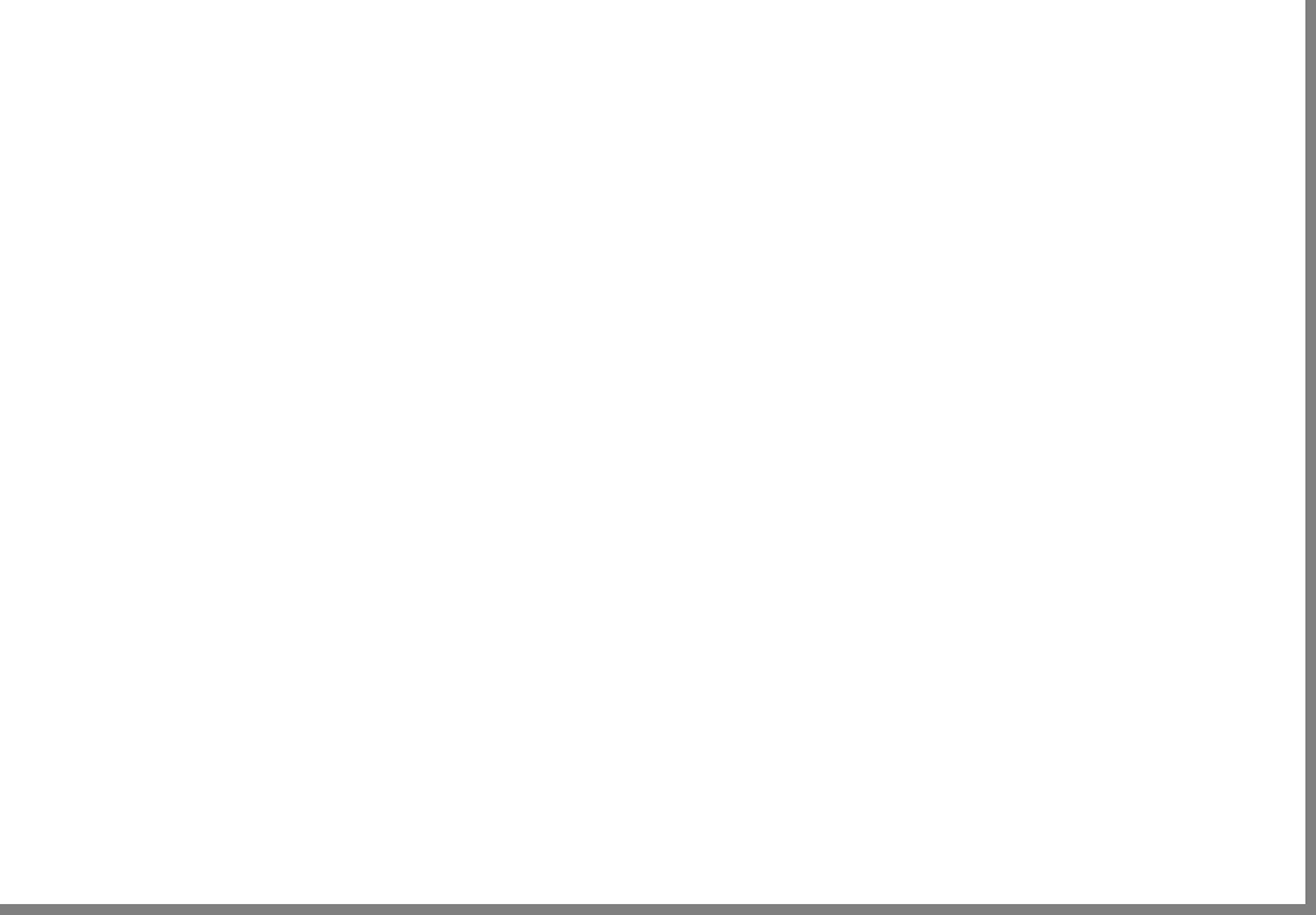


FIG. 6

ECH: 1/100

N-S CROSS SECTION THROUGH  
REACTOR CONTAINMENT





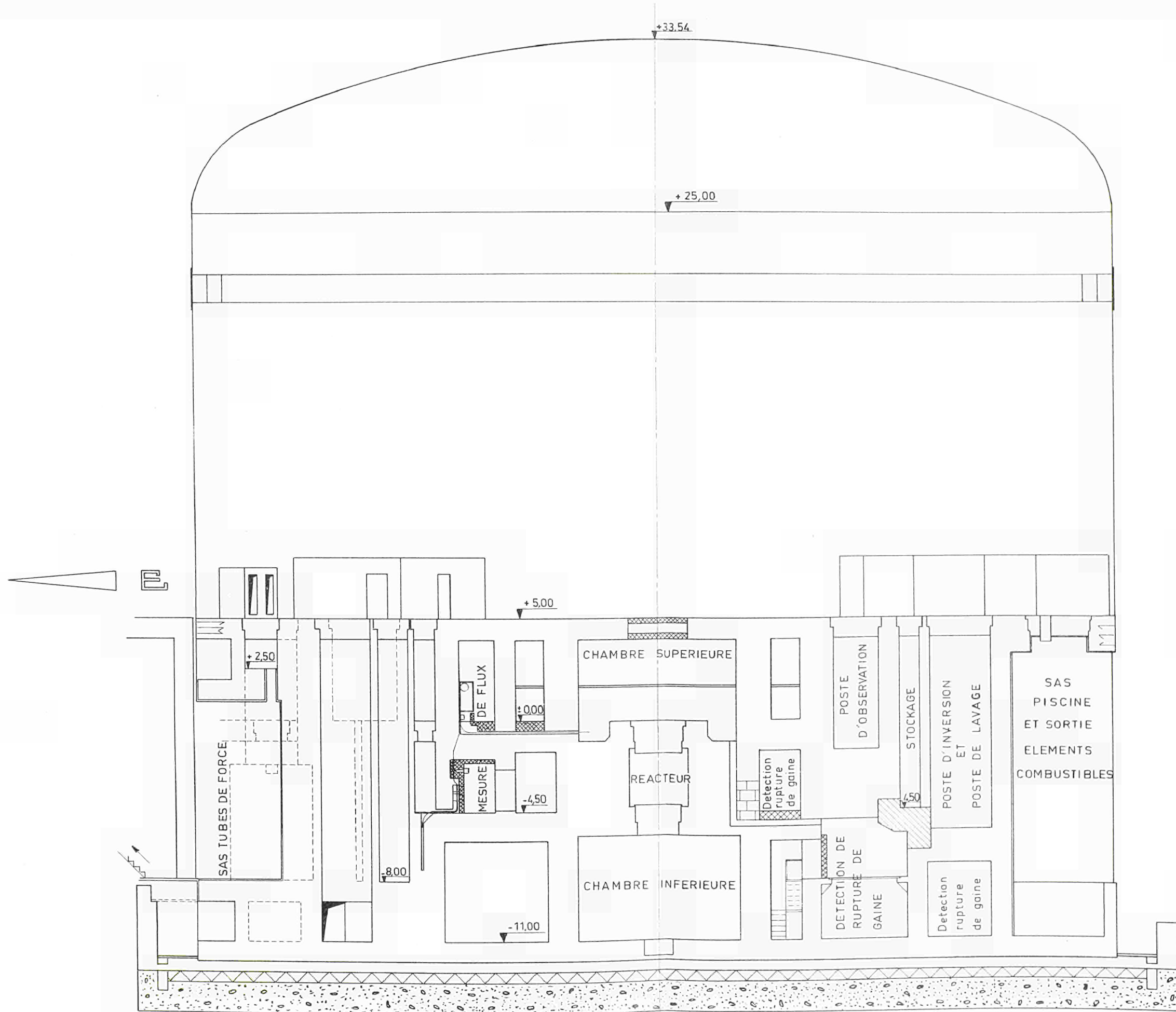


FIG. 7

ECH: 1/100

E-W CROSS SECTION THROUGH  
REACTOR CONTAINMENT



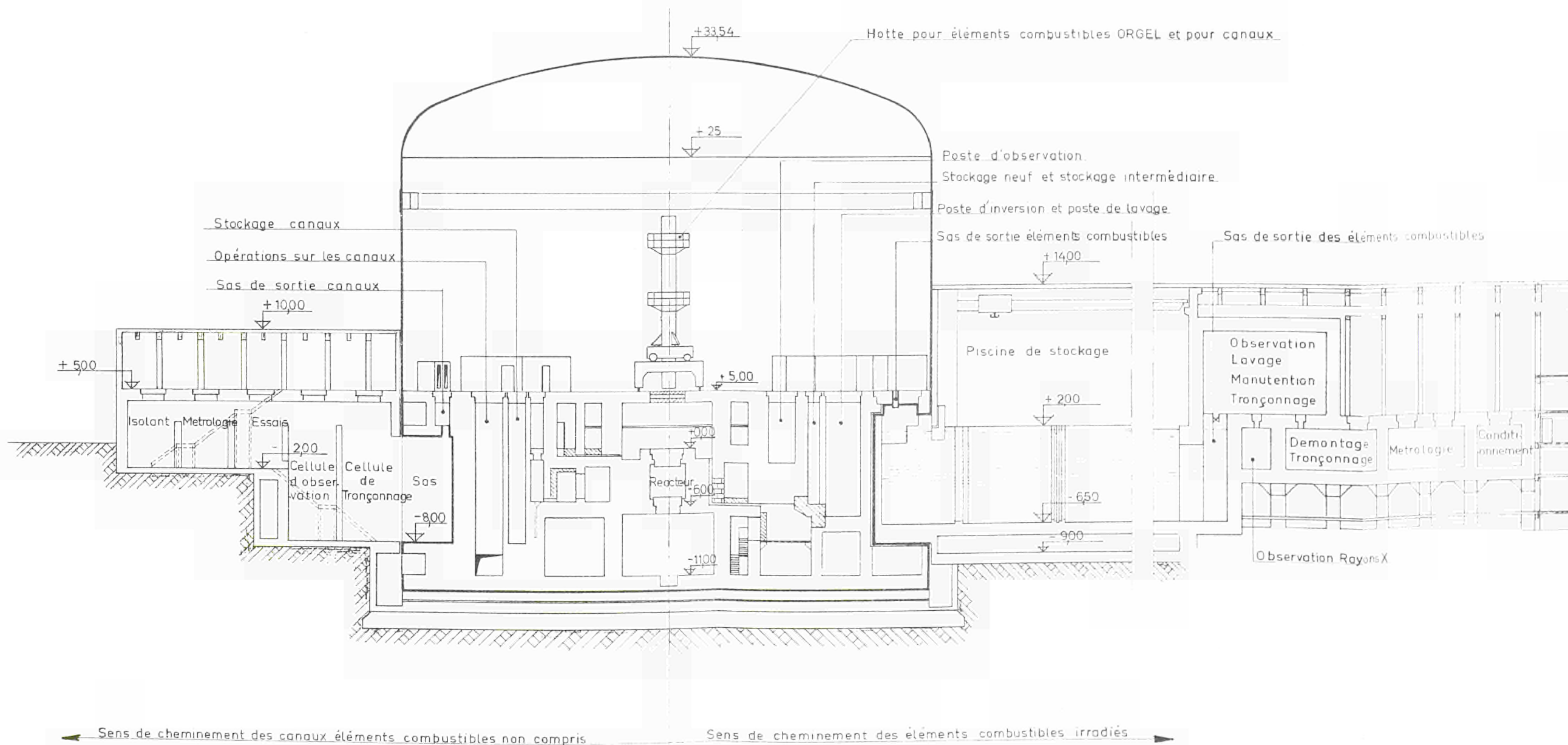


FIG : 8

ECH : 1 / 200

SCHEMATIC OF FUEL AND  
CHANNEL HANDLING



## CHAPTER IV — REACTOR PHYSICS

### 1 — ORGEL physics calculation methods

The reactor physics calculations are divided into the following parts :

#### 1.1 — Unirradiated lattice calculations

The calculations of the lattice parameters are performed by the CAROLINE I code. (\*)

This code is written in Fortran language for IBM 7090.

The method used to calculate the unirradiated lattice parameters has been established at Euratom as the basis of the French correlation on heavy water cooled and moderated lattices and tested on the results from recent Canadian and Euratom's critical experiments on natural uranium-organic cooled-heavy water moderated lattices.

Among the input data of Caroline I it is necessary to calculate some "spectral constants" to take into account the change of the spectrum due to the strong difference of temperature between the heavy water and the coolant.

The calculation of these "spectral constants" is performed by TERMIDOR (\*\*), a code written in Fortran language for IBM 7090. The assumption is made that the hardening of the spectrum due to the absorption in the fuel element and the heating effect due to the scattering interaction of the neutrons with the hot coolant, are independent from one another; on the basis of this assumption the evaluation of the latter effect is performed by superposing in the many thermal group model two pure Maxwellian terms at the physical temperatures of the moderator and coolant.

#### 1.2 — Xenon poisoning calculation

The calculation of the Xenon poisoning corresponding to equilibrium state is performed by the perturbation method.

An average factor G is defined which allows to reduce the calculation on the reactor to a calculation on a point. The curves of G as a function of the maximum flux of the reactor are plotted by assuming the following parameters :

$$\rho_0 = \frac{R_0}{R_1}; \rho_1 = \frac{R_1}{R_e}; h = \frac{H}{H_e}$$

---

(\*) G. Casini and al. "Caroline I, a calculation method for non irradiated organic liquid heavy water lattices" - Euratom Report EUR 134.e.

(\*\*) G. Rossi "Termidor, an IBM 7090 Fortran code to evaluate the thermal neutron spectrum in an ORGEL type fuel element" - Euratom Report EUR 105.e.

where :

$R_0$  = radius of flattened zone of the pile

$R_1$  = external radius of the pile

$R_e$  = extrapolated radius

$H$  = height of the pile

$H_e$  = extrapolated height of the pile

For the calculation of the Xenon poisoning the values of  $R_0$ ,  $R_1$ ,  $R_e$ ,  $H$ ,  $H_e$ , are established from a one-group calculation of the core.

### 1.3 — Effects of non-uniform structure materials on the reactor

The effects on the lattice balance of structure materials as joints between fuel elements in the channel, structures of the control system and so on, are evaluated by PDQ and CURE codes.

### 1.4 — Long term reactivity calculation and fuel cycle

The long term reactivity effects are calculated by a method established at Euratom.

The point reactivity curve is determined by using mainly the AECL proposed data for the fissions products, the Westcott factors for the spectrum effects.

The neutron temperature is calculated by means of a simplified model (\*) which evaluates separately by simple methods the heating effects of the coolant and the hardening due to the selective absorption of the fuel. A typical curve showing the dependence of the neutrons temperature on the coolant temperature is plotted in fig. 1.

Due to the fact that in our correlation for unirradiated lattices the  $p$  factor has no physical meaning, one cannot use this value to calculate the initial conversion factor. Therefore, we evaluate this factor by using the values suggested by Hellestrand to calculate the effective resonance integral.

The method established for point reactivity calculation is being tested on the experimental Canadian results for rods irradiated in NRX and oscillated in GLEEP.

The variation of the reactivity balance following the fuel cycle assumed in the design is calculated by the RLT2 code.

The method utilized in this code is based on the perturbation theory. The steady state conditions are supposed.

The following types of fuel cycles have been considered up to now in the code :

- Homogenized fuel model
- Single rod fuelling
- Two slug bidirectional fuelling
- Continuous bidirectional fuelling.

---

(\*) A. Kind, G. Rossi "A simplified model for the determination of the thermal neutron spectrum in a fuel element" - Euratom Report EUR 260.e.

This program will be compared in the next months with the more elaborated "fuel move" code (\*) to test the validity of the approximations done.

### *Critical size and control rod calculations*

Two group calculations to determine the critical size are performed by WANDA code.

After having fixed the total reactivity to be controlled, it was possible to determinate the number of control rods by means of the supercell method (infinite assembly, one energy group, homogenized core).

A more accurate calculation of the efficiency of the control rods was successively made by the equivalent poison method, using the programmes WANDA 4 (1 dimension, 2 groups, homogenized core) and PDQ for 2 dimensions. With the latter a certain fine structure can be considered. The extrapolation length for the thermal group at the rod surface has been found by the KUSHNERIUK method, while the one for fast neutrons has been taken as infinite.

## **2 — ORGEL dynamics**

The ORGEL dynamic behaviour is being studied in two ways :

- 1) a detailed core dynamics study with simplified plant by means of a relatively complex model; carried out by EURATOM'S Dynamics Group with the help of CETIS' analogue computers;
- 2) a plant dynamics study with the core only as a simplified point reactor, carried out by the German firm Siemens-Schuckertwerke, also with the help of CETIS' analogue computers and under EURATOM's supervision.

The reactor kinetics are described by the usual equations, where the main variable is the total reactor power supposed to be rigorously proportional to the neutron density. The number of delayed neutron groups is reduced to two by a least square method; influence of photoneutrons from D<sub>2</sub>O is included.

The reactivity feedback is represented by several temporally constant temperature coefficients times the temperature excesses of the corresponding materials over their steady state initial values. The neutron temperature is a linear combination of the D<sub>2</sub>O and the coolant temperature.

The materials involved are the fuel (UC), the can (SAP), and the coolant.

Heat losses through pressure tube are described by an overall heat transfer coefficient, whilst the moderator temperature is kept constant.

Since all temperatures and also their transient excesses are space dependent they must be averaged over the volume before introducing them in the kinetic equation by the squared neutron flux. (one group method).

---

(\*) N.B. McLeod and al. "The effect of fuel and poison management on nuclear power system" - NYO - 9715.

Nevertheless the spatial temperature distribution is considered in the heat transfer equations. For each material the thermal balance is established. The axial derivatives in the coolant's balance are replaced by finite difference quotients which force to introduce some inlet and outlet temperatures. In order to keep a sufficient fine structure, the channel length is thus subdivided into several zones, formerly 5, now 3. The zone inlet (or outlet) temperatures are proper averages of the mean temperatures of adjacent zones.

On account of the pyrolytic disintegration danger a uniform core outlet temperature for all channels is desirable. Thus the channel flow rates must be adjusted proportionally to the power developed. Provided the same geometry for all channels, the radial coolant speed distribution is proportional to the neutron flux distribution. Though a centrally flattened flux is assumed, the heat transfer coefficients then vary considerably in radial core direction.

The can and fuel temperature excesses are for this reason better described when introducing 2 (formerly 3) concentric shells of the core. Thus  $2 \times 3 = 6$  subvolumes exist, the heat transfer behaviour of which is described in parallel.

Special care has been devoted to a good description of the temperature-dependent thermal contact resistance between fuel and can, since this value is responsible for inherent reactor stability, the fuel temperature coefficient being practically the only negative one.

Normally, the system is not closed without describing back-reactions on the inlet temperature propagated through the primary circuit. But we simulate some kind of regulator which allows a control rod motor to drive as long as the coolant outlet temperature deviates from a reference temperature (400 °C). The characteristics of the regulator should be found out from the simulation itself. Then the original regulator can be coupled with the simulator. In this way each manual action on the reactivity is more or less rapidly counter-balanced by the regulator action and no power change follows.

It has been shown that mass flow changes are not desirable in order to change the reactor power. Thus the only remaining control method is to change the inlet temperature. If the secondary flow rate is decreased, an increase in the thermal resistance through heat exchanger results. Since the heat exchanger inlet temperature is constant its outlet temperature grows up which is just the desired effect for the core. Some advanced signal from the secondary plant can be foreseen for the shim rods, if necessary.

As long as the time behaviour of the core inlet temperature is not known from plant simulation, arbitrary variations of it are introduced in order to study the power and temperature development inside the core. The complete system consists of 22 differential plus 42 algebraic equations.

To 2) : The plant dynamics considers as main components : (point) core, heat exchanger, turbine with intermediate superheating, condenser, pumps, preheating of supply water; and in the primary circuit : moderator cooling, organic pressure control. All necessary control loops are simulated in such a way that a minimum number of true inputs exists. The heat exchanger type is a BENSON boiler without steam drum and shifting limits between economizer; evaporator, and superheater. A primary bypass loop is probably not necessary. Perturbations like power changes as well as accidental cases like ruptures etc. shall be studied.

This work is done under contract by the German firm SIEMENS-SCHUCKERTWERKE AG. and will pass into the Ispra analogue machine in July and August 1962.

After having exercised these two problems, which each one requires the whole analogue facility of two PACE computers, it is intended to couple the systems. Then 3 computers will be available, but the description of both parts must be simplified. The purpose is to examine such accidents like primary pump failures (with flow rate changes) which influence markedly the temperature field inside the core.



From the theoretical standpoint there is a severe drawback of the model insofar as the core heat transfer can be described spatio-temporally (repartition into subvolumes), but not the neutronics. The usual kinetic equations are the temporal part of separated solutions of the partial differential equation for neutron diffusion. Thus no spatial distortions of the neutron flux or the power distribution can be taken in account.

Of course, such distortions exist as well already for the steady initial state due to rod insertions and the temperature field as for the transients due to shim rod movements and new temperature excesses.

As a basic study it is thus intended to abandon the known kinetic equations and to treat a time spatio-temporal dynamics starting from the neutron diffusion equation itself. The complication is considerable because the problem is an initial value problem for the time but a boundary value problem in space. The number of space coordinates to be considered as well of neutron energy groups in the diffusion equation is a question of digital machine capacity. The calculation must be started from zero power where the neutron flux is not yet distorted by temperature reasons.

Studies on self stability of ESSOR have been carried out essentially by the Groupement Atomique Alsacienne Atlantique (GAAA - France) and Interatom (Germany) and have also been calculated on CETIS' computers at Ispra, while the design was still in evolution, and the stability appeared to be sufficient, due to temperature coefficients alone.

Now, a detailed mathematical model has been worked out by Groupement Atomique Alsacienne Atlantique and Interatom, taking into account the different control devices and test-loops regulation, with special attention to the interference of loop regulations on the kinetics of the reactor, and its control.

The model was initially represented by a set of 95 equations. Due to the limited capacity of the computers available at Ispra (two PACE 231 R, i.e. 200 amplifiers), the problem has been simplified to 80 equations. This ultimate problem is now undergoing preliminary tests on computer, and results should be available later.

### 3 — Aquilon II. Critical experiments

A set of experiments was carried out during the months of June and July 1961, on the Aquilon II heavy water, natural uranium research reactor at Saclay, France (\*).

The object of these experiments was to determine the material buckling of natural uranium oxide lattices, moderated by heavy water and cooled by organic liquid of ORGEL type.

The measurements were performed, using the method of progressive substitution developed by R. Naudet and co-worker at Saclay, on the Aquilon II reactor in the form of a contract with the French Atomic Energy Commission.

The ORGEL elements were made up of a cluster of 19 rods of clad natural uranium oxide, submerged in organic liquid and held in an hexagonal tube (fig. 2).

---

(\*) G. Casini, C. Foggi, F. Toselli "Critical experiments on natural uranium oxide, organic cooled, heavy water lattices" - Euratom Report EUR 114.e.

The characteristics of the three ORGEL element types used for the measurements are the following :

Type	AO 120	AO 121	AO 161
Fuel rod diameter (mm)	12	12	16.2
Uranium oxide density (g/cm <sup>3</sup> )	10.15	10.15	9.85
Can inside diameter (mm)	13	13	17
Can thickness (mm)	1	1	1
Can material	Mg	Mg	Al
Magnesium density (g/cm <sup>3</sup> )	1.74	1.74	
Aluminium tube and can density (g/cm <sup>3</sup> )	2.70	2.70	2.70
Volume organic liquid cm <sup>3</sup> /cm	12.33	12.33	17.43
Equivalent inside tube diameter (mm)	76.50	76.50	95.38
Tube thickness (mm)	1.2	1.2	1.0
Center-to-center distance between rods (mm)	15	16	20

The organic liquid used was monoisopropylidiphenyl having the empirical formula C<sub>15</sub>H<sub>16</sub> with a density at 20 °C of 0.973 g/cm<sup>3</sup> (4.78 10<sup>22</sup> hydrogen atoms per cm<sup>3</sup>).

A chemical analysis carried out on an aluminium sample piece taken from a tube showed the presence of the following impurities (% by weight) :

Cu	< 0.01
Mg	< 0.01
Mn	< 0.01
Si	= 0.18
Fe	= 0.22
Zn	< 0.01
Ti	= 0.006

The buckling results B<sup>2</sup> and the corresponding uncertainties (B<sup>2</sup>, shown in table 1, relate to a heavy water purity of 99.8 % and to a measurement temperature of 20 °C.

Table I

Element	AO 120 (Mg)			AO 121 (Mg)			AO 161 (Al)		
	19	21	24	19	21	24	19	21	24
Pitch (cm)									
B <sup>2</sup> (m <sup>-2</sup> )	5.97	3.59	3.19	4.12	3.83	3.43	2.91	3.39	3.71
B <sup>2</sup> (m <sup>-2</sup> ) ±	0.125	0.15	0.13	0.12	0.14	0.12	0.14	0.15	0.12

The comparison between the experimental buckling results and those calculated by the CAROLINE I method is shown in Fig. 3, 4, 5.

## 4 — ORGEL experimental physics program

Measurements of the effective resonance capture integral and of the fine structure of the flux in ORGEL type fuel elements will be performed by the Neutron Physics Service, C.C.R. Euratom, Ispra, Italy, within the framework of the experimental program related to ORGEL lattice physics.

### 4.1 — Effective resonance capture integral

The fuel element investigated is of the ECO type, and consists of an hexagonal array of 19 natural uranium metal rods, 1.2 mm dia., contained in an aluminium tube filled with organic liquid. Two geometries (corresponding to rod spacings of zero and 1 mm., respectively) and two organic liquids (diphyl and monoisopropyldiphenyl) will be tested.

The measurement will be performed by the activation technique, using gold as the standard. The irradiation facility selected is the Ispra-I reactor at the Euratom Center of Ispra (a 5 MW, 90 % enriched uranium, CP-5 type reactor). Experimental work should start during the second semester 1962.

### 4.2 — Fine structure measurement

The fuel elements investigated are :

- A. Natural uranium metal rods, 44 mm dia., contained in cylindrical aluminum tubes filled with organic. The thickness of the organic layer in the element is 3 and 5 mm, respectively. Organic liquids employed will be diphyl and monoisopropyldiphenyl.

These experiments have been carried out in the Aquilon II reactor at Saclay.

- B. ECO elements, with the same geometries and organic liquids as above.

The measurement will be performed by activation of dysprosium detectors placed in the fuel and in the organic. The irradiation will be carried out in the Aquilon II facility, CEN, Saclay, France (a natural uranium, heavy-water moderated critical assembly), replacing the central portion of the reference lattice with the lattice under consideration. Experimental work should start during the second semester 1962.

## 5 — ORGEL critical experiment (ECO)

ECO is a critical experiment conceived especially for buckling measurements by substitution method.

Its purpose is essentially the study of heavy water moderated and organic cooled lattices, the fuel is metallic uranium, uranium oxide or carbide.

Anyhow, according to the Commission's wishes, ECO may be used for buckling measurements on lattices using cooling fluids other than organic liquids.

Schematically ECO consists of an aluminium tank which can hold 20 t of heavy water and which lays on a 90 cm thick lower graphite reflector. Radially the tank is surrounded by a thermal insulator and a 90 cm reflector. The upper end of the fuel elements plunged in heavy water, hang

on an automatic mechanism which allows a continual pitch variation of the lattice between 170 and 300 mm. The assembly is closed in a light concrete biological shielding having 1,70 m thickness; this allows experiments up to 1 KW power.

The ECO control is performed by the heavy water level adjustment (by means of pumps of different speeds and by means of a set of dosing vessels), as well as by a set of two vertical regulating plates sliding between the tank and the reflector and two horizontal regulating plates circulating in the lower reflector under the reactor tank.

ECO is an extremely flexible working instrument and it includes a large number of facilities allowing numerous physical experiments both inside and outside the reactor.

Besides the automatic lattice pitch drive we mentioned before, there is the possibility of using the reactor as a bare pile by means of the introduction of a boron skirt between tank and side reflector. The temperature coefficient measurements are made easier by the possibility of adjusting in a continuous way the moderator temperature between 10 and 80 °C, whilst the coolant temperature of the 25 central fuel elements, forming the substitution lattice, may be controlled between a low value corresponding to the moderators temperature and a high value of approximately 300 °C.

A swinging channel being able to move inside the reactor between the lattice fuel elements allows the extraction of a neutron beam from the center of the reactor; this is intended for spectrum measurements by the time-of-flight-method.

An accelerator moving under the reactor shielding can send its beam on a target placed in the mid of the reactor.

A 10 m long axial channel crossing the reactor axially from bottom to top allows the oscillation of two fuel elements linked end to end.

In order to compare the irradiated or synthetic fuel to the unirradiated fuel a large number of experimental accessories is presently being studied to allow the physicist to obtain as much information as possible from this critical experiment; let us mention for instance the facilities allowing the periodical variation of organic liquid apparent density in the clusters and allowing oscillation of certain cluster elements, some pre-set automatic counting units, a generalized set for the processing of critical experiments data, some samples oscillators for cross section measurements, a source jerk facility for pulsed studies, a semi-hot cell for dismantling the lightly or moderately irradiated fuel elements, some sets of miniature drills and of activable detectors allowing flux mapping by different methods, a controlled poisoning circuit and so on...

## **Progress Report**

The building was studied by the Architecture Office of the Ispra - JRC and an Italian firm COGECO is in charge of its realization. The contract has been signed on the 8th May 1962, but works already started in March and the foundations are now achieved.

At this moment the underfoundations of the real reactor bloc are being built.

Neeratom, an atomic group of nine Dutch firms has been charged by a contract signed on December 15th, 1961 of the reactor engineering, the preliminary design of which had been executed at the Reactor Physics Department. The construction of the reactor itself will start practically against the end of May 1962.

Buildings should be achieved at the end of 1962 and the reactor circuits will be in a position to work with light water against May 1963, whilst the official divergence would take place at the 1st of July, 1963.

Nearby the ECO building, another building is simultaneously being constructed; it will contain laboratories for the groups assuring ECO operation and maintenance.

A first set of fuel elements constituting the reference lattice, (clusters of 19 uranium metal pencils) is presently being manufactured by the firm NUKEM (Germany) and will be delivered to Ispra at intervals of time beginning on the 1st of July, 1962.

The reflector's rough graphite is delivered by S.A. Pechiney (France) and its nuclear control is made by the French CEA. The machining and the creation of the reflector is made by S.A. Savoie Acheson (France).

The Reactor Physics Department is now studying the transport and handling problems of the heavy water which will be supplied by the USAEC for the critical experiment and the Brussel's Free University is presently performing an hydraulic test on a full size mock-up in order to study the influence of the hydraulic circuits of the reactor on the thermal homogeneity and moderator disturbance.

The oscillation mechanism of fuel elements in the axial channel works already as a reduced scale mock-up; the accelerator, a 1 Mev Van de Graaf, has been ordered to the High voltage Corporation and should be delivered at Ispra at the end of 1962.

The remaining accessories are presently being studied or realized.

## 6 — ESSOR physics calculations

The work made for the ESSOR reactor may be divided into two parts.

In the first part we performed the neutronic study of a variant of the reactor. Namely, we studied a reactor in which the ORGEL channels were arranged on a circular ring and inside there were the feeding fuel elements; therefore an arrangement exactly opposite to the primitive one. The aim of this change was to reduce the power produced in the feeding zone and to increase the uniformity of the irradiation of the ORGEL channels. The main results of this study are reported in "Dossier de comparaison ESSOR" written by G.A.A. (France) and INTERATOM (Germany) in order to compare the two variants.

In the second part we studied the way of flattening the axial distribution of the neutron thermal flux in the ORGEL fuel elements in order to satisfy the following condition : the difference between the flux values at the centre and each extremity of a portion of fuel element 700 mm long cut into halves by the horizontal plane of symmetry of the core, must be smaller than 10 %.

The calculations made by us showed that the use of feeding elements with a central zone without uranium is an effective way of flattening.



VII.  
T<sub>n</sub>  
(°C)

Fig. 1

Neutron effective temperature in an  
Orgel type fuel element

300

200

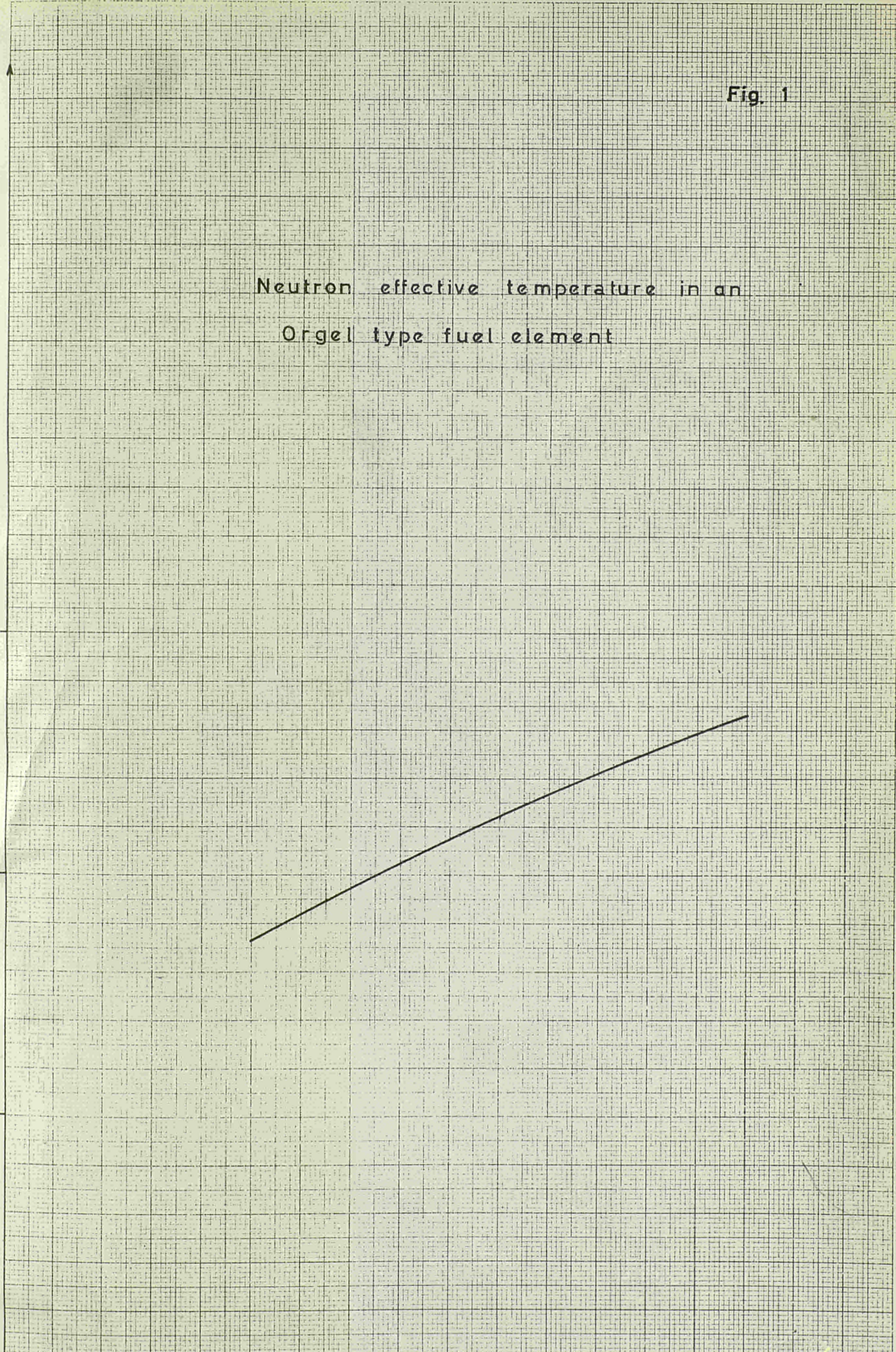
100

200

300

400

T<sub>c</sub> (°C)







AQUILON II CRITICAL EXPERIMENTS

ORGEL FUEL TYPE ELEMENT

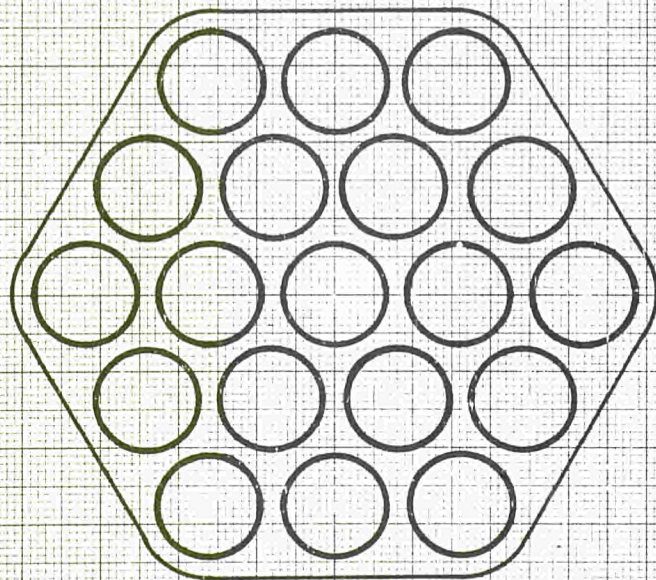


Fig. 2



$B^2$  [ $\pi^2$ ]

5

4

3

2

17

18

19

20

21

22

23

24

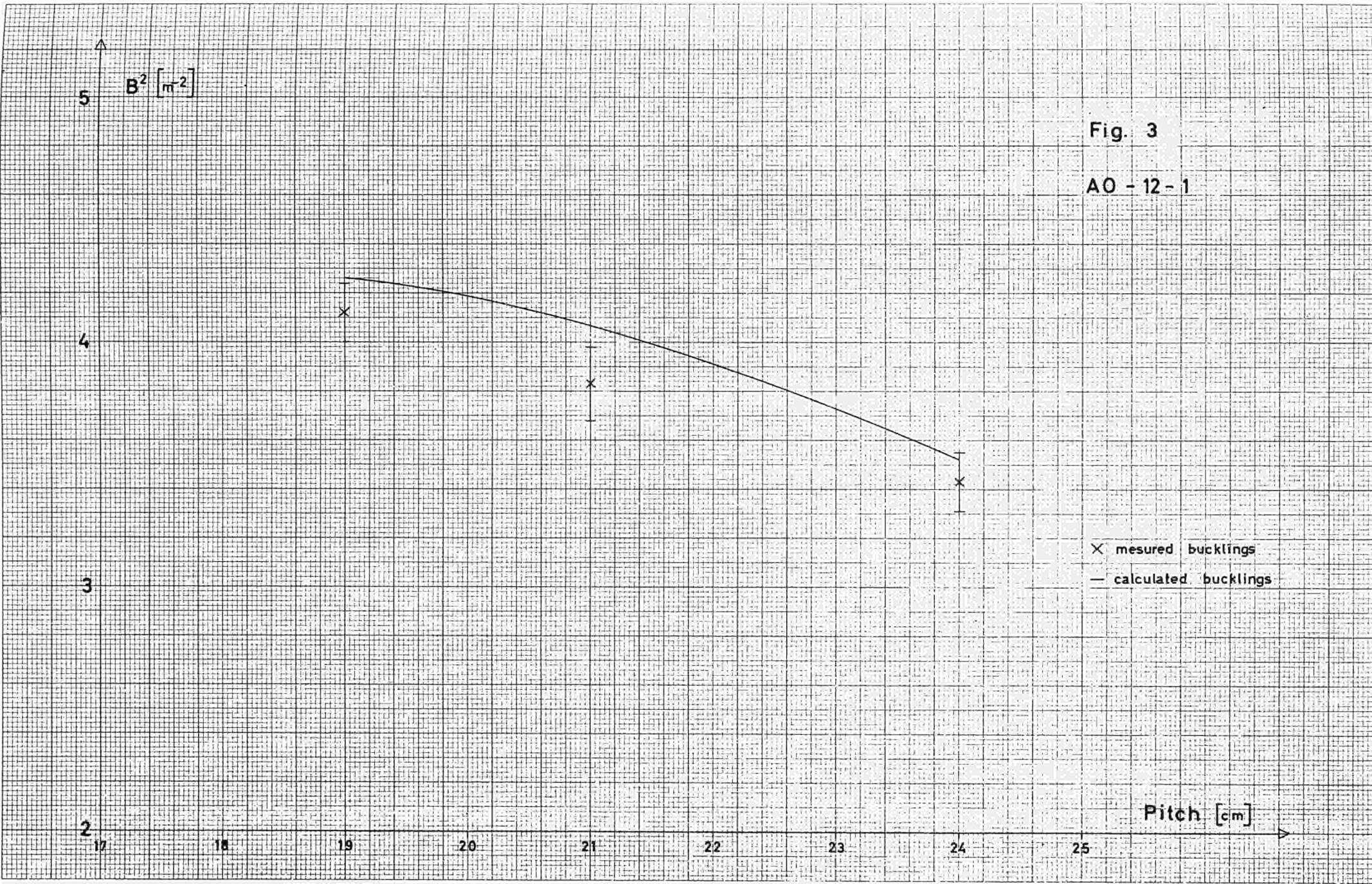
25

Fig. 3

AO - 12 - 1

× measured bucklings  
— calculated bucklings

Pitch [cm]





5  $B^2$  [ $m^{-2}$ ]

4

3

2

18

19

20

21

22

23

24

25

Fig. 4

AO-12-0

× measured bucklings  
— calculated bucklings

Pitch [cm]

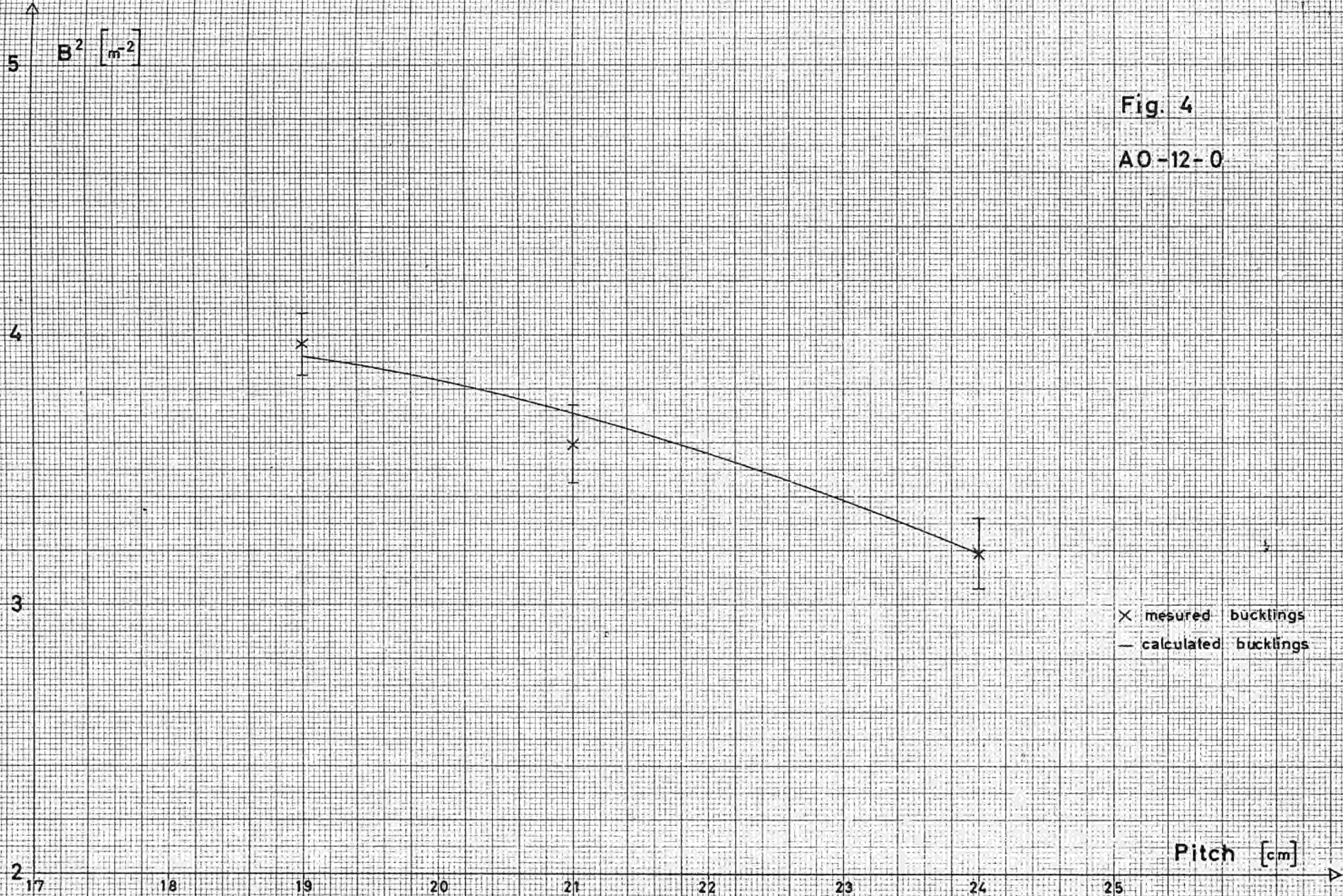
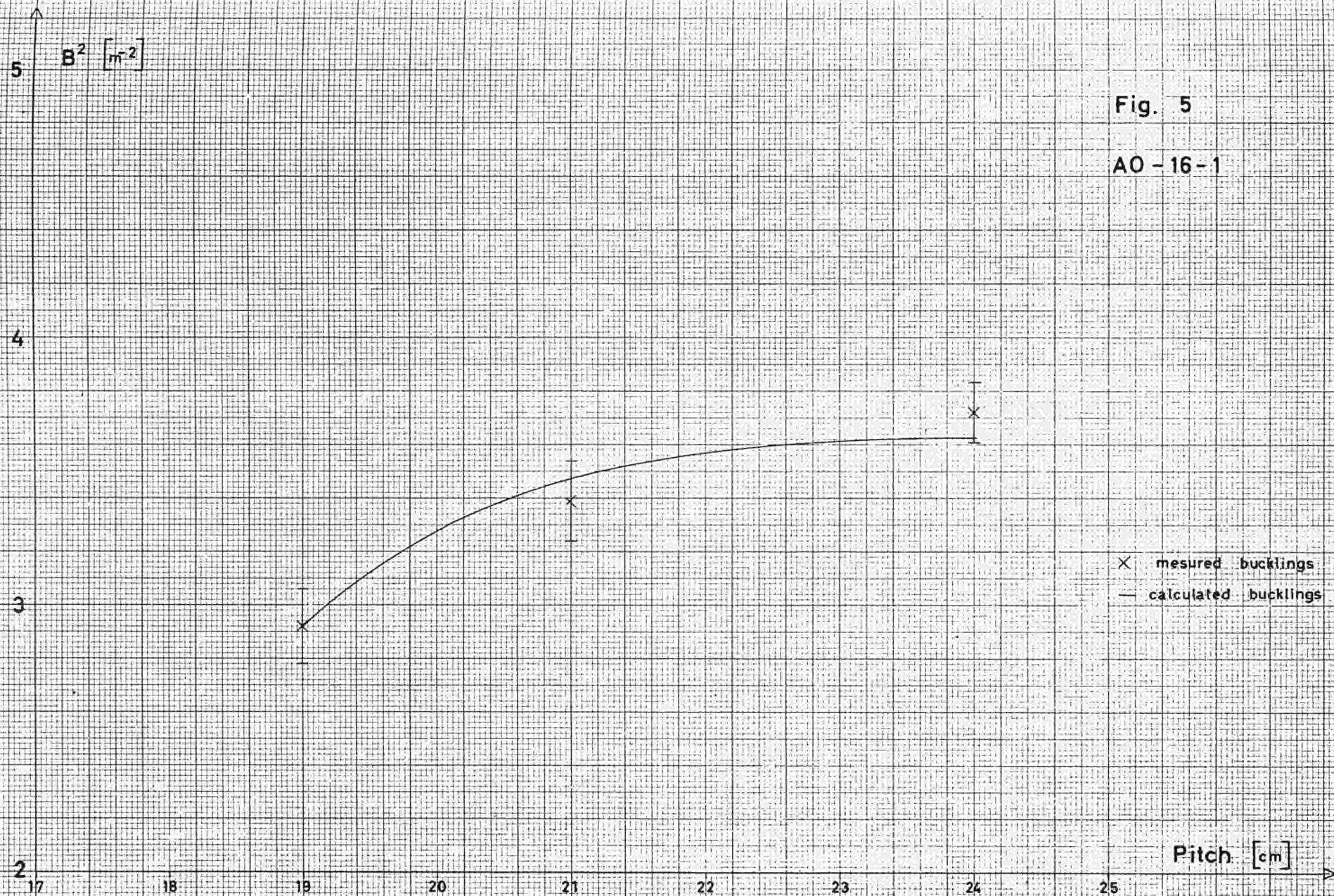




Fig. 5

A0 - 16 - 1

× mesured bucklings  
— calculated bucklings







## CHAPTER V — TECHNOLOGY

### 1 — Introduction

The research program related to technology of ORGEL type reactors is under development. Some programs have been readapted on the basis of preliminary results and new problems arising from further studies of conceptual design.

This paper is mainly a survey to show what lines are followed in carrying out the investigations and the partial results obtained. The most significant results concern the elaboration and construction of the experimental set-up foreseen for each assignment.

### 2 — Channel Connections

The problem of the connections of channel tubes to the primary circuit and the reactor vessel have been tackled analytically.

A distinction was made between cold aluminium or zircaloy to stainless steel, hot SAP to steel and junctions using gaskets. The main effort was concentrated on the two last points.

#### 2.1 — Hot SAP to steel connection

The requirements of a SAP steel junction are related to the leaktightness to be achieved under design temperature and the fatigue resistance implied by temperature and pressure variations.

For the experimental investigation a gas loop has been built in which these connections are tested under conditions of thermal and pressure cycling. The thermal cycling is obtained by regulating the power of an internal heating element and the cold gas circulation inside the test section. The pressure cycling is obtained by switching alternatively two tanks at different pressures on the test section. Series of tests are carried out on various connection designs which differ either in the material and the thicknesses involved or in the machining of the steel surfaces in contact with SAP or in the connecting systems.

The results of a particular test considered satisfactory for a sandwich type rolled joint of following dimensions :

Stainless steel tube (304 AISI)	Ø 96 - 102 mm
SAP-AIAG 14 % oxide	Ø 90 - 96 mm
Stainless steel ring (304 AISI)	Ø 84 - 90 mm

are :

Cold tests : Leak detection with helium gas spectrograph showed no leakage

Axial load test : 5 900 kg pull-out strength

Hot tests performed in the gas loop (see photo No. 1) :

45 temperature cycles between 250 °C and 400 °C

1,8.10<sup>6</sup> pressure cycles at 400 °C between 19,5 kg/cm<sup>2</sup>  
and 17 kg/cm<sup>2</sup>

1.10<sup>6</sup> pressure cycles at 20 °C between 19,5 kg/cm<sup>2</sup>  
and 17 kg/cm<sup>2</sup>

No leakages have been measured during all the tests with a special rig using a calibrated glass capillary for volumetric measurements of the leaks. This result will be checked further with a helium mass spectrograph leak detector.

Tests with a hydraulic mandrel have been done as a tentative to avoid the problems of torque and the necessity of a rigid external support during rolling. This mandrel deforms the tubes by hydraulic pressure, transmitted through a copper membrane. Tests on this type of connecting system are in development.

A new approach to the problem of connections of SAP to steel tubes is a technique studied under contract by TNO (Holland), involving the detonation of explosive charges inside the tube assembly. The resulting shock waves create an instantaneous high pressure and temperature condition which can lead to metallurgical bonds.

Preliminary tests performed with SAP on aluminium and SAP on SAP using this technique are very satisfactory (photo No. 2 and 3). The welding of SAP on stainless steel and aluminium on stainless steel present a rather brittle interlayer (900 Vickers hardness) (photo No. 4). A recent test on a connection of Al tube plated before with a layer of copper (12/u thick), and stainless steel tube gives an interlayer of 415 Vickers hardness and a pull-out strength of 4 000 kgs on a diameter of the inner tube of 60 mm. This result looks promising.

In order to simplify the problem of connections, a research has been launched to form SAP tubes, with a reduction or increase of diameter. Increase of diameter with the ordinary system of mandrel with rolls is limited to values quite smaller than the elongation at rupture of cold SAP.

An important variation in diameter can be obtained by explosive forming as shown by the studies made at TNO, Delft (Holland). A tube of SAP AIAG 14 % Al<sub>2</sub>O<sub>3</sub>, Ø 90/96 mm has reached successfully a reduction of 20 % in diameter (photo No. 5). In order to avoid ripples on the tube it was found out that it was helpful to provide vacuum between the tube and the inner mandrel.

## 2.2 — Junction using gaskets

Systematic tests on gaskets at pressure and temperature corresponding to normal operating conditions with the real medium or helium gas will be performed.

The sealings on which tests will be performed are :

Metalflex gaskets, K-seals, Flat gaskets, Conoseals, Bar-X-seals.

Influence of following parameters will be measured :

inner pressure, temperature, bolt forces, creep, surface finishing, bending and radial displacement of flanges, temperature and pressure cycling.

Testing apparatus :

An apparatus for high temperature tests with helium leak detection in which all the above mentioned parameters will be measured is already under test at T.N.O. Delft (Holland) (photo No. 6). Another apparatus has been constructed in order to compare the leakages of a gas and an organic liquid under the same physical and geometrical conditions (photo No. 7). Measurements of leakages of organic are performed by means of an ionisation chamber.

### 3 — Thermal Insulation of the Channel

#### 3.1 —

As far as the liquid insulation is concerned, the program has been centered on omitting the use of a thin liner tube by a special design of the fuel assemblies which would include at their periphery the device for limitation of the flow in the insulating space. Measurements of the flow rate versus the pressure drop in the insulant space have been done for different devices, with water. One of them (metallic O-ring, coated with silice tissue) looks promising. With a pressure drop of the order of 0,5 atm. for each ring, it is possible to obtain a  $N_{Re}$  (less than 80 in an annular space of 2 mm.

#### 3.2 —

The solid insulation test program has been defined. The basic design for the tests is a channel with liner tube and pressure tube axially connected and prestrained mechanically or thermally.

The program has been started with the construction of a first model (see Fig. 8) which has to be considered as a mechanical test apparatus for solid insulated channels.

In this apparatus the liner and pressure tubes are connected by a mechanical jack which allows free expansion of the liner tube or a variable amount of prestrain. This model will be used first for experimental stress analysis in static condition, and afterwards, will be submitted to thermal cycling and to a residual stress analysis. Special attention will be given to the behaviour of the insulating material (porous alumina, in the first tests) in operation. This model will operate in next July.

Two other models (one 30 cm long, the other 2 m long) including rolled joints are now under project. Some samples of the insulating material under development in private firms are now available (see photo No. 9). The characteristics of porous alumina made by Norton Company which will insulate the first model are the following :

— porosity	55 %
— radial compression resistance	200 kg/cm <sup>2</sup>
— tensile resistance (circumferential)	36 kg/cm <sup>2</sup>
— elasticity modulus	2 000 kg/mm <sup>2</sup>
— thermal expansion coefficient	$8.10^{-6} \text{ }^{\circ}\text{C}^{-1}$

It has been delivered in 6 mm thick tubes. Tests for obtaining thinner tubes have been undertaken.

CSF firm has delivered alumina tubes of 70 % of porosity, the conductivity of which is about  $6.10^{-3}$  W/°C cm, available in 6 mm and 3 mm thickness. The material is very homogeneous but rather friable and will probably give problems for full scale use.

Zirconia is under development at Desmarquest (Paris) : 5 mm thick tubes are available with a porosity of 50 % and thermal conductivity of about  $2.10^{-3}$  W/°C cm. A new process for obtaining 3 mm thick tubes is now under research. The dimensional tolerances of the tubes available are approximately :

- diameters :  $\pm \frac{2}{10}$  mm ( $\pm \frac{1}{10}$  mm on the same tube)
- thickness :  $\pm \frac{5}{100}$  mm ( $\pm \frac{3}{100}$  mm on the same tube)

Another process avoiding problems of the feasibility of tubes of small thickness and high tolerance requirements, in addition to the difficult problems of their mounting in the channel, is to perform the insulation layer by means of ceramic spraying carried out at T.N.O. (Holland).

Thermal conductivity and mechanical characteristics measurements concerning zirconia layers sprayed on SAP tubes have been undertaken. The results are following :

- thermal conductivity :  $5.2.10^{-3}$  W/°C cm ( $\pm 15$  %) at 300 °C. The layer had a porosity of about 10 %, controlled by microscopic examination and density measurements.
- traction resistance : 215 kg/cm<sup>2</sup>
- modulus of elasticity : 2 000 kg/mm<sup>2</sup> ( $\pm 10$  %)
- thermal expansion coefficient :  $8.10^{-6}$  °C<sup>-1</sup> between 0 and 400 °C.

Actually, the research concerns especially the improvement of the thermal resistivity of sprayed layers using special techniques for spraying to increase the porosity. Appreciable gains in this field would allow the use of sprayed alumina instead of zirconia, the behaviour of which under radiation is less known up to now than that of alumina.

### 3.3 —

A gas insulated channel has been chosen for the first full scale experiment in the technological loop, on the basis of the following considerations :

- it is easier to fabricate since it implies fewer technological problems.
- good insulation properties are foreseen.

On the other hand we studied a particular solution (see Fig. 10) in order to limit the thickness of the hot pressure tube. This solution, if the test will be successful, is very interesting from the neutron economy point of view and technological aspect. Reference data for this channel are : Vertical channel, up to down flow.

Active lengths :	4.8 m
Maximum organic velocity :	10 m/sec
Maximum flow rate :	11 l/sec
Outlet pressure :	8 kg/cm <sup>2</sup>

Maximum pressure drop :	12 kg/cm <sup>2</sup>
Maximum temperature :	420 °C
Inner hot tube (SAP) thickness :	2 mm
Outer cold tube thickness aluminum-magnesium-alloy :	1 m
Alternatively zircaloy 2 :	0.8 mm
Insulation thickness (nitrogen) :	3 mm

The pressures in the gas insulation space and at the exit of the channel are equalized. This is obtained by putting in communication the insulation space with the lower collector which acts also as a pressurizer for the loop. To avoid organic vapour diffusion and condensation into the insulation space a small flow of clean nitrogen is provided in counterflow with the organic vapours through an annular gap around the hot tube.

A preliminary test has been done in a small organic loop at Progil Laboratories to determine the minimum flow rate to avoid the organic diffusion through the annular gap. First results show that with an annular gap  $\varnothing$  64/66 mm, 40 mm high, the minimum velocity of the gas counterflow in the pressure and temperature operating conditions corresponds to the theoretical diffusion velocity of organic vapour in non turbulent nitrogen.

The application of this principle of channel in the reactor implies the presence of a tank at the outlet of the channel with a gas cushion connected with the gas of the pressurizer of the primary circuit. Every channel can also be connected to a single collector which may constitute the organic circuit pressurizer.

### 3.4 —

The flow-sheet of the technological loop in which the channel will be tested is given in Fig. 11.

The operating conditions of the loop are :

— maximum pressure :	40 kg/cm <sup>2</sup>
— maximum temperature :	420 °C
— flow-rate :	40 m <sup>3</sup> /h
— total head of the circulation pumps at 40 m <sup>3</sup> /h :	25 kg/cm <sup>2</sup>
— maximum length of a vertical test section :	6 m

The loop is composed of 2 different circuits which may run independently at different temperatures and be switched on alternatively on the test section in order to perform a thermal cycling and thermal shocks as occur in the outlet end of the channel after a reactor scram.

Experimental program on the test channel is the following one :

- Measurement of thermal insulation. Around the channel a jacket is provided with water circulation at a controlled temperature equal to the moderator temperature in the reactor. The cross section of the water jacket is relatively small in order to increase the accuracy of the measurement of thermal losses.
- Stresses and displacement measurements on the internal and external tubes at some particular points of the channel.
- Behaviour of spacers between the hot and cold tube as a consequence of thermal cycling.

- Leak measurements and diffusion of organic vapour in the insulating gas.
- Mechanical behaviour of end plates and connections, vibrations of fuel rods and filler pieces of fuel assemblies.

#### 4 — Thermo-mechanical Stability of Fuel Clusters

A theoretical study of the problem of temperature distribution in the cladding of fuel elements and of the deformation of the fuel rods has been carried out in order to evaluate the relative importance of the various hydraulic, thermal and mechanical parameters. (Influence of the local heat transfer coefficient, along the circumference of the thermal resistance between pellets and cladding, of the free length of a rod between spacers.)

It was found that for a relative variation of 20 % i.e. of the local heat transfer coefficient, where the specific power is assumed to be 100 W/cm<sup>2</sup>, the temperature difference along the circumference is about 3 °C or 13 °C depending on whether the distribution has a symmetry of the order of 6 or a maximum and minimum diametrically opposed. In the second case, where deformation of the rod is maximum, the circumferential conduction in the cladding has little importance and almost equal temperature differences are found between cladding made of SAP of 1.3 mm thickness and steel claddings of 0.2 mm thickness. The thermal resistance between pellets and cladding influences not only the average temperature of the fuel pellets but also the circumferential temperature variation of the cladding. When this thermal resistance is inferior to 2 °C/W/cm<sup>2</sup>, the thermal conductivity in the fuel pellets lowers the temperature variation in the cladding. For higher value of this resistance the local heat transfer coefficient becomes the governing factor.

An additional factor leading to temperature differences along the periphery of the fuel cladding is the non uniform temperature distribution of the organic coolant in the cluster sub-channels.

As a consequence of all the above mentioned factors and for a cluster of 7 rods (uranium carbide - Ø 1" SAP cladding) circumferential temperature differences of about 10° to 15 °C are expected on the peripheral fuel rods in nominal conditions.

It is the object of the experimental program to ascertain this estimate, to study the resulting deformation in the cluster, and to define the values of the hydraulic, thermal and mechanical parameters which will insure a fuel element which is thermo-mechanically stable.

The experimental program includes :

- a) The study of fluid velocity distribution in channel cross sections, of sub-channel mixing and of pressure drops due to spacers.
- b) The study of the local heat transfer coefficient.
- c) The measurement of deformations of rods.
- d) The analysis of temperature distribution in the cladding.

The following test equipments have been constructed :

1. A water loop (photo No 12) for the study of point a) and b). The model is at scale 2. The radial position of peripheral rods can be changed.
2. An organic loop (photo No 12) constructed by Société d'Etude de Propulsion par Réaction-SEPR (France) for the study of point c). The test section (photo No 13-1) contains a dummy fuel cluster of seven rods. One peripheral rod will be heated internally by a thermocoax wire

inbedded in a silver core, the SAP cladding being free to deform. The gap is filled with silver powder simulating the contact resistance between fuel and cladding. The boundary conditions for this rod are satisfied by heating the surrounding three rods.

3. A rheoelectrical analogy installation using paper "Teledeltos" for the study of point *d*). Results given by points *a*), *b*), *c*) are used in defining boundary conditions.

## 5 — Experimental Stress Analysis on Fuel Element Cage by Application of Photostress and Strain Gages Techniques

Among the various configurations of fuel element clusters we have started to investigate the mechanical behaviour of a beryllium cage fuel support working in compression, the axial loads being transmitted from cluster to cluster through a central hinge point. The test piece was made from anticorrosional also to take advantages in measuring strains of the lower modulus of elasticity.

The load was applied by an Amsler traction-compression machine, this load reaching the maximum value of 600 kg, expected on the last fuel cluster of piled up fuel units in an ORGEL channel.

Both photostress methods and strain gage measurements have given same results and indicated high bending stresses. Consequently we tested a new concept where the axial load is transferred to the periphery directly. The compressive stresses obtained are allowable.

This design is better suited for longer cages since safety coefficient with regard to buckling can be set with respect to the theoretical value of the buckling load.

## 6 — Friction and Wear

A wear machine (photo No 14) has been built at T.N.O., Delft (Holland) to investigate resistance to wear of materials foreseen in the ORGEL channel and primary circuit. The machine is designed to simulate point-line-contacts as can occur in the channel due to thermal expansion and vibrations. The specimens are submitted to rotational and hammering movements at various frequencies, amplitudes and loads.

Preliminary program includes tests in terphenyl at 400 °C on following pairs of materials :

SAP/SAP

SAP/Aluminum

SAP/Stainless Steel (304 AISI)

SAP/Sprayed ZrO<sub>2</sub>

SAP/Sprayed Al<sub>2</sub>O<sub>3</sub>

SAP/Metal containing graphite

SAP/Soft material

Stainless Steel (304 AISI)/Stainless Steel (304 AISI)

The final object is to improve the resistance to wear if necessary by metal coating the surfaces.

## 7 — Channel Rupture in the Reactor Core

Aim of the study is to determine the consequence of the rupture of a channel on the surrounding channels and on the vessel. Two phenomena resulting from the rupture of the stress tube are the shock wave due to pressure release and the effect of the local increase in pressure due to vapour formation consequent to the heat transfer between the hot organic and the water. On the basis of theoretical study it is justified to say that energy absorbed by elastic deformation result in a negligible stress increase of the surrounding tubes.

The water vapour amount resulting from heat exchange between hot organic and moderator is a function of the organic temperature and the shape assumed by the organic jet streaming out of the fissure. This energy release could be quite rapid and be of primary importance in causing damages and therefore influence the safety criteria. A third phenomenon that has to be considered is the heating of the surrounding tubes, which could endanger particularly a cold pressure tube.

For the solution of the problems of rupture of the pressure tube, different steps of experiments are foreseen. The aim of the first step is to find out the shape of the fissure which can be expected when a SAP tube explodes.

These experiments are now performed with a small test loop (photo No 15) equipped with strain measuring devices at high temperature (photo No 16). One of the SAP tubes tested is shown on photo No 17, showing the fissure and the kind of fracture of the material.

The second part of the experiments is meant to measure the coefficient of heat transfer between hot organic and water, by injection of a controlled amount of hot organic in water, and visualisation of the mixing as well as measurement of pressure rise.

A third global experiment is foreseen in a vessel whose geometry reproduces a model of a part of the ORGEL core. Pressure and temperature rise and mechanical strains will be measured.

## 8 — Conclusions

The work done on the different research program has been undertaken with the emphasis on the basic aspect of the problems in order that the results satisfy a rather large field of application. At the same time, the conceptual design evolves along different lines since we do not want to fix a single configuration of ORGEL for the moment.

On the other hand the program established so far was intended to fulfil a planning which includes the construction and the tests of ORGEL channels in ESSOR : this fact corresponds to a precise and pressing task.

---

(\*) Photos No. 2, 3, 4, 5, 6, 7, and 14 are due to the T.N.O. Delft Holland.



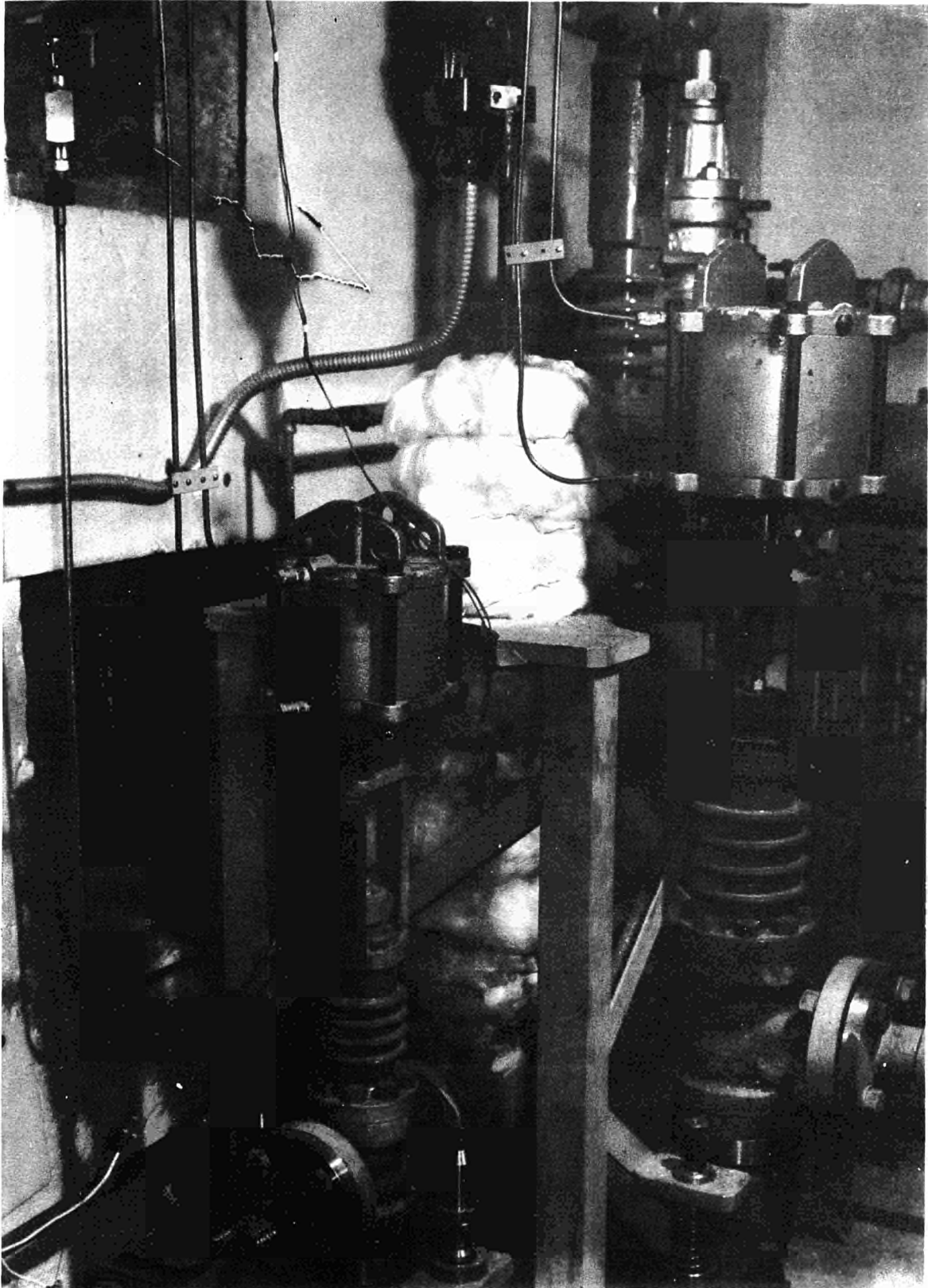


Photo n° 1 Rolled joint test section during experiment with extensometric bridge, leak detection tube, inspection window, heating element connexions, and operating valves.



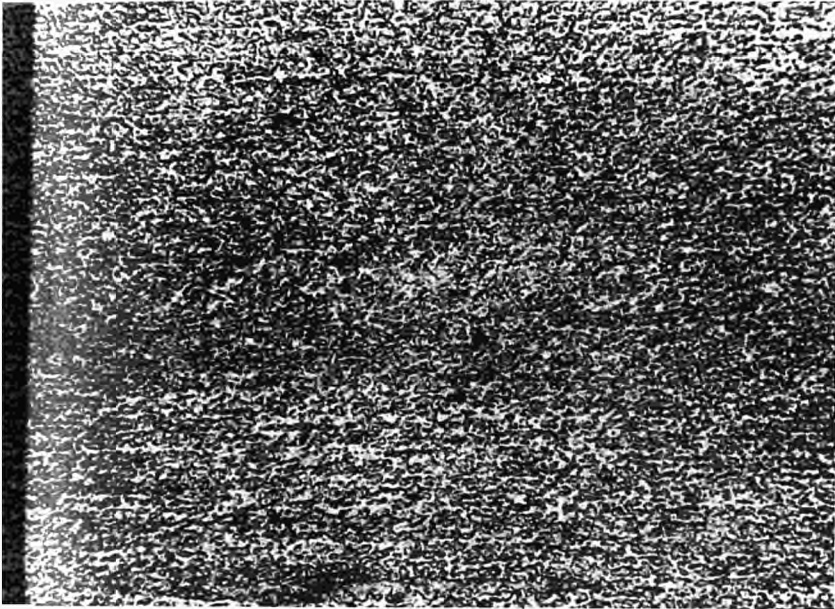


Photo n° 2 Explosive welding  
SAP - SAP  
enlarged 600 x etched.

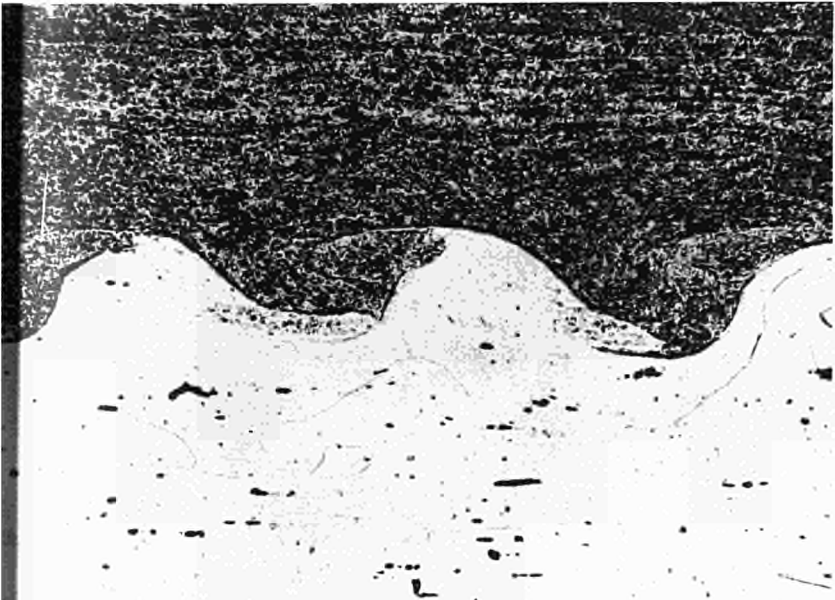


Photo n° 3 Explosive welding  
SAP - Aluminium  
enlarged 400 x etched.

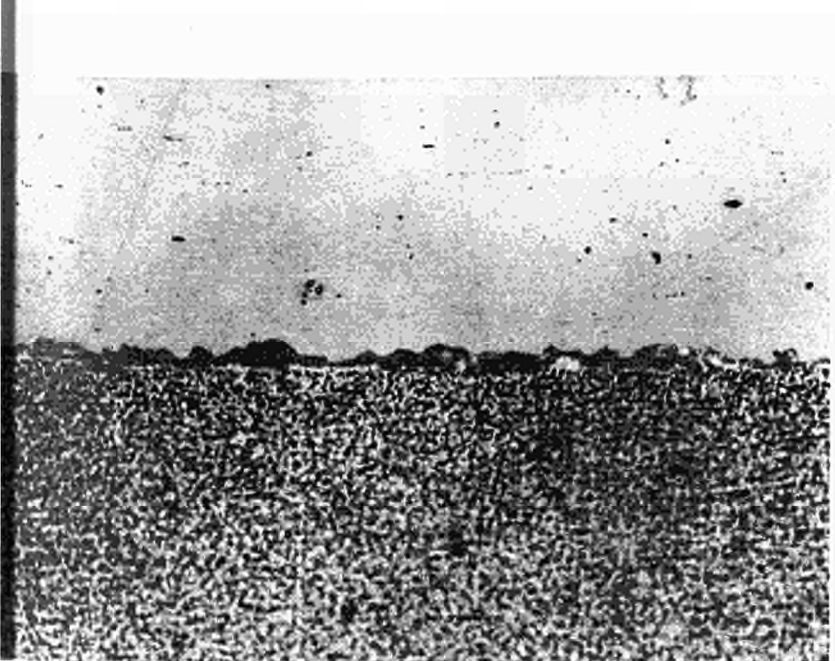


Photo n° 4 Explosive welding  
SAP - Stainless stell  
enlarged 400 x



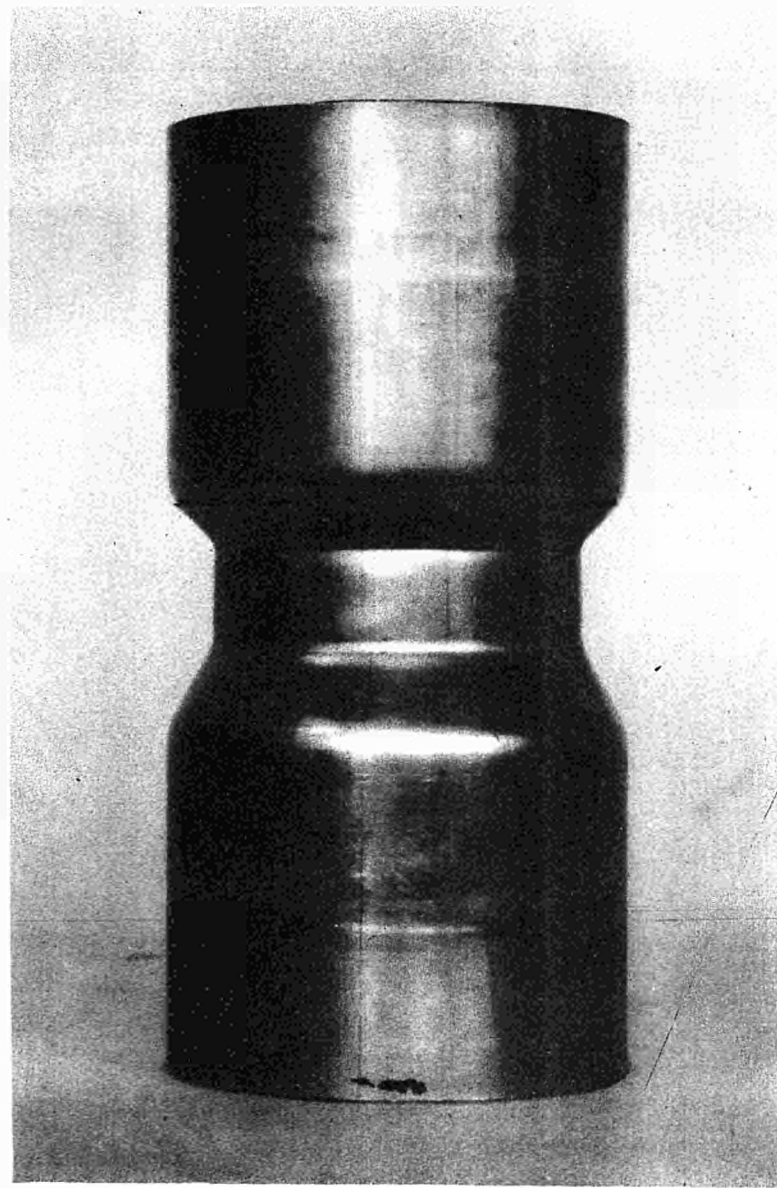


Photo n° 5 Deformed tube



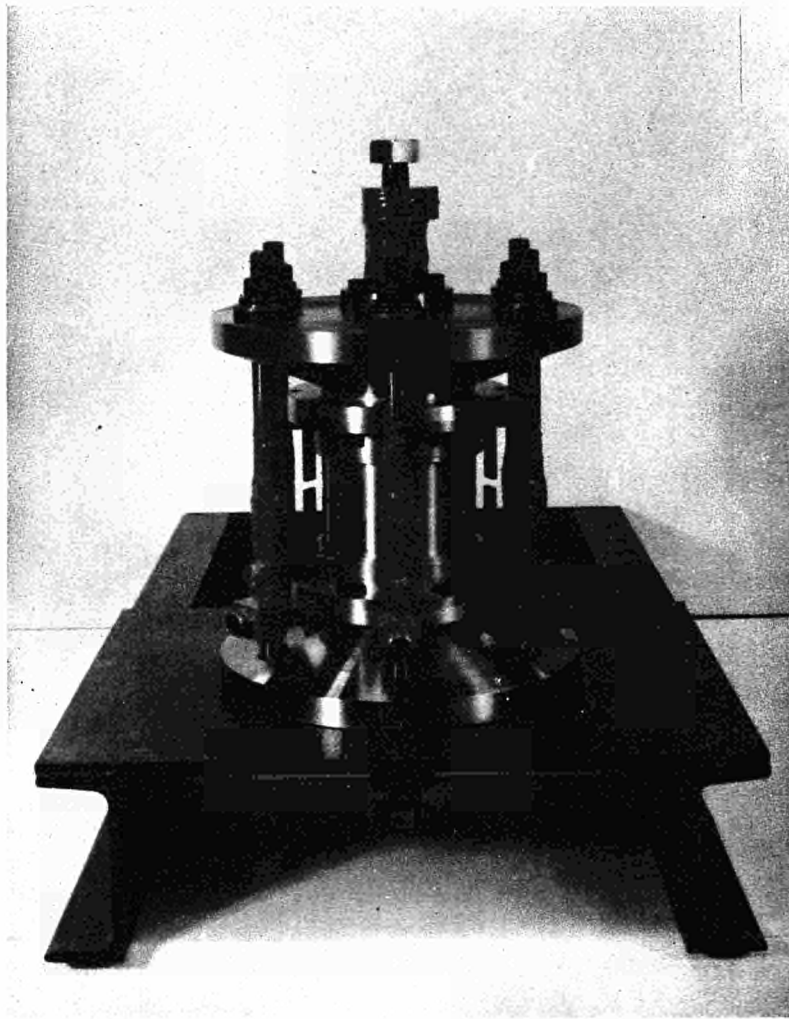


Photo n° 6 - Sealings testing apparatus

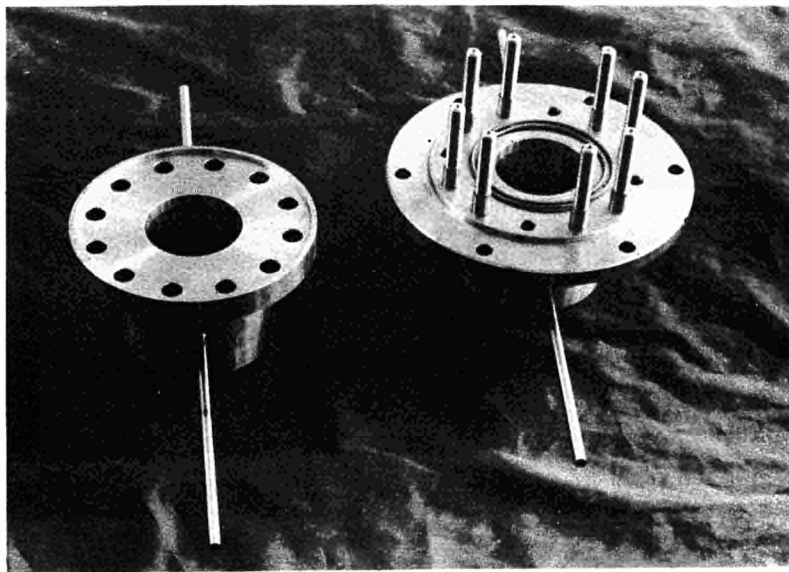


Photo n° 7 Gasket and leak test apparatus





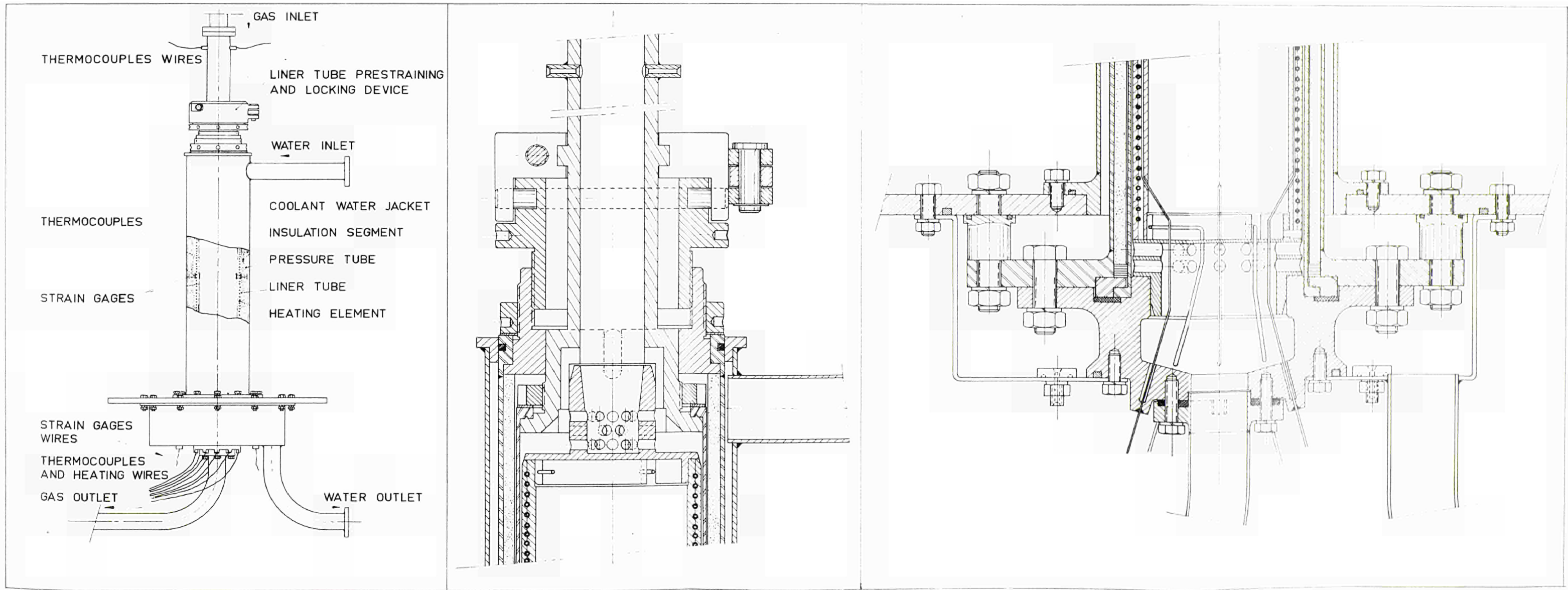


FIG. 8



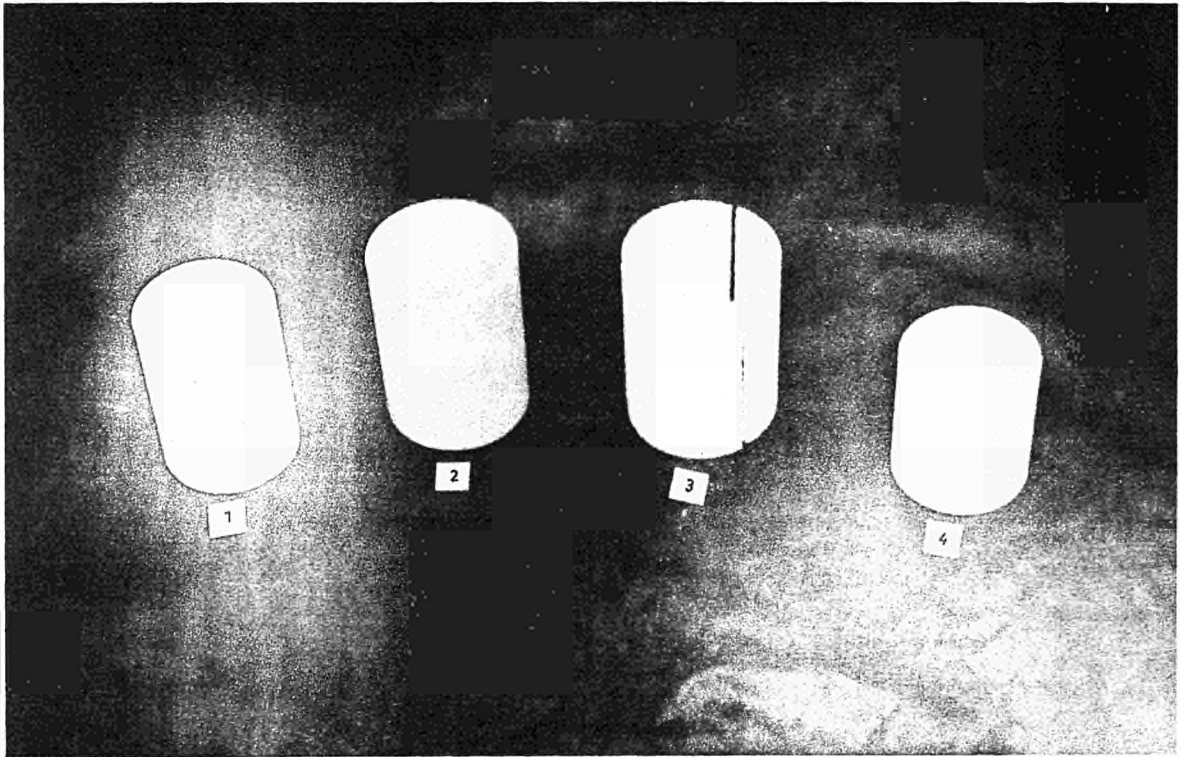
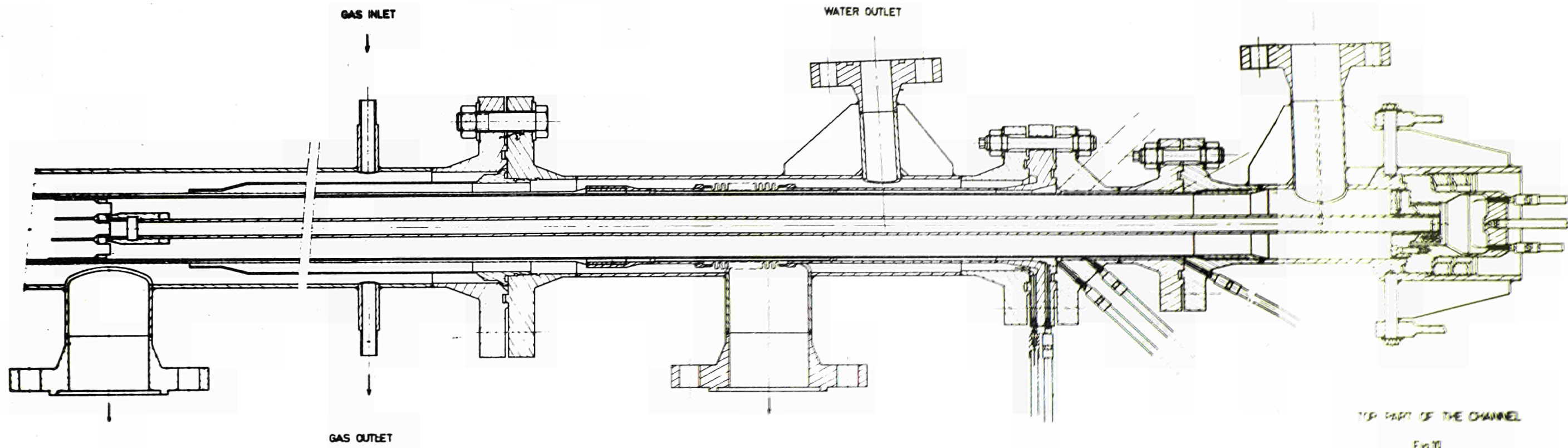
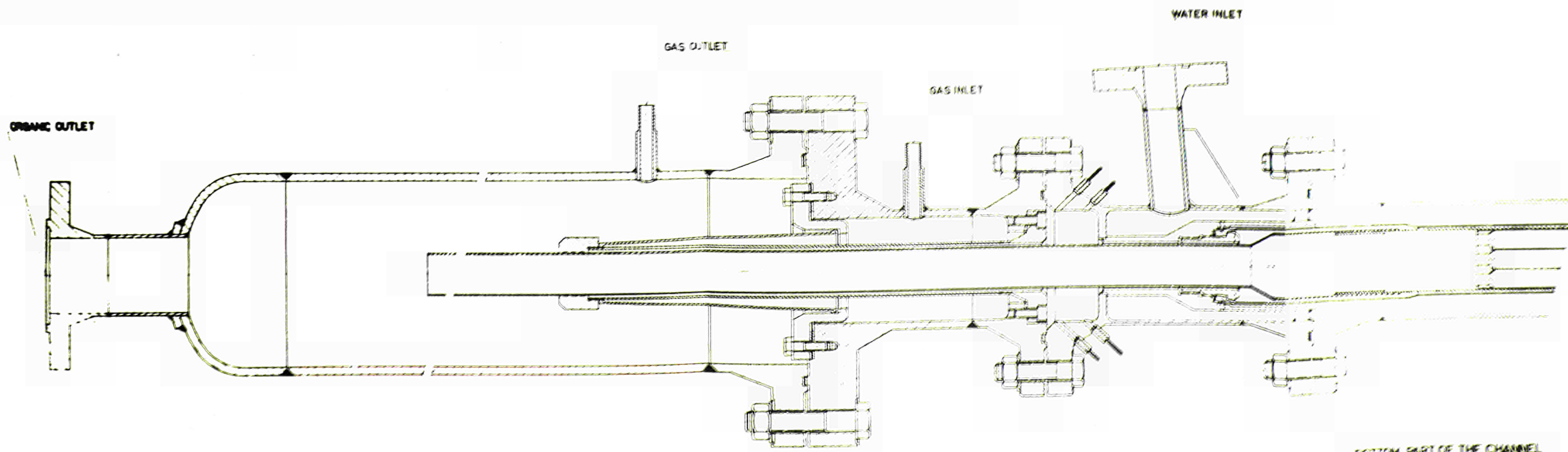


Photo n° 9



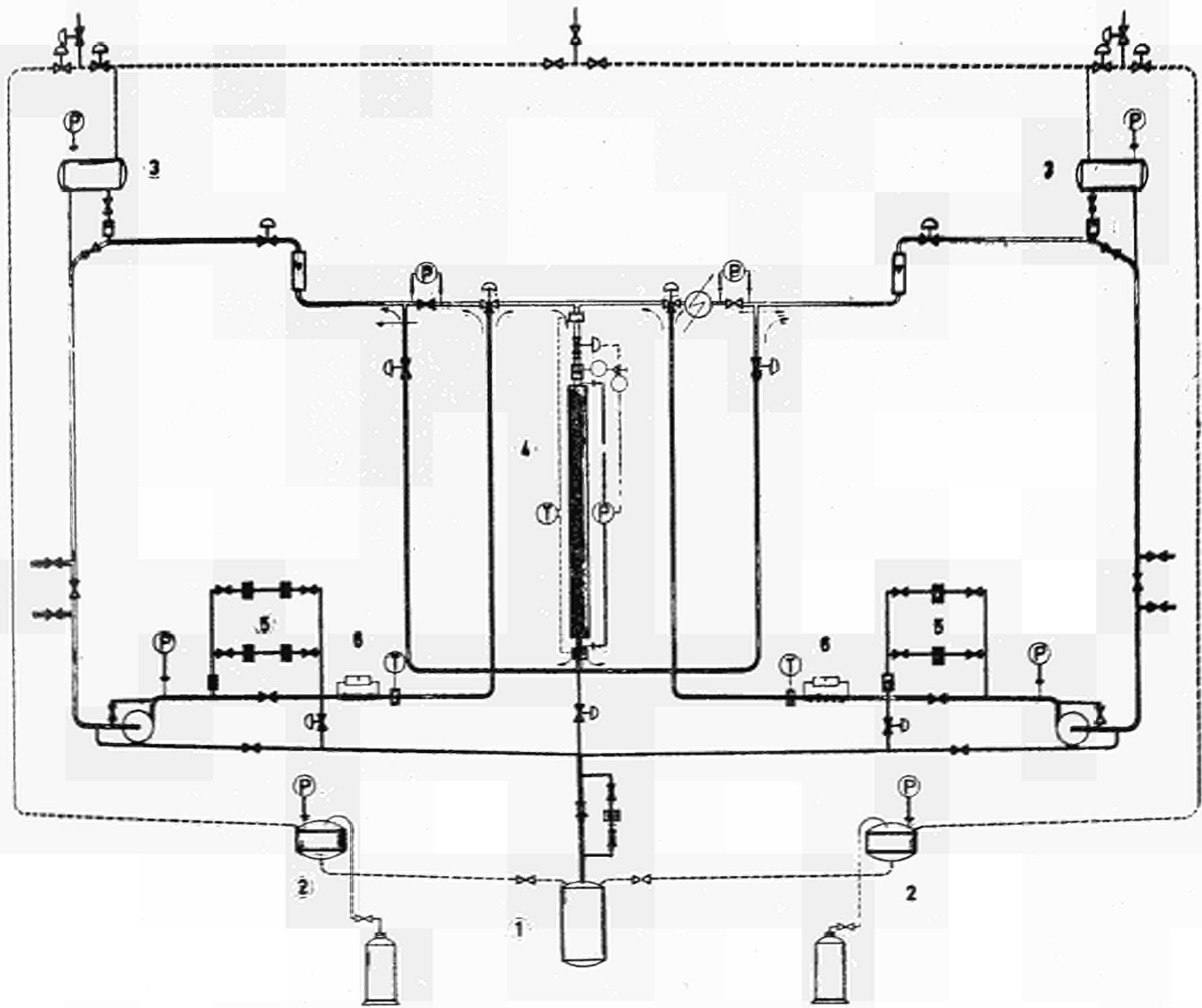


TOP PART OF THE CHANNEL  
Fig 10



BOTTOM PART OF THE CHANNEL  
Fig 10





① DUMP AND FUSION TANK

② PRESSURIZER

③ DEGAZIFIER

④ TEST-SECTION

⑦ FILTER

⑧ HEATING SYSTEM

— HIGH TEMPERATURE TEST

- - - LOW TEMPERATURE TEST

- - - - NITROGEN

..... CAPILLARY TUBES

Figure 11





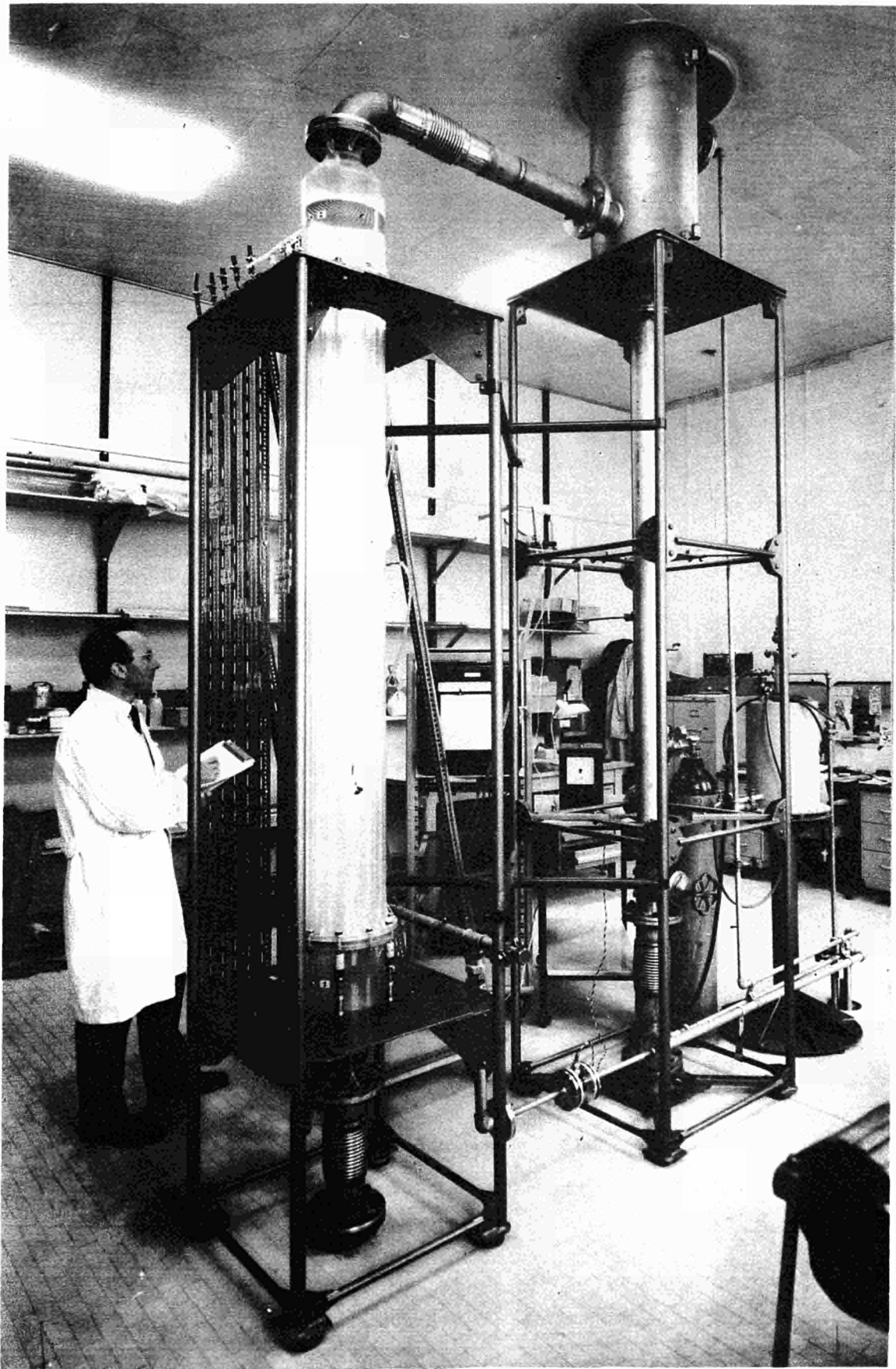


Photo n° 12 Upper part of water test loop with experimental model



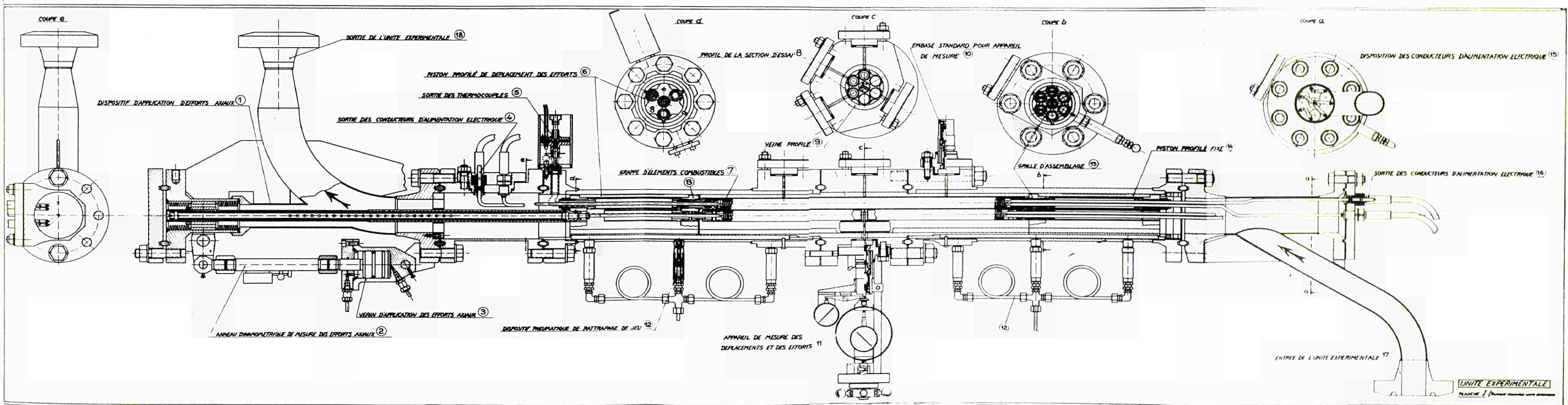
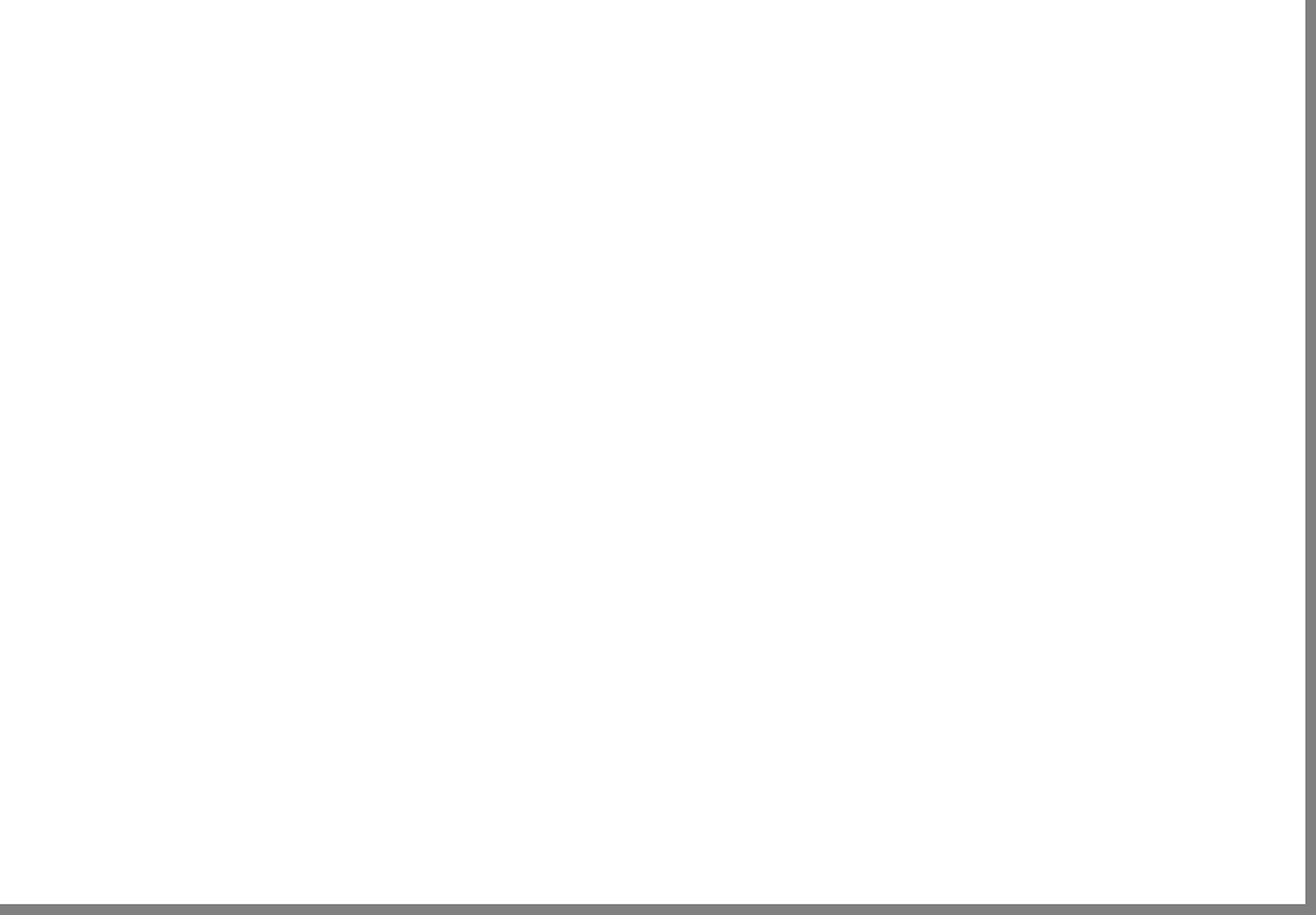


Photo n° 13-1 Test Section for Organic Loop  
 1) System to impose axial loads of traction or compression  
 7) Fuel cluster  
 11) Instrument to measure displacements and deformations  
 12) Pneumatic device to avoid effect of radial forces due to 11  
 13) Assembly grid



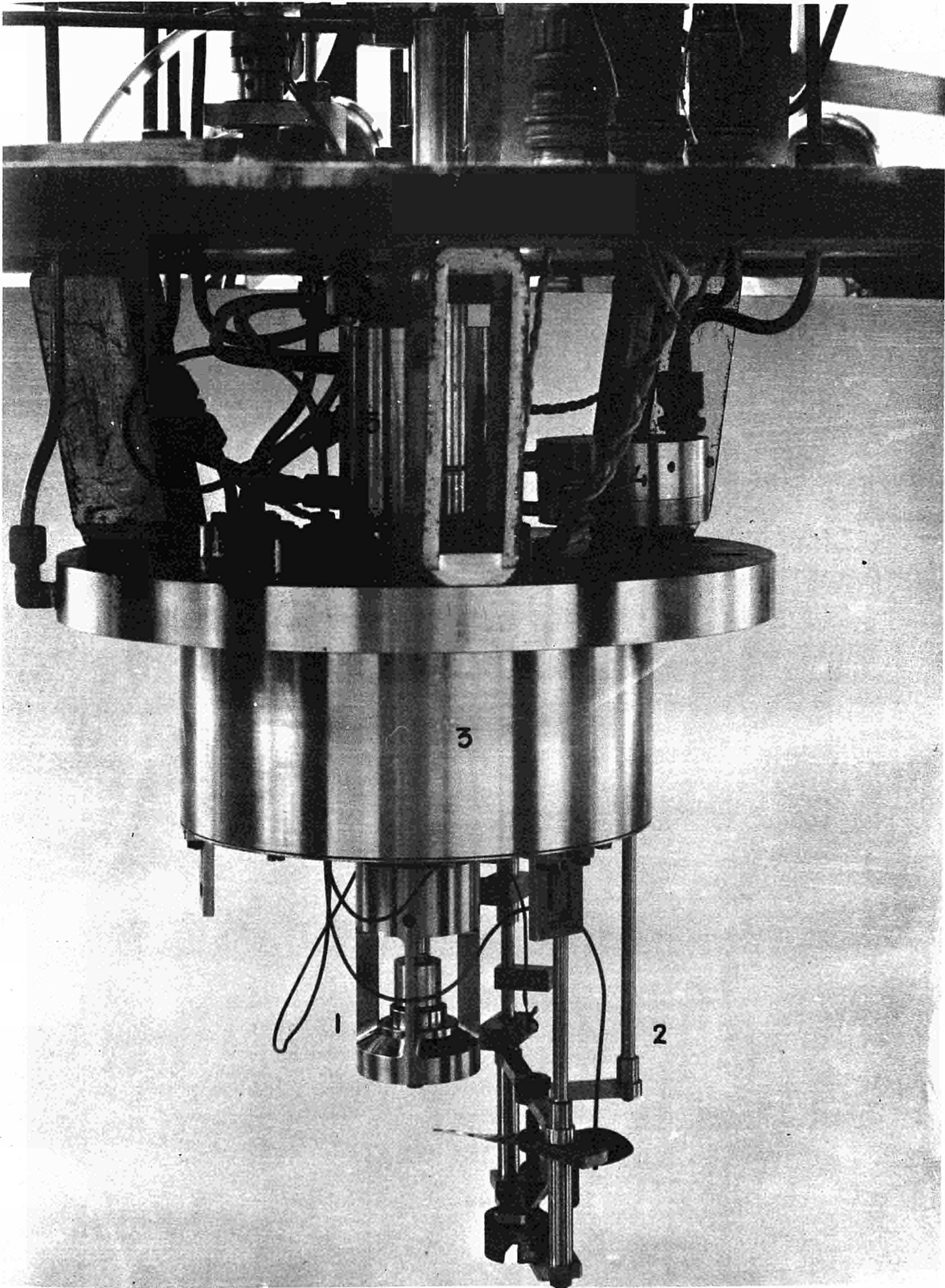


Photo n° 14 Detailed view of the contents of the reaction vessel, showing :

- 1.- specimen assembly
- 2.- magnetic stirrer and rotation indicating system
- 3.- cooler, filled with boiling water  
(to prevent the access of hot terphenyl vapours to the measuring equipment)
- 4.- manometer for measuring the alternating oil pressure
- 5.- column containing the lower vibrating piston and the vertical amplitude measuring system.





Photo n° 15 Test loop equipped with instrumentation ready for the test.

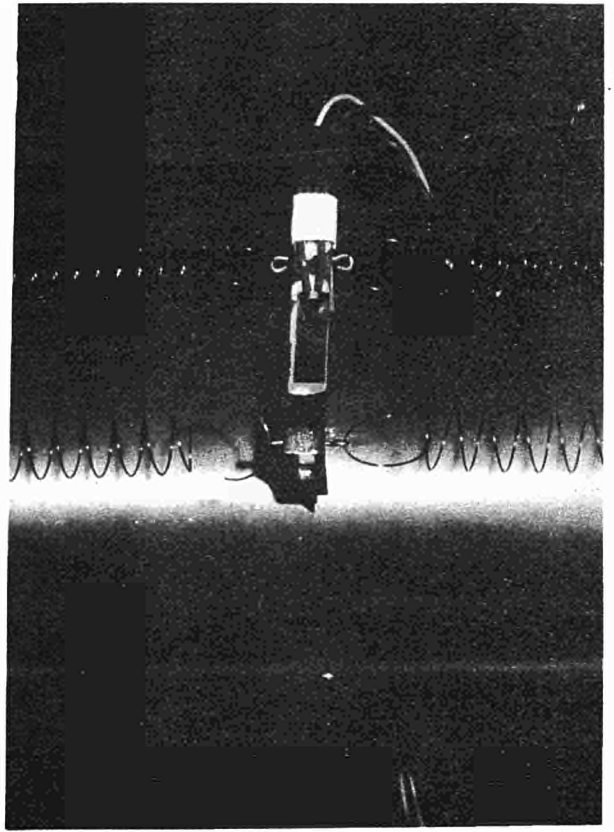


Photo n° 16 Strain transfer system for measuring high values of elongation at high temperatures.

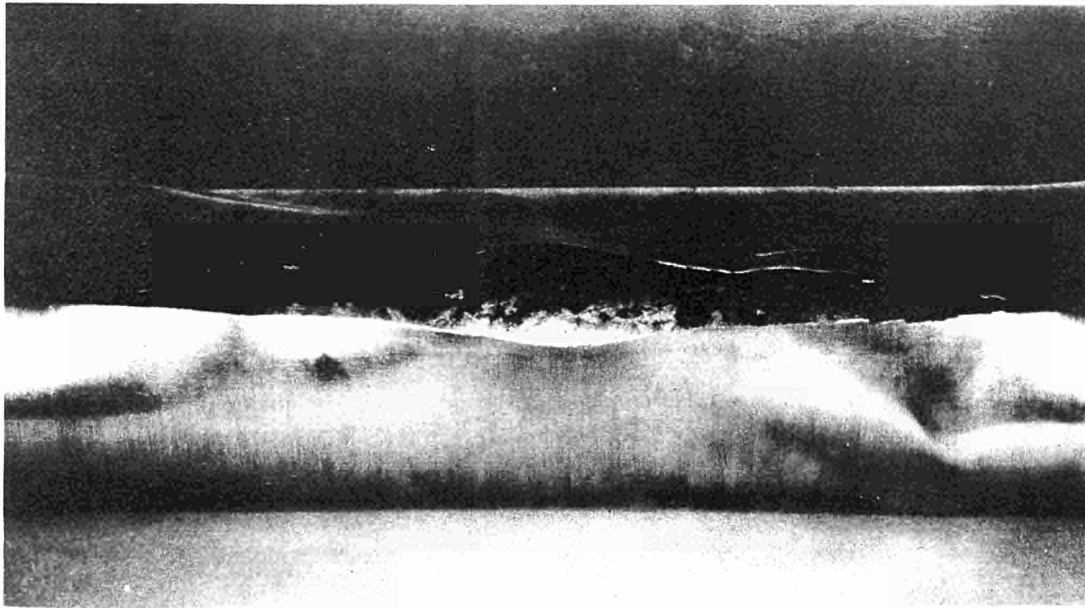


Photo n° 17 Test N. 2  
Tube after explosion.





## CHAPTER VI — CHEMISTRY OF ORGANIC COOLANTS

The research undertaken by the Chemistry department within the frame work of the ORGEL program is specially directed towards the following items of investigation :

1. Fundamental research
2. Organic Syntheses
3. Organic and inorganic analysis
4. Study of possible substitutes of terphenyls
5. Technology of organic coolants
6. Miscellaneous

### 1 — Fundamental Research

#### Object

Determination of mechanism and kinetics of the polyphenylic hydrocarbon degradation reaction.

#### 1.1 — Studies of mechanism

We are aiming at the investigation of the nature and configuration of the radicals appearing in the course of the reaction studied, in order to be able to explain certain preferential structures being found in the high boiler fraction.

Trying to solve this problem, we have fixed our attention upon the magnetic properties that distinguish fairly well between molecules and radicals. For the interpretation of the ESR Spectra which is obtained during the irradiation of polyphenyl molecules, we first carried out electron resonance spectra of different types of radicals obtained in a special chemical way ,e.g. "negative ion" radicals, "positive ion" radicals and "neutral" radicals. We have, first of all, performed the synthesis of the diphenyl negative ion in order to check our methods. The obtained spectrum (Fig. 1) is entirely in agreement with data found in the relevant literature. A total resolution has been obtained. All the peaks that had been theoretically predicted could be recorded at a  $10^{-3}M$  concentration.

For the time being we have succeeded to establish the synthesis of negative ion radicals (Potassium) of the three terphenyls the purity of which had been brought up to an extremely high degree.

The experiments carried out until now with the aid of paraterphenyl have shown us the real presence of radicals, without precisising the conditions suitable for a spectrum completely resolved.

## Schedule

It is our intention to finish the calibration of the spectra by establishing the synthesis of positive ion radicals (by means of iodide) and of neutral ones (by means of metal complexes) and subsequently to study the spectra obtained by irradiation of terphenyls in order to examine the spectra obtained in the spectrometer. We also intend to compare the supplementary information resulting from Flash Photolysis or from another spectrometric method with conclusion emanating from ESR Spectra.

### 1.2 --- Kinetic studies

In this field we have undertaken — in collaboration with researchers from the Commissariat à l'Énergie Atomique (C.E.A.) - France and the Progil Company (France) — the study of pyrolysis and radiolysis of the terphenyls as well as of different commercial mixtures. All these reactions have been carried out in a static manner (ampules).

#### 1.2.1 In-pile radiolysis

The ampules are made of quartz, the container of zirconium

##### a) In-pile radiolysis of para-terphenyl

Fig. 2 gives a survey of the experimental results

##### b) In-pile radiolysis of the commercial mixture OM<sub>2</sub>

This mixture is composed of :

Biphenyl < 1 %	meta TP 81
O. T PH 15 %	para TP 4.0

The radiolysis was carried out at 300 °Celsius (572 °F).

Fig. 3 gives the table of the experimental results.

Fig. 4 gas formation as function of the absorbed dose.

Fig. 5 High boiler formed as function of the absorbed dose.

The dosimetry of the absorbed energy was accomplished with the Cyclohexane dosimeter.

Moreover, a more profound study was undertaken one year ago with the aim of developing an isotherm dosimeter and another one working on the thermoconductivity principle.

With all these numerous prototypes under investigation, there will be a good chance for us to differentiate in the near future  $\gamma$  and n energies absorbed by irradiated matter.

#### 1.2.2 Pyrolysis

A comparative investigation has been undertaken once more with the aid of CEA and Progil scientists in the field of the pyrolysis of the same two terphenyls as well as of some commercial mixtures.

##### a) Pyrolysis of para and meta terphenyls

Fig. 6 This table presents the differences in gas production

Fig. 7 shows the production of high boilers for the various pure products.

Moreover some analyses of the vapour phase of pyrolysed m-terphenyl were carried out and are presented in the next figure (Figure 8).

You will find other data of the solid phase in figure 9. The conclusion derived from these results is, both for the formation of gas and of polymers, that the meta-terphenyl is less stable than the para isomer as far as pyrolysis is concerned.

On the basis of these data we have established reaction rate constants by admitting the pseudo-order of one of them.

By plotting these results we gained the Arrhenius parameters in a graphic way, their values are :

H.B.  $E = 64 \pm 5$  Kcal/m

Gas  $E = 67 \pm 3$  Kcal/m

a) Pyrolysis of commercial mixtures. First a survey of the isomeric composition :

Products	W %		
	O	M	P
OM <sub>1</sub>	65	32	3
OM <sub>2</sub>	15	81	4
OM <sub>3</sub>	12	62	26

The following tables (Fig. 10 and 11) permit us to compare the formation of gas and H.B. and under equal conditions to collate the results obtained relative to the meta para ratio.

#### *Schedule*

We intend to continue these experiments with ortho terphenyl in a static state and to repeat certain determinations by pressurizing the ampules with different gases in order to check whether the equilibrium constants may influence the results.

If this is so, we might have to modify the interpretation of the results obtained in the solid state (pressure variable).

## 2 — Synthesis of pure standards

#### *Aim*

In order to identify the compounds by fractionation of the high boiler hydrocarbons we have carried out the synthesis of some twenty polyphenyls. This was done in collaboration with the Company SERAI (Belgium).

## *Results*

As it is evidently impossible and would, moreover, involve too much time and too many expenses, to undertake the synthesis of all the isomers which may be present in the H.B., we have made a selection based on a certain probability of appearance (Phillips).

Figure 12 shows the products which have been synthesized up to now.

## *Schedule*

We continue this program of syntheses in the field of quinqu- and hexaphenyls.

## **3 — Organic and inorganic analyses**

### *Aim*

This research has been undertaken with a view to a more precise and complete analysis of polyphenyls, both before and after irradiation.

### **3.1 — Organic analysis**

The recent progress made in this field is owed to the close collaboration between the research workers of Progil and the Ispra laboratories.

#### 3.1.1 Chromatography

This novel technique, the development of which is actually being pushed forward by a great number of organic chemists, comprises such a vast field of analytical possibilities that only two of them, e.g. Gas chromatography and Thin Layer chromatography, could be studied more closely.

- a) After having learnt the operating conditions of Phillips Petroleum last year (G.C. columns filled with LiCl), our repetitive experiments showed the resolution of the quaterphenyls to be insufficient. A prolongation of the column length would cause a partial pyrolysis of some hexaphenyls, the loitering time of which would be too long under the elevated temperature of approx. 420 °C. The separation of terphenyls as well as of quaterphenyls and the elution of hexaphenyls have been performed by using solid caesium chloride as stationary phase.

This phase is not too active to hold up quinqu- and hexaphenyls.

Its thermal stability is identical to that of LiCl. Furthermore we have observed that an addition of bentone 34 (octadecyldimethyl ammonium chloride) to the classical phase of silicone grease considerably improves the separation of meta and para terphenyls and enables the complete separation of seven quaterphenyls (the most current ones).

1, 2, 3 triphenylbenzene has never been checked but leaves the column certainly prior to para terphenyl, 1, 2, 4-Triphenylbenzene always leaves it exactly at the same time as O-P Quaterphenyl. The determination of H.B. has been thoroughly studied in the beginning in order to improve the method of microdistillation (A.I.).

As a matter of fact, the results were so unsatisfactory and disappointing as to induce us to change the working method of the distillation by raising the temperature up to 225 °C in order to ensure that all p-terphenyls are included in the distillation. Thus, the distillate

may contain small quantities of the more volatile quaterphenyls, too. After gas chromatographic determination these light high boilers percentages are added to the percentage of residue. The total is representing all H.B.'s. Although this method is more accurate, it is on the other hand more unwieldy. Further studies have led us to consider the application of a gas chromatographic method called "backflushing" for the global H.B. determination (sketch of the flowsheet is presented in Fig. 13). A mixture containing H.B. is injected into the chromatograph at a sufficiently high temperature. The carrier gas, which had passed the reference detector before, is loaded by the mixture to be analyzed. The column just separates the  $\text{O}_3$ . Immediately after the para-  $\text{O}_3$  has passed the detector, the direction of flow is reversed, the high boilers are flushed back and leave the entry altogether. They are recorded as one peak only by the original reference detector. Finally we have studied a method, usually applied in similar cases, for the H.B. determination by introducing an "inner standard" (triphenylmethane) to the sample to be analyzed by G.C. A critical check-up on the results obtained by these three procedures makes us believe that their accuracy is almost the same: At a low H.B. concentration (3 %) the accuracy is less than 30 % relative, beyond 50 % H.B. near to 1 % relative.

The microdistillation coupled with G.C. and the internal standard are procedures, the results of which for the several components are independent of the H.B. % and internal composition and in contrast to the back flushing system for which the percentages of terphenyls depend on the precision and accuracy of the direct measurement of the H.B.

All deviations caused by an H.B. peak asymmetry or by a possible incomplete vaporization or a partial decomposition influence the absolute analytical data.

b) Thin layer chromatography (with participation of T.N.O. - Netherlands).

Different attempts have been made for the separation of polyphenylic mixtures both on alumina adsorption column or on paper. The results achieved by elution of the columns are rather unsatisfactory. We only succeeded to separate the terphenyls. The experiments on paper failed entirely, probably because of the incompatibility of the hydrophylic substrate paper and the hydrophobic hydrocarbons.

For this reason we fixed our attention upon the novel thin layer chromatography ("Dünnschicht-Chromatographie").

The most commonly used stationary phases are alumina and silicagel. The three terphenyls are easily separated by these compounds. The plates have the important advantage to be absolutely resistant against spray reagents as aggressive necessary for the visualization of the chromatographic spots. In practice we succeed to separate some 15 compounds of a mixture on one line. An appropriate preparation of the layer allows us to favour either the light or the heavy products.

### 3.1.2 Distillation

This method has been used for the preparation of greater quantities of high pure terphenyls. Amongst them the meta isomer is the most difficult for purification.

Beyond this utilisation, distillation is used for pre-separation of  $\text{O}_4$  and  $\text{O}_5$  preparation processes.

### 3.1.3 Absorption Spectroscopy

By application of the UV technique we determined the relation between the absorption maxima and the configuration of the single molecules as well as of simple mixtures.

The conclusions were not too satisfactory. Thus we investigated the behaviour of the coloured complexes formed between tetracyanethylene and the polyphenyls. We can now identify in a rough manner the type of linkage preferentially present in a mixture. Utilisation of far infra red (beyond 15 $\mu$ ) is not yet well explored for the possibility of a distinct determination of o - m - p - linkage ratio. An appropriate equipment is being mounted.

#### 3.1.4 X Ray diffraction (diffractograph Philips)

This method has been foreseen not as a common means of a precise analysis but rather as a method of semi-quantitative control and of a rapid survey of the composition of mixtures, especially with a view to subsequent application as continuous in-line control.

The diffraction spectrum of a OM<sub>2</sub> mixture shows interferences of the bands for the pure compounds, therefore we have selected the most specific wave length without being able to eliminate any coincidence. These can be easily corrected by mathematical treatment. Fig. 14 shows the results obtained.

### Conclusions

- 1° This method is only a semi-qualitative one, but it is sufficiently precise for an in-stream control, e.g.
- 2° The sensitivity of detection for o and meta is 0,5 % and 1 % for para related to a 100 % sample.
- 3° Determination may become a qualitative one by changing some parameters (e.g. grain size, working in vacuum and utilizing transparent instead of reflected light).

#### *Schedule*

We are intending to study some more complex mixtures (e.g. O<sub>4</sub>).

### 3.2 — Analysis of inorganic impurities

Close attention is paid to this subject in order to determine with the maximum precision the metal traces being present in organic coolants before and after irradiation in the reactor.

Our special interest is directed to the determination of corrosion products and the attempt to interpret the phenomena of fouling by means of complementary methods. Each of the three methods can be helpful to check the results obtained by the aid of the two others.

#### 3.2.1 Spectrography RX (Spectrograph A 11 Vacuum Philips)

This method is reserved to some elements as iron, nickel and chrome.

The speed of determination (10 min) as well as its high sensitivity (0,5 ppm) are making this procedure a quite useful tool for routine analysis.

#### 3.2.2 Emission spectrography (Jarell Ash - Grating I 500 lines/inches)

This technique allows the simultaneous determination of a great number of elements being present in an organic coolant.

The utilisation of a copper spark source has furnished us with satisfactory results.

### 3.2.3 Inorganic wet analysis.

This method — although a little more time consuming — is preferentially used for the elucidation of cases of analyses where the emission spectroscopy is limited and for the determination of calibration standards utilised for Fe, Ni and Cr Determination. Its sensitivity amounts to some tenths of ppm.

The elaboration of this analytical method has been carried out simultaneously for neighbour elements. We only give global results.

Fig. 15 shows that the results obtained in the determination of iron content by XR spectrography are in agreement with those obtained by wet analysis.

Fig. 16 shows the results obtained by simultaneous determination of Fe, Ni and Cr in polyphenyls by aid of the three techniques mentioned.

Fig. 17 demonstrates an example of a complete analysis of different samples by emission spectroscopy only.

#### *Schedule*

##### a) RX

Application of this method for continuous measurements.

##### b) Emission spectroscopy

Amelioration of the precision by addition of internal standard.

##### c) Wet analysis

Elaboration for analytical measurements for the following ions and compounds

Al Cu Mn Na SiO<sub>2</sub> Ti U Zr

The sensitivity of which will be

0,1 0,5 1 0,5 1 2 0,5 ppm

for 10 gr sample each

## 4 — Ideal organic coolants (with C.E.A., France)

#### *Aim*

The following experiments have been carried out with a hope to finding not only a new revolutionizing product, which is not too likely, but rather to finding compound or a distillation fraction which possesses thermal and radiolytic stability equal to or somewhat lower than that of the terphenyls. It is also desirable that this product should be considerably cheaper than the terphenyls. It will be interesting as long as its physical properties remain admissible ( $\mu$  d).

#### *Results*

We have started this enterprise last year in collaboration with the French Institute of Petroleum. The first results did not present acceptable physical constants (e.g. vapour pressure too high).

In order to overcome this difficulty the IFP scientists have directed their investigations towards a fraction rich in alkylphenantren.

### *Radiolytic stability*

— AKP<sub>3</sub> fraction (in pile)

The preliminary results are quite encouraging and the following table shows the variation of the physical constants which are most important ones as a function of temperature (Fig. 18) —

Fig. 19 presents a variation of  $G_{\text{pol}}$  percentage of the monomers transformed as function of dose.

In order to increase the stability of the fraction it has been subjected to a pyrolysis involving: increase of mean distillation temperature, density, inflammation point, radiolytic and thermal stability, cleavage of side chains and decrease of viscosity.

Thus we may predict that such a fraction used as reactor coolant will undergo similar rearrangements as observed by pyrolysis and will finally gain a stable state by successive increase of its coolant behaviour.

AKP<sub>4</sub> (in pile)

Another new fraction has been irradiated at 360 °C (680 °F). A rate of 1,5 % for 24 hours has been observed. Under equal conditions OM<sub>2</sub> forms 1,9 % polymers in 24 hours.

Other experiments are being undertaken with fractions of increasing stability.

AKP<sub>4</sub> (Electron beam)

The same fraction as has been treated before in pile has been irradiated by rapid electrons up to a dose of 40 WH/gr.

Fig. 20

An excellent radiation stability has been observed.

OM<sub>2</sub> (in pile)

The figures 21 and 22 express the respective change of percentages of the different constituents as function of dose and the comparison of G values for the different irradiation experiments.

### **Observations**

- a) G varies only slightly with increasing dose for in pile irradiation and is evidently fairly low (0,16).
- b) the percentage of monomers transformed varies in a linear sense with increasing dose (o order reaction).
- c) the best stability is shown by para terphenyl.
- d) the electron beam irradiation yields G values which are rather different and hard to explain (the analyses have been performed by the same laboratories).
- e) An irradiation at 200 °C performed in order to eliminate the influence of pyrolysis yielded nevertheless a rather elevated G value for small doses. These strange results will have to be checked.

### *Dosimetry*

The measures have been carried out by integration of thermal and rapid neutron flux, the detectors of which are Co and Ni respectively.

A study which serves for the construction of an isothermal metal-graphite calorimeter is also in progress.



## 5 — Technology of organic coolants (with C.E.A., France and Progil, France)

### *Aim*

The in pile experiments, part of which have already been carried out, have been undertaken in order to obtain information on radiolysis in the reactor and under electron bombardment as well as of the pyrolyses of terphenyls and of products suitable to replace them.

These experiments will also be useful for testing the mechanisms and for establishing relations between the variation of physical constants as function of temperature, dose, water, polymers and concentration of mineral impurities.

On the other hand the availability of the H.B. formed under conditions similar to those of the scheduled reactor will be fairly appreciated, both by the analysts and the scientists treating the fouling problem.

### *Results*

Up to now the IFP (already mentioned as one of our contractors) has brought to an end a first series of irradiation experiments with OM<sub>2</sub> in order to check their loop equipment.

Their results have been presented and commented above.

This loop is actually used for irradiation of distillation fractions resulting from Power Forming treatment, from which we have learned that those are comparable or superior to the terphenyls from the point of view of radiolytic stability.

Especially fractions of methyl naphthalenes and alkyl phenanthrenes have been treated.

Fig. 23 gives a survey of the actual situation of loop serving for the chemistry program. The irradiation has been performed in Melusine, a reactor of CEA at Grenoble.

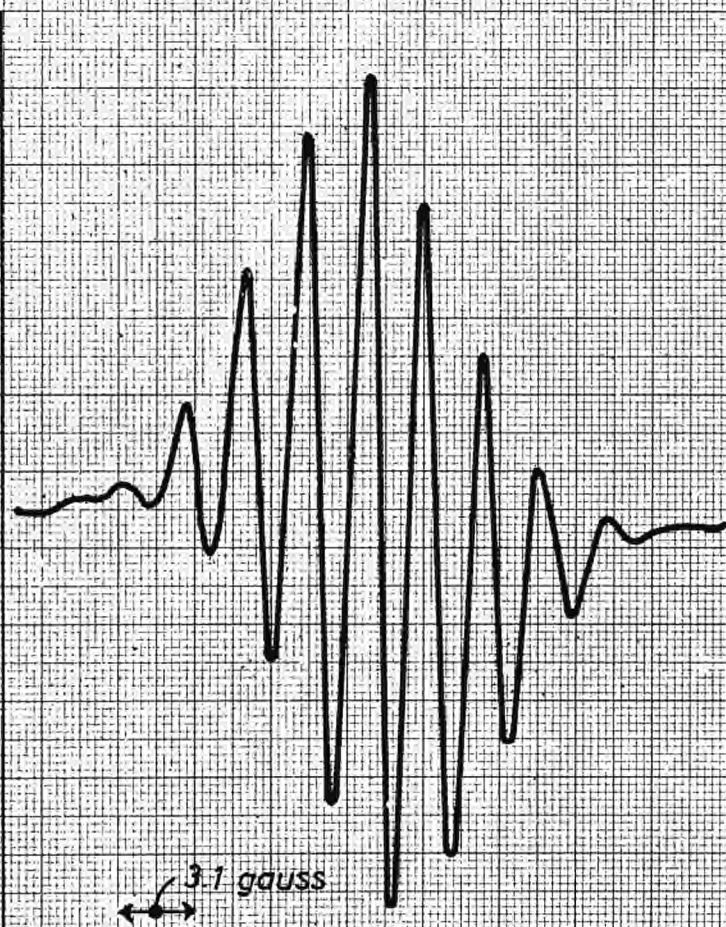
## 6 — Miscellaneous

In addition to the important studies outlined above we shall start two more working groups, one of which will be in charge of determination of physical constants at reactor operating temperatures, the other one of problems concerning coolant purification and reclamation.



SPECTRUM OF THE DIPHENYL  
NEGATIVE ION - E.S.R. -

FIG. 1



GAUSS



IN PILE RADIOLYSIS OF PARA - TERPHENYL							FIG. 2	
TEMP. °F	POSITION VESSEL	GAS VOLUME ml/gr	COMPOSITION VOL. %				H.B. W %	DOSE WH/gr
			H <sub>2</sub>	CH <sub>4</sub>	C <sub>2</sub> H <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>		
572	A	4.62	81.15	8.45	0.38	10.12	33	12.06
572	B	4.13	74.90	8.10	0.40	10.60	25	9.87
572	A	-	-	-	-	-	54.5	24.09
752	A	12.43	40.65	36.6	0	22.75	48.1	9.92
752	B	10.83	34.35	43.0	0	22.65	51.5	8.11
572	A	4.92	78.00	10.1	0.25	11.65	33	12.34
572	B	3.3	82.75	7.7	0.25	9.10	24.8	10.09



IN PILE RADIOLYSIS OF OM2 MIXTURE							FIG. 3	
TEMP. °F	POSITION VESSEL	GAS VOLUME cc / gr	COMPOSITION VOL. %				HB W %	DOSE WH/GR
			H <sub>2</sub>	CH <sub>4</sub>	C <sub>2</sub> H <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>		
572	A	6.15	76.20	12.30	0.1	11.4	39.10	15.05
572	B	5.10	77.50	12.70	0.2	9.6	42.4	16.51
572	A	3.65	83.30	8.75	0.45	7.45	24.3	8.53
572	B	3.24	80.80	8.15	0.55	10.50	20.50	6.98
572	B	5.94	85.0	10.10	-	4.9	38.20	14.39
572	A	1.93	90.0	5.8	0.45	3.7	13.75	4.02
572	B	1.72	92.0	4	0.6	3.2	8.80	3.29





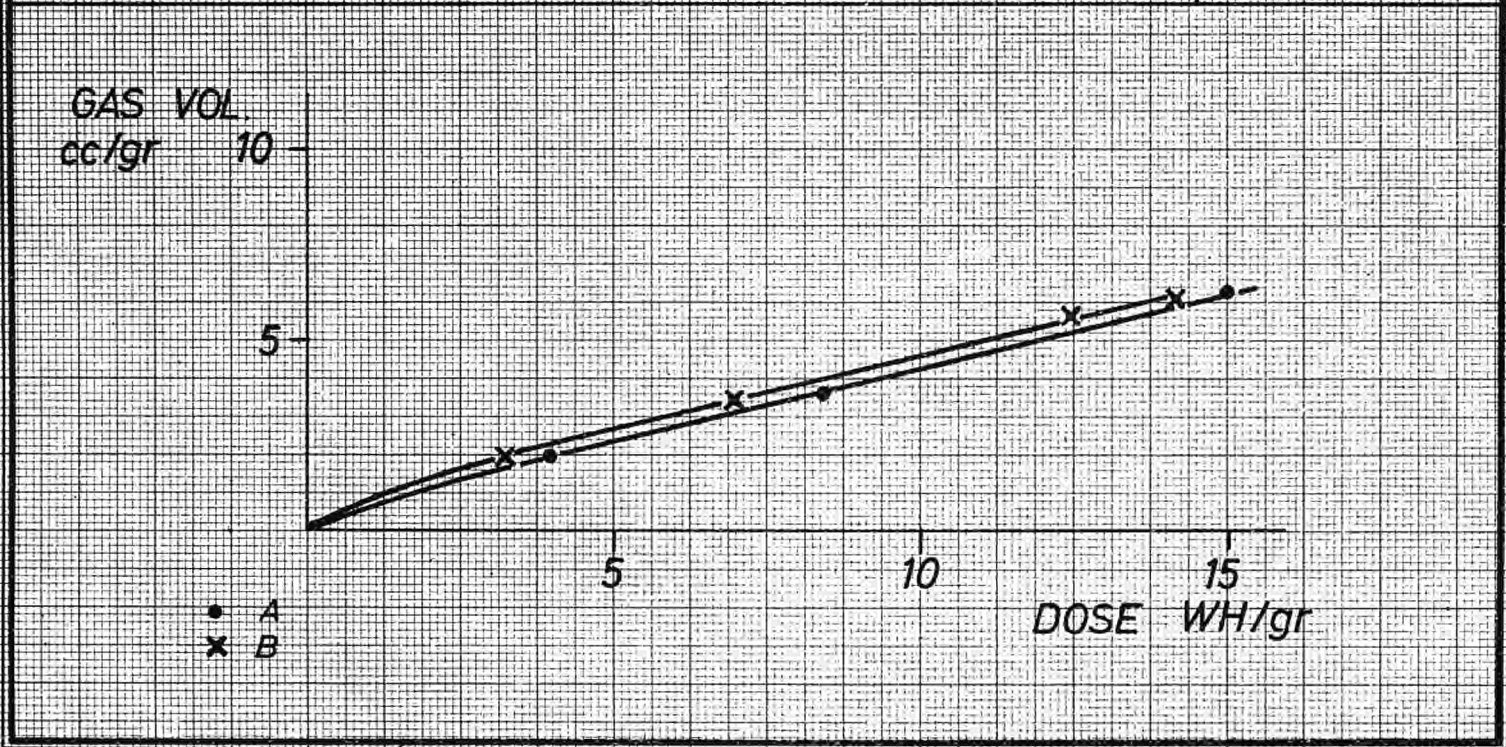
IN PILE RADIOLYSIS OF  $OM_2$  MIXTURE AT 572 °F VARIATION OF  
GAS PRODUCTION VS DOSE

FIG. 4

GAS VOL.  
cc/gr 10

• A  
x B

DOSE WH/gr





IN PILE RADIOLYSIS OF OM2 MIXTURE 572 °F  
VARIATION OF HB PRODUCTION VS DOSE

FIG. 5

HB  
%

44  
40  
36  
32  
28  
24  
20  
16  
12  
8  
4

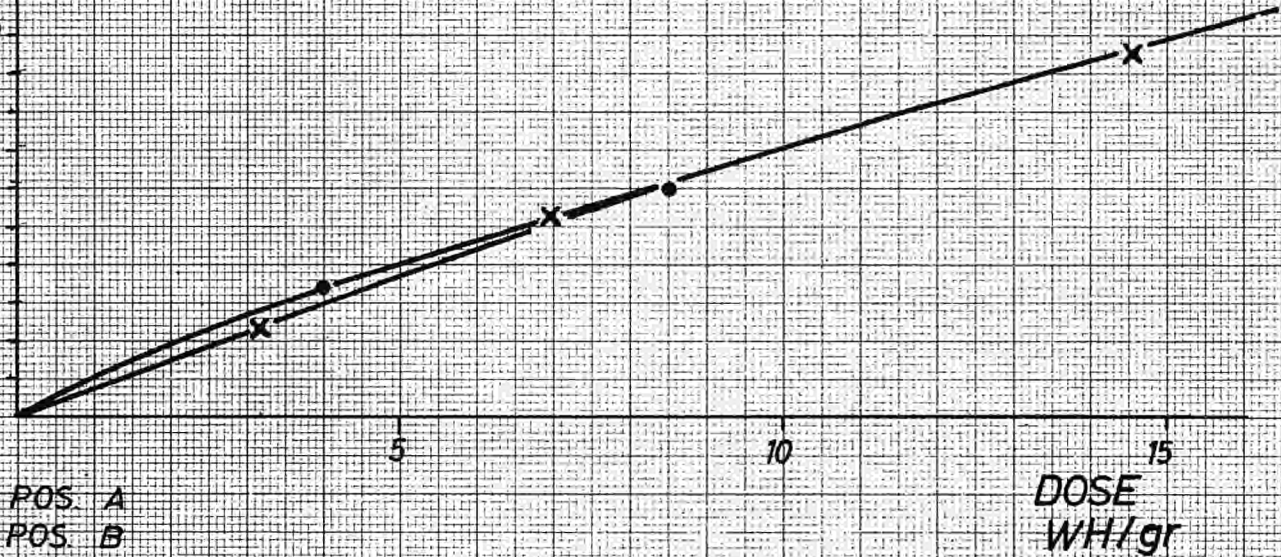
• POS. A  
x POS. B

5

10

15

DOSE  
WH/gr





PKROLYTIC LB GAS PRODUCTION OF PARA AND META TERPHENYL.

FIG. 6

META TERPHENYL			PARA TERPHENYL		
°F	TIME / DAYS	GAS VOL. cc / gr	GAS VOL. cc / gr	TIME / DAYS	°F
780	15	1.80	0.09	14	780
780	30	2.30	0.20	30	780
780	60	4.60	0.70	60	780
828	5	3.75	0.58	4.8	835
828	10	4.85	1.02	10	835
828	15	6.45	1.49	15	835
828	20	10.10	2.89	20	835
883	1	4.3	0.80	1	883
883	5	10.7	6.42	6	883



PYROLYTIC HB PRODUCTION OF PARA AND META TERPHENYL					FIG. 7
META TERPHENYL			PARA TERPHENYL		
°F	TIME / DAYS	HB %	HB %	TIME / DAYS	°F
780	15	22	3.5	14	780
828	5	64	23	4.8	835
828	10	74	41	10	835
828	20	78	58	21	835
883	1	64	29	1	883
883	5	74	72	6	883





PYROLYSIS OF META TERPHENYLS - GAS ANALYSIS							FIG. 8
TEMP. °F	TIME DAYS	GAS VOLUME cc/gr	GAS COMPOSITION VOL %				
			H <sub>2</sub>	CH <sub>4</sub>	C <sub>2</sub> H <sub>4</sub>	C <sub>2</sub> H <sub>6</sub>	CO <sub>2</sub>
780	15	1.84	53.2	30.2	0.2	13.1	3.3 *
	30	2.28	49.7	34	0	12.6	3.7 *
	66	4.65	56.7	28.2	0	13.8	1.7
883	2	2.29	87.9	9	0.2	3.0	0
	5	10.60	50.5	29.6	0.1	19.2	0.6
905	1	5.27	70.7	21.8	0.2	6.6	0.9
874	5	7.48	61.3	24.6	0.1	13.6	0.4
984	0.2	7.91	70.6	20.3	0.3	8.1	0.7

\* INCOMPLETE DEGASIFICATION BEFORE PYROLYSIS.



PYROLYSIS OF META TERPHENYL - SOLID PHASE COMPOSITION

FIG. 9

TEMPERATUR °F	TIME DAYS	SOLID COMPOSITION W %				
		BIPH	O - TERPH	M - TERPH	P - TERPH	HB
780	15	5.7	0	68.5	3.2	22.5
828	5	12.8	0	24.3	1	61.9
828	10	15.1	0	9.8	0	75.1
828	15	15.0	0	3.3	1.6	80.1
846	1	0.9	0	82.2	5.3	11.6
846	15	22.7	0.5	3.1	0.6	73.1
874	5	23	0	4.7	0.6	71.7
883	1	11.4	0	23.5	1.1	64.0
883	5	21.3	0	3.1	1.4	74
903	0.3	10.2	0	52.3	2.1	35.4
903	1	23.2	0	5.1	0	71.7
984	0.2	20.5	0.1	2.5	0.3	76.6



PYROLYTIC LB GAS PRODUCTION OF COMMERCIAL MIXTURES						FIG. 10
TEMPERATURE °F	TIME DAYS	GAS VOLUME CC/GR				
		META-TERPH	OM1	OM2	OMP	PARA-TERPH.
780	15	1.6	-	-	-	0.1
780	84	-	-	1.91	-	-
798	6	-	0.65	0.61	0.31	-
798	13	-	1.25	0.40	0.55	-
802	6.7	-	0.80	0.69	0.51	-
810	4.5	-	0.92	0.89	0.68	-
810	9	-	1.48	1.39	1.31	-
818	9	-	1.59	1.31	0.56	-
835	3	-	-	-	-	0.2
835	8	-	-	-	-	0.7
846	8	4	-	-	-	-



PYROLYTIC HB PRODUCTION OF COMMERCIAL MIXTURES						FIG. 11
TEMPERATUR °F	TIME DAYS	HB PRODUCTION Wt %				
		META-TERPH.	OM1	OM2	OMP	PARA-TERPH
780	15	22.5	-	-	-	3.5
798	12	-	24.4	25	-	-
802	6.7	-	7.3	7.5	8.3	-
810	4.5	-	12.6	14.3	12.2	-
810	9	-	-	31.2	27.6	-
818	5	-	-	20.7	21.4	-
828	5	62	-	-	-	-
835	5	-	-	-	-	23.3





ACTUAL SYNTHETIZED POLYPHENYLS			FIG. 12
QUATER Ph	QUINQUA Ph	HEXA Ph	VARIOUS
4' 4"	4' 4" 4'''	4' 3" 2''' 4'''	DIXENYLMETHANE
2' 2"	4' 3" 3'''	2' 4" 2''' 4'''	TRIPHENYLENE
3' 3"	4' 3" 2"	3' 4" 4''' 3'''	4 METH 3' 4" φ 4
4' 2"	4' 3" 4'''	3' 3" 2''' 4'''	
	3' 2" 4"	3' 5' 2" 4"	
	3' 4" 3'''	4' 3" 4" 4'''	
	3' 3" 2'''		
	3' 3" 3'''		
	2' 4" 2'''		

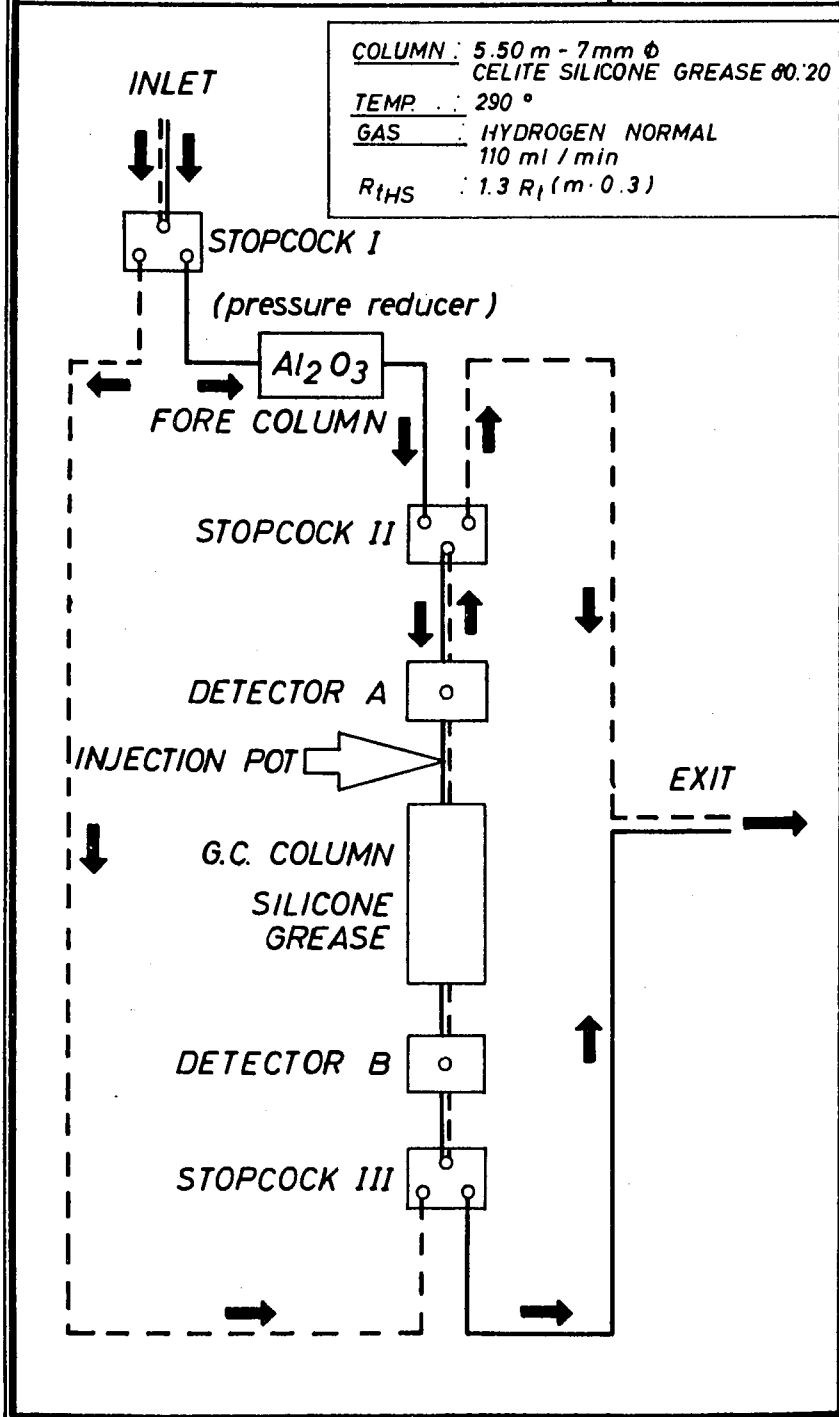
Diagram illustrating a linear chain of five hexagons (phenyl rings) connected by single bonds. The rings are labeled with numbers and primes to indicate their position and connectivity:

- Ring 1: 0 1
- Ring 2: 2' 3' (top labels), 1' 0 4'' (internal label)
- Ring 3: 1'' 0 4''' (internal label)
- Ring 4: 1''' 0 4'''' (internal label)
- Ring 5: 1'''' 0 4''''' (internal label)



FLWSHEET G.C. BACKFLUSHING  
( for HB determination )

FIG.13





DETERMINATION OF ISOMERIC COMPOSITION OF OM1 MIXTURE						FIG. 14	
SYNTHETIC SAMPLES							
TERPH.	VALUES OBTAINED				MEAN VALUE %W	REAL VALUE %W	RELATIVE ACCURACY %
	% W	% W	% W	% W			
ORTHO	19	18.5	18	20	18.9	19.2	4.5
META	51.5	48	48	47	48.6	49.2	4.2
PARA	32	28.5	30.5	29.5	30.1	31.6	7
OM1 MIXTURE							
TERPH.	VALUES OBTAINED		MEAN VALUE %W	REAL VALUE %W	RELATIVE ACCURACY %		
	% W	% W					
ORTHO	65	63.5	64.2	62	5.40		
META	37.5	35.0	36.2	33.2	14.0		
PARA	4.25	4.55	4.40	4.2	8.3		



DETERMINATION OF IRON IN TERPHENYLS BY X RAYS AND  
INORGANIC WET ANALYSIS.

FIG. 15

SAMPLE	R X ppm	CHEM. ANAL. ppm
S - 5	3	3
S - 10	12	11
S - 20	20	20
S - 30	37	49
S - 60	63	64
S - 100	99	108
S - 300	312	279
OMRE	190	171

S = SYNTHETIC SAMPLES





IRON - NICKEL - CHROME : ITS DETERMINATION BY DIFFERENT METHODS							FIG. 16		
ELEMENTS	Fe (ppm)			Ni (ppm)			Cr (ppm)		
METHODS SAMPLES	XR	CA	ES	XR	CA	ES	XR	CA	ES
OM <sub>2</sub> CORROSION TEST	-	751	-	319	216	-	-	87	-
OM <sub>2</sub> CORROSION TEST	18	25	19	4	6	-	-	1	-
IRRADIATED OM <sub>2</sub>	8	8	10	1.5	1	4	0.8	1	2
OMRE PRODUCT	190	180	200	4	2	2.5	0.8	0.3	-
AKP <sub>3</sub> (IN PILE IRRADIATED PRODUCT)	225	216	230	30	22	34	50	45	-

XR = X RAYS      CA = CHEMICAL ANALYSIS      ES = EMISSION SPECTROGRAPHY





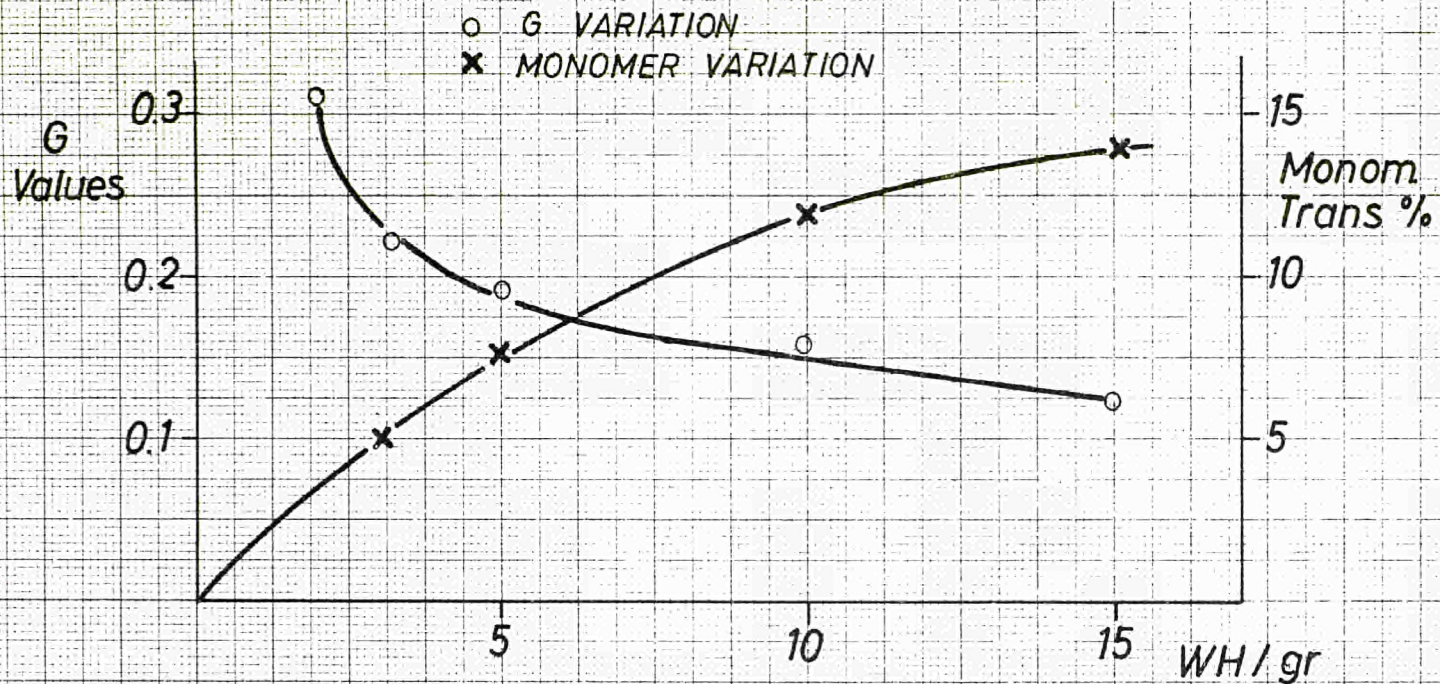






IN PILE IRRADIATION OF THE AKP3 POWER FORMATING  
DISTILLATION CUT - G AND TRANSFORMED MONOMER VS DOSE

FIG. 19

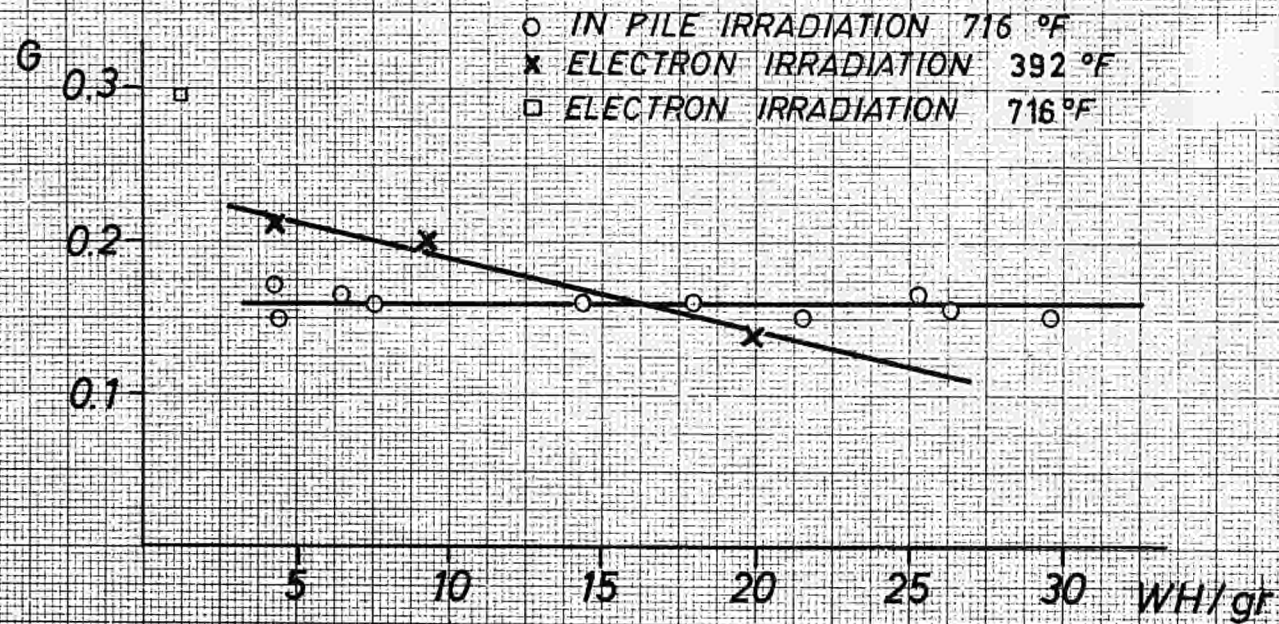






IRRADIATION OF OM<sub>2</sub> MIXTURE -  
G VALUES FOR DIFFERENT RADIATION SOURCES

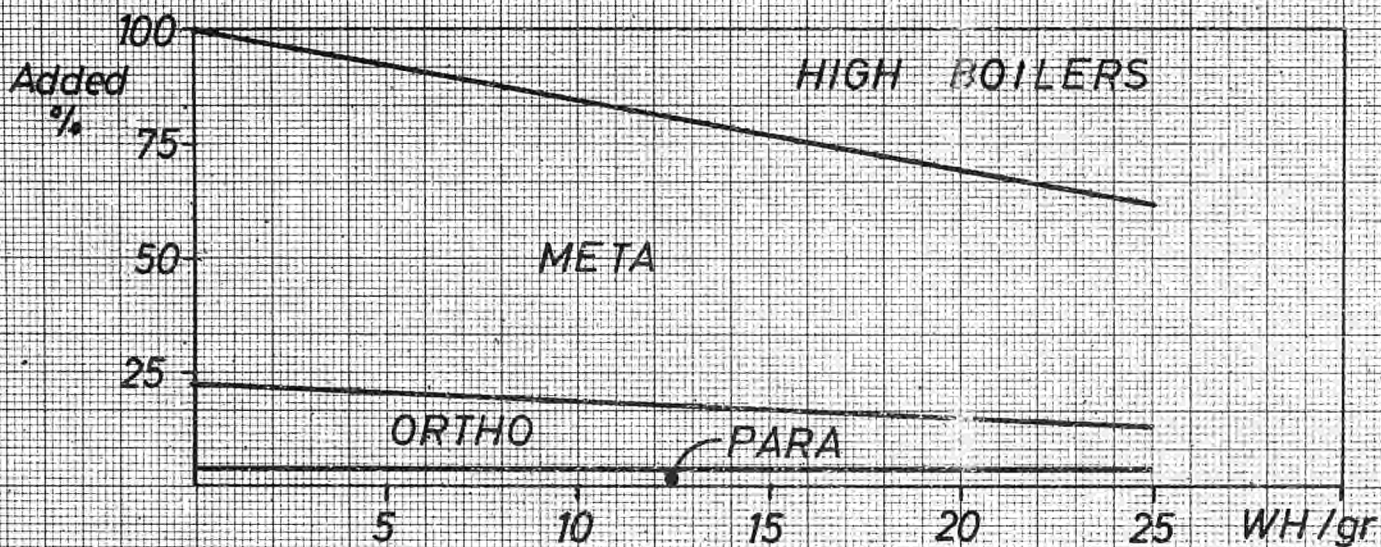
FIG. 20





IN PILE  $^{60}\text{Co}$  IRRADIATION AT 716 °F VARIATION IN  
ISOMERIC CONTENT VS DOSE

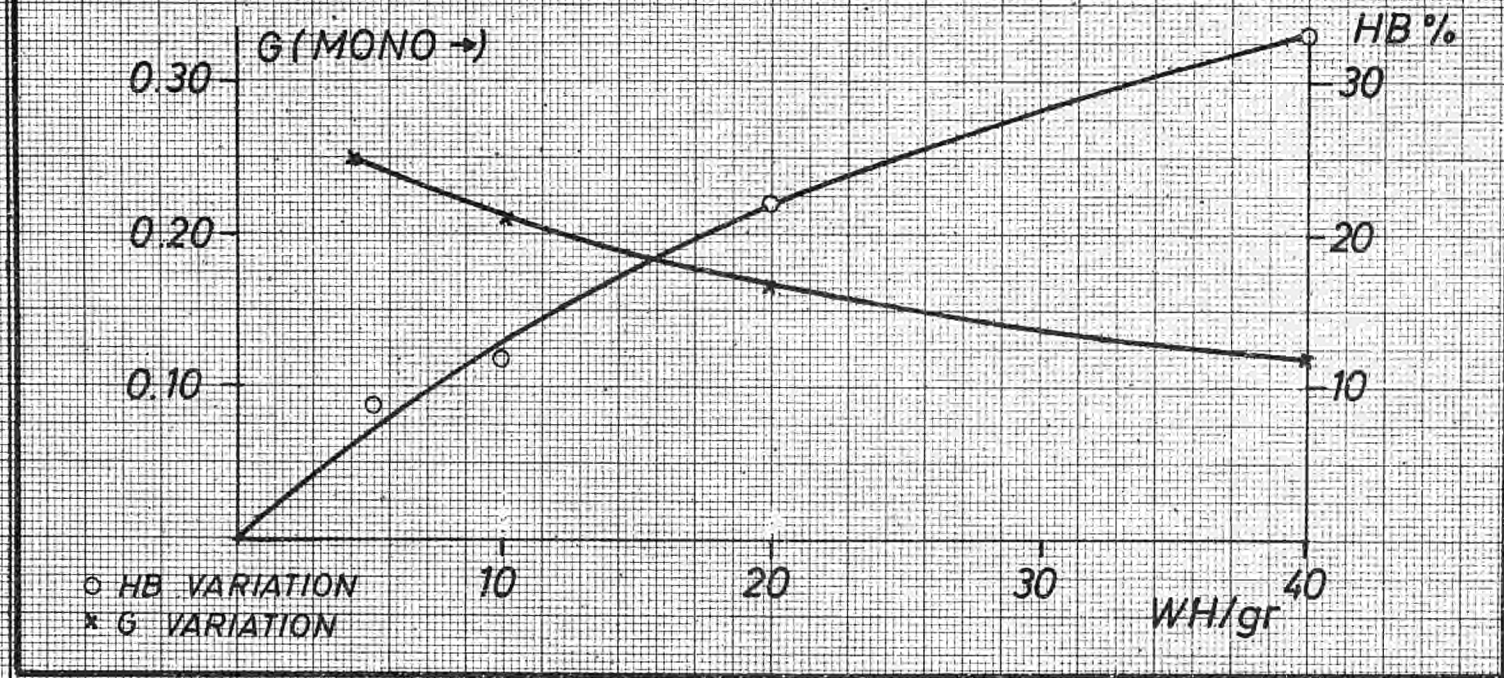
FIG. 21





ELECTRON IRRADIATION OF A AKP<sub>4</sub> DISTILLATION CUT -  
G. AND HB VALUES VS DOSES.

FIG. 22





LOOPS SITUATION, JUNE 1962

FIG. 23

LOOPS CHAR.	IFP 1	IFP 2	PROGIL CEA 1	PROGIL CEA 2	PROGIL CEA 3	PROGIL CEA 4	PROGIL IFP 1
IRRAD.	PILE	PILE	PILE	PILE	ε	ε	ε
PURPOSE	RAD	RAD	RAD	RAD	RAD	FOULING	RAD
COOLANT	SUBST	SUBST.	OM <sub>2</sub>	OM <sub>2</sub>	OM <sub>2</sub>	OM <sub>2</sub>	SUBST
TOTAL VOLUME	30 L	30 L	25 L	25 L	0.25 L	20	( ? )
NATURE	ISOTHERM.	ISOTHERM	HEATING	HEATING	ISOTHERM	ISOTHERM	ISOTHERM
STATE	WORKING	WORKING	IN PILE	CONSTR. FINISHED	CONSTR. FINISHED	UNDER CONSTR.	IN STUDY





## CHAPTER VII — PHYSICAL CHEMISTRY

### Introduction

The Physical Chemistry Branch devotes its activities to the investigation of the basic processes which can have a weight on the choice and the proper use of materials.

In this spirit we have attacked some problems that may have a controlling influence on the ORGEL concept, namely :

- Fouling, which may determine fuel rod spacing and, therefore, reactivity lifetime.
- Corrosion of filling, canning and other structural materials.
- Re-entry of fission gases, for its potential importance in the use of compacted fuels.
- Creep processes, which may determine clad thickness and, therefore, reactivity lifetime.
- Conductivity of UC and pellet-clad temperature drop which may limit power density or fuel rod diameter.

The following table gives a general picture of the Branch activities devoted to the ORGEL concept.

### 1 — Corrosion and compatibility

#### 1.1 — Determination of H<sub>2</sub>O in polyphenyls

A method was developed to determine water concentration in terphenyls during autoclave corrosion tests.

The operating principle is based upon the fact that water reacts with known amounts of iodine, which are electrochemically produced in a cell filled with exhausted Karl Fischer solution.

Completion of the reaction is ascertained by depolarization of an indicating platinum electrode.

A standardized sampling procedure was found to yield reproducible results with deviations of 2 - 3 % when the amount of water ranges at 20 - 40 microgram, i.e. concentrations of about 30 ppm. It was found possible to determine amounts of water as little as 1 - 2 microgram, i.e. concentrations ranging from 1 to 5 ppm. with a reproducibility of ±20 %. Present work is aimed at making these measurements continuous and also in using ethylene glycol to extract water from the solution. This procedure would be required for analysis of less soluble polyphenyls.

The tests have also shown that the volume of liquid withdrawn from the autoclaves, however small, has an effect on the water concentration itself. This is probably due to the fact that by varying liquid to vapor ratio a certain amount of water is stripped from the liquid phase.

**PHYSICAL CHEMISTRY BRANCH ACTIVITY MAP**

	OBJECT	MEANS
1) CORROSION AND COMPATIBILITY	Determination of H <sub>2</sub> O in polyphenyls Compatibility Mg, steels, graphite with polyphenyls	Modified Karl Fischer Autoclaves
2) FOULING	Behaviour of suspended particles in electric fields Microscopic processes : Formation and stability of suspensions Global assessment	Electrochemical apparatus Fouling capsules Loop out of pile in pile
3) STRUCTURAL PROPERTIES OF UC	Influence of impurities on lattice parameters Influence of irradiation on electrical properties	X-rays (Electron microscope) Conductivity and Hall effect apparatus
4) RE-ENTRY OF FISSION GASES	Trapping of high energy noble gas ions by UC surfaces Equilibrium pressure in compacted fuels	Heavy ions accelerators In pile capsule irradiations of UC powders with Xe and Kr
5) CONTACT CONDUCTANCE AND UC CONDUCTIVITY	Pellet-can temperature drop Development of a method to measure conductivity of fuels at high temperature	Capsules out of pile in pile Diffusivity apparatus
6) SAP STRUCTURE	Interpretation of creep phenomena Interpretation of annealing phenomena	Internal friction apparatus Electron microscopy

The procedure was applied for the control of corrosion runs in which water contents in the terphenyls ranged from 5 to 200 ppm.

**1.2 — Compatibility of Mg, steels, graphite with polyphenyls**

A series of corrosion tests were made in terphenyls at temperatures up to 500 °C and durations up to a few hundred hours. The high rates of corrosion of Mg samples were later ascertained to be due to unusually high concentrations of chlorine in the liquid (1 000 to 2 000 ppm.). Therefore, a new series of runs is being undertaken with a careful control of the amounts of impurities in the organic by means of neutron activation analysis.

Some checks carried on with normal-grade nuclear graphites (Pechiney and Union Carbide) at temperatures up to 470 °C show a complete impregnation of the samples which were about 1 cm thick and no appreciable loss of weight.

## 2 — Fouling

Preliminary estimates on the production of high polymers near the surface of the fuel element and their diffusion through the boundary layer showed that their concentration near the surface is only slightly higher than in the bulk. On that ground we did not pursue purely chemical studies and concentrated on the line of suspended matter.

The work done or under way is directed to the study of :

- a) Generation of particles
- b) Stability of the suspensions
- c) Formation of electric fields in the coolant
- d) Behaviour of particles and thick suspensions in electric fields.

Point a) is developed by our corrosion group and no results are yet available.

As to point b) we have tentatively found that iron and iron oxides do not give stable suspensions if introduced as powders in clean polyphenyls. Carbides give stable suspensions. Oxides are reduced to iron by boiling in polyphenyls but no carbide formation is observed.

The suspensions we use for current experiments are produced by sparking between submerged electrodes.

As to point c) detailed calculations have been performed to evaluate the electric fields produced by  $\beta$ -currents.

Missing parameters are conductance of the organic under irradiation and actual charge of the particles. We are performing out of pile measurements to establish both.

Further, flowing insulating liquids have a tendency to be changed electrically and can set up strong fields. This is also under investigation.

Assuming reasonable values for the unknown resistivity  $10^{-10}$  ohm<sup>-1</sup> cm<sup>-1</sup> for Santowax R and as a mean value for the electro-kinetic potential in organics, 30 mV, the rates of deposition are in the correct range.

As the suspension thickens in the boundary layer, the effect of the electric fields on their viscosity becomes important. Here also measurements are in course.

### *Global assessment*

To be able to evaluate the effect of different operating conditions on the velocity of formation of the crud deposits, three experiments are being carried on. The first of these is similar to A.I.'s P.C.F.T.

The second and third experiments are an out of pile and in pile loop.

The out of pile loop is in the stage of assembly. The in pile loop has reached the stage of design completion. Both loops have electrically heated test sections and operate near isothermally up to 450 °C and 10 meters/sec.

### 3 — Structure properties of UC

The initial stage of the research has been concerned with the growth of UC single crystals. The technique applied has been that of subliming UC crystals from sintered or molten UC rods. The procedure follows :

A longitudinal hole is drilled either with a ultrasonic drill or with a spark-cutter in a UC rod. This rod is then closed on both sides by a UC lid. The whole is then submitted to extended cleaning with ultrasounds and then placed in a high-vacuum, HF oven, degassed and heated to about 2 500 °C for several days. Two crystallisation processes take place :

- a) a grain growth of the sintered material up to about 6 or 7 mm,
- b) a sublimation of small perfectly looking UC crystals on the colder parts (the lids).

X-ray analysis (powder diagrams) have only revealed the UC phase, though the cell dimensions are still below the intrinsic parameter, meaning probably the presence of occluded gases within the unit cell.

### 4 — Re-entry of fission gases

There is evidence that fission fragments emerging from the fuel surface can knock fission gases back into the fuel. This process can help establish an asymptotic equilibrium pressure inside the fuel can, which can be fairly low in the case of subdivided fuels.

A basic experiment will establish the depth and probability of trapping noble gas ions impinging on a UC surface as a function of the energy in the range 0-10 KeV. An accelerator tube is in the stage of assembly and testing for this purpose. It will use Krypton gas labeled with Kr<sup>85</sup>.

A more global experiment will be made by irradiating UC powders of known grain size in capsules pressurized with either natural Xenon or Krypton 85. After irradiation the fuel is dissolved and the trapped gas is determined by mass spectrometry or by counting.

Our first aim is to check on the order of magnitude of the re-entry phenomenon. The capsules have been structured and are under test.

### 5 — Contact conductance and UC conductivity

#### 5.1 — Contact Conductance UC-SAP

According to the investigations carried out by Westinghouse (WAPD 228) for UO<sub>2</sub>-steel, interface conductance can be as low as 2 Watt/sq.cm °C. Due to the poor mechanical properties and high thermal expansion of SAP, interface conductance is expected to be on the low side.

With surface heat fluxes of the order of 100-200 Watt/sq.cm, the temperature drop across the interface can attain values of possibly 500 °C and a knowledge of the factors affecting this drop has some weight on the use of UC. In order to correlate such resistance against surface finish and contact pressure, three experiments have been undertaken :

— Plane geometry :

The apparatus, of a conventional type, is now under test.

— Cylindrical geometry, out of and in pile :

Contact pressure is obtained by differential thermal expansion of the electrically heated fuel pellet and the SAP clad. The contact pressure is estimated by putting strain gages on the clad. Temperature distribution in the pellet is obtained by optical pyrometry with holes of different depths drilled into the pellet. This apparatus is under construction.

In-pile, the same experiment will be carried out along the line of WAPD 228, that is with nuclear heating at low flux (about  $10^{13}$  n/sq.cm sec.) in the Ispra 1 reactor and at high flux (over  $10^{14}$ ) in the Pool Facility of the MTR reactor in Petten.

## 5.2 — High temperature diffusivity of UC

The method chosen was the following :

A thin wafer of UC is heated by means of a modulated wide-beam electron gun. Measurements of the phase shift between the electron heating and the light output from the hind face of the wafer yields a value for thermal diffusivity. The electron gun has been developed and operates satisfactorily. Temperatures up to 1 500 °C have been attained and a modulation of less than 10 °C is sufficient to yield a good signal output. The first series of runs seems to indicate a lower thermal diffusivity than estimated from published data.

## 6 — SAP structure

### 6.1 — Interpretation of annealing phenomena

The impurity content in SAP 960 has been determined by spectro-graphical analysis, based on the method of internal standard on doped aluminum samples.

The melting process and the characteristics of SAP 960, 930 and 865 have been studied by thermal analysis in the range 620 - 680 °C. The behaviour of the oxide grains in the melt and during solidification has been observed.

The annealing processes in cold rolled SAP 960 have been studied in the range 25 - 600 °C. The grain size distribution and the rate of growth have been determined as a function of time and annealing temperature. The activation energy for the first annealing stage has been defined.

The results can be summarized as follows :

- The content of metallic impurities in the examined samples is about 5 000 ppm. Other elements like carbon and nitrogen are contained in large amounts.
- Melting of SAP is completed at a temperature which is practically the same as of aluminum with the correspondent impurity content.

- Thermal analysis plots of SAP show the occurrence of endothermal processes at 651 °C during heating, and an hysteresis in the cycle melting-solidification which seem due to the presence of impurities dissolved in the solid matrix at high temperature, and to their absorption on the alumina when melting takes place.
- Cold rolled SAP presents a subcrystal structure. Subgrain size ranges from 0,12 to 0,4 with a mean value of 0,28.
- Subgrain growth occurs by annealing, accompanied by a larger spread in subcrystal dimensions.
- The growth rate in SAP is much lower than in aluminum in comparative conditions of subgrain size and temperature.
- The recovery rate decreases inversely proportional to time. Between r.t. and 300 °C more than 90 % of the growth process takes place within few minutes.
- The thermal activation energy for subgrain growth in SAP 960 is 3 700 cal/mol.
- The first recovery stage undergoes an exhaustion and no further growth is observed in SAP 960 between 300 and 500 °C. Dislocation motion is practically inhibited and the average grain size remains constant at 0,5.
- A second stage of crystal growth occurs in SAP 960 at temperatures higher than 500 °C.
- High interest is confirmed to investigate further the recovery phenomena which are connected to possible improvements of the mechanical properties of SAP.

The phenomena of subgrain growth in cold rolled SAP 960 have been quantitatively studied in the temperature range 30 - 300 °C.

By comparing the subgrain growth at constant temperature (300 °C), for different times of heating, we have observed that more than 90 % of the total growth happens in the first minutes, while no difference has been noted between 30 minutes and 1 hour.

The activation energy of this stage of the process results  $Q = 3\,740$  cal/mol corresponding to about 0,16 eV.

This value is remarkably lower than the activation energy for grain growth in pure aluminum (about 1,5 eV).

Further, it appears that the instantaneous rate of growth in SAP is much lower than in aluminum subcrystals, in comparative conditions of size and temperature.

An energy of about 2 500 cal/mol is deduced for the displacement of an aluminum atom for an atomic length. An energy of about 6 000 cal/mol is obtained for overcoming the obstacles.

To clarify the mechanism of the first growth stage and the reasons for its decay, further theoretical and experimental research is necessary, based also on the study of the growth phenomena at temperatures higher than 500 °C.

Our future work will concern these problems.

## 6.2 — Interpretation of creep phenomena

Internal friction measurements are performed in the Kc-range in the attempt to use this method to detect structural changes in SAP during creep. A machine to produce creep in samples which are under observation in the electron microscope is in the development stage.

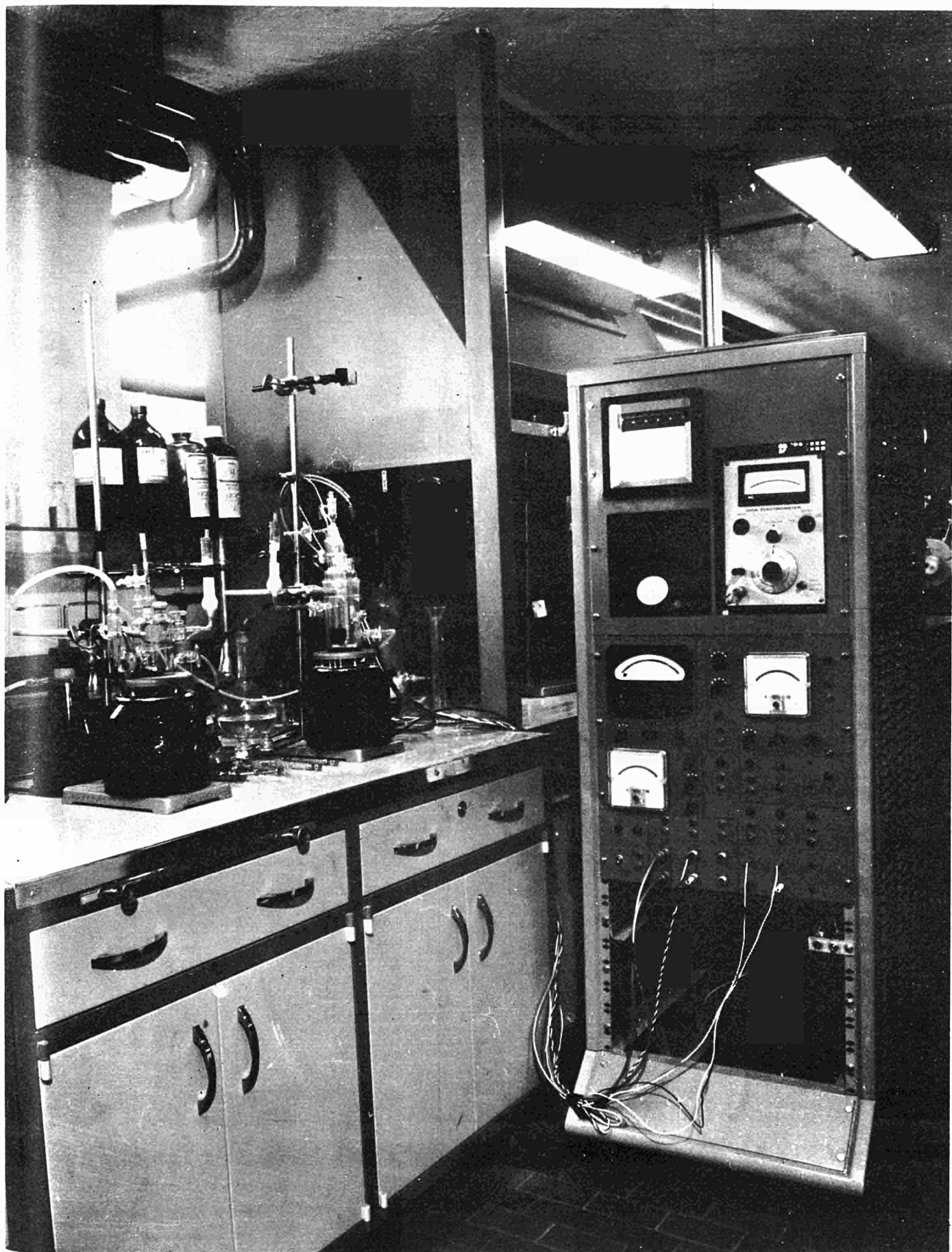
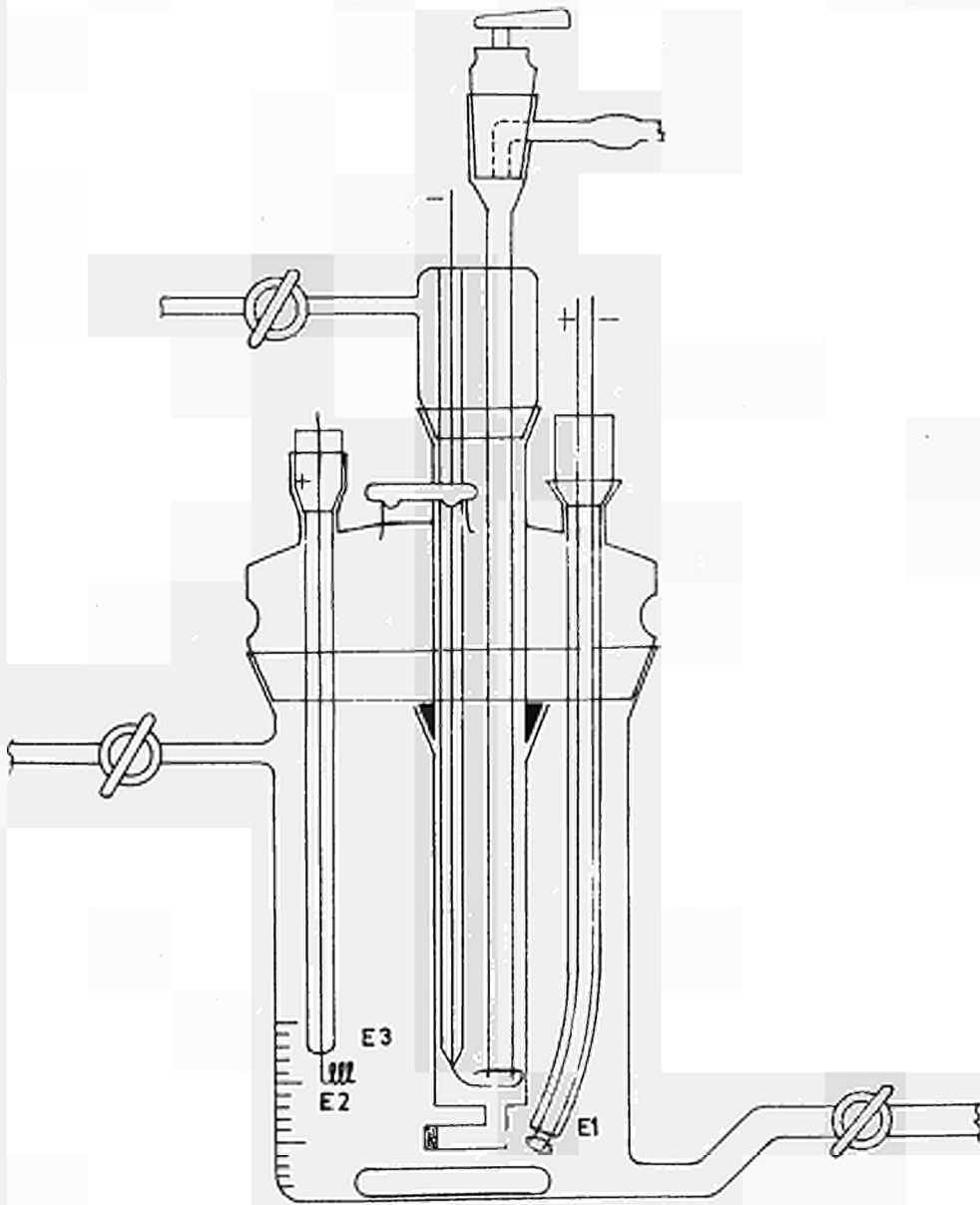


Fig. 1 - Assembly for water detection in terphenyls





FIG. 2



MODIFIED KF CELL



FIG. 3

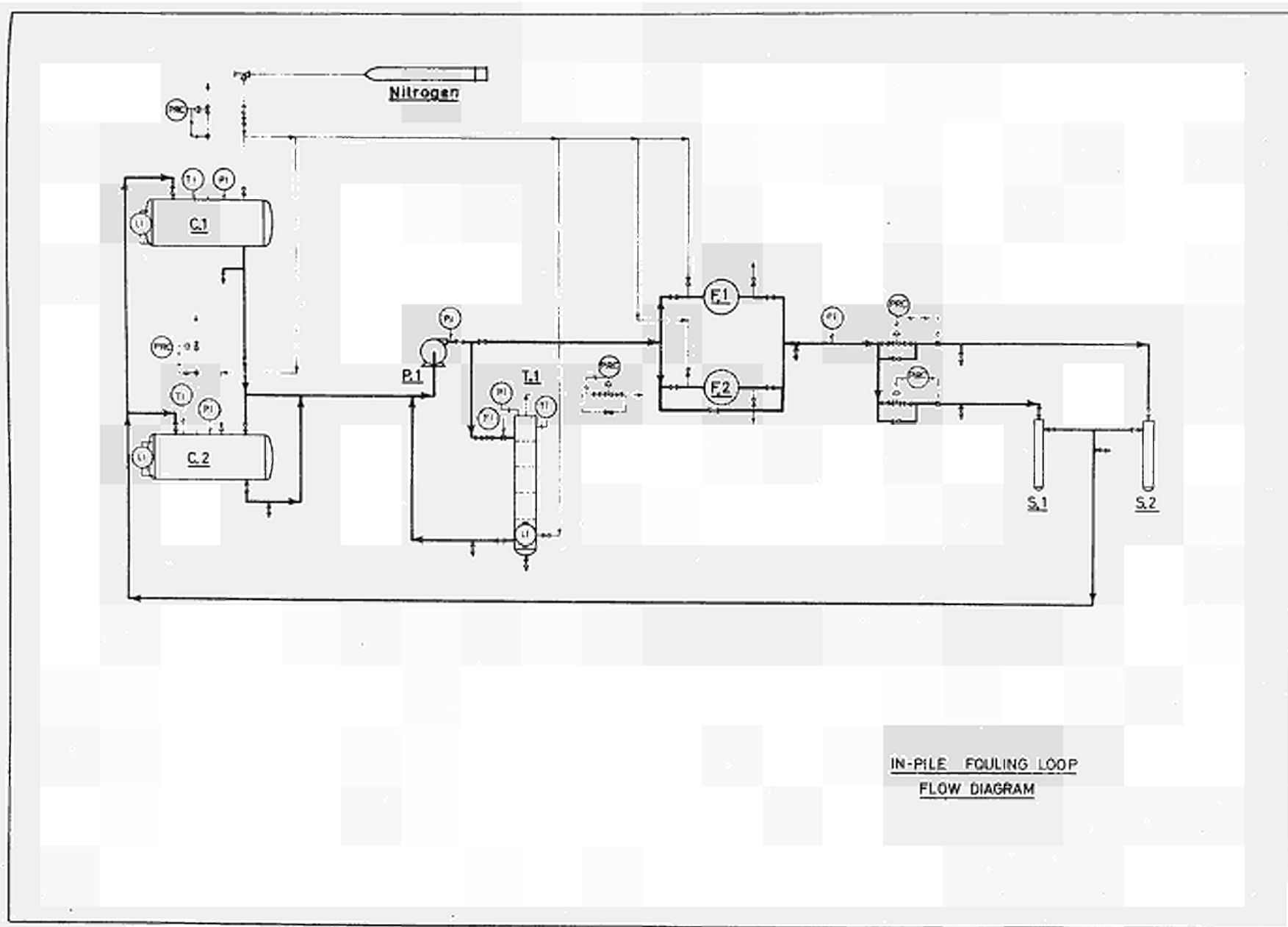
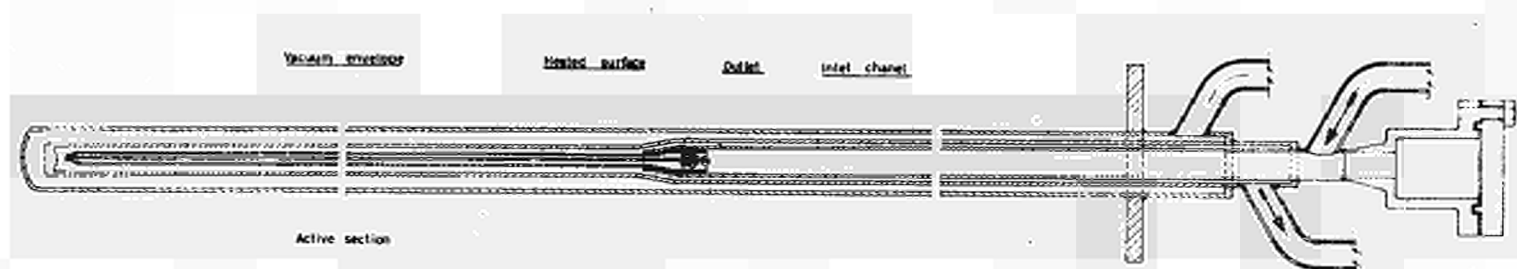




FIG. 4



IN-PILE FOULING LOOP  
TEST SECTION



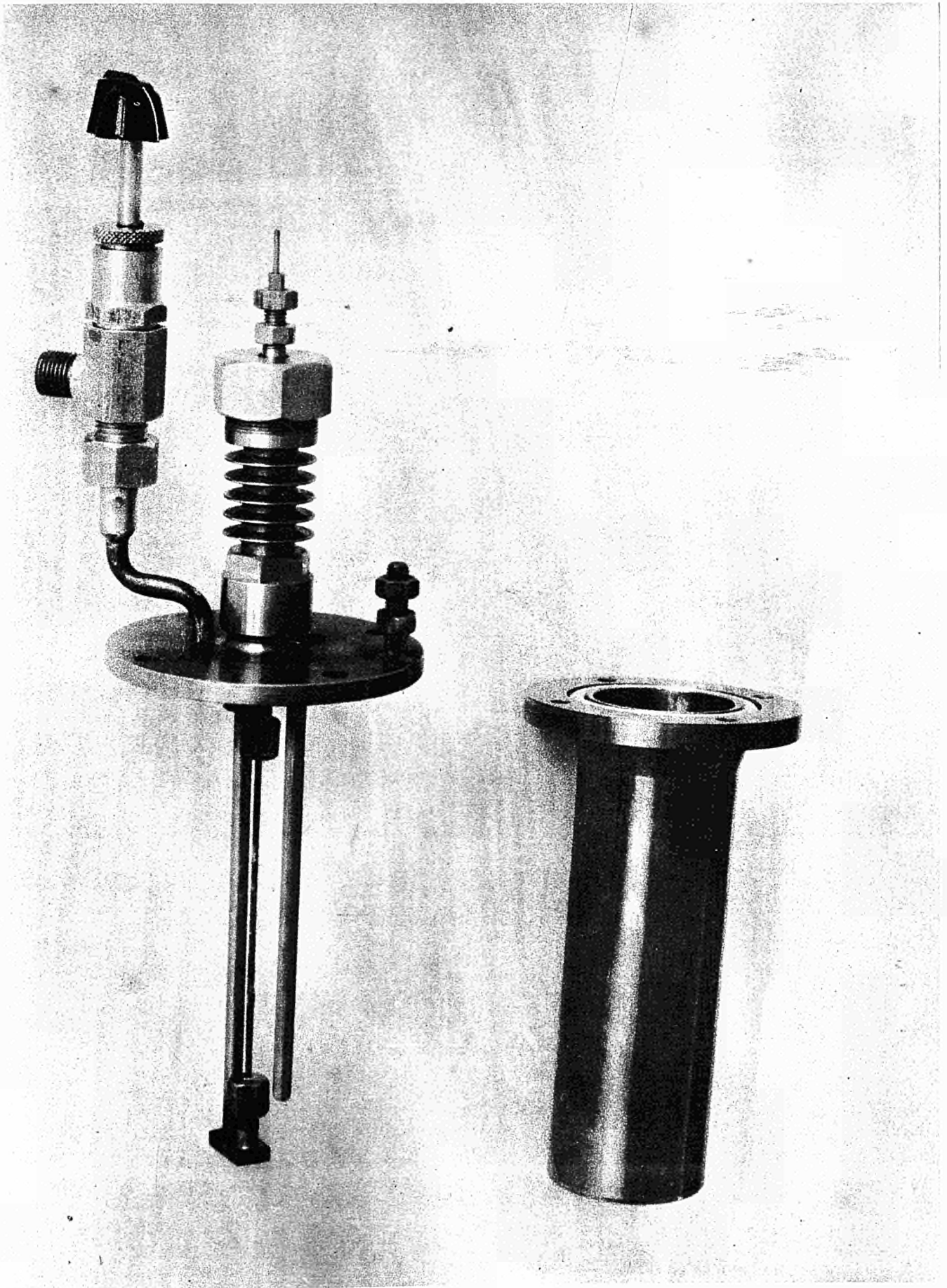


Fig. 5 - Fouling Test Capsule





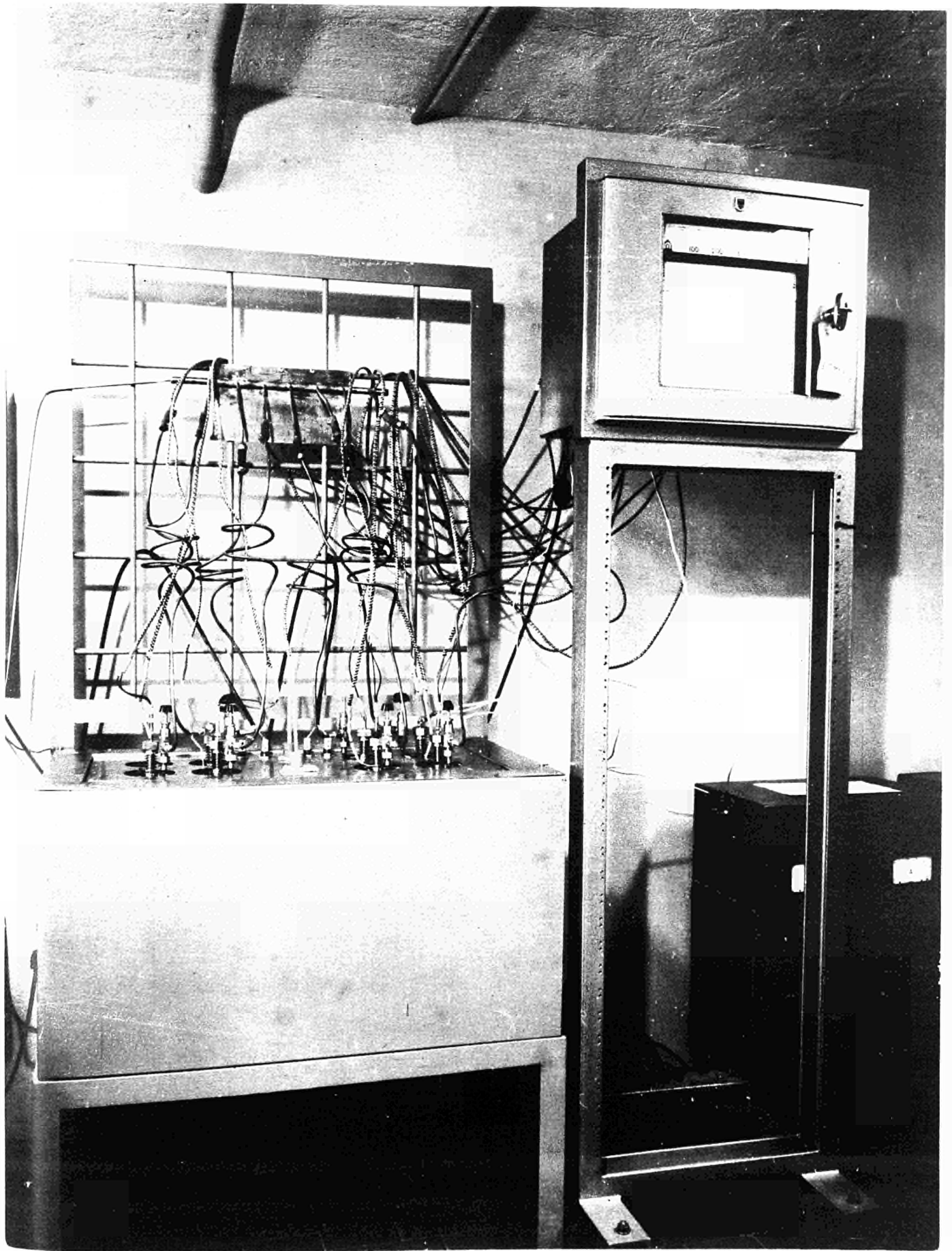


Fig. 6 - Fouling Test Bench



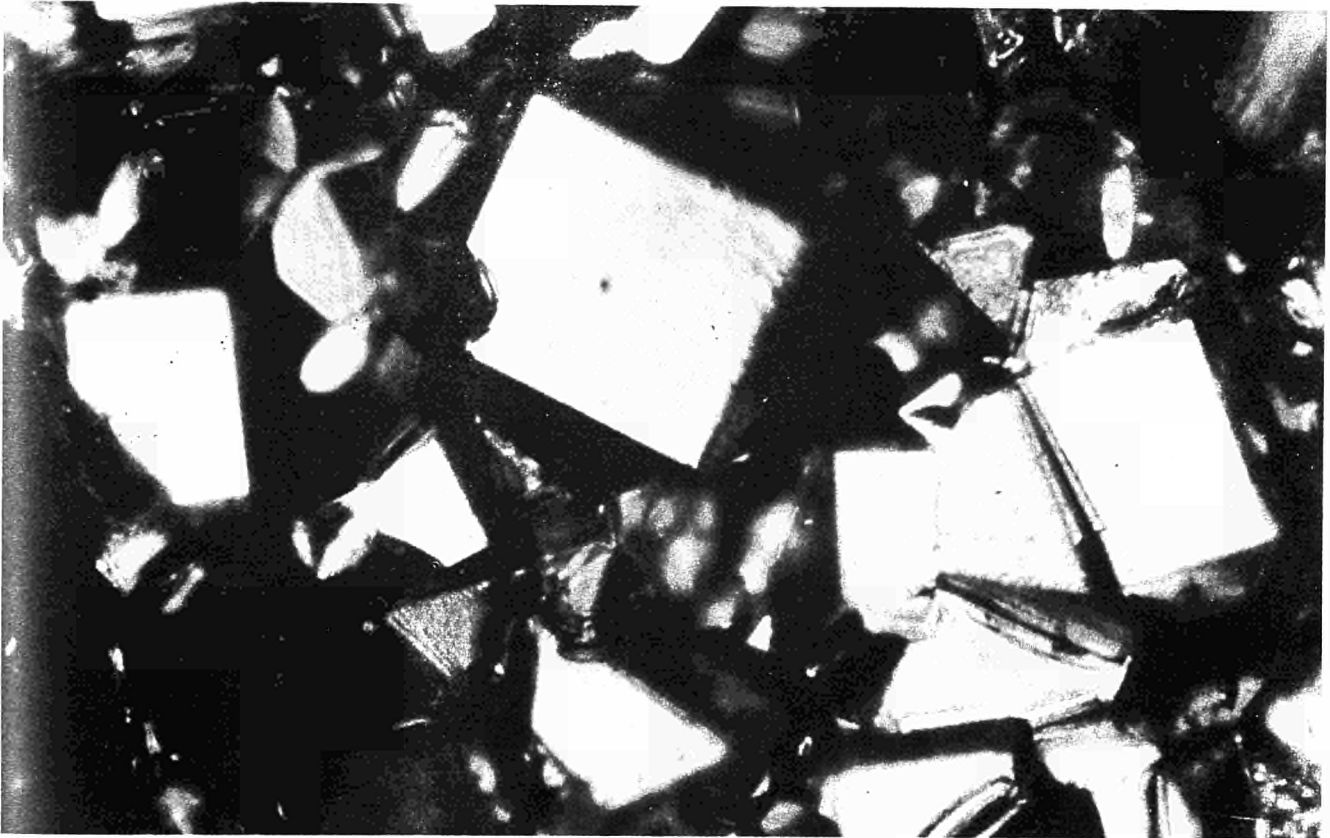


Fig. 7 - UC Monocrystals

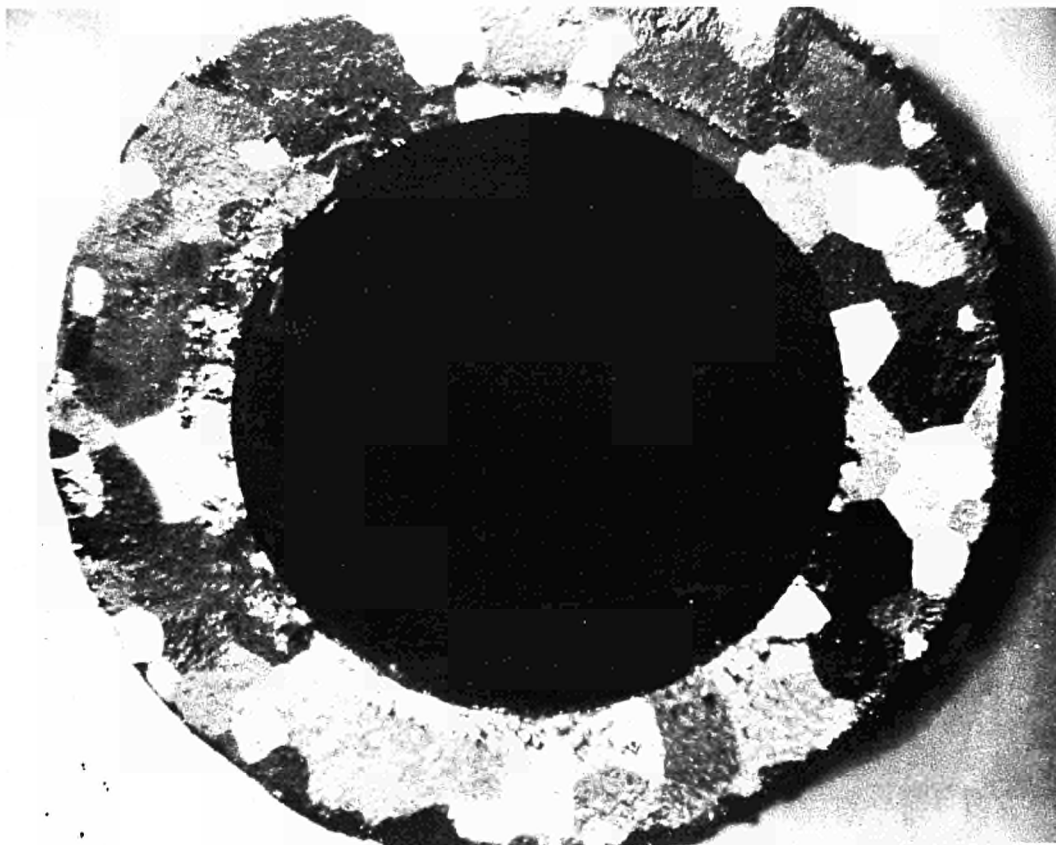


Fig. 8 - UC Sublimation Crucible



Fig. 9 - Re-entry capsules and counting chains

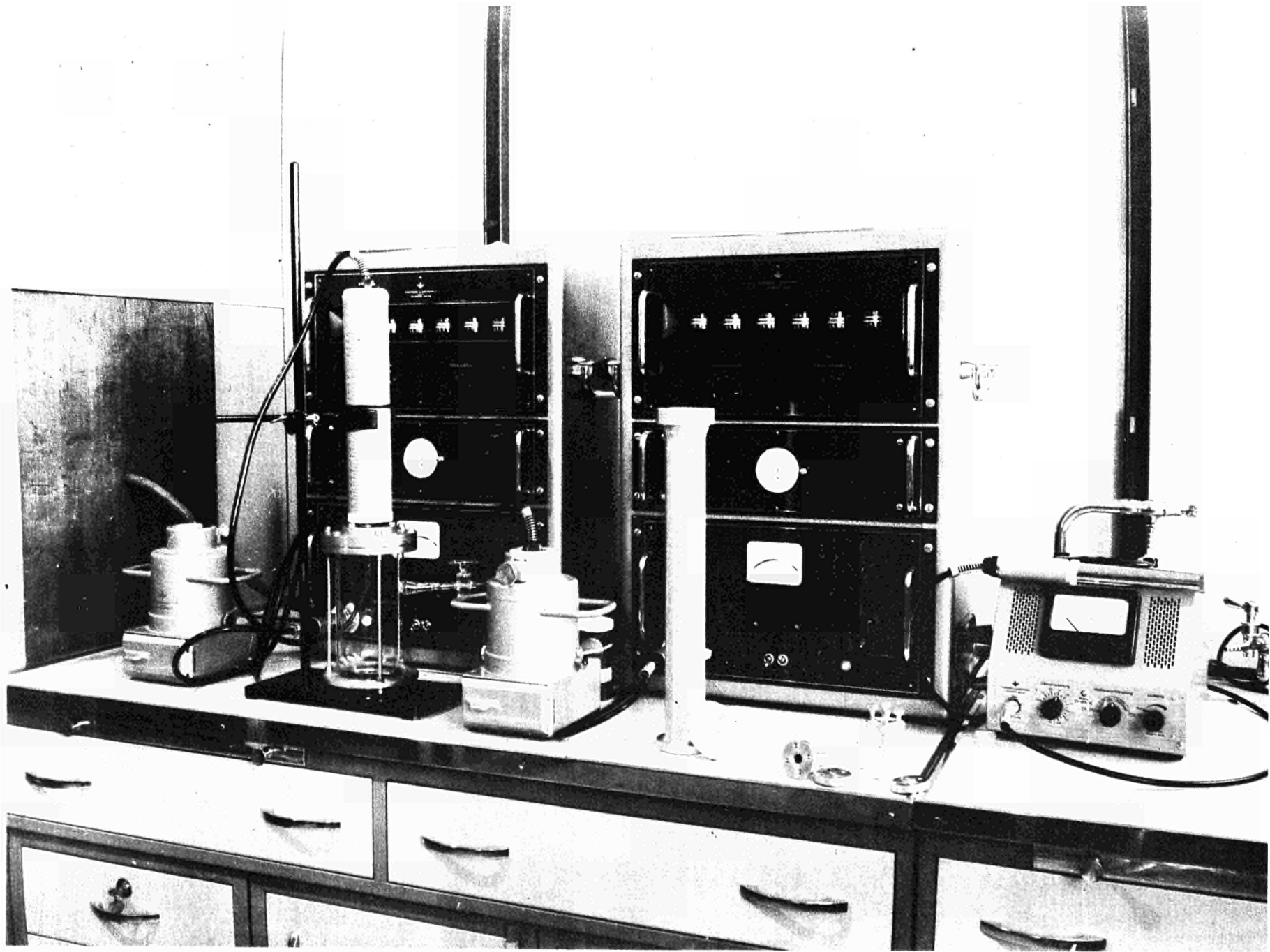
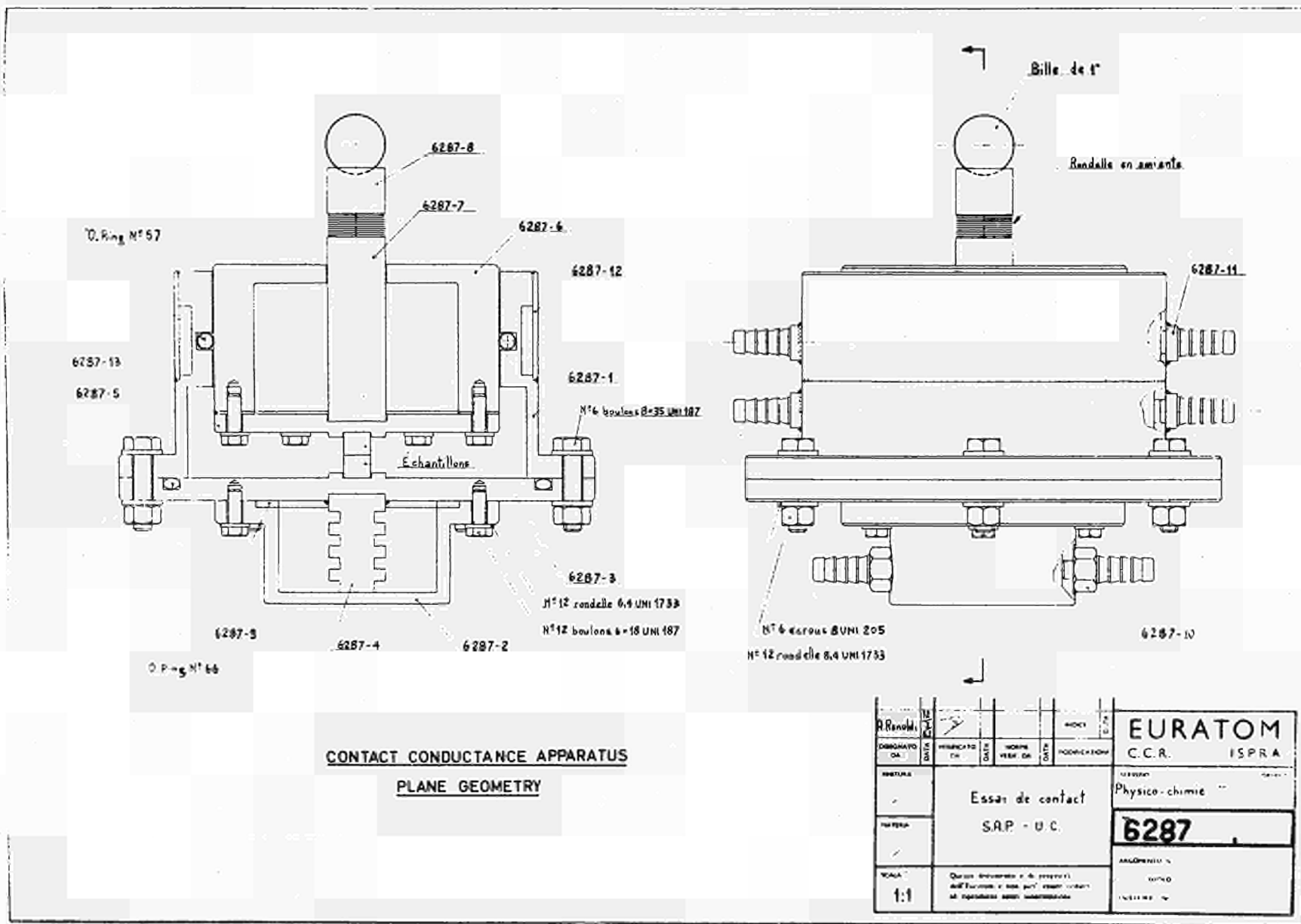




FIG. 10



R. Renoult		M. T. C.		INDUSTRIE		Z. U. D.		EURATOM	
ORGANISME	DA.	PROJET	CH.	DATE	VERIF. DA.	POUR	CHIFFRE	C.C.R.	ISPRA
NATURE		Essai de contact						Physico-chimie	
NATURE		SAP - U.C.						<b>6287</b>	
SCALE		1:1						6287	

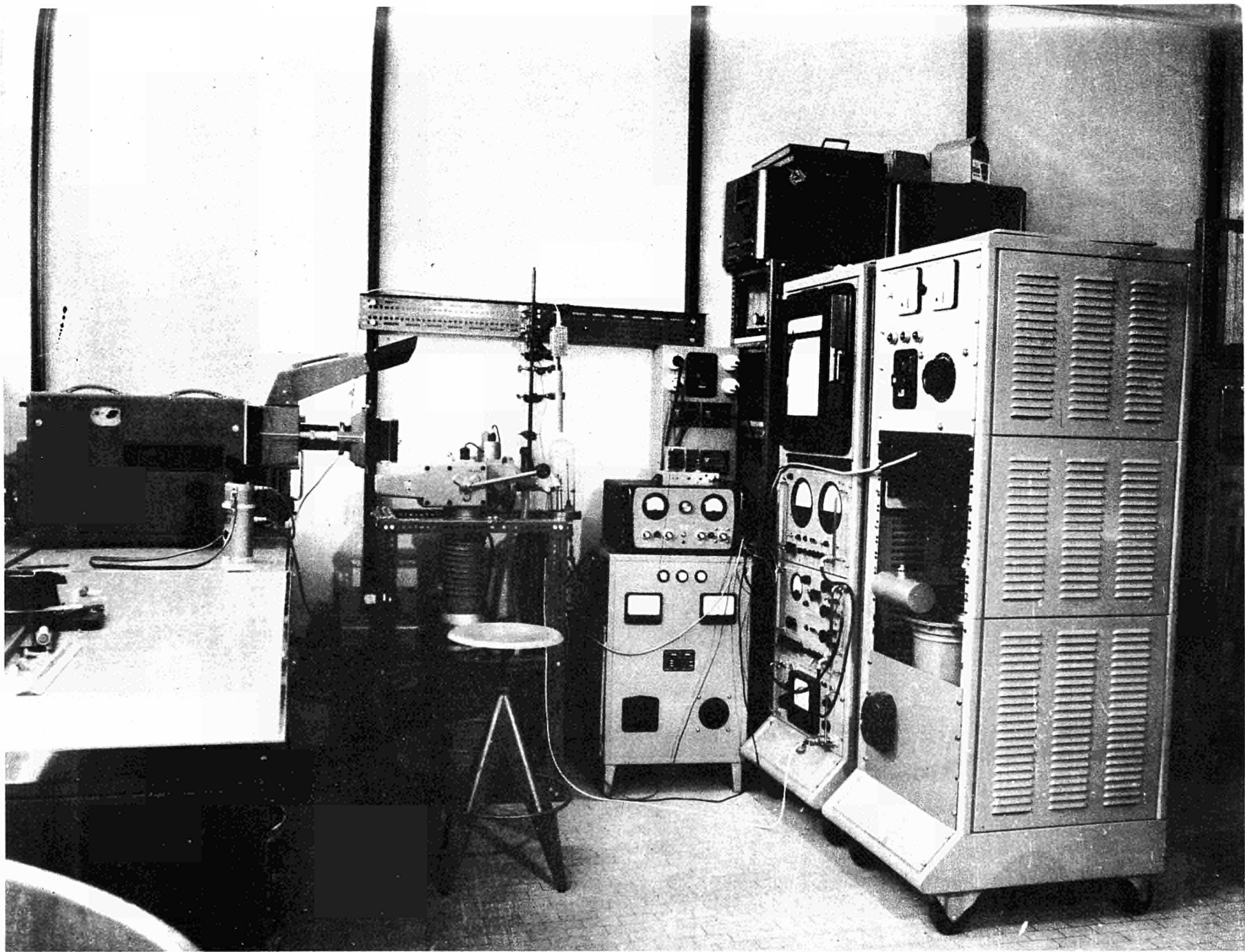








Fig. 12 - High temperature thermal diffusivity apparatus





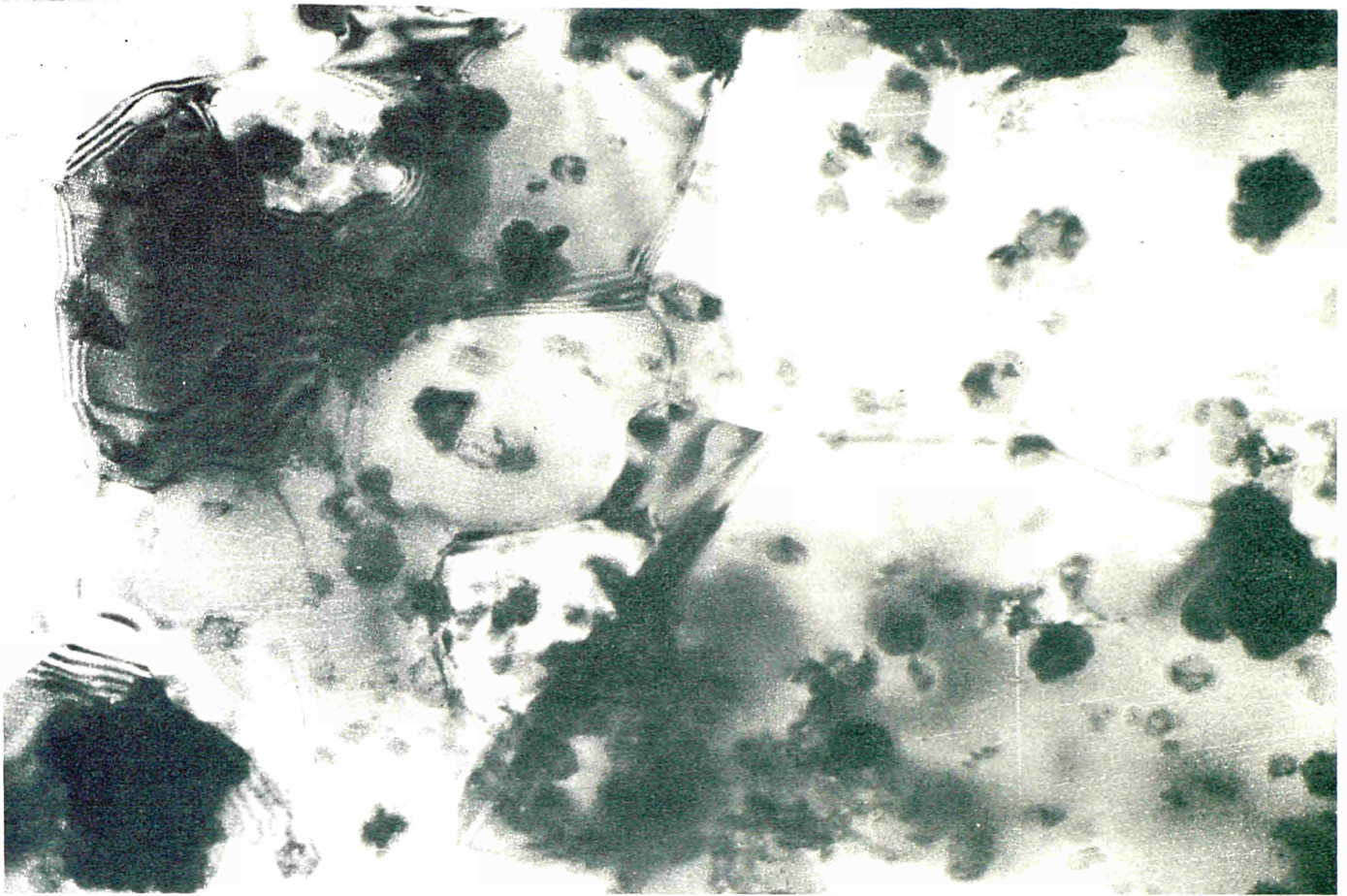


Fig. 13 - SAP 4% - Annealed 12 h at 650 °C  
Magnification : 45.000 x

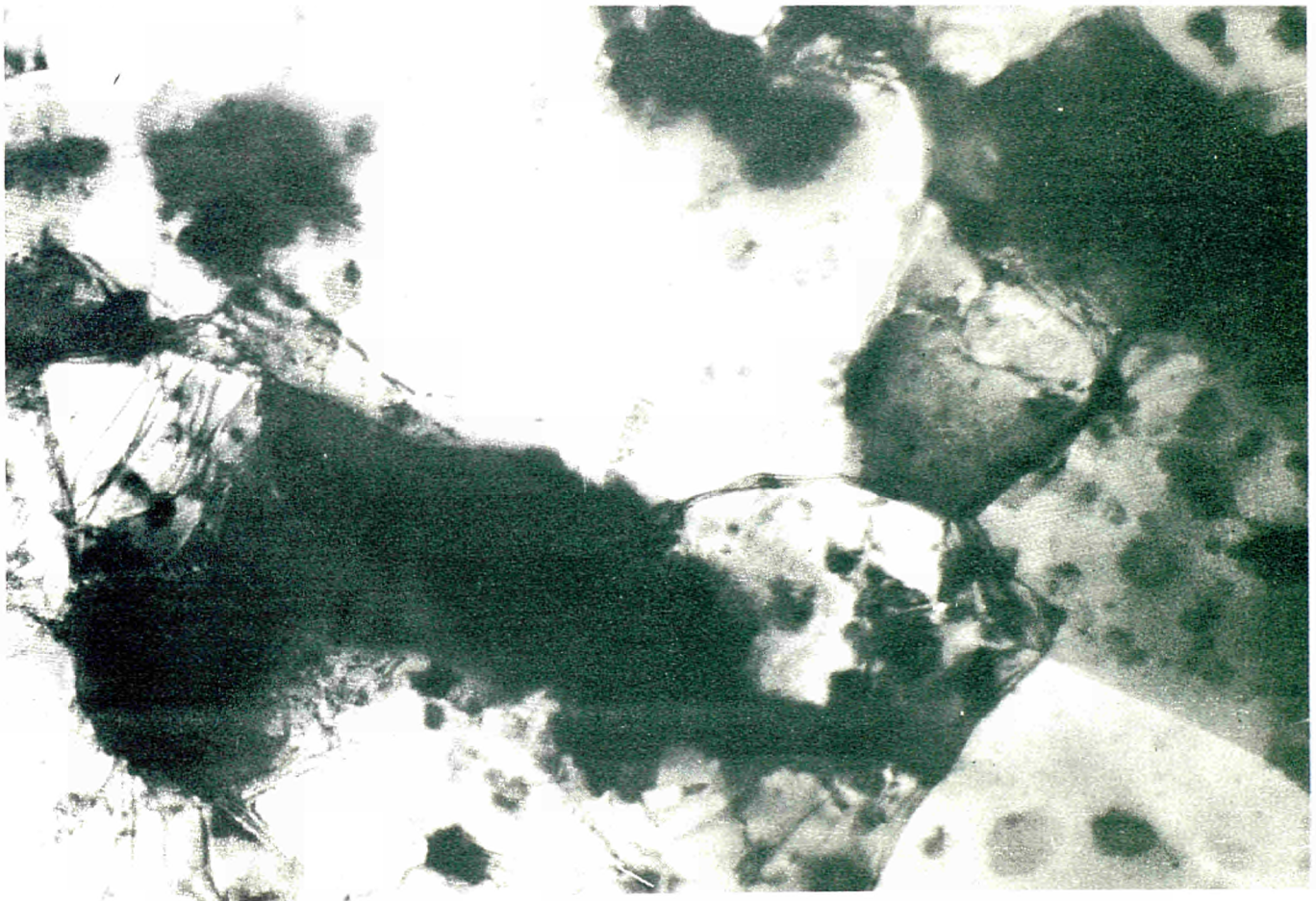


Fig. 14 - SAP 4% - Heated in a furnace 12 h at 650 °C  
Magnification : 45.000 x



## CHAPTER VIII — HEAT TRANSFER

### 1 — Introduction

#### 1.1 — Theoretical considerations

The heat transfer studies to be performed for ORGEL are aimed at providing quantitative information on phenomena of :

- fluid flow,
- forced convection heat transfer,
- burnout,
- and fouling,

in a fuel element of the Orgel type.

The most important problems arise from the fact, that a fuel element of the ORGEL type (a cluster of closely spaced parallel rods) represents a geometry which differs highly from the well known circular and annular channel. As a consequence the known heat transfer relationships valid for uniform simple geometries cannot a priori be applied here. An additional difficulty is presented by the radial and axial heat flux distribution in the fuel element.

The two most important questions arising from the use of a geometry of heat generating rods cooled by a fluid flowing parallel to these may be formulated as follows :

- what maximum deviation of local conditions from the average condition of heat transfer may be expected ?
- is it possible to make a prediction of average heat transfer conditions using empirical relationships obtained from experiments in uniform geometries ?

To answer these two questions one must necessarily analyse the complex phenomena in a cluster geometry. A theoretical analysis may be made on the basis of existing fundamental knowledge obtained in uniform geometries.

As a first contribution to such an analysis a report has been written which contains a general discussion on heat transfer phenomena specific to cluster geometries. Another report has been written, which deals with a discussion on the use of the hydraulic diameter concept in cluster geometries.

A detailed theoretical study concerning "velocity and coolant temperature variations around the periphery of heat generating rods, arranged in a triangular pattern" is in an advanced stage of preparation. These variations are evaluated on the basis of hydrodynamic and heat transfer data obtained in uniform, simple geometries. The study has not been finished yet, due to some difficulties in the programming of the mathematical problems for the I.B.M. computer. An approximate solution of the relevant differential equations however shows, the results to be

in good agreement with experimental data available. It is expected, that this analysis eventually supported by a few basic experimental hydrodynamic data, will permit an optimisation of the fuel element geometry, from the point of view of heat transfer.

The studies under way on an "Orgel" heat transfer, show the importance of the effect of radial heat flux distribution on the peripheral surface temperature distribution of outer fuel rods (7 rod fuel element). It furthermore shows the necessity of studying in detail the effect of a "variation" in contact resistance between cladding and fuel on the peripheral distribution of cladding temperature.

Subsequently will be shortly discussed some theoretical predictions concerning the various fluid heat transfer phenomena to be investigated for Orgel.

#### 1.1.1 *Fluid flow*

— For a cluster of smooth rods, (pitch to diameter ratio =  $1.07 \cdot \text{Re} = 50\,000$ ) the friction factor in developed flow is lying less than 10 percent below the value, to be measured in a "simple" geometry of the same equivalent hydraulic diameter.

— For the flow conditions envisaged for Orgel, the roughness of cladding surface is so small, that the assumption of "smooth" surface is justified for the evaluation of the friction factor.

— If the fuel rods are provided with longitudinal fins, of dimensions and shapes envisaged for Orgel, the flow resistance will lie only slightly below that measured in a simple geometry of the same equivalent diameter as that of the cluster.

— The variation of coolant velocity around the periphery of parallel rods, arranged in a triangular pattern is such that for

— a pitch to diameter ratio of 1.07,

— an overall Re-number of 50 000,

at the position, where rods are at closest distance, the velocity lies approximately 30 % below the bulk coolant velocity.

#### 1.1.2 *Forced convection heat transfer*

— Experiments have been performed under contract at the Centre d'Etudes Nucléaires de Grenoble (France), in simple geometries to determine the forced convection heat transfer properties of various polyphenyl coolant.

Up to now there is no reason to assume that turbulent heat transfer in simple geometries cannot be described by the conventional Dittus Boelter equation.

— The "average" heat transfer coefficient in a cluster geometry will be somewhat smaller, than in a simple geometry. It may be estimated provisionally that for the "19 rod" element and under the operating conditions of Orgel, the "average" heat transfer coefficient is not more than 10 % lower than that measured in a simple geometry.

— The "efficiency" of the extended surface, at present envisaged for the 7 rod fuel element, may be conservatively calculated to be larger than 0.95.

— The variation in heat transfer coefficient around the rod periphery in the 19 rod element may be estimated to be lower than 30 % for ORGEL operating conditions.



The peripheral variations in cladding surface temperature resulting from this, in case S.A.P. is used, appear to be very small.

— In contrast with the above, the peripheral cladding surface temperature variations, owing to the effect of a non uniform radial neutron flux distribution, are much larger. An estimate, shows these variations to be of the order of 30 °C, for the outer fuel rods of the 7-rod fuel element, and at the axial position of maximum heat flux.

### 1.1.3 *Burnout*

— It is necessary to obtain as soon as possible information concerning the mechanism of burnout in subcooled forced convection boiling of organic coolants. Especially it is here of importance to ascertain whether burnout can be really described in terms relating to local parameters. Furthermore it is of prime interest to determine if burnout is limited to small or large surface regions on the heating surface.

It is hoped and expected that on the basis of this information one can make an evaluation of the effect of geometry and heat flux distribution on the magnitude of the burnout flux.

— The coolant composition will have an influence on the magnitude of the burnout heat flux. At the moment it appears a conservative procedure, to use for all coolant compositions the relationships valid for the terphenyl mixture, taking into account however the influence of the coolant composition on the degree of subcooling. Especially the low boilers and gases will have an influence.

— The importance is stressed of disposing of a quantitative knowledge of "boiling" flow resistance in the evaluation of "burnout safety".

## 1.2 — Survey of experimental heat transfer program

### 1.2.1 *Fluid flow*

In a small hydrodynamic test circuit a test section has been mounted which simulates a characteristic part of an infinite triangular pattern of parallel smooth rods. The measurements of flow resistance in this test section have been started. Furthermore it will be tried to measure the velocity distribution.

The various characteristic parts of a cluster geometry will be investigated and additional measurements will be performed on surfaces provided with longitudinal and helical fins.

#### *Forced convection heat transfer*

Under Contract, at C.E.N. - Grenoble (France) forced convection heat transfer coefficients have been determined of various polyphenyl coolants.

In the future the test facility OL-1 in construction at S.E.T., Ispra, will also be used for the measurement of heat transfer coefficients.

### 1.2.2 *Burnout*

At S.E.T.-Ispra, in order to develop a burnout detection system, burnout measurements have been performed in a low pressure water loop. The influence of organic coolant composition is being investigated under contract at T.N.O. (Holland). Experiments on OM-2 have been started

and "semm" to indicate reasonable agreement with the Core-Sato predictions. It is expected, that these measurements also provide useful fundamental information concerning the phenomena of burnout.

Although originally not foreseen in the contract, also measurements of pressure drop under conditions of boiling will be performed.

The burnout study to be performed by C.E.N.-Grenoble (France) is especially aimed at providing design information for Orgel.

It will be tried to use a test section simulating a characteristic part from the Orgel fuel element.

### 1.2.3 *Fouling*

The experimental investigation being started at C.E.N.-Grenoble is aimed at providing information on "pyrolytic fouling".

The test section is of the annular type and contains a smooth heating tube made of stainless steel.

A second test section to be used later on, will contain a heating tube made of S.A.P., provided with a finned surface.

## 2 — Actual status

### 2.1 — Preliminary results

#### a) *Physical properties*

The most important heat transfer properties are :

- density,
- viscosity,
- thermal conductivity,
- specific heat,
- vapour pressure.

These properties are to be measured at temperature up to 450 °C.

Properties of secondary importance are :

- surface tension,
- latent heat of vaporisation,
- vapour density,
- specific heat of vapour,
- critical constants,
- vapour liquid equilibrium.

Two laboratories are working in this field, C.E.N.-Grenoble under contract in France and S.E.T. Euratom in Ispra.

The experimental work is divided as specified below :

- C.E.N.-Grenoble is constructing apparatus for the first group of properties. These apparatus enable rapid measurements.
- S.E.T.-Ispra is constructing control apparatus of more simple design. Additional methods for the second group of properties still have to be worked out. Methods enabling the investigation of small portions are chosen.

The various methods chosen for the determination of the properties are enumerated below :

Property	C.E.N.-Grenoble		S.E.T. Ispra	
	Method	Status	Method	Status
Density	Archimedes principle	finished	Dilatometer Archimedes principle without pressure	finished finished
Viscosity	falling plummet	finished	Capillary	prototype being tested
Thermal conductivity	non-stationary wire method	first results up to 250°	stationary wire	in construction
Specific heat	adiabatic calorimeter	in construction	high precision adiabatic calorimeter	design in contract with Dr. Wittig
Vapour pressure	Equilibrium at diaphragm	finished	Isotenscope for small portions	prototype tested

Property	C.E.N.-Grenoble		S.E.T. Ispra	
	Method	Status	Method	Status
Surface tension			horizontal capillary	finished
Latent heat of vaporisation			vaporisation and condensation	being tested
Vapour density			Capillary method	being tested
Specific heat of vapour			streaming calorimeter	planned
Artical constants			Capillary	planned
Vapour liquid equilibrium			industrial equilibrium apparatus	ordered

— *density*

The apparatus for density is finished. It is based on the Archimedes principle. The weight loss of a plummet is registered with a special balance. The equipment can be pressurized up to 20 atmospheres.

At Ispra a capillary method was developed especially for small portions. Starting with an open capillary it is a sort of pycnometer method. To measure above the boiling point the capillary is fused and works as a dilatometer, allowing pressures above 20 atm. Besides this, a glass apparatus, based on Archimedes principle, for precise absolute measurements under the boiling point was built.

— *viscosity*

The falling plummet apparatus is already working. The falling time is registered magnetically.

Reproducibility is good. The absolute accuracy could not yet been estimated because the influence of diameter changes of tubes and plummet. This effect must further be studied.

To have a control measurement a capillary apparatus will be built up in Ispra. A prototype was tested at room temperature on the reproducibility, which was found to be in the range of  $-2 \text{ o/100}$ .

— *vapour pressure*

An apparatus in Grenoble is finished. It is based on the principle, that the inert gas pressure balances the vapour pressure at a diaphragm. Two electric contacts give a signal when the reference pressure is too high or too low with respect to the vapour pressure. The precision is estimated to be in the range of 1 %. Results are obtained with OM<sub>2</sub> and OMP.

In Ispra a method for very little portions of material was developed. The data will be reported later on.

— *surface tension*

An apparatus to measure the surface tension of the horizontal-capillary type is working in Ispra. The principle is similar to the vertical-capillary type, but the latter requires well known density data, while the first type requires only pressure measurements. The disadvantage of the last one is, that working under pressure is difficult.

Diphenyl o-, p- and m-Terphenyl and Santowax R. are compared with the curves obtained at Winfrith in October 1961. The precision is estimated to be better than 1 %. The deviation of the two Santowax-curves may be derived from the differences in percentages of the compounds.

— *other properties*

The list on page 244 shows which apparatus are being tested or are in construction.

In the near future experiments with the apparatus for direct measurement of the heat of vaporisation will be started. A simple capillary method tested for the vapour density measurement was tested. The construction of a high precision calorimeter is planned by Dr. WITTIG, Munich. After working out these methods, the measurements of the last three properties of the list will be developed.

b) *Measuring methods to heat transfer problems*

— *Determination of the heat transfer coefficient in electrically heated tubes*

To determine forced convection heat transfer coefficient with high heat fluxes, test sections are generally heated by direct current. Since the bulk temperature can easily be calculated from inlet fluid temperature mass-flowrate and heat generated in the test section, the determination of the temperature of the wetted tube surface is the main problem for the calculation of the heat transfer coefficient (if the heat flow to the coolant causes an important radial temperature gradient in the tube wall), because it is only possible to determine the mean wall temperature (using the measured electric resistance) or the temperature of the "dry" surface (by means of thermocouples).

Assuming a constant heat source distribution the temperature of the wetted surface can be calculated from a simple equation. Due to the temperature dependence of the electrical resistance of the material, however, the heat source distribution will vary in radial direction. In this case the relation describing the radial temperature distribution becomes very complicated. A differential equation has been set up and solved numerically by means of the IBM 7090. Using the numerical results thus obtained, an analytical equation has been developed. In this way the temperature of the wetted tube surface can be calculated as a function of heat flux, for a measured "dry" surface- or mean wall-temperature.

The electrical resistance measuring method requires a high precision. It can be utilized for test sections with a few check points and steady temperature conditions. So far we have applied this method using stainless steel tubes. S.A.P. or aluminium test sections will be used in the near future. This implies a small electrical resistance and high currents. In this connection it is necessary to have a negligible resistance between the part of the tube being examined and the comparison resistance, and to take the Peltier Effect into account.

— *"JACQ"-Effect*

Several tests have been made regarding the effect of an extraresistance against heat conduction in the surface layer of a heated metal wall.

It was stated in a paper by JACQ(\*) that there is such a high temperature drop in a boundary layer of a heated metal plate, that it would appear uncertain whether the usual methods for the determination of heat transfer still are applicable. In fact, this phenomenon could be considered as a local variation of the heat conductivity in a thin surface layer of the metal wall. It is clear that this problem is of great importance for determining heat transfer coefficients, as pointed out before. Therefore, the Jacq-Effect, if it does exist, could falsify experimental results. Furthermore, the maximum fuel elements temperature could be highly influenced by such an effect, due to the fact that it can occur twice on the cladding and once on the fuel itself. Not to be forgotten is Jacq's statement that the importance of the effect grows sharply with heat flux.

The first experimental method chosen by us was to measure the thermal contact resistance between metal plates and liquids. In contradiction to Jacq's statements, in experiments on thermal contact resistance between liquid sodium and stainless steel, E. JUNG(\*\*) could not find any contact resistance greater than the reference limit of the measuring method. By applying a method which is very similar to that of E. Jung, we have tested the combination water/stainless steel and we too could not find a contact resistance lying beyond the permissible variation of the measuring method.

---

(\*) J. Jacq : *Journées de la Transmission de la Chaleur*, Paris 1963:

(\*\*) E. Jung : *Nucleonik* 1961, S. 250-256.

The measuring methods applied by E. Jung as well as ours are based on the comparison of resistance combinations, in which the heat flow passes through the same total lengths of the two heat-conducting media, however, with a different number of contact surfaces. E. Jung has successively placed different combinations of steel plates lying horizontally in the middle part of a tube which is put up vertically and filled with liquid sodium. The tube is heated on top and cooled underneath, the heat flow passing through the steel plates and the layers of liquid lying between. The heat flow is measured from the temperature drop along the upper and lower part of the tube, and the thermal resistance of the layers is measured from the temperature drop between the ends and the middle part.

Since the layers of steel and sodium are always of the same thickness, a different temperature drop in the middle part of the tube would indicate the existence of measurable contact resistances. According to the results achieved by Jung, such a contact resistance would have to be smaller than the thermal resistance of a layer of stainless steel of 0,015 mm thickness.

In the set up used by us, two resistance combinations with 12 respectively 4 contact surfaces are connected in series; the heat flow is consequently the same in both combinations. The temperature drop along the test section with 12 contact surfaces is on the average greater 1,5 % - 0,8 % than the temperature drop along the test section with 4 contact surfaces. Since the systematic errors of our apparatus are also in the range of 1,5 %, it can be deducted from the measurements carried out up to now that a thermal contact resistance must be smaller than the thermal resistance of a water layer of 0,02 mm.

In view of the above probability of the "Jacq-Effect" existence can be considered as very low.

The second experimental method employed by us was the heating of a metal slab by radiation on one side. The Fourier derivation gives for a constant heat flux, computable from the disk temperature increasing, a temperature difference between the heated side of the slab and the other one.

J. Jacq obtained by his experiments temperature differences 10 to 20 times greater than the theoretical differences. Such discrepancies are out of proportion with experimental errors.

Our tests were made under quite similar conditions. The samples were iron or copper disks, with a diameter of 40 mms, and a thickness between 7 and 50 mm. The heat flux was provided by a radiating plate, the temperature of which could be as high as 900 °C.

We have been very careful in testing the surface thermocouples, because it was the most probable reason of getting wrong results. The thermocouples were two single wires introduced in 0,2 mm holes at a distance of 10 mm one from the other. The set up was tested in an ultra-thermostat using a fast response recorder (frequencies up to 100 cycles/sec).

Many runs have been done covering a big range of samples thicknesses, and heat fluxes. The discrepancy between the theoretical temperature drop along the slab, and the experimental one has never reached more than 1,5 °C. In the worst conditions, the experimental temperature difference was twice the theoretical difference, but this was the case of samples having a very high conductivity (very low temperature differences).

Our results seem to prove that either the Jacq-Effect does not exist at all, or is much smaller than assumed. New experiments are under way on slabs having very well known physical properties, so that derivations will be still more accurate. Also, samples prepared by J. Jacq will be tested.

*Method for measuring conductivities of metals.*

If the foreseen experiments confirm our previous results, this method will be very useful to obtain a good value of the thermal conductivity of material very quickly. The expected accuracy should be better than 5 %. It will be interesting to examine the influence of the crystals arrangement on thermal conductivity in metals, (in connection with our test sections made of seamless drawn tubes).

*c) Development of burnout detection system*

A simple loop operating at present with water was designed for the "development" of a burnout detector operating on a test section made of S.A.P., the development of the measurement method and the training of the personal in performing burnout measurements on S.A.P.

The main purpose of these preliminary experiments was to develop a burnout detector system with a sufficiently small response time and sufficiently high sensitivity. This in order to be able to protect a SAP test section, which will be operated near 450 °C\*, against physical burnout. The problem is the more delicate since the "heating" voltages involved are low (10 V).

The operation of the burnout detector essentially consists in its ability to react to a change in heating wall temperature. To this purpose the test tube is divided into two parts, which appear as two resistances in a Wheatstone bridge circuit. The electrical signal resulting from a sudden temperature rise (i.e. a sudden resistance change) is amplified and triggers a thyatron, which acts directly on the power switch.

The essential feature of the system used consists in the fact, that only temperature changes are employed to cut the power. This has the advantage, that the Wheatstone bridge does not need to be in balance.

The first tests were made with circular tubes of stainless steel. The geometrical parameters used are :

Internal diameter (mm)	8	5
Heated length (mm)	320 500	200 500

Actually, aluminum tubes are used as test sections.

Furthermore, experiments will be performed using an annular section, the inside tube of which is made of SAP and is directly heated by direct current.

The main technological problem arising by direct electrical heating of a SAP tube regards the welding of SAP to the current busbar.

---

(\*) It has not been established yet under which conditions SAP can be used as test tube heater material for burnout measurements, on organic coolants.

In this respect the following requirements have to be fulfilled :

- good electrical contact,
- tightness,
- a reasonable mechanical strength,
- a good resistance against corrosion.

The Metallurgy Department has studied the above problem and proposes to realize welding by using an intermediate metallic diffusion layer of copper or silver in solid state.

## 2.2 — Organic Loops

### a) *LO-50-P - C.E.N.-Grenoble*

This loop, located at the C.E.N.-Grenoble, has been used for the measurement of forced convection heat transfer coefficients. Its characteristics are :

- Maximum coolant temperature : 450 °C
- Maximum pressure : 20 ato
- Maximum pressure head pump : 2,5 ata
- Maximum flowrate : 8 m<sup>3</sup>/h
- Maximum power of test section : 100 kW
- Material of construction : Carbon steel
- Control : hand operated
- Coolant contents : 60 liters

The coolants investigated are :

- Gilotherm OMP
- Gilotherm OM-2
- Gilotherm OM-2 10 % HBR
- Gilotherm OM-2 20 % HBR

### b) *Loop "A" - C.E.N.-Grenoble (France)*

This loop has been designed for "pyrolytic" fouling experiments.

Its characteristics are :

- Maximum coolant temperature : 450 °C
- Maximum pressure : 40 ato
- Maximum pressure head pump : 4 ata
- Maximum flowrate : 5 m<sup>3</sup>/h
- Maximum power to the test section : 100 kW
- Material of construction : stainless steel
- Control : automatic
- Coolant contents : 130 liters

The loop has been assembled and is being tested now.



The test section constructed for the first fouling experiment has the following characteristics :

- annular type : :
- construction material : stainless steel
- inside tube heated by directed current
- hydraulic diameter : 4 mm
- heated length : 20 cm
- non heated entrance length : 20 cm
- non heated exit length : 10 cm

The operational conditions chosen for the first experiments are :

- Coolant : OM-2
- Coolant temperature : 380 °C
- Coolant velocity : 3 m/sec
- Wall temperature : 480 °C
- Iron content of coolant : 10-15 ppm.

In a later stage experiments with a test section of SAP with finned surfaces are envisaged. If sufficient high boilers become available experiments with OM-2 containing 30 % of the former will be done.

c) *Loop - Burnout T.N.O. (Holland)*

The main characteristics of the loop intended to study the influence of organic coolant composition on burnout heat flux, are :

- Construction material : stainless steel
- Maximum temperature : 450 °C
- Maximum pressure : 30 atm.
- Maximum flowrate : 0.7 m<sup>3</sup>/h

Burnout measurements on OM-2 have been started.

d) *Loops OL-1 and OL-2 - S.E.T. Euratom*

The characteristics of both loops are :

- Maximum liquid temperature : 450 °C
- Maximum power to the test section : 150 kW
- Maximum pressure : 50 kg/cm<sup>2</sup>
- Maximum flowrate OL 1 : 3 m<sup>3</sup>/h
- OL 2 : 8 m<sup>3</sup>/h
- Maximum pressure head pump : 20 atm.
- Material of construction : stainless steel
- Control OL 1 : semi-automatic
- OL 2 : automatic
- Coolant contents : ± 1 m<sup>3</sup>

All tubes, containers, pumps and valves are installed in isolated channels through which hot air can be circulated to heat all parts of the loops up to operating temperature. Each loop has two pump lines with two pumps in series. The flow is controlled by turboflowmeters and a by-pass valve. An electrical preheater, provides a predetermined liquid temperature to the test section. Decomposition gases will be removed by a gas separator and solid particles by two parallel filters. Pressure fluctuations and thermal expansion of the liquid are balanced out in the expansion tank, the latter being pressurized by Nitrogen. A calibration tank is provided to check and calibrate the installed turboflowmeters. An evaporation cooler removes the heat taken up by the fluid in the preheater and test the section.

The supports for OL 1 and OL 2 have been constructed and mounted. In the near future, containers and tubings for OL 1 and OL 2 will be mounted. After this the loop instrumentation can be installed. In both loops experiments have been started in April '63. The detailed experimental program to be performed in OL 1 and OL 2 has been established on the basis of the experimental data available in the beginning of this year.

## CHAPTER IX — DEVELOPMENT OF FUEL AND CLADDING MATERIALS

### Introduction

The knowledge of the materials, which is far from being complete, allows us to foresee what the ORGEL fuel element could look like. It can be said, as a general remark, that, if sintered aluminium is to be used as canning material, the fuel element design will have to obey to the strong limitations which are imposed by this material.

This paper is divided in three major parts considering shortly namely the development of uranium carbide of various compositions, the development of sintered aluminium materials and finally some general remarks about their use in the reactor and the correlating irradiation program.

### 1 — Development of uranium carbide

This work was done in close cooperation under control with NUKEM (Germany) and CICAFA (France).

#### 1.1 — Fabrication methods

Uranium carbon compounds can be prepared by different ways, amongst others :

- Direct synthesis  $U + C \rightarrow UC$ . This reaction is obtained either by reaction sintering of a mixture of uranium and graphite powders or by arc melting of metallic uranium and graphite.
- Carboreduction of  $UO_2$   
 $UO_2 + 3C \rightarrow UC + 2CO$
- Carburization of metallic uranium by a gaseous hydrocarbon  $U + CH_4 \rightarrow UC + 2H_2$  leading to a powder of UC.

Of these three processes we have studied the two first ones due to the fact, at first approximation, they allow an easier shaping of the material.

From the theoretical point of view these processes are rather well known; from the practical point of view some difficulties have to be overcome as there are namely :

- reproducibility concerning carbon to uranium ratio and oxygen and nitrogen content;
- shaping of the material, this being an important economic factor (losses, grinding necessary or not etc.).

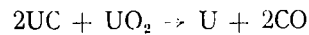
The results obtained to date are the following :

##### 1.1.1 Melting and casting.

It involves essentially : preparation of melting stock by solid state reaction under vacuum between  $UO_2$  and graphite in controlled proportion, arc melting of this prereacted material and centrifugal casting.

— Prereaction.

This is done on small pellets (5 mm Ø, 5 mm length) which are placed in an induction furnace under vacuum. The reaction proceeds around 1700 °C. The first semi continuous tests have shown that during cooling there was some back-reaction between UC and CO, producing a small quantity of UO<sub>2</sub>, the effect of this reaction being to change the composition of the finished product through the reaction :



In order to avoid this drawback another type of furnace is under construction which gives the possibility of isolating the reacted melting stock from the CO atmosphere during cooling.

— Melting and casting.

The prereacted pellets are introduced in an arc furnace especially equipped with a skull which can rotate rapidly when the pellets are melted.

Radial holes having the dimensions of the rods which are to be prepared are drilled in the thick wall of the skull so that centrifugal casting of rods is performed when the prereacted mass is melted. By careful control of the following parameters :

- atmosphere of the furnace
- current intensity
- electrode composition
- melting time
- cooling rate of the cast rods
- skull geometry

it is now possible to obtain on a semi industrial scale rods whose composition is between 4,75 % C and 4,85 % C for a wanted composition of 4,8 % C.

The carbide to be irradiated in the second NRX experiment will be prepared by this process.

### 1.1.2 Reaction sintering.

- *Hot pressing* of U powder + carbon powder mixtures has been fully described. This process has been used for the preparation of the pellets which have been irradiated in the first NRX experiment.

An improvement of this process is the extrusion sintering which gives interesting results - U + 4 % C mixtures have been successfully extruded between 760 and 800 °C. For extrusion of the mixture the two important parameters are extrusion rate and extrusion ratio, the particle size of both uranium and graphite does not seem to have great influence on sheath behaviour and densification.

On the other hand the particle size of graphite has marked influence on the reaction rate :

if the graphite particles are around 1 micron in size the reaction is almost complete at the exit of the die, if the graphite particles are around 30 microns in size the reaction has to be done by a subsequent annealing around 1000 °C with an appreciable decrease in density.

### — *Sintering and impregnation*

This is a way of preparing cermets. Pellets of controlled open porosity are made by careful control of the reaction  $\text{UO}_2 + 3\text{C} \rightarrow \text{UC} + 2\text{CO}$ .

We have obtained such pellets with an open porosity of about 20 % (pore sizes between 1 and 3 microns) and a closed porosity of about 9 %.

Uranium impregnation has been complete at 1700 °C (including closed porosities) giving a pellet of a composition 3,95 % C and a density of 13,6 (95 % TD).

Here again the problem to be solved is reproducibility. This process could be economically comparable with  $\text{UO}_2$  fabrication.

## 1.2 — Properties of the material

### 1.2.1 Grain size

This is a marked difference between the cast material and the sintered one. It may be that this parameter influences the fission gas release.

### 1.2.2 Hydrolysis

The reaction between uranium carbide and water is well known and is of some concern due to the fact that the organic coolants always contain some water. For safety reasons during irradiation of uranium carbide in water reactors the following experiment has been made :

uranium carbide canned in a defected stainless steel sheath (1 mm thick - a 3 mm  $\varnothing$  hole being drilled in one of the plugs) has been treated up to 770 °C under argon atmosphere. The rod was then immersed in water heated at 60 - 80 °C, argon being simultaneously evacuated from the rod. The reaction stopped quickly. About 50 gr of carbide had been involved in the reaction over 1 367 gr total.

Small scale experiments have shown that the behaviour of uranium carbide versus water was dependent on the fabrication process and more precisely on the grain size. Sintered material is attacked much more quickly than cast material. The mechanism seems to involve some intergranular attack.

### 1.2.3 Other properties

There is not much to be said in this respect. We have only so far verified the figures which can be found in the literature.

## 2 — Development of sintered aluminium materials

This work was done under contract with Montecatini - I.S.M.L. (Italy) for the SAP and with Trefimetaux (T.L.H.), France, for the frittoxal.

### 2.1 — Fabrication methods

Two types of material are considered which differ by their methods of fabrication namely SAP which is prepared starting with powders made by the AIAG process and FRITTOXAL which is prepared starting with a powder constituted of lamellar particles of aluminium.

For each of these two types of material, the scheme of fabrication is about the same, that is to say :

- a) Cold compaction
- b) Sintering under vacuum : the reasons for this sintering under vacuum have been given before. The resulting materials are called SAP - ISML and FRITTOXAL grade B.
- c) Extrusion
- d) Drawing

No important change has been made to this fabrication method. Principally there are to be noticed improvements in tolerances and surface finish of the tubes and little changes in the vacuum treatment of cold compacted billets leading to lower gas content.

## 2.2 — Joining

Due to the structure of the material we are obliged to keep investigating solid state joining methods. A great number of them are under investigation.

### 2.2.1 Ultrasonic welding (Work done under contract by Société Réalisations Ultrasoniques (France))

This method has not given satisfactory results for joining SAP to SAP. It may be worth of consideration for joining SAP to another metal. Our main problem being the closure of fuel sheaths (so joining SAP to SAP) we have temporarily dropped the investigation of this process.

### 2.2.2 Flash welding

This process has given good results from the points of view mechanical resistance of the join (about 90 % of basic material resistance) and tightness. On the other hand the plugs suited for flash welding are also well suited for building fuel assemblies.

The main drawback of this method still is that the material is badly treated especially during the enclosure of the fuel rod full of pellets.

### 2.2.3 Magnetic butt welding has been tried with success on a few samples. This method is certainly less detrimental to the material than flash welding.

### 2.2.4 Hot pressure welding

Two processes have been studied :

- a) Hot knurling of a deep drawn plug against the sheath. This process has been used for the fabrication of the fuel rods which have been irradiated in the X 7 loop of the NRX reactor. Post irradiation examinations will tell how they have behaved.
- b) Welding in a hot die.

This process consists in forcing a massive plug placed in the sheath formerly widened out, through a hot die. Diffusion is still rather difficult to obtain due to surface oxidation. Tests are being repeated under argon so to avoid this oxidation.

2.2.5 Electron bombardment welding (work done under contract - Centre d'Etudes Nucléaires, Mol (Belgium))

Eventhough this process leads to the fusion of the material it has been studied due to the following advantages :

- welding under high vacuum
- high specific power.

In fact this has been a good method of testing the quality of the material regarding gas content. We obtain now good welds which support a constant helium pressure up to 500 °C, a normal aluminium weld supporting the same pressure only up to 300 °C.

Another amelioration has given us perfectly good welds : the plug to be welded caps the end of the sheath and the electron beam knocks this part of the plug leading to a superficial melting and by heat transmission in the plug to diffusion between the plug and the sheath. This type of weld resists the test described before up to 580 °C and at this temperature it is the sheath which explodes.

2.2.6 Brazing

A better definition of the types of test which will be described lateron would be to relate them with "welding by diffusion with an intermediate metal". The following combinations have been tested :

	Intermediate metal		
	Ag	Cu	Alpax
SAP tube-plug in SAP	X	X	X
Al	X	X	
Cu	X		
SS	X		X

Good results have been obtained with copper and silver : it is possible to join SAP to SAP, SAP to copper and SAP to silver. Heating conditions have to be very well defined. It is generally necessary to heat just over the eutectic temperature so as to accelerate the diffusion by formation of a liquid phase. It is also necessary to apply a pressure this being easily done by placing around the weld a low dilatation ring.

Alpax has been essentially used for brazing thermocouple sheaths in a SAP plug for irradiation tests. This type of brazing is satisfactory but the heating rate has to be controlled very carefully.

2.3 — Properties of the materials

2.3.1 Tensile tests

The following general remarks can be made on the results of these tests :

- It is a general trend of sintered aluminium materials to show a very low plastic reserve at temperatures over 350 °C.
- Annealing is generally benefical from the point of view of elongation, this being offset by some decrease in strength and elasticity (room temperature properties).
- The dispersion of the results is such that the safety coefficients to be used in design are large. It would certainly be advisable to find a selection test allowing to lower these safety coefficients.

### 2.3.2 Creep rupture tests

- The creep rupture test curves are very flat so that the material is to be rather sensitive to overloads. As a consequence, here again, the safety coefficient has to be rather large
- The fracture keeps the same aspect for all specimens tested at 460 °C : a clean break starting at 45 °. The breaking mechanism seems rather complex. Metallographic examinations reveal a remarkable density of holes in the breaking zone. It could be that it is a cavitation mechanism but it has to be said that in this case the holes are growing parallel to the direction of traction and not perpendicularly.

### 2.3.3 Fatigue tests

The tests which have been done show that at room temperature there is a fatigue limit around 107 cycles. SAP 960 and 930 have the same fatigue limit. For the other materials the fatigue limit increases with oxide content but less than rupture strength.

### 2.3.4 Notch effect

This effect has been explored at room temperature for tensile tests and fatigue tests. As general remarks it can be said that the material does not seem to be sensitive to the shape of the notch, the depth of it having only to be considered.

### 2.3.5 Blowing tests (Work done under contract by S.E.P.R. - France)

The results of those tests confirm the important dispersion. For the finned tubes the number of fins does not seem to have a great influence on the blowing pressure.

The deformation rupture tests under pressure at various temperatures have shown a linear and elastic behaviour up to 350 °C and important plastic deformation over this temperature. The fracture obtained has the same aspect as the fracture obtained in the creep rupture tests.

### 2.3.6 Thermal cycling (Work done partially by the C.N.E.N. - Italy and the Ispra Metallurgical Service)

Cycling the material between 20 and 450 °C does not induce appreciable changes neither in dimension nor in mechanical properties of the material. There is a change in the metallographical aspect in the sense that the pure aluminium zones show a tendency to increase in area and to randomize in direction.

### 2.3.7 Thermal expansion

The measurements show that the mean expansion coefficient between 20 and 500 °C varies linearly with the oxide content.

### 2.3.8 Compatibility

2.3.8.1 Corrosion (Some parts of this work have been carried out by PROGIL - France)  
Although the exposure times are hitherto still too short to allow an extrapolation of the behaviour to longer corrosion times, some conclusions may be drawn from the qualitative static tests which have been done. The amount of corrosion observed so far does not give



an indication of special danger in an ORGEL reactor, if the necessary precaution is observed. The limits of temperature and water content have still to be established. The surface treatment is of importance to the behaviour of the material not only with respect to corrosion but also with respect to the formation of iron oxide which may act as nuclei for fouling deposits. From the practical point of view the following recommendations should be observed:

- Sintered aluminium material has to be etched before insertion in terphenyl
- Iron content should be reduced as much as possible to diminish pitting corrosion and also production of fouling nuclei
- Chlorine contamination of the terphenyl should be avoided. Water should be kept to a minimum whose value has still to be evaluated.

#### 2.3.8.2 Compatibility with fuel material

Orientation tests have shown that interdiffusion between UC and SAP is excessive at temperatures over 600 °C. It is envisaged to limit this diffusion by either anodization of the sheath or utilization of a diffusion barrier. Deposition of niobium on sintered aluminium materials and anodization are studied for this purpose. (under contract by CERCA - France and CEN - Mol - Belgium).

#### 2.3.9 Influence of thermal treatments

Both SAP-ISML and normally FRITTOXAL grade B do not experience blistering up to 600 °C.

Annealing at 600 °C has some influence on the room temperature mechanical properties but does not change the high temperature properties. There does not seem to be any recrystallization due to the fact that an increase of annealing time over 1 hour does not induce any appreciable modification of mechanical properties and metallographical aspect (except a small growth of the subgrains from 0,3 to 0,5 micron).

### 3 — Irradiation program

#### 3.1 —

Our first aim was to reach the point where materials of reproducible quality and means of controlling this quality are in hand. Although this is not yet completely achieved, we are in the position to get under reasonable conditions some 3 tons of UC rods canned with sintered aluminium material for the ECO reactor, the tolerances either on dimensions or on compositions being those of a furniture of real fuel elements.

As a consequence we feel to be now in the position to irradiate representative samples taken out of a semi industrial production which may be considered as a prefiguration of an ORGEL fuel element fabrication.

In this connection we have to say that the first NRX experiment has to be considered as orientative and not as an ORGEL rod test, this being particularly true for the fabrication method chosen for UC and for the joining method used for closing the rods.

### 3.2 —

The irradiation program is shaped by the following considerations :

#### 3.2.1 Carbide

It seems reasonable to consider, in first approximation, that central temperatures of uranium carbide and cermets should be limited at 1 200 - 1 500 °C in the first step of exploration. This affirmation has to be supported by careful measurements of temperature drop between fuel and canning.

There is an exception to this proposition :

For economic reasons we are considering the use of vibration compacted fuel rods. In such rods the central temperature would certainly be very high in the beginning of the irradiation leading to in-pile sintering of UC.

#### 3.2.2 Sintered aluminium materials

Some preliminary tests of SAP creep resistance of fuel element sheath are being done under contract by the firm SORIN (Italy)

We have met so far with sintered aluminium materials strong limitations, namely :

- The material has a rather low capacity to sustain overloads (this term been taken in general sense) and moreover to accomodate even short and even small fluctuations over the optimal working conditions. This has to be kept in mind in design work by the use of well taken safety coefficients. In this respect we point out that 450 °C seems to be the maximum temperature to be considered reasonably.
- Due to the dispersion it seems to be only possible to select by non destructive testing sheath tubes for instance leaving a certain degree of uncertainty which is relevant of another selection test having only a statistical value. This second test has still to be determined from the points of view selectivity and signification (this signification being cleared up by an irradiation test).

### 3.3 -- Irradiation program

#### 3.3.1 Experimental fuel elements

- A first irradiation test on 8 elements (sintered UC, canned with SAP, diameter 13 mm) has been done in the NRX - X7 - loop. Examinations of those elements will be performed in June 1962.
- Another irradiation in the same loop will be realized at the end of this year with fused carbide pellets of 29 mm Ø, canned with SAP.
- Then the next step will be the irradiation of fuel elements or trifoils in the BR II organic loop which is actually studied.

#### 3.3.2 Irradiation of UC specimens

- We are preparing an irradiation series of UC specimens in capsules under different temperature and specific power conditions. This experiment will be performed in order to measure the variations of physical and structural properties after irradiation. We want to measure also the fission gas release in these specimens.

— Another experiment is foreseen for the measurement of thermal conductivity of uranium carbide during irradiation.

This test will also be performed in a rig containing several capsules.

— We are preparing the design for an organic loop which should allow us to realize short time irradiations. This loop enables us to study essentially the conductivity integral  $\int k d \theta$  in carbide fuels and the influence of dimensional factors.

### 3.3.3 Sintered aluminium

We are now doing a creep rupture test on SAP tubes under irradiation in order to measure the changes of life-time and the total deformation of these tubes. The first is performed in a low flux reactor ( $1 - 2.10^{13}$  n/cm<sup>2</sup> E > 1 Mev); if the results are significant we envisage to repeat those experiments in a high flux reactor (BR II).

## 4 — Conclusions

The present situation appeals the following remarks concerning the future evolution of our program :

### a) Fuel material

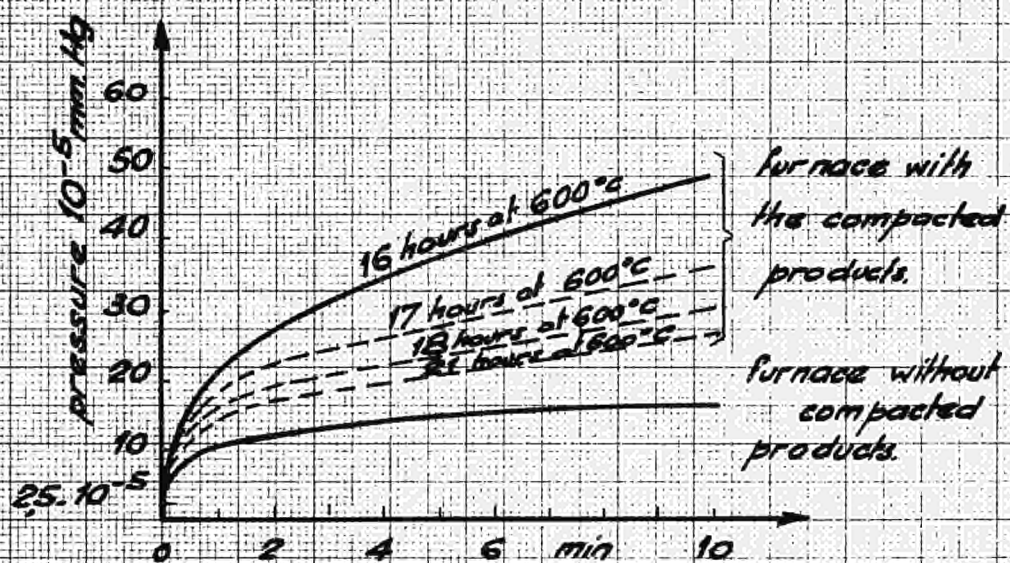
Much work has still to be done especially concerning properties determination before, under and after irradiation. We remain convinced that uranium carbide and U - UC cermets are well suited fuel materials for an ORGEL reactor fuelled with natural uranium. The situation could change if enriched uranium was considered.

### b) Canning material

The use of sintered aluminium material rises some delicate problems; among them compatibility with carbide and dispersion of mechanical properties seem to be the most important. The first one should receive an answer in a few months, the second one can be dealt with by careful control of the powder fabrication. This is the direction we are following now on a laboratory basis.



Figure 1



*Influence of time of "sintering" under vacuum\* on the curve pressure-time, after isolation of the furnace.*



JOINING METHODS  
DIFFERENT SHAPES OF THE PLUGS

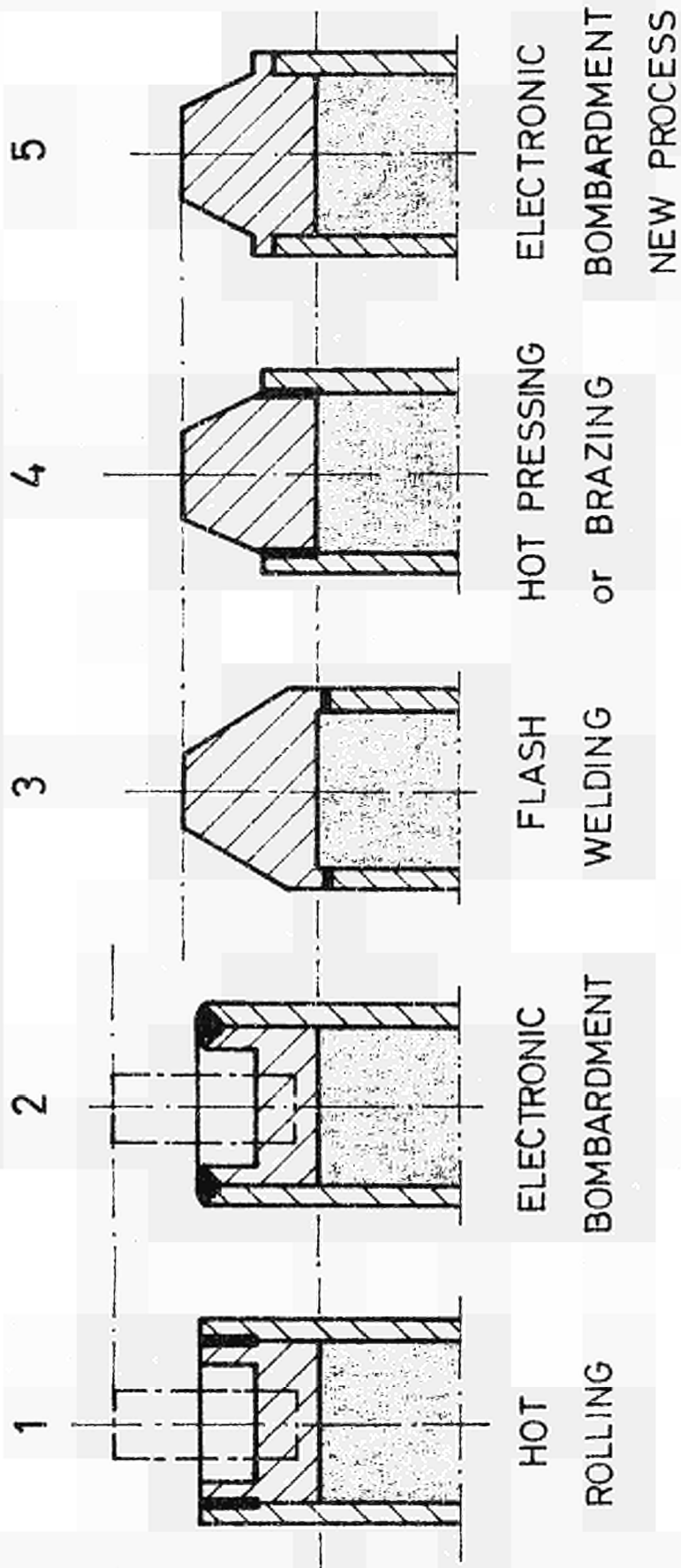


Figure 2





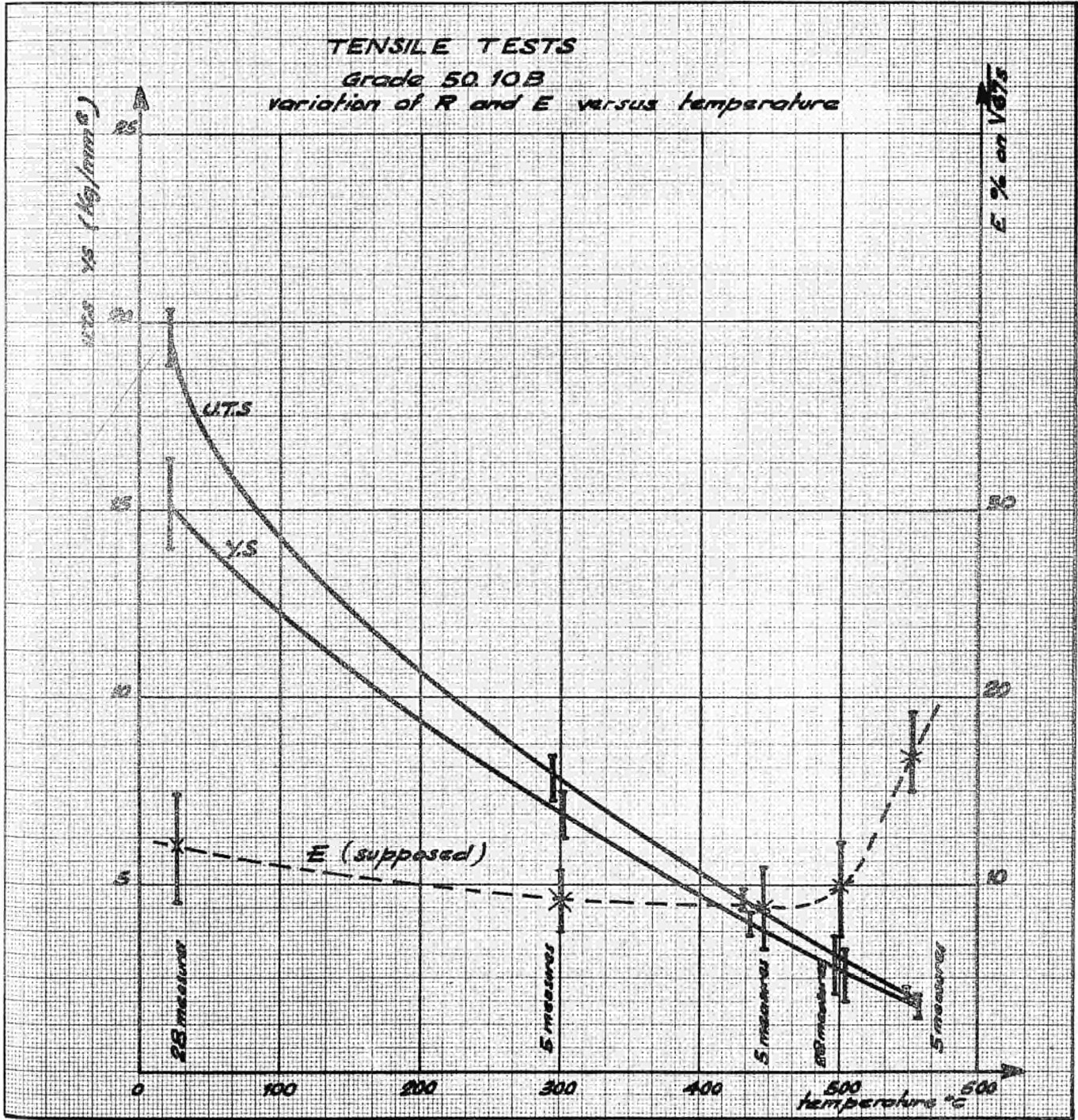


Figure 3



VARIATION OF MECHANICAL PROPERTIES  
 AT 25 AND 500°C  
 VERSUS TEMPERATURE OF "ANNEALING"  
 (ANNEALING TIME: 1 HOUR) - FRITTOXAL

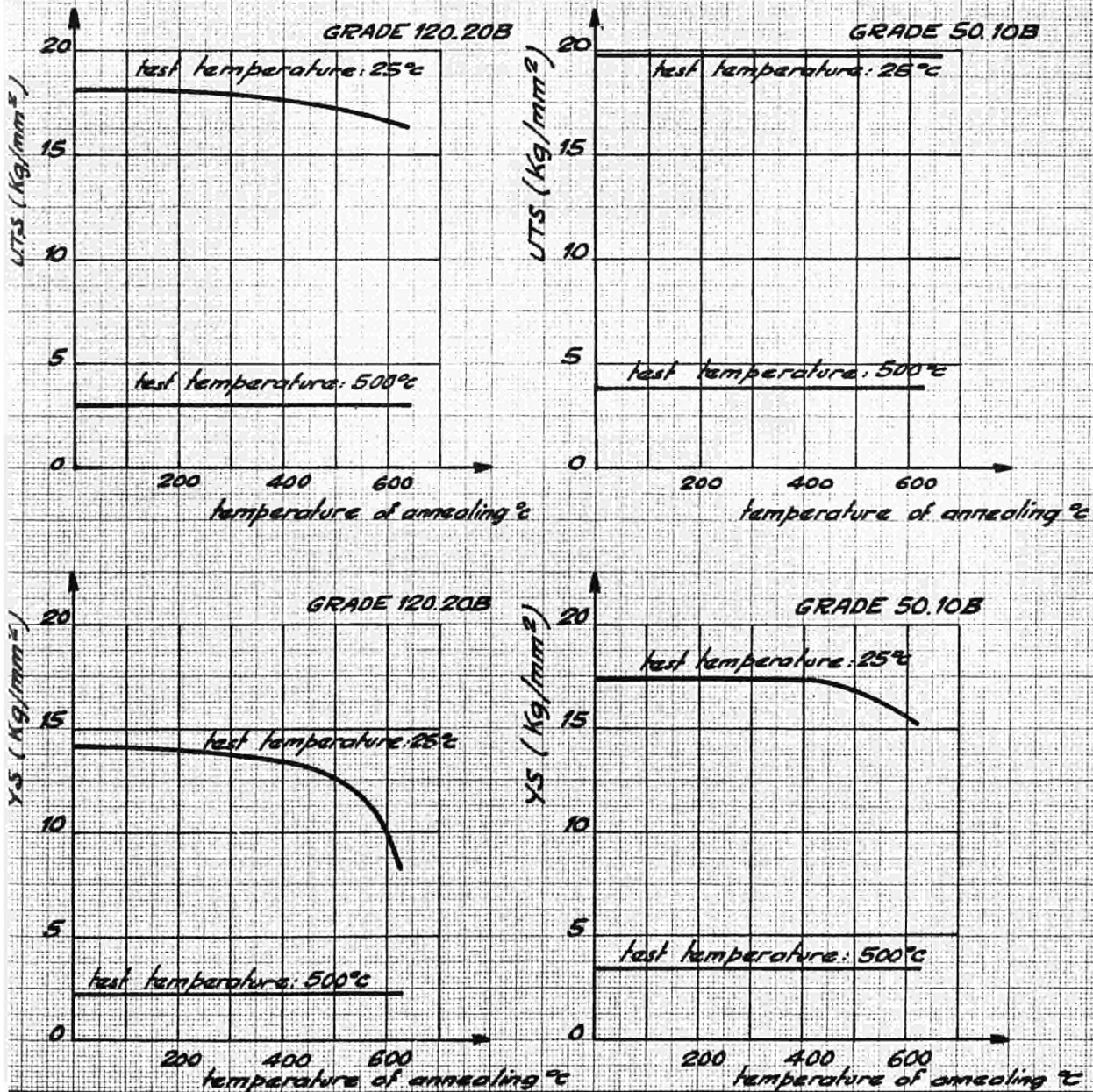


Figure 4



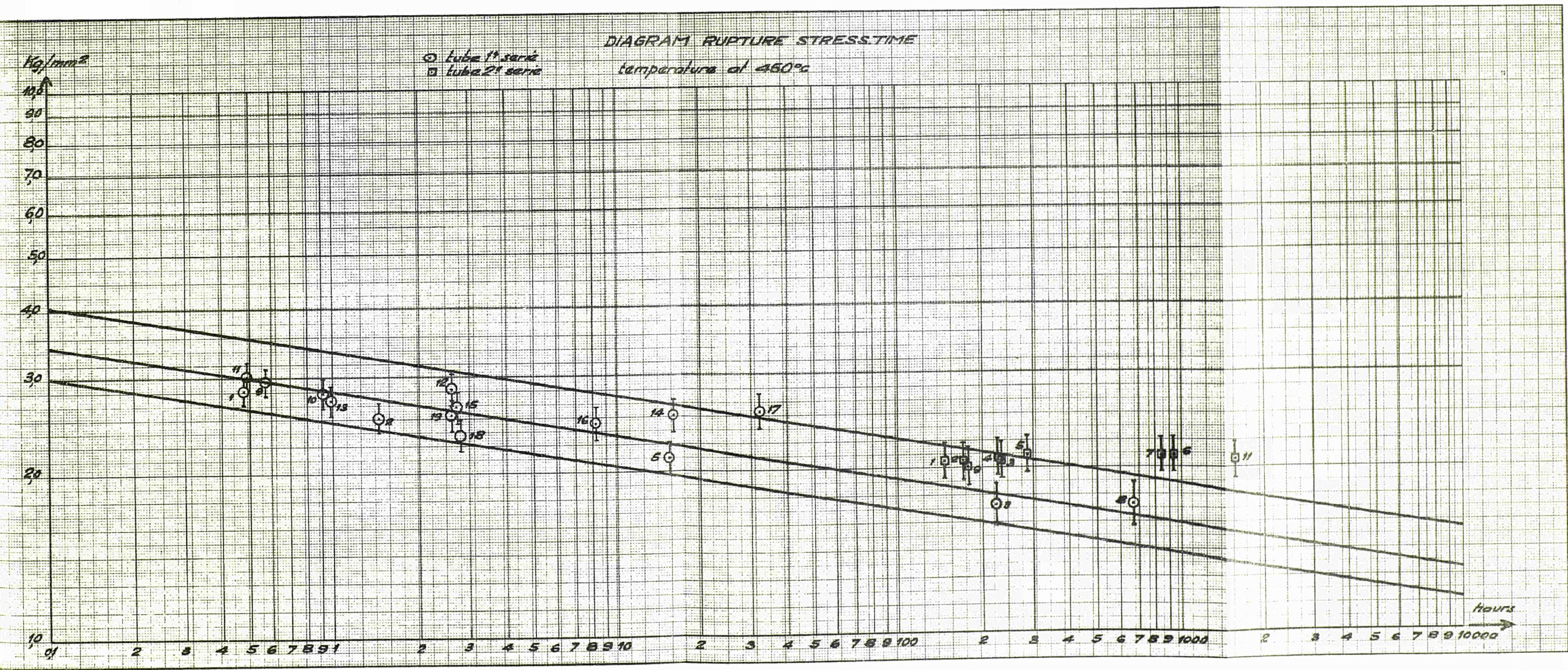


Figure 5



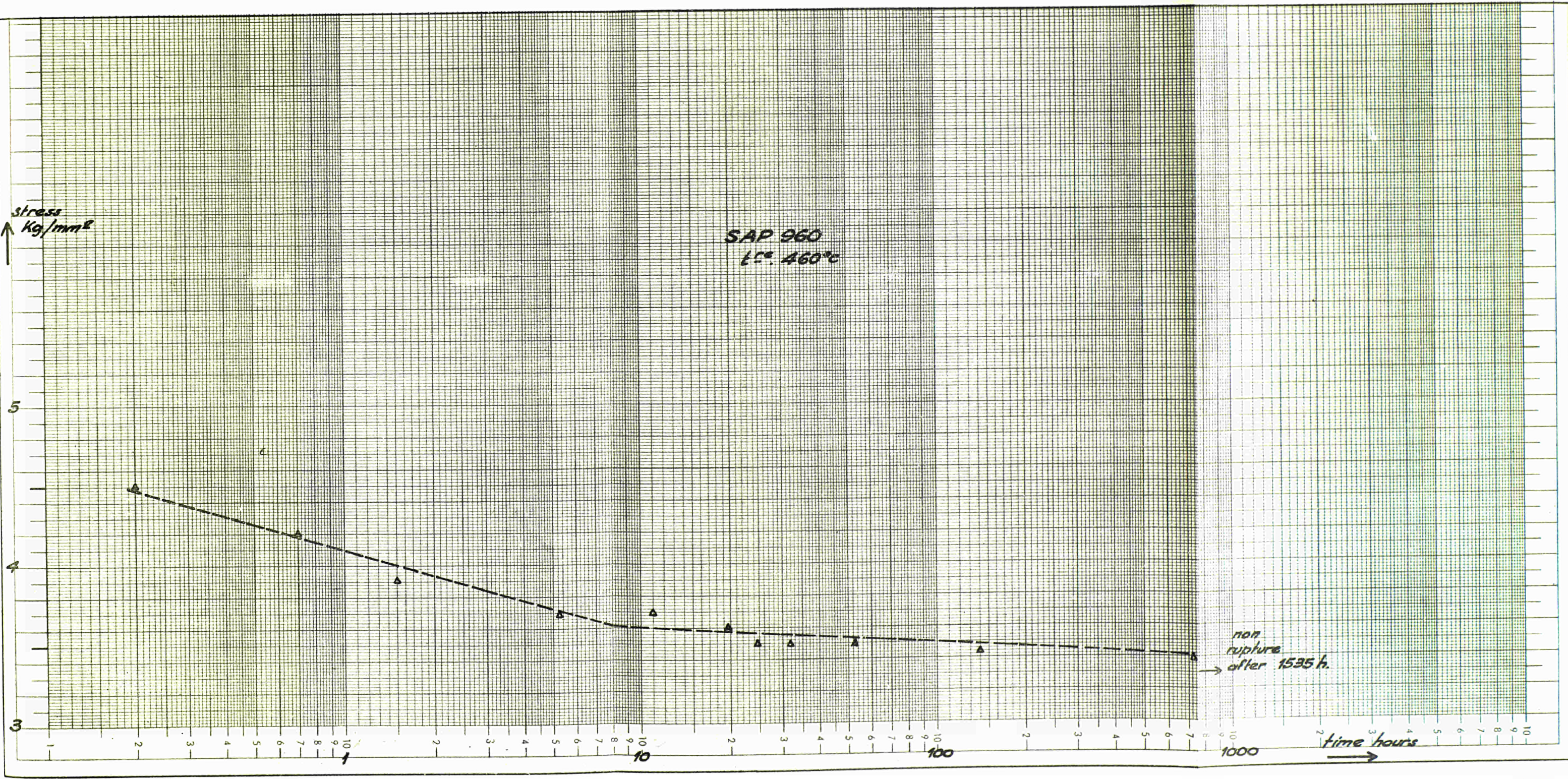
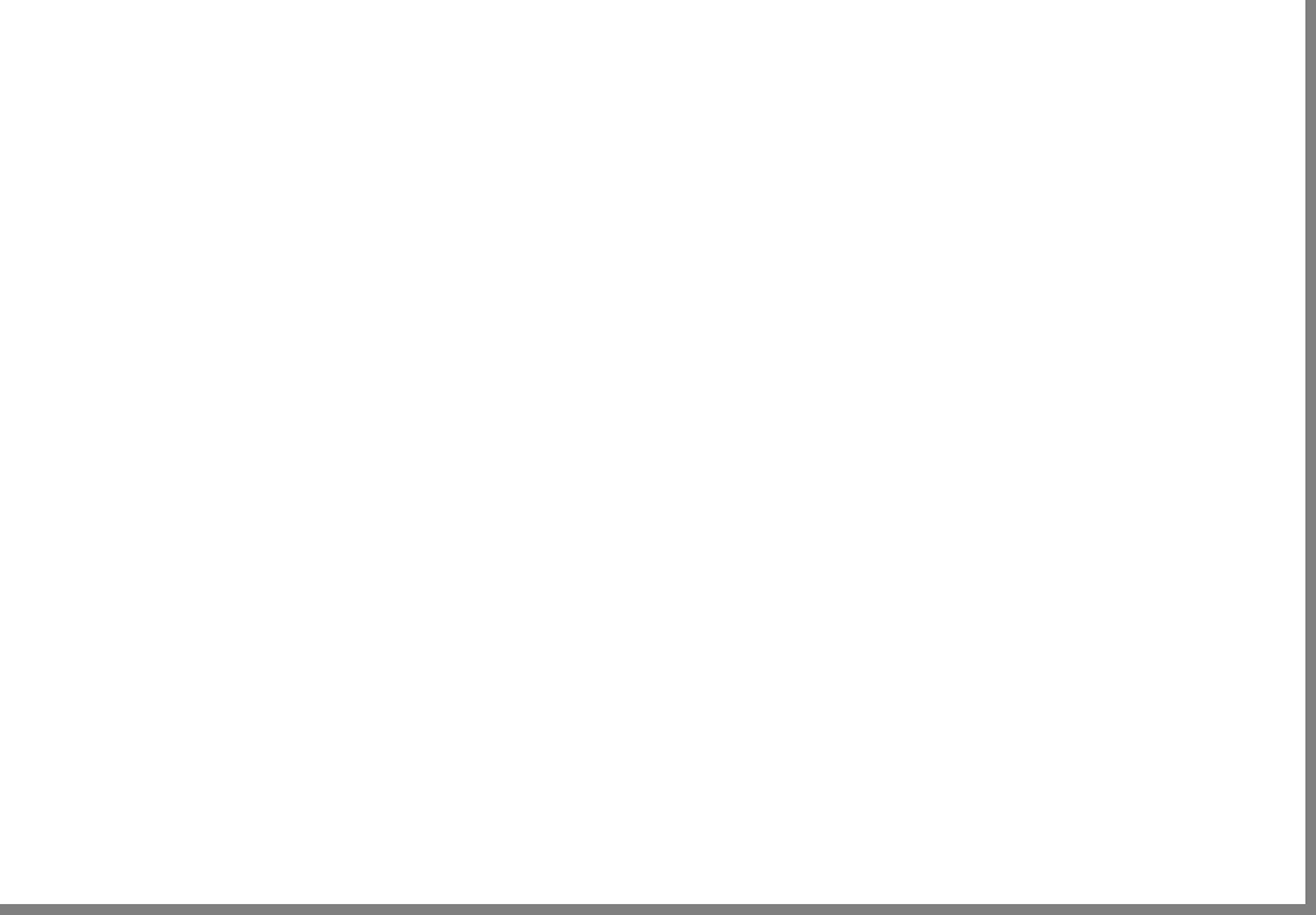
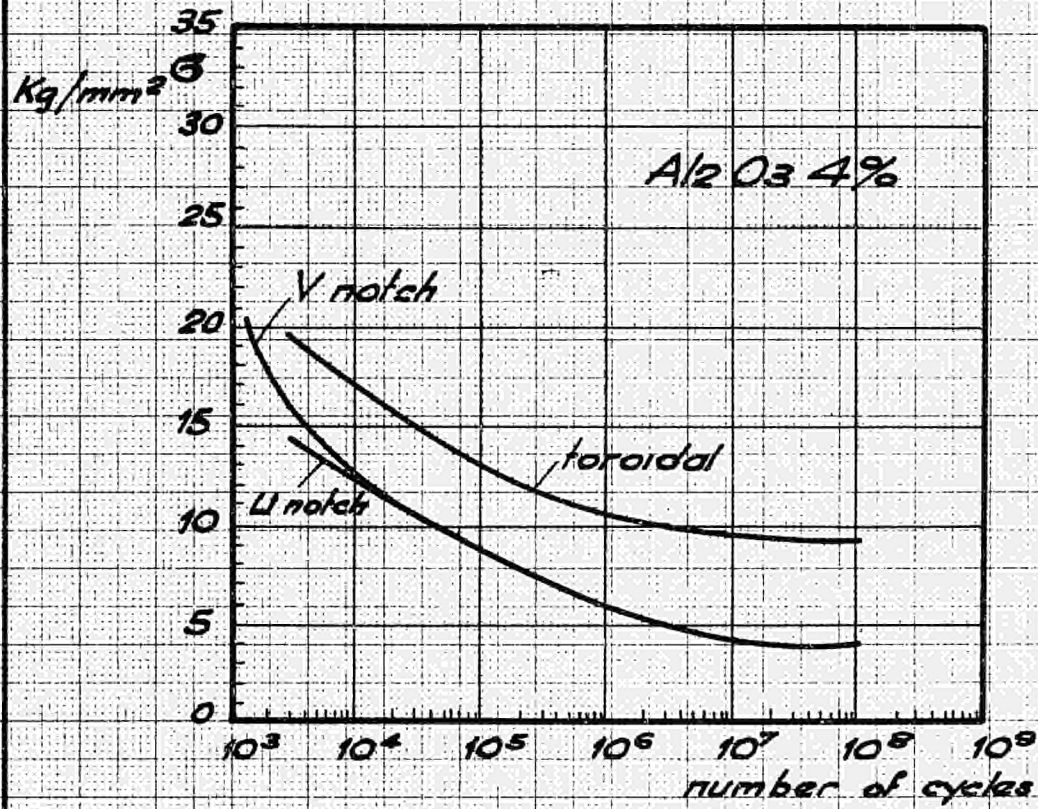


Figure 6







Fatigue curves at 20°C (rotative flexion) of SAP ISML 960 for toroidal samples (without notch) and samples with U notch and V notch.



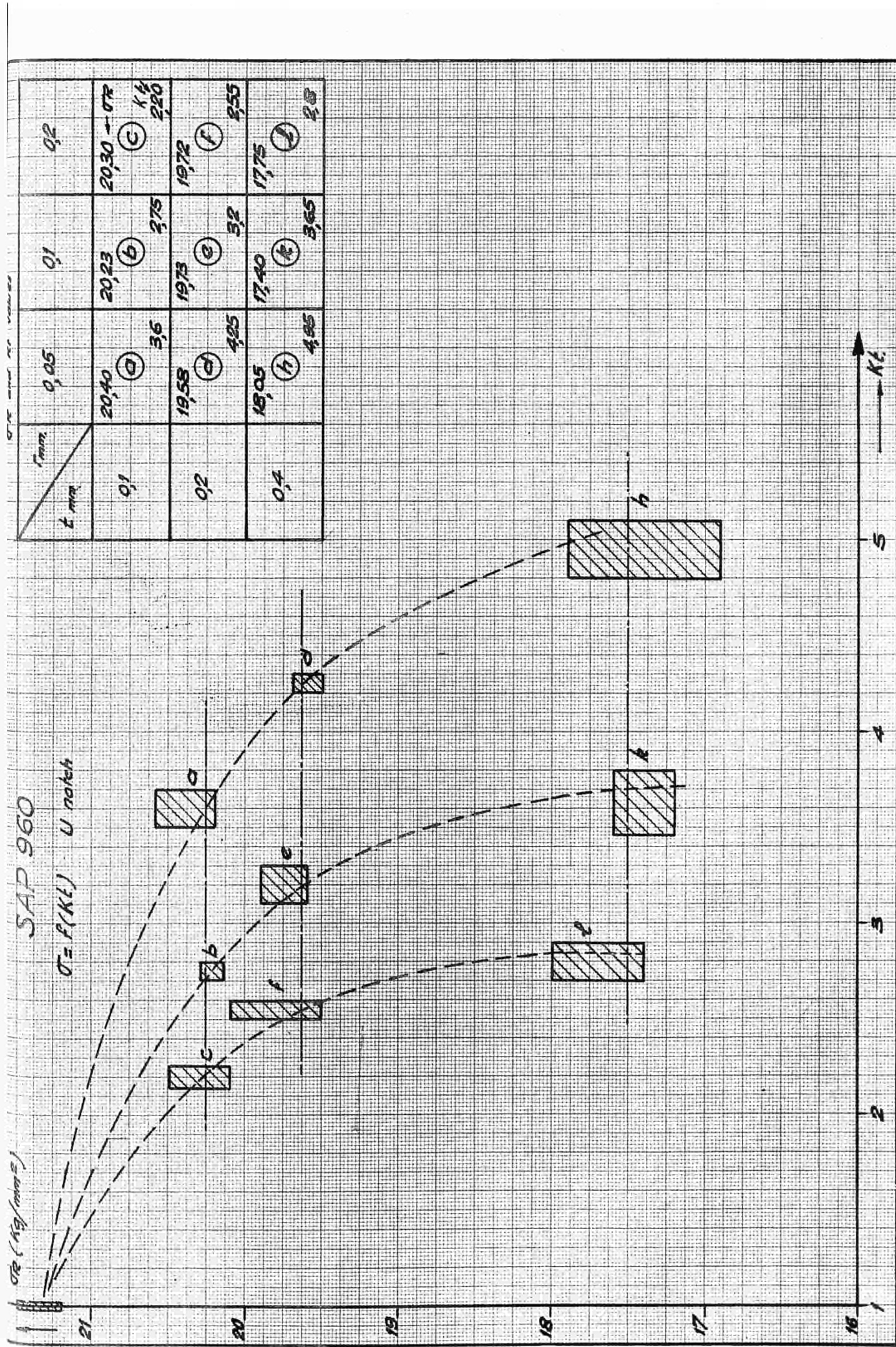


Figure 8



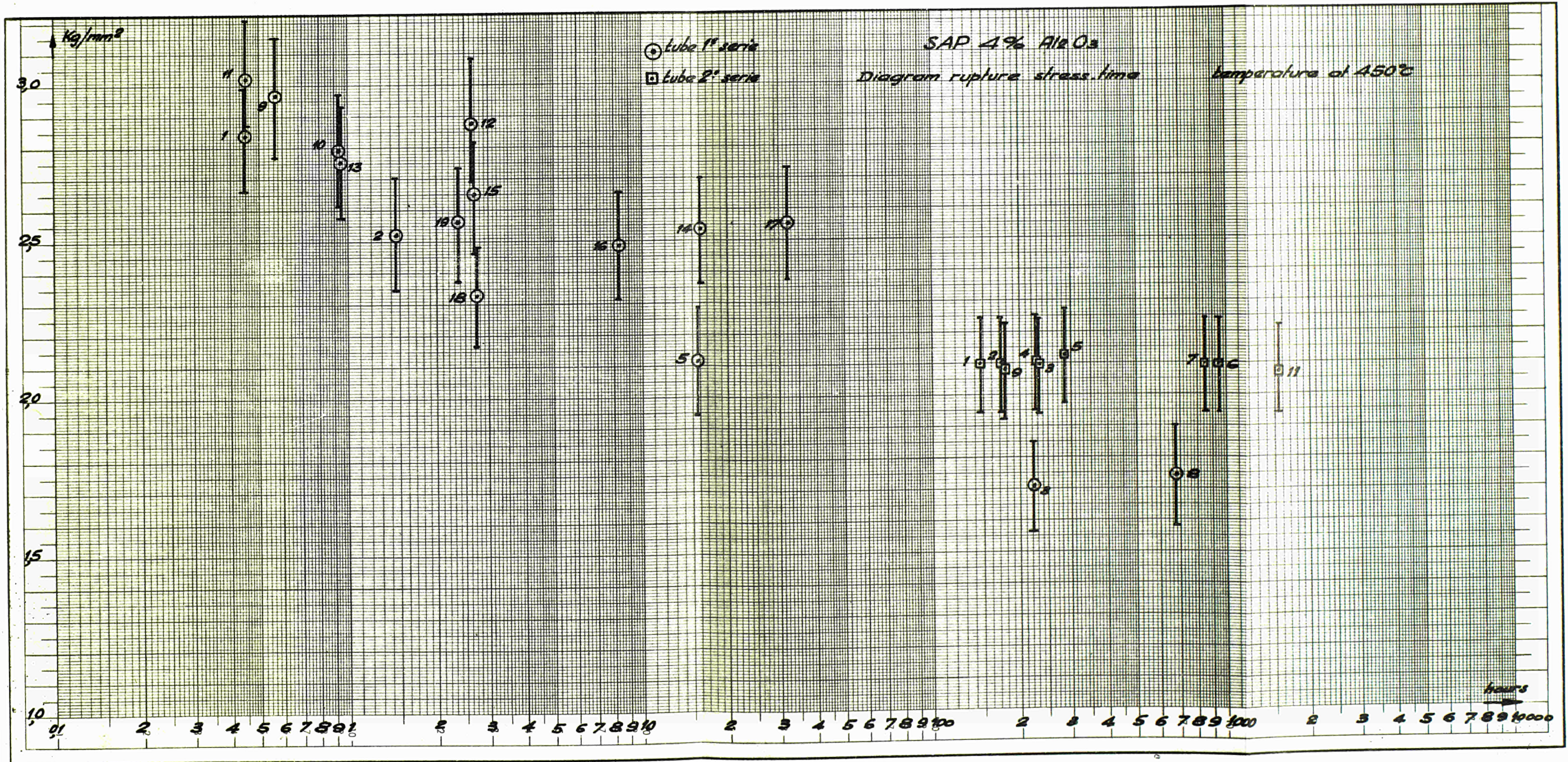
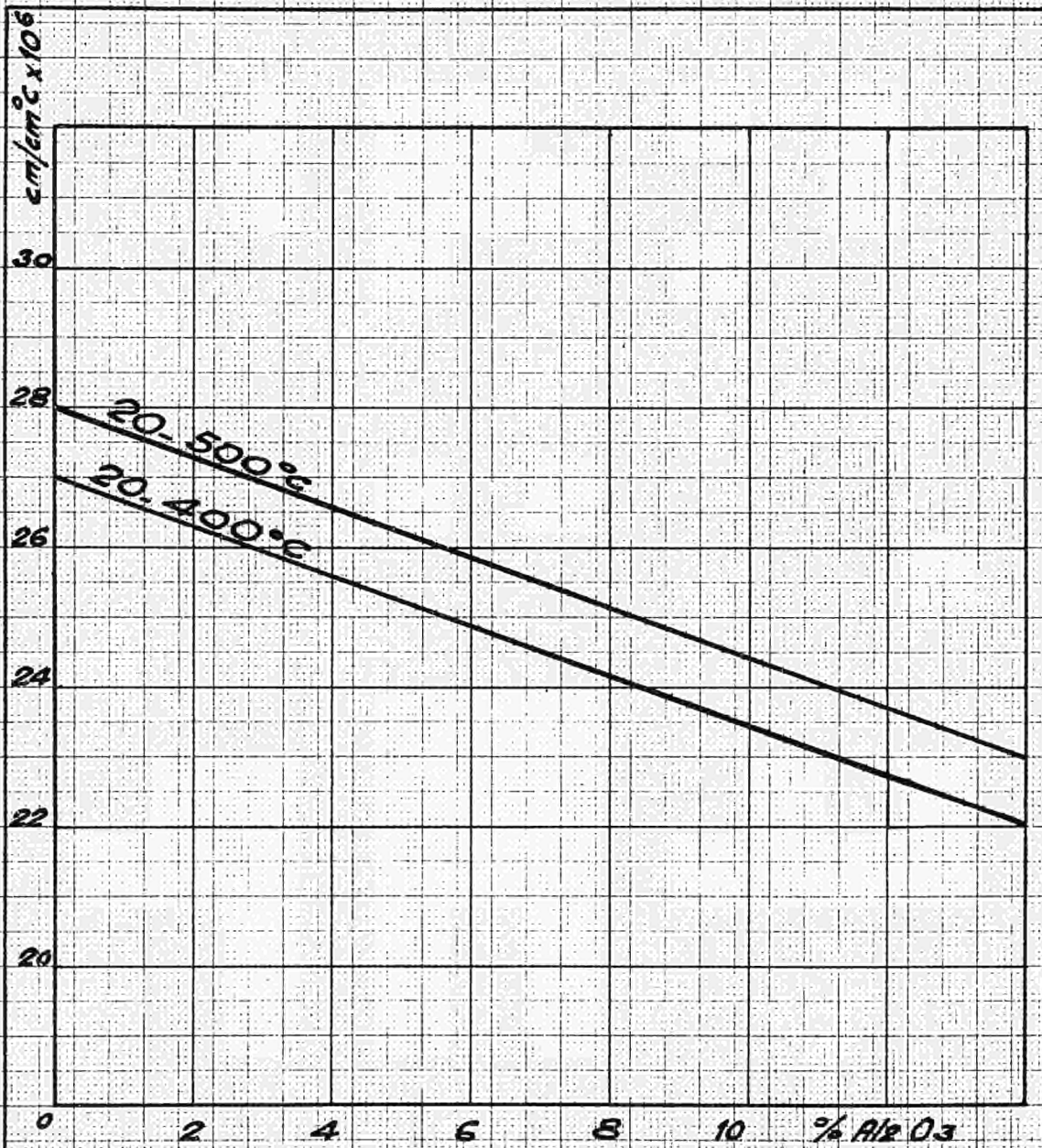


Figure 9



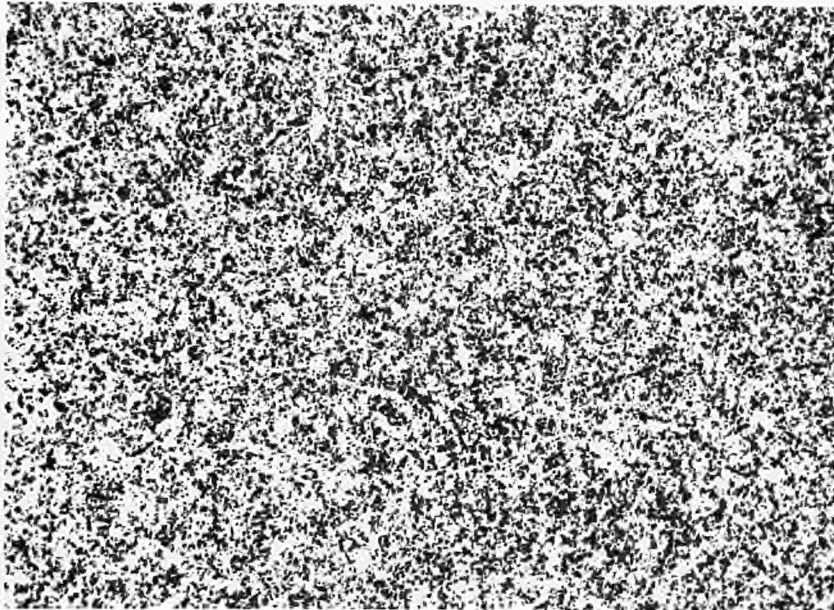
Figure 10



Average coefficient of linear dilatation  
of SAP ISML versus  $\text{Al}_2\text{O}_3$  %

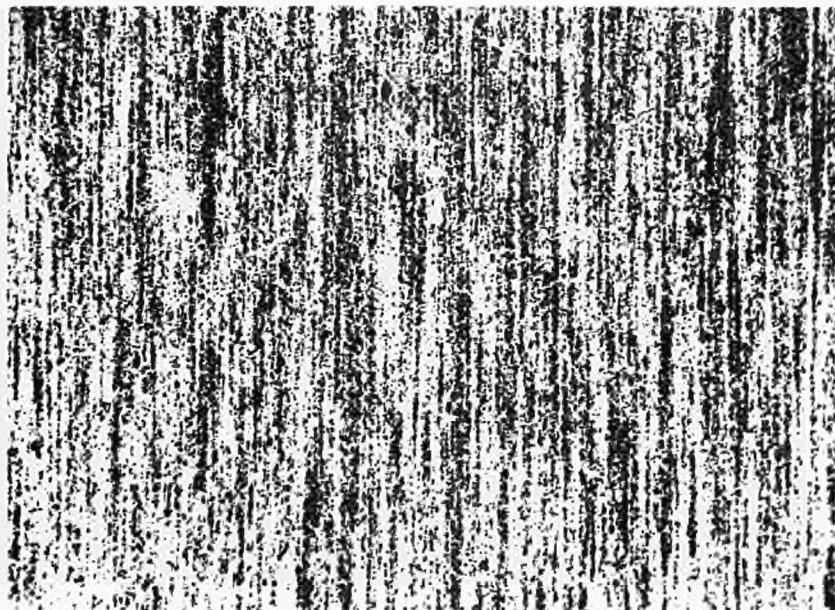






Transversal section

x 300



Longitudinal section

x 300

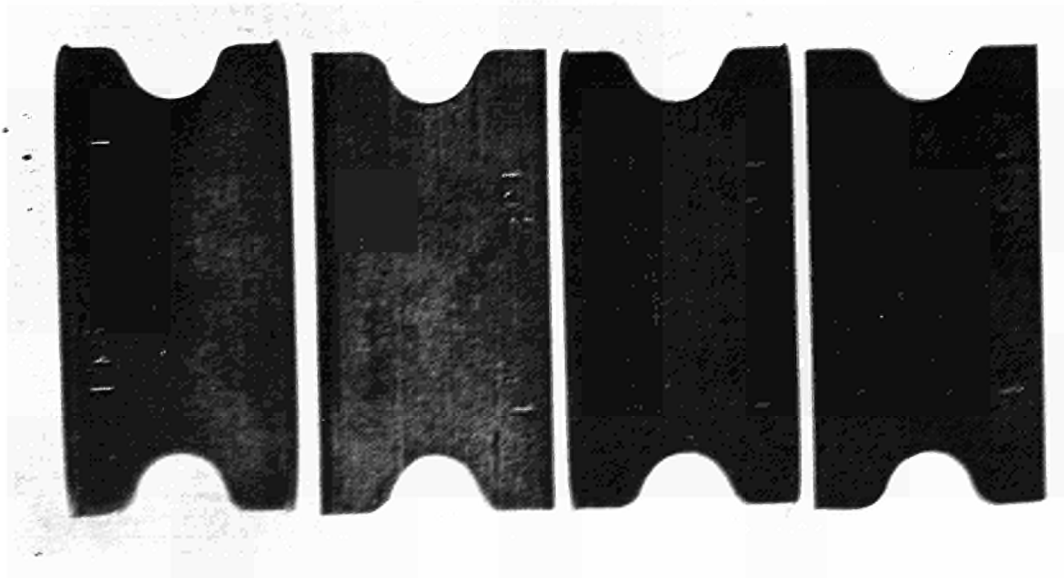
SAP 4 % - Microstructure of a non-cycled specimen  
Etched (HF 0.5 %)





Micrographie of SAP grain

( x 1000 )



a

b

c

d

Aspect of SAP samples, after corrosion  
treatment : 48 hours at 400°C in terphenyl

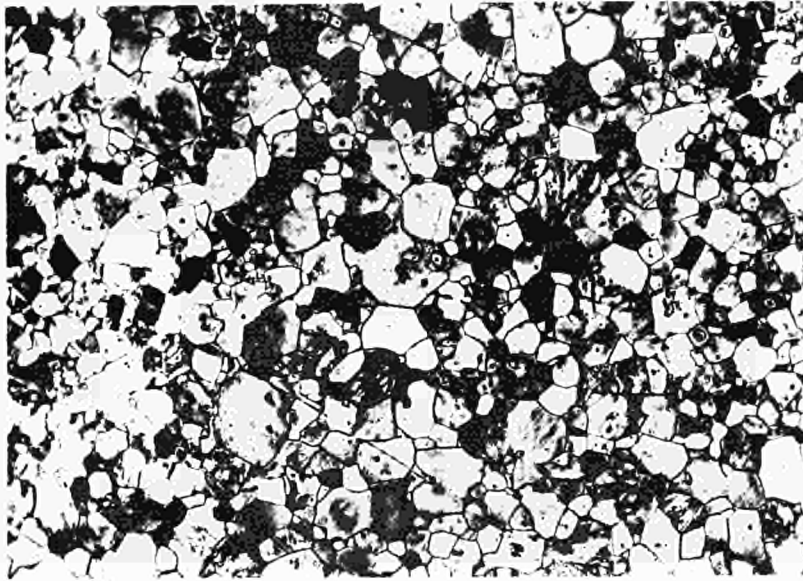
a)  $Al_2O_3$  : 4 %

c)  $Al_2O_3$  : 10 %

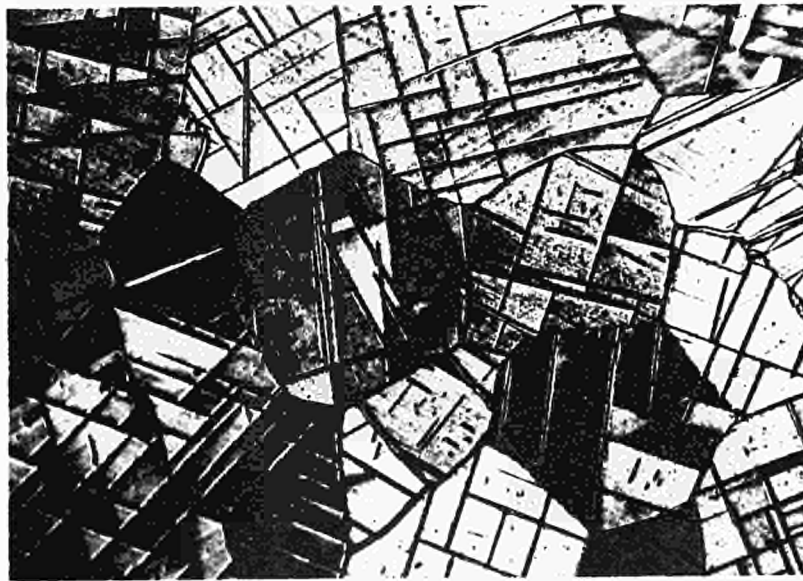
b)  $Al_2O_3$  : 7 %

d)  $Al_2O_3$  : 14 %



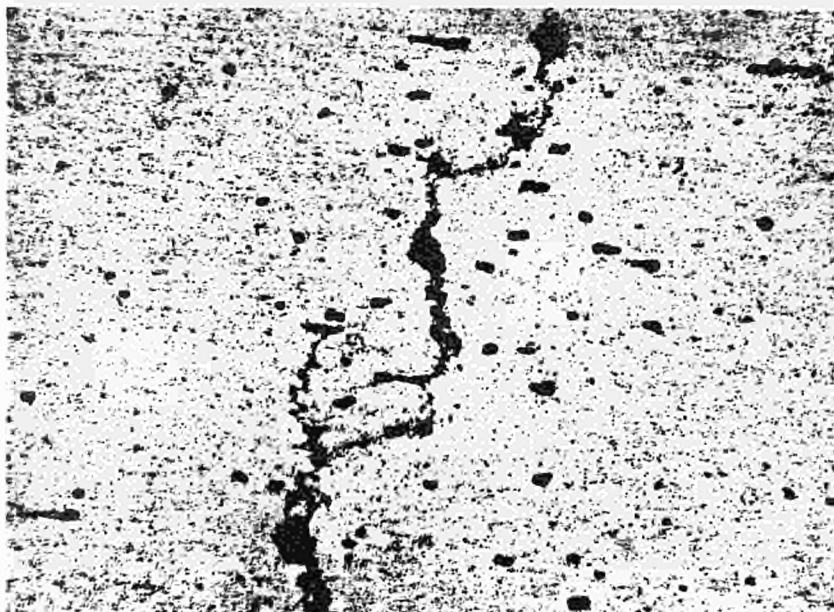


Microstructure of sintered uranium monocarbide (x 300)



Microstructure of arc melted uranium monocarbide (x 300)

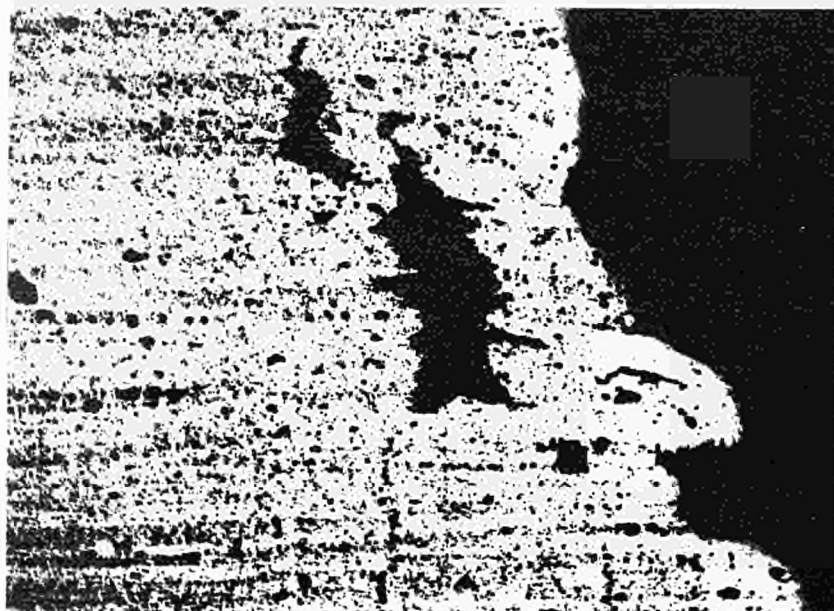




Microstructure of a SAP 4 % tube : transversal section through a creep fracture.

Etched (HF 0.5 %)

x 300



Microstructure of a SAP 4 % specimen.

Creep fracture

Stress :  $3.500 \text{ Kg/mm}^2$

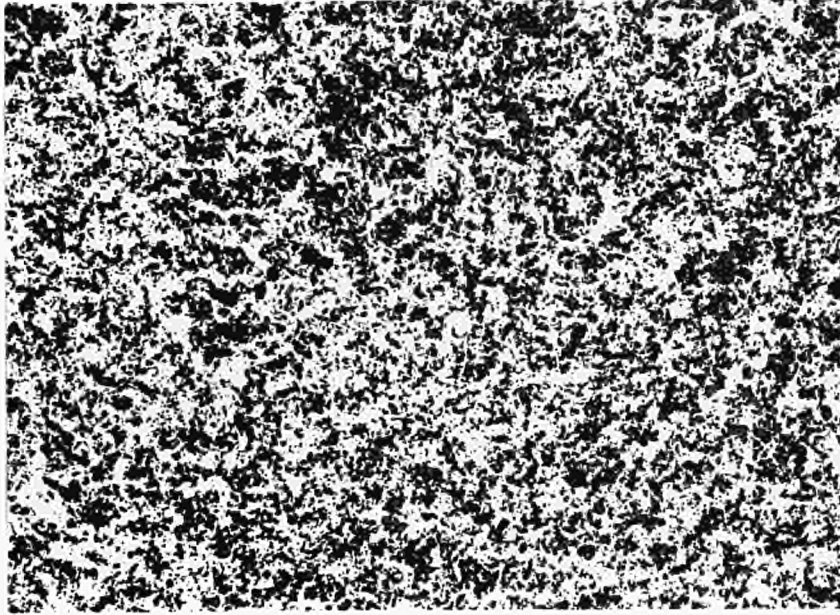
Time to Rupture : 320 h

Etched (HF 0.5 %)

x 300

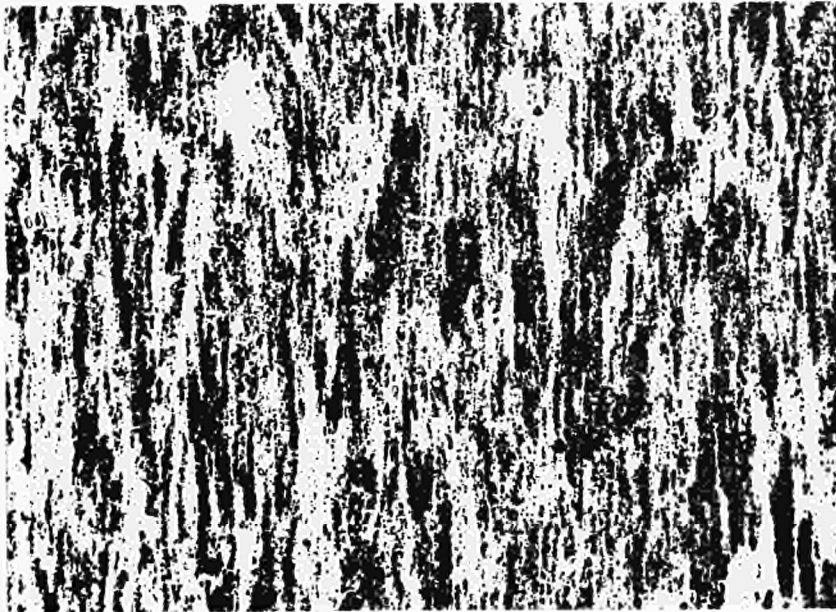






Transversal section

x 300



Longitudinal section

x 300

SAP 4 % - Microstructure of a specimen after thermal cycling (n. 1400 cycles - + 30°/ + 500°C).

Etched - (HF 0.5 %)



## ANNEX 1

### Characteristics of gross 250 MWe ORGEL-Type Power Plant

Gross Electrical Power		250 MW
Net Electrical Power		234 MW
Fission Power		737 MW
Net Electrical Efficiency		0.317
Reactor Outlet Temperature of Organic Coolant		400 °C
Reactor Inlet Temperature of Organic Coolant		265 °C
Velocity of Coolant		8 m/sec.
Fission Power of Central Channel		2.42 MW
Maximum Specific Power'		23 MW/T
Neutron Flux		$6.5 \cdot 10^{13}$ n/v
Pinch Point at Boiler Inlet		10 °C
Steam Temperature at Re-Heater Outlet		390 °C
Steam Pressure at Turbine Inlet		60 kg/cm <sup>2</sup>
Efficiency of Conventional Part of Plant		0.3516
Condenser Pressure		44 g/cm <sup>2</sup>
Height of Reactor Core		5.5 m
Radius of Reactor		2.85 m
Lattice Pitch		23.7 cm
Number of Channels		452
Axial Reflector Saving		2 × 5 cm
Radial Reflector Saving		50 cm
Axial Reflector Thickness		—
Radial Reflector Thickness		50 cm
Flattened Zone Radius/Extrapolated Core Radius	Ratio	0.36
Radial Form Factor		0.748
Core Periphery Flux/Centre Flux Ratio		0.31
Heavy Water Tonnage		196 T
Fuel Tonnage in Reactor		79 T
Organic Tonnage in Reactor, 400 °C assumed		2.2 T
Average Burn-up		
Central Zone		8,900 MWJ/T
External Zone		6,400 MWJ/T
Organic Consumption		77 kg/h
Fuel Cycle Charges		
Fixed Charges		0.27 mills/kWh
Fuel Consumption		1.91 mills/kWh
Fixed Charges (Heavy Water, Channels and Fuel)		1.20 mills/kWh
Organic Make-up		0.20 mills/kWh



## ANNEX 2

### SUMMARY OF ESSOR DATA

#### 1 — Reactor

##### 1.1 — Lattice

###### ORGEL SITES

Number of ORGEL sites	12
Lattice pitch	25.6 cm.
Number of channels connecting with a single loop	4
Number of channels connecting with a multiple loop	8

###### FEEDING SITES

Number of BR2 fuel elements situated on a ring of diameter	16 118 cm.
--	---------------

##### 1.2 — Feeding zone fuel elements

BR2 type with 90 % enriched uranium	
Length of uranium-aluminium alloy	140 cm.
Uranium 235 in a fuel element	443 g.
Burn-up expected	40 %
Cooling by heavy water circulation independent of the heavy water moderator	
Power of a channel	1.1 MW
Total power of the feeding zone	15 MW
Total power for heavy water circuit dimensioning	18 MW
D2O inlet temperature in the channel	45 °C
D2O flow in the channel	70 m <sup>3</sup> /h
Velocity	5.5 m/s.

##### 1.3 — ORGEL zone fuel elements

In this zone, we intend to test fuel of one ORGEL power reactor. For the design, three reference fuels have been chosen

Fuel	UC	UO <sub>2</sub>	U
Sheath	SAP	SAP	SAP
Number of rod bundles	7	19	19
Radius of rod	1.17 cm	0.71 cm	0.71 cm

Fuel section	30 cm <sup>2</sup>	30 cm <sup>2</sup>	30 cm <sup>2</sup>
Channel internal radius	4.4 cm	4.23 cm	4.62 cm
Filling	yes	no	no
Maximum height of active part			1.70 m
Organic liquid circulation			downwards

#### 1.4 — Shim and control rods

Situated on a ring of radius		74 cm
<i>Grey rods</i>		
Number		4
Material		steel
Diameter		6 cm
Efficiency		40 MK
<i>Black rods</i>		
Number		6
Material		cadmium
Diameter		6 cm
Efficiency		80 MK
<i>Safety rods</i>		
Number		4
Material		cadmium
Diameter		6 cm
Efficiency		> 35 MK in 0.5 sec.
<i>Fine control rods</i>		
Number		2
Material		cadmium
Diameter		6 cm
Efficiency		12 MK

#### 1.5 — Vessel

Material	steel
Internal diameter	238 cm
Wall thickness	1.2 cm
Heavy water in the vessel	10 m <sup>3</sup>

#### 1.6 — Thermal shielding

Cylindrical form - iron and water cooling by water

#### 1.7 — End shields

Upper shielding thickness	160 cm
Lower shielding thickness	150 cm
"Dummy shield"	100 cm

## 2 — Handling system

Gauge of railway for the casks	5.70 m
ORGEL fuel element cask	
Height	17.50 m
Weight	150 T.
Gas	nitrogen
Feeding zone fuel element cask	
Height	9 m
Weight	60 T.
Gas	nitrogen
Storage of feeding zone fuel element	in water
Storage of ORGEL zone fuel element	in container with organic liquid

## 3 — Organic circuits

Multiple loop	
maximum flow	575 m <sup>3</sup> /h
maximum power	12 MW
maximum pressure	30 kg/cm <sup>2</sup>
Single loop	
maximum flow	72 m <sup>3</sup> /h
maximum power	2 MW
maximum pressure	30 kg/cm <sup>2</sup>

## 4 — Heavy water circuits

Feeding zone	
Total flow	1 200 m <sup>3</sup> /h
Total power capacity	18 MW
Pressure	3 kg/cm <sup>2</sup>
ORGEL zone	
Total flow	400 m <sup>3</sup> /h
Maximum power	3.6 MW
Pressure	20 g/cm <sup>2</sup>

## 5 — Building

Leaktight containment	
Diameter	45 m
Height above the ground	+ 23 m
Inferior floor level	— 11 m







CDNA00101ENC