EUR 4505 f, e

COMMISSION OF THE EUROPEAN COMMUNITIES

THE ORGEL PROJECT
1959 - 1969

by

J.C. LENY and S. ORLOWSKI

1971

ORGEL Programme

Joint Nuclear Research Centre
Ispra Establishment - Italy

Directorate of Heavy Water Reactors

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Printed by Van Muysewinkel, Brussels
Luxembourg, September 1971

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ABSTRACT

In June 1969, the Commission of the European Communities decided to close down the ORGEL Project, just at the time when its logical sequel would have led to the rapid building within the Community, first of a large-scale prototype and then of a series of power stations. Considering the hopes originally placed in this project, the sums expended on its development and the concrete achievements resulting from it, it was essential to summarize its history and draw a few conclusions therefrom. The report starts by reviewing the conditions under which a heavy water reactor was selected for the Community programme, and then explains the reasons for choosing the ORGEL variant, cooled with organic liquid. After sketching in the context in which ORGEL was launched, the report details the aims and achievements, and evokes ORGEL's progress in the international context, the agreement with Canada and the approaches to an understanding with the USAEC. Lastly, the report recounts the evolution of the Community climate, on one hand, and of the general nuclear situation on the other, which led the Commission to stop the project as soon as the objectives set for ORGEL by the two first Five-Year Programmes were reached, in spite of the fact that the technical prospects were good. The report includes an annex containing a summary of the main technical principles adopted as guidelines for the research programme.

KEYWORDS

ORGEL REACTOR
PLANNING
CANADA
USAEC

ACKNOWLEDGEMENTS

The authors of this report, faced with the impossibility of mentioning so many people by name, wish to thank all those who, in the service of the Commission or of public or private organizations in the Member States, shared in the ORGEL[1] Project and in its achievements.

[1] ORGanique-Eau Lourde (= Heavy Water/Organic Liquid)

CONTENTS

FOREWORD *)

J. Gueron

"Start, finish, publish". These three imperatives, said to be Faraday's advice to scientists, apply to any activity, abstract or technological, especially where public funds and a large number of workers are involved.

Were the ORGEL Project, and the various consecutive operations comprised in it, well started as to their conception and the decision taken?

Was its termination well justified, expedient, logical, serene?

Whatever the answers may be, it was necessary to publish a study (in addition to the great number of essentially technical reports and articles) to bring into perspective the multiple technical, political and structural factors whose nature and interaction formed the inseparable essence of the project.

Like any other adventure or undertaking, ORGEL had its supporters and its adversaries, its friends and enemies; the intense passions it aroused would be astonishing were it not well known that passions depict the people who feel them far more than the object they are centred on.

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*) Manuscript received on March 15 1971

But this is neither the time nor the place to assign praise or blame; that must be done from the distance of years - and who will give a thought to ORGEL in twenty or thirty years' time?

The purpose here is to tell the history of an enterprise and to draw certain lessons from it. At my insistence the Director of the ORGEL Project and his principal co-workers have performed this task and, in my opinion, have made an excellent job of it.

The technical report gives a clear account of the initial options and the way both they and the design studies and solutions progressed.

The complex interplay of all the different decision factors is also described with clarity and without any omissions or distortions.

Admittedly these last words suggest a judgment not based on a twenty years' perspective; but they really express, rather my involvement alongside men who, with me and under my responsibility, worked so well for ten years and who, in writing the following pages, have yet again carried out their twofold job as European civil servants and as nuclear engineers.

October 1969

REPORT

J.C. Leny

INTRODUCTION

In June 1969 the Commission of the European Communities decided to put a full stop to the ORGEL Project, just at the moment when its logical sequel would have led to the early construction, in the Community, first of all of a large-scale prototype and then of a series of nuclear power plants.

In view of the hopes originally placed in this project, the sums expended to develop it, and the achievements it produced, we think it would be useful to sum up its history and draw some conclusions therefrom.

As regards the technical aspects, the ORGEL Project was the subject of a great many reports in the course of ten years, which are still available for reference[1]. We shall therefore confine ourselves to giving, in an Annex to this report, a summary review of the main technical options adopted as guidelines for the research programme.

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[1] Short Bibliography, pp. 48-50

1. Conditions governing the choice of a heavy-water reactor for the Community programme

The nuclear energy scene in 1959 could be described by three factors - the economic, depending on the cost evaluated in terms of different energy sources; the political and military, dominated by the urge for independence in the civil field as well as in the production of military explosives; and the "provident management" factor, determined by concern to make the best use of the natural resources.

1.1 The estimates of the period show that the economic factor was favourable to heavy water reactors, though not overwhelmingly so, in several countries including France, West Germany and Canada, but unfavourable to them in the United States, where there were uranium enrichment plants already in operation and financial conditions propitious to light-water reactors[1].

1.2 Outside the United States, the military and political factor lay on the side of the natural uranium reactors. But if the Community introduced heavy-water reactors on the industrial scale it would have to build heavy-water manufacturing plants, unless it relied on American production.

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[1] First, the high price of money militated in favour of reactors such as the PWR, which required moderate capital investment; secondly, the USAEC, by leasing enriched uranium at the rate of 4% enabled the fuel cycle of enriched-uranium reactors to avoid the high rate of interest charged on normal borrowings.

The Canadians, who were not troubled by the dependence[1], directed (and are still directing) their attention almost exclusively to heavy-water reactors. In Europe, on the contrary, France and Britain launched out, as early as 1952, into a vigorous programme of natural uranium/graphite-moderated reactors. Nonetheless, the economic potential of the heavy-water reactors, theoretically higher than that of the graphite reactors, warranted further work on heavy-water systems. France therefore tackled this line, starting work on the EL-4 series[2], as did West Germany, where the construction of the Karlsruhe "Mehrzweck"[3] reactor was put in hand.

1.3 The "provident management" factor never played a decisive role, but it favours the heavy-water reactors, as numerous Canadian publications have shown (W.B. Lewis, "Low Cost Fuelling without Recycling" - 2ECL 382 - "Heavy Water Reactor Review and Prospect" - AECL 2774, etc.).

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[1] At that time. Since 1966 they have had to build several heavy-water manufacturing plants in order to sustain the industrial growth of their reactor system.

[2] A heavy-water moderated reactor cooled with carbon dioxide in pressure tubes.

[3] A reactor moderated and cooled with heavy water in a steel pressure vessel.

In all these circumstances, therefore, it was reasonable to incline towards a heavy-water moderated, natural uranium fuelled reactor as the target of a programme designed to promote a Community system of nuclear power plants[1].

2. Conditions governing the choice of the CRGEL variant

2.1 Owing to the remarkable moderating properties of heavy water, there was a great temptation to build reactors moderated with this liquid and capable of using natural uranium fuel, and in fact many heavy-water reactors were constructed either for research purposes (NRX, ZOE, NRU, etc.) in the early days of nuclear energy, or as plutonium and/or tritium breeding reactors (Savannah River and, later on, Marcoule). But in order to produce electricity it was necessary to raise the temperature of the heavy water, i.e., to pressurize it and to refuel during operation so as to extract sufficient energy from the natural uranium to keep the fuel consumption costs low; these two characteristics make for design problems, particularly as regards circuit leaktightness and the consequences of any leaks that may occur.

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[1] The foregoing reasoning is extremely qualitative. As far as we know, more quantitative assessments were not done on the subject and would, in fact, have been difficult in view of the subjective nature of certain major parameters.

As a result the engineers in concerns interested in heavy-water reactors addressed themselves to discovering ways of utilizing the good moderating qualities of heavy water whilst suppressing its failings as a coolant. They found a solution, namely, to separate the moderator and cooling circuits and to use another coolant, more manageable than the heavy water.

Four were studied - sodium, light water, carbon dioxide and the organic coolants. In 1958-59 these various versions of heavy-water reactors were the subject of design studies some of which (e.g., the organic variant) were reported on at the Second Geneva Conference (1958). The organic-cooled variant had been considered in several places (Canada, France, Denmark, Spain) and its prospects had been considered attractive.

2.2 At that time the First Five-Year Programme for the nascent European Atomic Energy Community was being discussed among the competent authorities[1]. One of the objectives of that Institution was to evolve a reactor system which would be developed in such a manner as to become the property of the Community. The system was moreover, to form the "backbone" of the Euratom Joint Research Centre, then being set up.

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[1] Only the outline budget and general trends of this programme were defined in Annex V of the Euratom Treaty.

As we have seen, the environment prompted the choice of a heavy water, natural uranium fuelled reactor system. Research had recently started on two variants of this system inside the Community - the CO_2-cooled variant under study by the French CEA, and the heavy-water-cooled variant in a pressure vessel, being studied by Siemens on behalf of the West German Ministry of Research.

Euratom sought to pool the Community countries' efforts and centre them on a single variant which could have been developed in the Euratom framework in cooperation with the Community Member States. An agreement for cooperation with Canada (p. 27, Section 7.1) was negotiated and this would have enabled all the organizations engaged on heavy-water research with substantial funds to combine their efforts. But this attempt, which if successful could have appreciably, if not radically, altered the future of the heavy-water reactors and of the atomic energy Community, ended in failure.

The Scientific and Technical Committee[1] suggested, and the Council decided, on a proposal from the Commission, that Euratom should develop ORGEL, which was a promising variant[2] though different from the ones studied in France and Germany. The two countries reacted differently. In France, Euratom's commitment to a path of which the CEA had already explored certain aspects was approved.

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[1] A body set up under the terms of the Treaty to advise the Commission on programmes. It consists of 20 leading industrial and specific figures from the Six countries, appointed in their personal capacity.

[2] In view of the importance of this point, we reproduce in Annex 2 (pp. 91-93) the relevant extracts from the Commission's communication to the Council concerning its programme.

In Germany, industry argued that an institution using public funds had no right to handle the development of reactors intended for power production. This fact was probably the underlying cause of the reserve the West German government always displayed towards ORGEL - a reserve which turned to opposition as the years went by.

3. The technical attractions of ORGEL

Generally speaking, natural uranium fuelled reactors feature a high capital cost and a low fuel cycle cost. Hence anything that can bring down the capital cost is worth investigating, such as, in the case of heavy-water reactors, the use of an organic fluid instead of heavy water as coolant. With such a substance it is generally speaking possible to operate at low pressure (less than 20 atmosphere) and use cheap materials (aluminium, mild steel). Furthermore, it is reputed to undergo little activation, and this should simplify the shielding problems. In fact, the promoters of organic cooling hoped, in 1958, to apply to reactors the techniques and materials in use in the oil industry.

In the Annex to this report summarizing the technical projects undertaken to develop ORGEL, the reader will see in some detail how sound or optimistic these initial assumptions were.

Be that as it may, the potential of the ORGEL-type reactors was assessed several times after 1958, not only at Euratom but in Canada and the United States as well.

The findings were always highly promising, and it was this that in 1964 decided the USAEC[1] to go ahead with the heavy-water organic-cooled reactor, which was given a vigorous launching (p. 30, Sections 7.5 and 7.6).

Again in May 1969 the AECL[2], through its Senior Vice-President, stressed the very high potential offered by the organic-cooled heavy-water reactor[3]. This conclusion was shared by the European industrial group[4] which, in December 1968, had submitted a 250 MWe ORGEL reactor design to the Commission of the European Communities, in response to the Commission's invitation to tender (p. 39, Section 9).

It can thus be said that ORGEL's technical potential was and still is good, and that from this point of view the 1958 choice was well founded. But that potential could be exploited only on one vital condition - i.e., very rapid development, which meant resolute and effective support within the Community institutions and on the part of the Member States.

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1 United States Atomic Energy Commission

2 Atomic Energy of Canada Ltd

3 Nucleonics Week, 19 June 1969

4 GAAA-Interatom-Montedison

4. ORGEL - The intrinsic development context

4.1 The project's first handicap was that it was born at the same time as the organization which had to manage it. The process of recruiting 2500 people of different nationalities and setting up working structures, in a context where no precedent existed, gave rise to quite understandable hesitations[1], which were worsened by the delays in ratifying the agreement to transfer the Ispra Establishment to the Community; it was not ratified until 19 July 1960, several months behind schedule.

4.2 Another handicap lay in the way the Project was to be developed. It should have been organized with the single purpose of reaching the goal in the shortest possible time, backed by the best resources available anywhere in the Community[2]; instead, it had to provide the newly created Ispra Centre with a focus for action and give it priority in the design studies. In return, the Ispra Centre was supposed to devote its best efforts to the Project[3]. But it took a long time to get the laboratories going, and although some of them wanted to establish their competency in regard to ORGEL, others preferred to

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1 Which it was hoped, however, would be offset by the enthusiasm of combined technical and political creation.

2 Which, at that time, would assuredly not have been up to the job.

3 For this purpose the project had been assigned part of the equipment funds, which enabled it to bring financial influence, as well, to bear on the Centre's line of development.

take a very general line.

4.3 The Project Management ought to have been able to balance things by contracting work out to private or public Community laboratories, as it had had to do at the outset of the Project when the Ispra Centre did not exist. But by 1961 the theory of "fair return"[1] had emerged and now had to be applied, not simply within the overall Euratom budget, but actually in each separate project. An administrative procedure set up in July 1962 turned the awarding of contracts into an enormously lengthy process.

Then, from 1964 onwards, matters came to the point where the sums to be spent by the Project on research at the Ispra Establishment and those it could allot to research and development contracts had to be entered under different budget heads[2]; the R&D contracts were gradually chiselled away and then stopped completely. Throughout

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[1] To the effect that each State should get back the equivalent of its contribution to the Euratom budget.

[2] In the Euratom Research and Investment Budget, the budget head under which the ORGEL Project was entered bore the number 43. In 1963 the head was divided into two sections: Section 430, which covered the construction of the ECO and ESSOR reactors, and Section 431, covering the research connected with development of the Project. From 1964 onwards Section 431 was subdivided into two items: 4311 entitled "Contract research", and 4312 entitled "Own research".

this process the technical aspects failed to receive the attention they deserved.

5. Aims and achievements

> "The ORGEL Project consists in the whole set of studies preliminary to the construction of a prototype heavy-water moderated, organic-liquid cooled reactor".

Such was the definition bestowed on this Project at the outset of 1960.

5.1 Nine years went by, down to the recent decision to stop the Project; during that time a research infrastructure was laid, numerous experimental circuits were built and operated, materials were developed up to the pre-industrial production stage[1], technological assemblies were perfected; a research reactor for the study

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[1] E.g., SAP pressure tubes and claddings, uranium carbide (see Annex).

of heavy-water lattices was built (ECO)[1], likewise a huge complex for testing channel sub-assemblies[2] (comprising a reactor and two high-activity laboratories) (ESSOR)[3].

5.2 Fig. 1 shows the growth in the numbers of Commission personnel who worked on the Project. It will be observed that at the height of activity, in 1965-66, a little over four hundred people, or 35%, of the Ispra Establishment were working on the ORGEL Project. In all, the manpower devoted by the Commission itself to this Project can be estimated at 4,000 man-years[4].

5.3 The sum earmarked for the programme under head 43, entitled "Organic reactors", in the Euratom Research and Investment Budget, was approximately 17.5 million u.a. for the First and 64 million u.a. for the Second Five-Year Programme; 1.7 million u.a. were added for 1968. These sums do not include the cost of the staff used on the Project by the Commission, or the fraction of Euratom's general running costs which related to the Project; these costs are entered,

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[1] Orgel Critical Experiment

[2] The name given to the assembly composed of a calandria tube and a pressure tube containing the fuel in the coolant flow line.

[3] ESSai ORgel (Orgel test)

[4] To find the total manpower devoted to the Project one must, of course, add the far greater volume contributed by industrial firms during the construction of ECO and ESSOR, and by the various research organizations that worked under ORGEL contracts.

though not itemized, in another part of the budget. Out of the 83.2 million u.a. of investment and research appropriations, the ESSOR complex, including studies, accounted for 45 million and ECO for 5 million u.a.

The remaining 33 million u.a. went to the research programme, to be shared between the activities carried out in the Commission's laboratories and those put out to contract. Fig. 2 shows the change in the ratio of these sums over the years; the continual drop in the contract work (the reasons for which were given on p. 10, Section 4.3) is clearly evident, as is the fact that the "Own research" credits were very substantial in 1961-62, the period of fitting out the Ispra laboratories, which were very largely financed with the Project appropriations.

It is difficult to determine the exact total cost of the ORGEL Project, for want of a central analytical accounting system. If the estimate of 4,000 man-years, mentioned above for the Commission's manpower expenditure on the Project, is accepted as a fairly realistic figure, the cost of the personnel and related running expenses should be assessed at about 60 million u.a., which would bring the total cost of the operation up to 143 million u.a. So for want of a more exact figure we can estimate that total spending on the ORGEL Project in ten years amounted to 150 million u.a. at the outside.

Comparisons in this field are very difficult because, even where the bodies concerned - public or private - give overall figures, these may include ancillary expenditure (contribution to a centre's equipment, special laboratories, etc.) varying widely from case to case.

Here are some examples, for guidance purposes:

(a) The Dragon project, in eleven years up to 31 March 1970, cost £31.25 million. This sum comprises all expenditure, including the building and operation of the Dragon reactor, and the services supplied to the project by the Winfrith centre (general services, use of Zenith reactor). On the other hand, the project made no contribution to the expenditure on infrastructure and general equipment of the centre. At the current rate this sum is equivalent to 76 million u.a. If the variations in exchange rates during the life of the project were taken into account, it would be more than 90 million u.a.

(b) The development of the AGR and of its short-term improvements amounts to £110 million, or roughly 300 million u.a., whilst for all the advanced versions of the AGR and the SGHWR together, the total up to 31 March 1968 was quoted as £600 million or, calculated on the same basis as for Dragon, 1700 million u.a. ("Journal of the British Nuclear Energy Society", January 1969).

(c) As to the fast reactors:

(i) The German studies (Euratom Association) cost, from 1960 to the end of 1967, about 75 million u.a., but they did not include a demonstration reactor or "hot" laboratories ("Atom und Strom", January 1968, 146);

(ii) The British studies, up to the end of 1968 and excluding the initial exploratory phase, consumed £75 million, or about 200 million u.a.;

(iii) The French project (Euratom Association) also reached nearly 200 million u.a. - excluding Phenix - by the end of 1969.

In the Annex we describe some of the significant aspects of the ORGEL research and development programme and the way they developed.

6. ESSOR (photographs 1 and 2) and ECO (photograph 3)

6.1 We shall first of all discuss the ESSOR complex, the centrepiece of the ORGEL Project.

ESSOR is a complex comprising a reactor, with a total power of 45 MWth, a huge storage pond for active components, and two high-activity laboratories.

The decision to build was taken in October 1962; the civil engineering work started on site on 24 August 1963. The reactor first went critical on 19 March 1967 and reached full power on 19 June 1969. Annex 1 (pp. 89-90) gives a very brief description of the plant.

6.1.1 From the beginning of the studies, in early October 1959, the technical heads on the project were aware that the fuel element studies and irradiations must be given priority. Euratom had signed an agreement in 1959 with AECL[1] (p. 27, Section 7.1) which enabled some irradiations to be done in the Chalk River NRX reactor, but these operations lacked flexibility. Because of this,

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[1] Atomic Energy of Canada Ltd

the irradiation facilities inside the Community and outside (Denmark, for instance) were prospected at the same time, and studies for the construction of the project's own facilities launched. The prospects outside the Community proved disappointing. Inside the Community, the two reactors which offered space were the BR-2 at Mol, still in the course of construction, and the HFR at Petten, which was to come into service in 1962[1].

But neither of these two reactors was really suitable for irradiating ORGEL reactor sub-assemblies. A heavy-water reactor implies relatively large sub-assemblies, and a largely thermal neutron spectrum. Only the BR-2 could offer holes of sufficient diameter to hold an ORGEL channel, but the height under flux, less than 50 cm, was far too small and would give rise to non-typical stress gradients. Moreover, the gamma heating alone in the natural uranium exceeded 20 W/g, which was precisely the specific fission power aimed at in the fuel at that time.

Lastly, the planning of the BR-2 power run-up was still uncertain, as was the issuing of the operating licence.

6.1.2 Meanwhile, the initial specifications for a test loop reactor were prepared and printed on 20 September 1960. Beforehand we had visited all the nuclear designers in the Community to ask them if they would be

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[1] First normal operating cycle, 29 October 1962.

interested in constructing a test reactor for the ORGEL system; nine had replied in the affirmative. On 28 October 1960 the specifications for the test reactor were sent to them and they were asked to submit a tender. One firm cried off; eight replied, two or three of which stood out clearly from the others through their general experience in nuclear matters and their special knowledge regarding heavy water.

But the Commission thought that for such a big construction job, the only one on its programme, it would be more suitable to call in the industry of the whole Community rather than a firm of only one nationality. An invitation was therefore issued to set up consortia. Two consortia were formed and three firms remained isolated.

The Commission awarded contracts to each consortium to produce a preliminary draft design. For the construction of ECO, only the three firms who belonged to no consortium were consulted (p. 26, Section 7.2.2).

The two consortia sent in the file of their work on 20 May 1961, the two proposed versions - both technically viable - were compared, and the choice fell on the one prepared by the GAAA-Interatom consortium.

6.1.3 A year had already passed since the first studies on the problem. It was arguable that this delay was necessary to bring the affair to maturity and that, now that a designers' consortium had been formed, we must

make up for lost time by going ahead as fast as possible;

There were still a number of advocates, however, of two other solutions, rivals to the test loop reactor; one of these consisted in mounting one or more loops in the BR-2, Mol, and/or in the HFR, Petten, reactor; the other was to build a small experimental reactor (40 MWth) entirely organic-cooled.

The latter solution did not lack supporters on technical grounds, since many thought the overall soundness of the concept ought to be demonstrated as early as possible and that the experimental reactor would provide the shortest and most convincing proof. Yet we had to make sure that adequately proven answers to such problems as the pressure tube, the fuel element and the coolant cleaning system would be ready at the right time. The Annex makes it clear that in 1961, when the ORGEL programme had barely got off the ground, the uncertainties in the key fields were so great that one might well hesitate at such a gamble.

The Canadians did not share this view and were designing a prototype reactor, the OCDR[1], which was to have a capacity of 350-400 MWth and embodied the principal features of a power reactor.

But their position was not the same as ours, for they, with the elements developed for CANDU, had solutions they could fall back on in the way of fuel and channels which could be used if the organic coolant temperature was lowered.

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[1] Organic-Cooled Deuterium Reactor

Thus, with Euratom building a loop reactor and AECL a prototype, a certain division of labour emerged[1].

6.1.4 The Commission did not think a decision to build the loop test reactor could be taken as early as July 1961 and it asked for additional information; a contract for more detailed studies was signed on 20 October 1961 with the GAAA-Interatom group, who, as a result, submitted a detailed preliminary design on 16 July 1962; and a full project for an irradiation loop in the BR-2 was prepared by a Belgian industrial firm, SERAI, and submitted on 30 April 1962. The different solutions were examined in comparative studies; numerous discussions were held, particularly within the Scientific and Technical Committee. Furthermore, in the context of preparing the Second Five-Year Programme, a joint ad hoc committee, composed of members of the Consultative Committee on Nuclear Research and members of the Scientific and Technical Committee, considered this problem[2] and decided unanimously in favour of building the specific test reactor rather than the irradiation loops.

For the Second Five-Year Programme all the paths were nevertheless left open, since the construction of both a BR-2 loop and a loop test reactor figured in the proposal regarding ORGEL, but the 10 million u.a. cut that

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1 In actual fact the AECL partly came round to Euratom's point of view, deciding in September 1961 to abandon the OCDR concept and replace it with the OTR (Organic Test Reactor 1), a loop reactor much closer in design to ESSOR than to the former OCDR.

2 This committee met in Brussels on 12 February and 13 March 1962 with Mr Gibrat as its Chairman. It comprised experts from the six countries. It submitted its report on 5 April 1962.

was imposed in the last minute in ORGEL's five-year appropriation, to bring the total programme budget down to an acceptable figure, left no alternative but to drop the in-pile circuit.

After discussions which dragged on through the whole of the summer of 1962, the Commission decided, on 10 October 1962, to build the loop test reactor. By then 29 months had gone past since the officials in charge of the project had advised that the irradiation devices should be developed with all possible speed.

The project was never to recover from these delays which occurred at the start of its life, the most critical period when time is doubly valuable.

6.1.5 The Commission had decided to build ESSOR at Ispra. A site therefore had to be chosen and the necessary preliminary work done. At the same time an industrial architect's contract was awarded to the GAAA-Interatom design-study consortium, expanded to take in the Italian company of Montecatini[1], with GAAA acting as leader. The architect formula was preferred to that of a main contractor, because the Commission wanted to reserve the right to select the companies for the main contracts. This was not a trouble-free process since, for example, the Commission took no less than eight months - at such a critical planning period and in spite of several warnings from the industrial architect - to decide how to split up the various "regulation and control system" contracts. (And of course, once the breakdown was decided on, all the administrative and technical procedure leading up to the signing of the contracts still had to be gone through.)

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[1] Now Montedison.

6.1.6 Finally, it was July 1963 when the first concrete was poured for the foundation-raft of the leaktight enclosure. From then on, the goal was to get the reactor to the criticality stage. To achieve this, we did our planning by the PERT method, which had proved itself in the United States, more especially in the military field, but had been used very little in Europe at that time. Although the industrial architect followed our lead quite quickly in this method, we sometimes ran into great difficulties with the suppliers.

It was certainly due to the general application of this method that the date set in 1962 for going critical was met in 1967, to within 20 days. The fact that with PERT one can foresee the sequences well ahead and make the necessary adjustments enabled us to absorb most of the administrative delays[1] we encountered during this operation.

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[1] An example of administrative red tape: Euratom's Second Five-Year Programme, worth 415 million u.a., was to cover the five years from 1963 to 1967. The Council's budgetary experts announced straightaway that, to prevent any temptation to use up the funds too quickly, each annual budget was to keep fairly close to one-fifth of the five-year appropriation. This decision was patently a hampering one at a time of heavy capital investment. As it was impossible to divert the the funds for one sector into another sector, the experts' reasoning was extended step by step to cover each head and even each item in the budget, although it is obvious that in the case of ESSOR, the commitments curve was bound to go through a very sharp peak in the year following the decision to build, after which it would drop again. To get the log-jam moving, we were instructed to commit equivalent sums in each year! The legal and financial departments had to work out a procedure of fractional commitments which complicated everyone's life and wasted time, without doing any good anywhere in the end.

6.1.7 After the reactor had gone critical, the facility still had to be brought into operation. To do this, it was essential to increase the staff assigned by Euratom to this project. In deciding to build ESSOR, the Commission had not thought it its duty to grant the personnel needed to set up an operating unit. Even so, an embryo unit was formed of a few individuals in 1964, but it grew very slowly as it was not given a proper staff.

Until the reactor went critical this staff shortage had been concealed by the industrial firms' contributions, but when it came into "nuclear" service the staff clearly had to belong, like the responsibilities, to Euratom. The Commission then decided to step up the forming of the ESSOR Operating Division. But we were entering the era (1967) when the Member States resolved to put a ceiling on Euratom's personnel establishment. All the available slots were assigned to the ESSOR operating team but, with the time lost in getting the people to the site and training them, this team was not ready in due time; moreover, a feeling of frustration grew up in the Ispra laboratories, who saw their own recruiting stopped.

6.1.8 Another difficulty arose out of the budget problems. Most of the ESSOR supply contracts, covering one to three years, contained price revision clauses. There resulted a rise in the real costs which, though moderate in percentage terms, was appreciable in absolute value because of the large sums involved. But the Community's research budget is inflexible.

The Commission's powers to transfer from one head to another are very limited[1] and, even where they exist, they are not easy to exercise.

The ORGEL Project was not alone in this situation and in 1964 the Commission embarked on a procedure to modify the Second Programme to meet the rise in the cost of living. This procedure was completed after more than a year and supplementary sums were allocated, on definitive terms however, for the three years the Programme still had to run. Naturally costs went on rising. To cope with the contract commitments we had to use up a good part of the funds earmarked for starting up the facility, and in particular for paying temporary skilled personnel.

The Member States, notified several times of the situation, adopted different attitudes: some suggested that the staff of the Ispra Establishment services should be used temporarily, while others opposed this. Hence, although ESSOR went critical at the scheduled date, its power run-up took a year longer than it would normally have done.

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[1] The financial regulation authorizes transfers under each budget head. In principle, therefore, there should be no subdivision of heads in the published budget. But it is for the Council to decide what is a head and what is not; so that the power of transfer vanishes in practice.

6.1.9 By the way of illustration of the kind of difficulties we encountered between criticality and the run-up to full power, mention may be made of the fact that in December 1968, at the meeting of the Council of Ministers to discuss the Euratom programme for 1969, the commissioning and operating of the ESSOR organic circuits were ruled out although no decision had yet been taken to stop the ORGEL Project, since the industrial consortium's "Prototype" file (p.36, Section 9) had just been submitted and the Ispra laboratories were preparing the ORGEL channels and fuels which were to be irradiated[1].

Thus ESSOR reached its full power in 1969 with only the boiling light-water experimental loop constructed for the Cirene programme. At its meeting of 30 June 1969 the Council of Ministers entered the start-up of the organic loops on the programme, for six months, but did not allocate funds for this operation, and asked that other experiments than the ones planned in the ORGEL context be found for irradiation in the organic loop.

To sum up, the time devoted, during the development of ESSOR, simply to overcoming the various forms of resistance can be estimated as at least three years[2]. In such a rapidly changing field as that of nuclear technology, such delays were bound to be fatal to the future of the Project.

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[1] ORGEL was abandoned on 30 June 1969.

[2] A year between the autumn of 1959 and the decision to build, in October 1962; a year between the decision to build (October 1962) and criticality (March 1967); a year between criticality (March 1967) and full power operation (June 1969).

6.2 ECO

6.2.1 The building of ECO was not an essential part of the ORGEL Project (see Annex). In 1960, heavy-water reactor physics was being studied experimentally in France, Canada, Sweden and the United States, where zero power heavy-water reactors were in operation. Admittedly the introduction of organic coolant into the lattice raised new problems, but the findings most necessary to the Project could have been obtained by way of specific test contracts (this method was in fact employed at the outset of the Project).

The building of ECO was a typical example of how the Ispra Establishment was given an ORGEL bias and how the Project contributed to the Establishment's major equipment.

To justify the construction of a new zero power heavy-water reactor, it had to offer new facilities unobtainable with existing reactors. ECO was therefore designed with characteristics that were both new and relatively complex; instead of the very simple fuel suspension system ordinarily found on the critical experiments, it was decided to use an automatic pitch-changing device. The design also included a device for heating the heavy water, with the requisite controls.

One of the still unexplored areas of heavy-water reactor physics was the study of lattices containing reprocessed or irradiated fuels with a plutonium content. With this in view, ECO was equipped with substantial shielding so that it could receive irradiated fuel.

It was also planned to mount an accelerator beneath the reactor vessel, in line with its centre-line.

ECO likewise allows "square wave oscillation" of a complete fuel element, new or irradiated; this demands space, machinery and substantial shielding.

In short, ECO was to be a big step forward in facilities for studying heavy-water lattices and, from the standpoint of wise coordination of facilities inside the Community, the more out-of-date installations ought to have been given up when it came into service, or at the least the various work should have been shared out by joint agreement.

7.2.2 In April 1961 the Commission issued an invitation to tender, limited to the three firms who had joined a consortium for the second stage of the ESSOR bidding (p. 16, Section 6.1.2) and awarded a turnkey contract for ECO to one of them, Neratoom.

The contract came into force on 15 December 1961. The time allowed up to provisional acceptance was 22.5 months, which meant that the reactor would be commissioned at the beginning of November 1963. But Neratoom was first of all held up by slippages in the schedule of the firm doing the civil engineering work, and then ran into unforeseen difficulties. The actual construction time was 40 months. The Commission took over the unfinished reactor on 20 May 1965, completed it, and took it into service on 11 December 1965.

The consequence of these delays was that ECO arrived too late on the heavy-water scene. The CEA went on using Aquilon, and then built Eole at Cadarache[1]; finally, Aquilon was sold in 1967 to the CNEN who, adding it to the RB-2 reactor, formed a unit for heavy-water lattice studies at Bologna.

Admittedly ECO provided useful and numerous results, after the Ispra teams had put it in working order, but the original intention of concentrating Community research was a failure.

7. ORGEL's development in the international context

7.1 In 1958 the Euratom Commission and the AECL had signed an agreement for cooperation in the field of peaceful uses of atomic energy. This agreement[2], which came into force on 18 November 1959 for ten years, included a technical agreement by which the contracting parties would undertake a common research and development programme centred on the type of heavy-water moderated reactor that would be utilized in the Community and in Canada. Although the heavy-water cooled and moderated type of reactor had been explicitly mentioned in the agreement, a fact which would have allowed the large-scale concentration we referred to in Section 2.2 (p. 5), the agreement was focused on the organic-cooled reactor as soon as Euratom decided to centre its efforts on this variant.

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[1] The work was started in mid-1964.

[2] Published in the "Journal Officiel" of the Communities, No. 60, 24 November 1969.

The technical agreement also stipulated that each contracting party would contribute an equal share to the joint programme, up to a total of 5 million u.a. each, for a period of five years. There were clauses providing for exchanges of information and knowhow. An annual meeting was to be held, to review the programmes and results. The first took place at Chalk River from 30 May to 3 June 1960, and the second at Ispra on 19-23 June 1961.

7.2 At that time the American "all organic" programme[1] was in full swing: the OMRE[2] reactor was functioning well, the town of Piqua had decided to have its lighting supplied by an organic reactor which was under construction; a 150 MWe "all organic" power plant (known as AKS) was proposed by Atomics International to West German electricity producers[3]. If agreed to, research on organic coolants might be included in the well-known US-Euratom agreement which linked the USAEC[4] and Euratom together. Lastly, Canada and the USAEC had agreements concerning, on the one hand, heavy-water reactors, and on the other, the use of organic liquids in reactors.

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1 A distinction must be made between the reactors which, in nuclear jargon, are known as "all organic" and the "organic/heavy-water" reactors. The former are both moderated and cooled with an organic fluid. Hence their nuclear characteristics (enrichment, core structure) are close to those of the pressurized light water reactors. In the second type, however, the moderating is done by heavy water and the organic fluid is used only to extract the heat.

2 Organic-Moderated Reactor Experiment

3 KBWP: Kernkraft Baden-Württemberg Planungsgesellschaft, a body acting on behalf of several electricity producers.

4 United States Atomic Energy Commission

7.3 Thus there existed a triangle; its sides did not all meet exactly, but an effort to achieve a genuine triangular cooperation was accomplished and as a result the annual Euratom-AECL meeting was held, on 11-15 June 1962, at Los Angeles in the presence of the USAEC and its contractors. Unfortunately the difficulties encountered in the operation of the OMRE[1] reactor discouraged the Americans, who cut back their "all organic" programme (10 December 1962) and decided to shut down OMRE on 30 June 1963, pending the results of the Canadian "organic/heavy-water" programme on the one hand and the Piqua reactor operating results on the other. The offer to build the AKS reactor was not followed up.

7.4 The AECL reacted by slackening its effort on its "organic/heavy-water" programme in favour of a hastily launched programme relating to the boiling light-water cooled variant, for which it was proposed to build a prototype (Gentilly). At the end of 1963 the ORGEL Project therefore found itself far more lonely than at its birth. This did not fail to evoke, inside the Community, numerous criticisms which, although they did not stop the Project, nevertheless generally increased resistance to its progress.

And yet the initial results of the research programme were appreciable and the construction of ESSOR was getting on.

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[1] Both we and the Canadians had foreseen these difficulties, which were due to the fact that, in their haste to build, those responsible for the OMRE programme had completely overlooked the absolute need for rigorous purification of the coolant. Fig. 8 illustrates this point.

7.5 It was at this juncture that the USAEC, on the strength of extremely affirmative reports submitted by the Oak Ridge teams in the first half of 1964, decided to take up organic cooling again, this time in conjunction with heavy-water moderating: this was the HWOCR[1] project (24 July 1964). Combustion Engineering and Atomic International were chosen to be the chief contractors. A sum of 20 million u.a. was alloted to the project for the first year. At a single stroke the USAEC leased half the WR-1 reactor from the AECL, likewise the U-3 organic loop of the NRU reactor, and took over for its own account the greater part of the work done by the Canadians.

7.6 On 10 September 1964 the Chairman of the USAEC, Mr Glenn Seaborg, visited the Euratom Commission on his way through Brussels, congratulated it on having had the sense to persevere along a good line, recognized that ORGEL was ahead of the HWOCR and proposed an agreement for collaboration between the HWOCR and ORGEL projects. He added that the USAEC was going to put so vigorous an effort into the HWOCR that he hoped to see ORGEL's lead shortened. Everyone interested in ORGEL saw that this was a second chance. Even so, Mr Seaborg's proposal failed to receive a reply until five months after it was formulated. Then, when the Commission proposed a draft agreement to the Member States (4 May 1965), they were unable to reach agreement on its content.

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[1] Heavy Water Organic-Cooled Reactor

After 22 months[1] of argument, the problem solved itself with the decision to abandon the HWOCR, announced by the USAEC on 9 March 1967. In spite of excellent technical results, budgetary considerations had prevailed[2]. There was also a shortage of qualified reactor staff owing to the boom in orders for light water reactors. The HWOCR project was demolished as energetically as it had been mounted.

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[1] Dates, rather than words, will give the clearest picture of this episode:

10 September 1964:	Mr Seaborg visits Brussels.
16 February 1965:	Euratom Commission's provisional reply.
4 May 1965:	First memorandum from Commission to Council proposing collaboration.
11 November 1965:	Another memorandum from Commission to Council urging the proposal.
21 March 1966:	Draft "Memorandum of Understanding" forwarded to Council.
8 June 1966:	An additional table specifying the fields for cooperation forwarded to the Council.
13 December 1966:	Modified tables forwarded successively.
20 December 1966:	
23 February 1967:	
9 March 1967:	USAEC announces that HWOCR project is being abandoned.

[2] Visit to the USAEC, in Washington, on 5-6 June 1967.

8. ORGEL's progress in the Community context

8.1 A reproach often levelled at the Commission by the Member States was that "they were not given sufficient information on the development of its programmes". Arduous debates on the problem of "Dissemination of Information" continued for several years. Although a great many reports and papers had been prepared and delivered to the recipients nominated or approved by the Member States, information on the Commission's programmes did not seem to be spreading sufficiently.

It was to improve the situation in regard to ORGEL that the Euratom Commission decided in 1965 that a general and detailed view of the Project and its prospects should be set before the interested bodies, industrial firms and electricity producers, of the member countries. This meeting was held at Ispra on 25-28 October 1965, in the presence of delegates appointed by the six countries and drawn from private industry as well as from public enterprises and research centres.

They were given a comprehensive review of the various guidelines chosen for the research programme, and a description of the results obtained. Literature was distributed in abundance and visits were paid to laboratories.

8.2 It was at this moment that the Project's principal technical option was discussed in detail - the use, for the fuel element, of uranium carbide as fuel and SAP[1] as cladding.

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[1] Sintered aluminium-alumina powder (see Annex).

This combination was far from generally known in 1960 and the ORGEL Project had the merit of bringing it to light, sticking to it and, finally, convincing Canadians and Americans of its soundness[1,2]. The latter had centred their studies on Zircaloy-clad oxide, simply because they were already familiar with these materials, separate and in combination; but this fuel element quite early proved to be unsuitable for organic cooling, because the zirconium alloy hydrided very quickly at the temperatures to which, as cladding, it was subjected, and furthermore the natural uranium oxide had rather too low a density of fissile nuclei to allow sufficient burn-up, allowing for the fact that the hydrogen in the organic liquid absorbs neutrons.

Uranium carbide, on the other hand, had a higher density of fissile nuclei and, above all, its excellent thermal conductivity meant that fuel elements could be designed with solid rods, favourable to the neutron balance. SAP, which in its turn has far greater conductivity than zirconium, combined very well with carbide. The Americans, in their HWOCR programme, successsfully carried out irradiations of SAP-carbide fuel reaching burn-ups of over 16,000 MWd/t in the Canadian Whiteshell organic reactor (WR-1).

Thus with the SAP-carbide fuel ORGEL, fuelled with natural uranium, would be a reactor with reasonable performance values, comparable or slightly superior to those of the other natural-uranium fuelled reactors.

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[1] For its HWOCR programme the USAEC purchased large quantities of SAP from Montecatini, who had researched and developed it under an ORGEL contract.

[2] p. 59, Annex, Section 1.3.2

8.3 But in 1965 it was already apparent that this was no longer enough and that a project must have a distinctly higher potential than its rivals if it was to be developed further. The use of SAP-carbide fuel made this possible, but this time by dividing the fuel and exploiting the carbide potential far more thoroughly. Naturally, to carry off the generated fission heat, the organic coolant channel cross-section had to be considerably enlarged and the fuel slightly enriched (by about 1.25% absolute).

This enriched ORGEL reactor, which incidentally needed a less exacting technology[1] than the natural uranium version, offered an appreciable economic potential. Our arguments were, of course, debated, criticized and challenged, but the impression that remained was strongly positive. Interest in carbide soared and other organizations found that by substituting carbide for oxide in their projects they made a great leap forward. Nevertheless, although the carbide was wholly compatible with the organic liquid, it was less so with CO_2 and not at all compatible with water; so ORGEL still kept its lead.

8.4 The German reaction was not long in coming, however; they thought "all this would be far more credible if it had the support of industry". We had no objection from this angle, as the results of the research programmes were by then substantial enough to serve as the basis for an industrial project.

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[1] p. 54, Annex, Section 1.2

Unfortunately, the Community context was deteriorating; the Commission found both its term and the Second Five-Year Programme coming to their end in an atmosphere thick with uncertainties. There seemed to be difficulty in getting talks going with the Council on programme problems; the Consultative Committee on Nuclear Research, which had been conceived for the express purpose of discussing the preparation of programmes with the Commission, had ceased to meet. In the more specific matter of ORGEL the situation was no less critical; the agreement with the USAEC, mentioned in Section 7 (p. 27) had failed to mature. In practice, Germany was showing more and more reluctance to pursue the ORGEL Project; Italy, having recently decided to build a small (30 MWe) demonstration reactor of the boiling-water cooled type (Cirene) was no longer interested in ORGEL. Belgium officially disclaimed any interest in heavy-water reactors.

In such a setting the Commission, itself irresolute regarding ORGEL, did not care to propose to the Council to undertake the construction of a prototype. It confined itself to promoting a more limited scheme which it could cover with the funds available - the "ORGEL Prototype Competition".

9. The "ORGEL Prototype Competition"

9.1 This scheme was prompted by two desires, first, to transfer the file of acquired knowledge to the nuclear industry, and secondly, to obtain from the industry a tender suitable for consideration by a customer. In November 1965, when this operation was started, it was not as clear as it is now that new types of reactors hold practically no interest for electricity producers, who demand more warranties for them than for the "proven" types. Also, a chemical company producing organic liquids had expressed interest in the combined production of steam and electricity from an ORGEL power plant.

What was needed, therefore, was a firm tender accompanied by a certain number of guarantees concerning the fuel cycle and the power generated by the power plant. Naturally this could only stem from a very detailed preliminary design which would take all the existing work into account. Such an operation would be costly and no industrial firm would take the risk without a good prospect of building the reactor, and this only the Council could provide.

An incentive was therefore found: a premium would be paid to the group(s) of firms under certain conditions[1] and retained if the prototype was not built. Should it be built, however, the amount of the premium would be deducted from the group's fees, if it was engaged as the Industrial Architect. Lastly, in exchange for this premium, the Commission would be given larger user rights over the

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[1] These were essentially connected with the quality of the tender itself.

specifications file than are normally granted in such matters and, in particular, the right to consult anyone it wished. This system carried the inherent risk of a price which, unhampered by the penalties of building with genuine warranties, might harm ORGEL's cause: if it were low, nobody would believe it; if high, they would say "I told you so!".

The other aim fulfilled by the ORGEL Prototype Competition was that it would permit of completing the studies in the Commission's own departments. The development of ESSOR was making progress, but the failure to reach agreement with the USAEC regarding the HWOCR and the dropping of that project had been a harsh blow.

The unpropitious Community atmosphere and the mounting uncertainties sapped all initiative. Interest was flagging in the laboratories. The prototype competition enabled us to gather up the threads and continue the ORGEL Project to its end.

9.2 Only one consortium responded to the invitation to tender, the same one as had built ESSOR[1], expanded to include Benelux firms for the supplies estimates.

The capacity had been set at 250 MWe, which at that time was high for a prototype; we did not think it possible to go any higher without the risk of scaring off a possible customer. Moreover, this capacity averted dissension on the "natural or enriched" question, because

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[1] GAAA-Interatom-Montedison

at 250 MWe the prototype had to be enriched, by reason of its mere size. On the other hand, the design study showed that, precisely through the effect of scale, a slightly larger capacity (300-350 MWe) would have appreciably reduced the capital costs.

The study began in July 1967 with a detailed briefing of the consortium on all the work already done in connection with ORGEL. A collection of reports had been specially prepared by the Ispra departments or the Project. Then the preliminary design work proper began, a certain number of studies relating particularly to the core being sub-contracted by the consortium to the ORGEL Project's design office. The consortium submitted its preliminary design to the Commission on 31 December 1968.

9.3 The price quoted was, as regards the capital costs, a fair one for a prototype of that size, but of course it did not provide a kilowatt/hour cost to rival that of a large-scale proven-type power plant.

The specifications file showed up three important points. First, the fuel consumption cost was too high for a heavy-water reactor. This was due to the fact that the SAP-clad uranium carbide fuel was expensive, not being backed by a big production line. There was a good prospect that the price could be lowered substantially, but only in the context of a production line supplying a number of reactors. It was becoming clear that a whole series of commercial power plants would have to be built; this question is discussed in Section 10.2.2 (p. 41).

Offered the alternative of a reactor fuelled with natural or with slightly enriched uranium - with the latter, as we said in Section 8.3 (p. 34), one could use a less exacting reactor technology and obtain spectacular savings on the cost per kWh - the consortium decided upon a middle way which provided a solution to two other problems common to heavy-water variants that use a coolant with a higher absorbing power than the moderator, namely, the reactor's inherent instability, and the reactivity introduced by a drop in the coolant level. The only way to limit the effects of these drawbacks is by under-moderating the lattice and slightly enriching the fuel. That is what the consortium did (following the Birtish example in the SGHWR[1]) and they chose an enrichment rate of 1.28%.

The consortium also suggested that certain well-defined additional research work should be done, and stressed the urgency of using ESSOR to irradiate the channel assemblies.

10. The context surrounding the Commission's decision to stop the project

10.1 The intrinsic context

We mentioned in Section 6.1.9 (p. 24) that the 1969 programme made no provision for operation of the ESSOR organic circuits. This decision had been taken on 20 December 1968, i.e., at the time

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[1] Steam Generating Heavy-Water Reactor, enrichment about 2%.

when the Commission was receiving the consortium's file for the ORGEL prototype. No proposal to drop the Project had been formulated by the Commission at that time. The Second Five-Year Programme, however, had been at an end since 31 December 1967.

The year 1968, and then 1969, were "transition" years during which, in actual fact, the Atomic Energy Community was no longer endowed with a real programme. Hence there were scant grounds for hoping that, in such a context, a quick decision would be taken involving large sums of money and a fundamental aspect of industrial policy, especially as the "outside" nuclear context had also changed considerably since ORGEL was first launched.

10.2 The outside context

10.2.1 In 1969, there are various proven-type reactors on which industry is expending an enormous effort[1]. The fast reactors are still in the development stage, but their advent is predicted for the decade 1980-90. The "intermediate" reactors, which include the heavy-water and "high-temperature" types, seem to have got caught between the proven-type and the fast reactors.

In consequence, the tendency is to justify them as an insurance against possible, though not certain, troubles - major uranium price rises, enriched uranium

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[1] For example, the light-water reactor capacity in operation, under construction or on order throughout the world totalled, in round figures, 82,000 MWe on 1 October 1969; of these, 48,000 MWe are of the PWR and 34,000 MWe of the BWR type.

supply difficulties, late arrival of the fast reactors. To be justifiable, the cost of developing these intermediate systems ought to be moderate. Unfortunately, they are subdivided into too many variants.

For the heavy-water systems, there are six variants[1], some of them with more than one version; for the high-temperature system, two, one of them in two versions.

Not one of these variants enjoys a big existing or prospective market, apart from CANDU which reposes on a total capacity of 6,000 MWe in operation, under construction or decided upon.

The variants of intermediate reactors cooled with heavy or light water can hope to profit by the "spin-off" from the industry's vast development of light-water reactors; not so the other variants cooled with a medium- or high-temperature gas or with organic liquid.

10.2.2 In 1969, a decision to build an intermediate reactor prototype means a clear committal to launching into an industrial series that will enable development costs to be offset and the techniques employed to be based on sufficiently broad

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[1] Cooled with carbon dioxide (CEA-Siemens), organic liquid (ORGEL), boiling light water (Canada, Italy, UK), heavy water in a reactor vessel, either boiling (Sweden) or pressurized (Siemens), heavy water in pressure tubes (Canada).

foundations[1]. To do this, one must feel certain at the outset that on all levels, technical and economic, the prototype will not be merely semi-successful. One must also know with certainty that the power plant will contribute more than a minimal kWh saving over the reactors already on the market[2] and, moreover, that this saving will not be offset by any lack of reliability. It is clear that one cannot have this certainty regarding ORGEL any more than any other advanced type of reactor.

Faced with unfavourable intrinsic and external contexts, the Commission decided to bow to the facts and not propose the building of a prototype to the Member States, i.e., to terminate the Project. It is to be regretted, nonetheless, that the subject was not more widely debated so as to gain recognition for what had been achieved and to bring the whole problem of systems and prototypes out into the light.

The fact is that whilst the dropping of the ORGEL variant is a step in the imperative direction of cutting down the number of intermediate reactor variants, it did not stem from an overall decision and it still leaves far too many varieties for any one of them to have a serious chance of making a breakthrough in time.

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1 This is written in the light of the present situation. A really concerted effort by the Community countries would, if made in time, have enabled them to avoid duplications or pseudo-rivalries and bring a larger number of variants up to the prototype stage, for the same price and in the same time. A selection could have been made on a practical basis.

2 Which are in any case moving targets.

CONCLUSION

For those engaged on it the ORGEL Project was an enthralling experience. Whilst it achieved the targets set for it by the two Euratom Five-Year Programmes, it did not attain its essential purpose, namely, to be a Community reactor system. Circumstances prevented this. Nevertheless, the Project gave rise to developments of sufficient importance to have left notable traces and enriched the experience of those who worked on them.

The ORGEL experiment could still be turned to good account if the lessons it provided on the pitfalls to be avoided in Community-wide technical cooperation were borne in mind. Without claiming to be exhaustive or original in so complex a field, we can say that the procedure laid down in Article 7 of the Euratom Treaty, which has governed the Euratom programmes, including ORGEL, up to now, is not ideally suitable for the carrying out of a large-scale technical project, where time and efficiency are all-important, and that it is highly likely to bring such a project to a halt.

Yet this procedure could conceivably be employed effectively, and other more suitable machinery can probably be found in the Treaty, but to be any good it must enable the industry to play its proper part. It may appear attractive at first sight to share the expenses involved in the construction of large prototypes by building them on a Community basis, but we must not forget that prototype-building is not an end in itself and that the resultant reactors have to be sold under market conditions.

Thus we come back to the competence of the industry, for which provision must be made from the very start by furnishing acceptable answers, not only to the problems of industrial property rights and the dissemination of information (which have now been dealt with), but above all to the questions of structure and financing.

And lastly, if answers were found to these knotty problems, one could still never sufficiently emphasize the necessity, if a Community enterprise is to succeed, of a profound common motivation to forge ahead - not forgetting that the strength of a motive depends largely upon awareness of the need.

HISTORY OF THE ORGEL PROJECT

First mention of ORGEL in official Community proceedings:	1958
Scientific and Technical Committee consulted:	28 Apr. 1959
First ORGEL studies:	1 Oct. 1959
Canada-Euratom Agreement came into force:	18 Nov. 1959
Canada-Euratom Agreement: Joint Committee meeting held at Chalk River, Canada:	30 May to 3 Jun. 1960
Ispra Establishment handed over to Euratom:	19 Jul. 1960
Specifications for a test reactor, for testing ORGEL fuels and structures:	20 Sep. 1960
Nine Community nuclear firms consulted regarding construction of the test reactor:	28 Oct. 1960
Two multinational consortia formed:	20 Jan. 1961
Launching of consultation for ECO:	**13 Apr. 1961**
Test reactor project submitted by each consortium:	20 May 1961
Canada-Euratom Agreement: second Joint Committee meeting held at Ispra, Italy:	19-23 Jun. 1961
Choice of one of the two ESSOR test reactor projects:	27 Jul. 1961
Design contract signed with GAAA-Interatom consortium:	20 Oct. 1961
ECO construction contract came into force:	15 Dec. 1961
Change of Euratom President:	11 Jan. 1962

Meetings of CCNR-STC Joint Ad Hoc Committee to examine the ORGEL proposal for the Second Five-Year Plan:	12 Feb. 1962 13 Mar. 1962
CCNR-STC Ad Hoc Committee's report submitted:	5 Apr. 1962
Design study submitted, for two in-pile irradiation loops in BR-2 and HFR:	1 May 1962
Canada-Euratom Agreement: third Joint Committee held at Santa Monica, California, with USAEC present:	11-15 Jun. 1962
ESSOR specifications file submitted by GAA-Interatom	16 Jul. 1962
Council's decision regarding the Second Five-Year Plan:	23 Jul. 1962
Decision to build ESSOR:	10 Oct. 1962
Start of Second Five-Year Programme	1 Jan. 1963
Start of on-site work at Ispra	12 Apr. 1963
ESSOR civil engineering work started:	24 Aug. 1963
Scheduled date for completion of ECO:	beg. Nov. 1963
Budget head "ORGEL Research" split into two items: Contract Research and Own Research projects:	Jan. 1964
Second Five-Year Programme revised:	1964
Mr Seaborg's visit to Brussels, proposing ORGEL-HWOCR collaboration	10 Sep. 1964
Commission's provisional reply:	16 Feb. 1965
Memoranda on this subject sent to Council:	4 May 1965 to 23 Feb. 1967
ECO taken over by Commission:	20 May 1965
ORGEL Colloquium:	26-28 Oct. 1965
ECO started up:	11 Dec. 1965
Years in which, owing to protracted budget discussions, the year had to be started with provisional twelfths:	1965 1966 1967
First discussion of the "ORGEL Prototype Competition" operation:	17 Nov. 1965

HWOCR abandoned:	9 Mar. 1967
ESSOR went critical:	19 Mar. 1967
Merger of Executives of the European Communities:	1 Jul. 1967
Start of "ORGEL Prototype Competition":	3 Jul. 1967
End of Second Five-Year Programme:	31 Dec. 1967
"Prototype Competition" specifications file submitted by the industrial consortium:	31 Dec. 1968
Years of transitional budget:	1968 1969 1970
ESSOR first operated at full power:	19 Jun. 1969
ORGEL Project stopped:	June 1969

SOME DATES RELATING TO THE AMERICAN ORGANIC PROGRAMME

Start of organic fluid studies in United States:	1950
Meeting at Downey, California, as a result of which polyphenyls were selected as the most suitable coolants:	1953
"TID-7007", a collection of data on organic coolants:	Jan. 1957
OMRE went critical:	17 Sep. 1957
Start of construction of Piqua reactor:	July 1959
Decision to scale down the OMRE research programme:	10 Dec. 1962
Piqua reactor went critical	14 Jun. 1963
OMRE project stopped:	30 Jun. 1963
Piqua reactor shut down:	1 Feb. 1966
HWOCR project launched:	24 Jul. 1964
HWOCR project stopped	9 Mar. 1967

SOME DATES RELATING TO THE CANADIAN PROGRAMME

Start of OCDR studies:	end 1956 beg. 1957
Canada-Euratom Agreement:	18 Nov. 1959
OCDR programme stopped:	22 Sep. 1961
Decision to build OTR (WR-1):	3 Nov. 1961
OTR brought into service:	2 Nov. 1965

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Year	Author(s)	Title	Publication	or Euratom Report No.
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ANNEX

The Principal Technical Options and Their Development

S. Orlowski

1.0 Guidelines of the Project

The ORGEL Project consisted in developing a reactor cooled with an organic liquid and moderated by heavy water.

1.0.1 In Europe, in 1959, moderation by heavy water ruled out any idea of enriching the fuel; the reactor would have to operate on natural uranium. With such a fuel, together with a relatively absorbent organic coolant, there would be little margin in the neutron balance; we therefore had to use a fuel with high uranium density and cut down parasitic absorption in the structural materials (cladding, channel) and the coolant to a minimum, so as to keep a sufficient margin of reactivity to consume the fuel; the latter had to be capable of reaching a burn-up that would make the fuel cycle economically attractive without any neutron physics or technological obstacle (excessive swelling) and that would in any case be higher than the burn-up obtained in graphite reactors.

1.0.2 The desire for improved thermodynamic efficiency led to the choice of a mean in-reactor coolant temperature higher by several tens of degrees than that found in the light-water reactors of those days, namely, of the order of 320°C. The coolant channel cross-section being limited, the coolant outlet temperature had to be in the vicinity of 400°C and the maximum cladding temperature 450-500°C.

1.0.3 To keep down the capital costs we had to use inexpensive materials, already available on the nuclear market or likely to become so at an early date; the core rating per litre also had to be as high as possible, so as to lessen the impact of the cost of the immobilized heavy water on the installed Kw production cost.

1.1 Degree of readiness of the materials and components available in early 1959

A review of the materials capable, in 1959, of fulfilling these performance requirements revealed the following.

1.1.1 Fuel

Low-alloy uranium metal and uranium monocarbide; uranium oxide had to be discarded owing to its low uranium density and its poor thermal conductivity.

1.1.2 Organic coolant

A polyphenyl with low vapour pressure at 400°C; the mixture chosen, composed of 25% orthophenyl, 71% metaterphenyl M, 3-4% paraterphenyl and less than 1% diphenyl, had the disadvantage of being solid at ambient temperature[1] and therefore needing preheated

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[1] This mixture melts at about 80°C.

pipes; but experience with OMRE (Report, p. 28, Section 7.2) showed that this was not a serious problem; moreover, the product was available on the market[1] and was under study at several laboratories.

1.1.3 Cladding and channel

SAP, a dispersion of fine alumina particles in an aluminium matrix, which would, at the required temperatures, give the cladding sufficient mechanical strength and allow the channel to contain the relatively low coolant pressure (20 kg/cm^2) without any corrosion problems.

As can be seen in Table 1, these materials or components were relatively new or were to be subjected to more strenuous working conditions than any they had been tested for up to that time. Thus ORGEL was going to need advanced R&D activities.

1.2 Interdependence of reactor components

1.2.1 In a nuclear reactor, neutrons occupy every component area of the core, whether that area be occupied by fuel, coolant, or structural material. From the reactivity standpoint, the components contribute, positively or negatively, to the neutron balance - a contribution measured by their fission, slowing-down and absorption cross-sections. From the

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[1] The trade name of the mixture mentioned here is OM-2 (Progil).

Table 1

	State of the art (1959)	Performances required
A. Fuel		
a) Uranium metal	Product known in the "adjusted uranium" form used in gas graphite reactors under following conditions:	
	specific power: 4-6 MW/t	At least three times greater spec. power
	burn-up: 3000 MWd/t	At least double the burn-up
b) Uranium carbide	New product: some laboratory research and irradiations under following conditions:	
	conductivity integral: 200 W/cm	4-6 times higher conductivity integral
	burn-up $\leq$ 5000 MWd/t	1.5 - 3 times higher burn-up
B. Structural materials		
a) SAP cladding	Product at start of development	$t \leq 500^{\circ}C$
b) SAP pressure tube	New product	$t \leq 400^{\circ}C \pm 20^{\circ}C$ permissible stress ≥ 3.5 kg/mm^2 lifetime 20 years
C. Coolant		
Terphenyl	Product being tested in OMRE ($t \leq 370^{\circ}C$)	($t \leq 400^{\circ}C \pm 20^{\circ}C$)

energy standpoint, heat is everywhere released "in situ", essentially through fission, but also by bremsstrahlung and nuclear reactions.

1.2.2 The interdependence of the main components is largely due to this shared exposure to radiation and is a specific feature of reactor development projects. The interdependence is particularly close when the neutron balance is limited by the use of natural uranium, because it is then very difficult to modify the final design of one component without revising all the others; but such changes are more likely to prove necessary if the component is new or if the performances required of it are outside the proven range.

Hence, for a relatively advanced project like ORGEL, it was undoubtedly a handicap that only small "margins of adjustment" could be allowed in the design of the different reactor components, more especially as there were a great many of them - moderator, coolant, channel, clads and fuel.

1.2.3 Let us, for instance, consider the simplified cell consisting of the channel tube, the fuel element inside it, and the coolant flowing through it. A good neutron economy called for a cluster type of fuel element with 19 pins of adjusted metal uranium and the smallest amount of organic liquid (absorbent) needed for cooling purposes (Fig. 3a); i.e., the pins had to be almost touching one another. Under these conditions, a 2% rate of fuel swelling under irradiation would reduce

the coolant flow cross-section by 20%, causing an unacceptable rise in the coolant and cladding temperatures. It was not possible, without adversely affecting the neutron balance, to set the pins further apart or alloy[1] the uranium enough to lessen the swelling, at the burn-ups envisaged. Nor could lower burn-ups be accepted, as the fuel cycle cost would then be too high.

1.2.4 In the case of a uranium carbide element, the fabrication costs are in inverse proportion to the pin diameter[2]. A cluster of seven (or perhaps four) large-diameter pins was therefore considered (Fig. 3b); but this geometry fits badly into a circle and, in order to reduce the amount of absorbent organic liquid, it was decided to put a low-absorption filler in the cell, in the form of an impermeable graphite jacket. To enable the fuel element to be handled we had to leave a clearance, in which the coolant flowed slowly, between the jacket and the channel tube. The Piqua experiment showed that a ring of organic liquid circulating slowly was very liable to become polymerized under radiation, thus jamming the element and making it impossible to remove from the channel. The development of this fuel element was thereupon abandoned.

When the decision was taken, in 1965 (Report, p. 34, Section 8.3), to study a reactor variant with slightly enriched uranium, the interdependence became less stringent and it was possible to revise the designs of certain components completely.

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[1] An addition of 1% molybdenum, for example, led to a reactivity loss of nearly 1000 milliniles.

[2] See Section 2.1.1 (p. 63) and Fig. 4.

1.3 The alternatives

1.3.1 Fuel

Low-alloy metal uranium and uranium monocarbide appeared to be suitable at the outset of the Project.

1.3.1.1 The former was used in the gas-graphite reactors at specific powers of 4-6 MW/t and burn-ups of 3000-4000 MWd/t, with a magnesium alloy cladding. The ORGEL conditions called for four times the specific power, twice the burn-up and an aluminium-base cladding[1]. By choosing this type of fuel we could start with solid knowledge acquired in the Community, but it would have to be used beyond the known limits and under different conditions.

1.3.1.2 The second, uranium monocarbide, was at the stage of laboratory studies in Europe, the United States, and under a joint Euratom-USA programme. Some promising irradiations at temperatures of 700-800°C and low specific power had been done in the United States as part of Atomics International's SGR[2] programme; the problems of production and price had not been tackled anywhere.

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[1] Magnesium was not compatible with the organic coolant.

[2] Sodium Graphite Reactor.

1.3.1.3 In consequence it was decided, at the beginning of 1960, to regard metal uranium as the reference fuel and uranium carbide as the alternative.

Experience proved that this caution was justified. Because uranium combines with aluminium to form brittle intermetallic compounds, a diffusion barrier is needed. Nickel, chromium, niobium, silicon and vanadium were tried; some success was obtained with the last-named[1], but it was neutron-absorbing and the deposition technology was tricky. At the same time, it was becoming apparent that the economically desirable burn-ups and specific powers were liable not to be attained without excessive swelling of the "adjusted" type of uranium[2] and that a major programme would be necessary to develop new alloys with more stable dimensions under irradiation. There were only moderate chances of success, because the nature and quantity of the potential additives were limited by reactivity considerations.

1.3.1.4 For these reasons metal uranium was abandoned in 1962 and uranium carbide remained the Project's only fuel until the end (1969 - Report, p. 32, Section 8.2). How the uncertainties regarding this fuel were reduced is described in Section 2.1, p. 62.

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[1] The formation of intermetallic compounds was limited to 10 microns/year at 450°C.

[2] At the temperatures envisaged, the high specific power required led to swelling through cavitation, described shortly afterwards in the literature (Geneva Conference 1964: paper A/CONF 28 p. 145, R.S. Barnes et al.).

1.3.2 Structural materials (cladding and channels)

The combined requirements of low neutron absorption, adequate mechanical strength at 400°C (channel) and 500°C (clads), good corrosion strength in organic liquid at 400°C and a reasonable price, left little choice of materials, given the state of the art at that time (1959).

1.3.2.1 The only widely-known zirconium alloy was Zircaloy-2, satisfactory from every angle except for its behaviour in organic liquid at high temperature, where it underwent hydrogen embrittlement.

1.3.2.2 SAP[1], which had been under study for some years, appeared to combine good aluminium/organic compatibility with sufficient strength at high temperature, owing to the hardening effect produced by the dispersion of alumina particles in the aluminium matrix.

SAP alone, therefore, was adopted as the structural material in the preliminary projects of the time (1959 - ORGEL, OCDR[2]). The absence of an alternative solution was dangerous to the Project, especially since the material was new and its properties were not well known.

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[1] Sintered Aluminium Powder.

[2] Organic Cooled Deuterium (-moderated) Reactor: name of the Canadian project.

1.3.2.3 That was one of the reasons[1] why the Canadian General Electric team recommended experimental studies on the behaviour of Zircaloy in organic liquid at lower temperatures (320°C), at which a high degree of protection against hydrogen absorption appeared feasible through surface oxidation of the zirconium.

Around 1962-63 the Canadian research showed that hydrogen absorption could be reduced by using improved alloys, provided that the organic coolant contained enough water (200 ppm) and was free of chlorine (less than 1 ppm).

After 1963, zirconium alloys were to become an alternative for SAP; they replaced it definitively as the channel material in 1967-68, when the creep strength of large-diameter finished products in SAP proved to be too low (p. 28, Section 2.3).

On the other hand, SAP successfully retained the role of fuel cladding material, the zirconium/uranium carbide association having proved less favourable than carbide/SAP under irradiation.

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[1] Another reason was the Canadian reluctance to leave the paths already mapped in the heavy-water/heavy-water reactor development field, where the structural material was Zircaloy (p. 17, Section 6.1.3).

1.3.3 Coolant

A great deal of research was devoted during the first years of the Project to seeking substitutes for the polyphenyls which would be more stable under radiation and heat and, if possible, cheaper[1]. No really encouraging results were obtained and the research was abandoned. It was decided to keep to the terphenyl mixture already mentioned (p. 53, Section 1.1.2).

Towards 1966, however, the AECL chose to use, for its WR-1 reactor[2], a hydrogenated terphenyl, HB-40, which unlike OM-2 was liquid at ambient temperature. The reasons given were that the product needed no preheating and was available at competitive prices on the American market. But, in the first place, the technical attractiveness of the fluid as against another is only clear if one compares their properties as a whole; and secondly, HB-40 is more volatile than OM-2, which means that its use demands greater precautions (p. 81, Section 2.6.4.2). It should be remarked, however, that the consortium which did the 250 MWe ORGEL prototype Project (Report, p. 36, Section 9) likewise chose HB-40.

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[1] Possible substitutes included the methylnaphthalenes, eliminated for over-high vapour pressure, the phenanthrenes, the ternary eutectic diphenyl/terphenyl O/ terphenyl M, liquid at ambient temperature, but costing three times as much as OM-2.

[2] Whiteshell Reactor 1 (p. 17, Section 6.1.3 - p. 30, Section 7.5).

2. Progress of studies; reduction of uncertainties

2.1 Uranium carbide

The uncertainties essentially concerned:

a) the definition of an economical fabrication process;

b) behaviour under irradiation (swelling, fission gases) and, in particular, the carbide's tendency to crack.

The 1959 data, mainly obtained from American work (e.g., NAA-SR-3625, BMI-1441) showed that:

a) fabrication was at the laboratory stage; several processes were under study (CH_4 + U, U + C, UO_2 + C, etc.) with a special effort on the arc melting and casting processes; no economic assessment had been done, even for a pilot production system;

b) a certain number of small samples had been irradiated in capsules, at maximum temperatures of about 800°C, burn-ups of less than 10,000 MWd/t, and heat ratings of not more than 200 W/cm; limited swelling of the carbide had been observed and the rate of fission gas release, which was quite low, had been measured.

The limit performance values still had to be discovered, likewise the reasons for the cracking of the samples observed during post-irradiation examinations.

2.1.1 The reduction of these uncertainties within the ORGEL Project was successfully achieved as regards a) by means of a seven-year study (under contracts)[1], centred on the UO_2 + C melting and casting process (1961-67). Nine tonnes of carbide were fabricated, including 4.4 tonnes in 1964 by a single supplier. The first price estimates[2] arrived in 1965 and were confirmed and amplified in 1967.

Three parameters have a great influence:

2.1.1.1 <u>The fuel pin diameter (Fig. 4b)</u>

The smaller diameter, the more work (casting, machining, checks, packaging) is required per kg of the product. Similarly, the recycling of waste and the material losses increase; hence the cost per kg of pin rises rapidly as the diameter decreases.

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[1] Conducted mainly by Nukem.

[2] Pins with 25 mm diameter; production, 100 t/year; cost, $30/kg.

2.1.1.2 Specifications (content in carbon, oxygen and various impurities, dimensional tolerances, density, defects and, particularly, surface state defects (Fig. 4a)

The rejects, and therefore the fuel cost, increase with the stringency of the specifications. On the other hand, the rejection of a few pins costs less than the failure of a physics or irradiation experiment. For those reasons, strict specifications were maintained throughout the ORGEL Project for experimental uses; milder requirements were studied from 1966 onwards and then finalized in the context of the competition for a prototype reactor (Report, p. 36, Section 9); expanded specifications - which would have to be proven by irradiations in a prototype reactor - were considered prospectively for a reactor family.

2.1.1.3 Annual production (Fig. 4a)

The higher the annual production, the lower the unit costs.

2.1.1.4 It can be concluded that, on the basis of the semi-industrial scale researches carried out in this field, the feasibility of manufacturing uranium carbide pins at attractive prices was confirmed.

2.1.2 As regards point b), the most important results came from the United States and Canada; they were highly satisfactory; the ORGEL irradiation programme later brought in complementary results which showed the excellent behaviour of carbide with conductivity integrals

of the order of 120 W/cm[1] and over (see Fig. 5); as to the cracking phenomenon, it disappeared by itself, probably because of the care taken not to introduce internal stresses during fabrication.

2.2 SAP as cladding material

A process for fabricating a sintered aluminium-alumina mixture (SAP) had been discovered some fifteen years earlier by the Swiss firm Aluminium Industrie AG[2], when several countries considered using this material for cladding organic reactor fuel elements - Canada (OCDR programme), the USA (OMR programme), Denmark (DOR programme), France, etc.

In 1959, the inherent uncertainties regarding the use of this material for cladding were connected with:

a) the diffusion of fission products through the SAP;

b) the appearance of pimples and cracks after prolonged heating, leading to leaky cans;

c) the welding of the can plugs;

d) the low ductility in the hot state.

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[1] In the context of the search for high specific power linked with slight fuel enrichment.

[2] AIAG, which has since become Alusuisse.

Uncertainties a), b) and c) were solved, one of them (b) very quickly by degassing at high temperature the billets from which the tubes were to be drawn, and the others in the course of the following years.

Here we shall only discuss point d). The mechanical strength and hot ductility of a SAP type of material depend upon a number of factors such as the size of the alumina particles, the homogeneity of dispersion, the percentage of alumina in the aluminium matrix, the quantity and nature of the impurities, the nature of the contacts at the aluminium/alumina interfaces, etc.

Certain of these factors depend in their turn on the fabrication process, and in particular on the preparation of the powders. Consequently every effort was made, throughout the whole ORGEL Project, both by direct action at the JRC Ispra and through contacts with the industry, to develop new processes and new products, meanwhile continuing to develop the AIAG type of SAP, the reference material.

Fig. 6, which groups together data relating to 13 different products[1] and some thirty combinations of the different factors, shows that so far it has proved impossible to prevent any progress in ductility contributed by a new product from being accompanied by a chop in mechanical strength under rapid tensile stress; the experimental points are distributed along a relatively narrow belt in the "elongation-rupture load" plane.

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[1] Some include another dispersion besides alumina; others include metal (magnesium) additives with the object of elucidating the influence of the nature of the dispersion and of the aluminium/alumina contacts.

In regard to the ratio of elongation to creep rupture around 450°C, it appears, in spite of the relative scattering, scantiness and heterogeneity of the measured results, that the foregoing phenomenon repeats itself, although considerably attenuated when the experiment has gone on for a few hundred hours.

Only "Microxal", a product obtained by evaporating aluminium in a controlled atmosphere, appears to deviate significantly from the above-mentioned belts; for a definite opinion, however, long-term creep results would be necessary. This confirms the desirability, already evidenced in other studies, of trying to obtain finer dispersions of alumina particles than in the AIAG type of SAP; for the diameters achieved here are smaller by an order of magnitude (0.003 - 0.02 microns).

Action was not pursued in that direction, however, owing to:

a) the need to devise and perfect completely new fabricating methods;

b) the satisfactory in-pile behaviour of the carbide/SAP pins up to burn-ups of over 15,000 MWd/t;

c) the termination of the Project.

2.3 The SAP pressure tube

The intrinsic uncertainties concerning the SAP pressure tube essentially concerned:

a) the development of a fabrication process that would provide large-diameter (about 100 mm) tubes with satisfactory tolerances and quality, against a reasonable wastage rate;

b) the permissible stress value to use in the calculations, this value being proportional to the thickness to be given to the tube.

In 1959 the knowhow came essentially from the experience of the Swiss firm AIAG, work by the American firm Alcoa[1], and laboratory studies. The situation was as follows:

a) the extrusion of large-diameter tubes had never yet been tried systematically; the fabrication of small-diameter tubes (to order) had not got past the small pilot-scale stage;

b) there were more or less scanty data concerning the fast physical and mechanical properties. Creep test results were even scarcer and were obtained from flat test-pieces.

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[1] By 1960, however, Alcoa, a licensee of AIAG, decided to give up fabricating the basic powders necessary for the manufacture of SAP, and to obtain supplies from AIAG.

2.3.1 The first inherent uncertainty was cleared up under the ORGEL programme, and required roughly six years (1961-66). More than 350 tubes, 90 mm in diameter and 6 m in length, were fabricated by a single firm (Montedison[1]) working under a Euratom contract; the wastage rate, which was some 50% at the outset, dropped by a factor of over 2, even though the specifications always remained very severe. It should be noted that a number of European tube makers, consulted in 1964 for test productions of ten tubes, obtained results inferior to those secured at the time by the firm under contract, a fact which appears to underline the importance of specialized, concentrated, long-term action for such developments.

2.3.2 As to uncertainty b), Fig. 7 shows how the assessment of the permissible stress evolved with time, in the context of various organic/heavy-water reactor development projects. It is interesting (and greatly to the credit of the American engineer responsible) to see that the evaluation (Fig. 7, Ref. 1) done in 1957 on the strength of a careful examination of the few, rather academic studies known at that time, is identical with the evaluation adopted after eight years of the ORGEL development programme.

These two evaluations rest on the fullest possible analysis of the behaviour of a SAP tube under various stresses. On the other hand, the figure shows the danger of summary appraisals (Fig. 7, Refs. 4 and 9) based on results relating to only one type of stress.

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[1] In addition, when the HWOCR project was started up in 1965, the USAEC purchased from Montedison large quantities of SAP billets and cladding tubes (p. 28, Section 7.2).

The latest collection of results (Fig. 7, Refs. 8, 10 and 11) show that the permissible stress value is lower than its value of interest[1] for an organic heavy-water reactor fuelled with natural uranium.

2.4 Organic coolant

Knowledge in this field in 1959 relied on the studies that had been conducted in the United States[2] and Britain for some years. The aromatic carbides were recognized as being among the most radiation-stable of the organic compounds and evidence had been given of their promise as coolants for nuclear reactors. OMRE[3], the first reactor cooled and moderated by an organic liquid, had already been operating at full power (16 MWth) for a year.

Two major uncertainties remained, however:

a) Could an organic/cooled reactor operate over long periods without prohibitive fouling of the heat-exchange surfaces?

b) Was the decomposition of the organic coolant under the action of heat and radiation sufficiently limited not to give rise to coolant replacement costs greater than the economy of the organic/heavy-water concept could stand?

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[1] The corresponding pressure-tube thickness is about 3 mm.

[2] p. 28, Section 7.2

[3] Organic-Moderated Reactor Experiment.

2.4.1 Everyone thought uncertainty a) would be cleared up when OMRE had operated satisfactorily for another year; but OMRE developed serious fouling and brought this problem to the fore on the various American, Canadian and Euratom (ORGEL) "organic" programmes. It quickly became clear, especially in the light of the Canadian studies, that the coolant would have to be far more highly purified than the liquid used in OMRE. Fig. 8 shows the development of these ideas, using a somewhat rough "purity index" representing the relation between the concentrations of impurities (oxygen, ash, chlorine, very high polymers, water, etc.) permitted in the light of the operating results[1] from various plants between 1958 and 1968, and the concentrations adopted at the end of that period for the WR-1 reactor, which has been working successfully for four years. Thus eight years of experiments, the most fruitful of which were conducted in-pile, led to the purity requirement being multiplied by ten thousand. So uncertainty a) can henceforth be regarded as solved[2].

It is curious to note the parallel with the trend of ideas concerning the light water for the PWR and BWR reactors, where the purity requirement as regards oxygen and insoluble substances likewise grew by a factor of 10,000 between the time of the pilot channel tests at Oak Ridge, Hanford and Chalk River (1952) and the 'sixties.

At the start of a project it seems that the coolant purity requirement is often underestimated; a good many miscalculations could be avoided by rapidly determining the harmful substances and eliminating them ruthlessly, only later relaxing the specifications if it can be done safely.

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[1] In the main the theoretical studies yielded little success.

[2] The very positive Canadian results obtained in-pile recently suggest that the same also applies to a boiling organic coolant!

2.4.2 The second uncertainty, b), concerns the decomposition of the coolant under the effect of heat (pyrolysis) and radiation (radiolysis). The former is slight up to about 400°C, but the Euratom experiments confirmed that pyrolysis is more extensive in a substance that has been irradiated than in one that has not, a phenomenon which has been named radiopyrolysis[1].

The results obtained on this point between 1958 and 1967, particularly in-reactor, are quite consistent enough to satisfy project engineers.

2.4.3 As regards pyrolysis, the initial OMRE operating results in 1969 showed that, with a mixture of terphenyls at 320°C containing 30% of high polymers, 0.15 molecules of coolant were destroyed per 100 eV energy deposited (G = 0.15) by radiations of any type. Assuming this value to be applicable to other reactors, one can calculate the amount of coolant decomposed in each case (calculation 1). This hypothesis assumes that neutrons, beta and gamma rays have the same efficiency, although their share in the total radiation varies from one reactor to another. The electron (van de Graaff) tests done at the same period yielded a value of 0.08 for G, thus demolishing the above hypothesis and enabling the ratio of neutron efficiency to gamma efficiency[2] to be calculated. The value obtained was 4 (calculation 2).

The in-reactor tests conducted under the ORGEL programme from 1962 to 1968 were designed to provide a

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[1] This phenomenon, predicted by us, had not been demonstrated before.

[2] Assuming the latter to be the same as that of the electrons, and the additive effects.

firmer basis for the value of G and of the neutron/gamma efficiency ratio, evaluated at 4.5 ±0.5 in 1966 (calculation 3) and then fixed finally at 4 in 1967 (calculation 4); in this way it became possible to determine fairly precisely the organic consumption due to radiolysis in an ORGEL-type reactor, where the radiation spectrum is very different from that in an OMR[1].

Fig. 9 shows how the estimated consumption cost changed with the years. It will be remarked that calculation No. 2 gives practically the same value as No. 4, but in 1960 certain experts preferred method 1, which they considered more realistic (see "Organic Make-up Data", J. Scrivins, Nuclear Engineering, February 1960, p. 63).

It will also be noted that the error of evaluation between calculations 1 and 4 is roughly $\$3.5 \cdot 10^6$ for a 250 MWe ORGEL power plant operating for 20 years at 7,000 h/year; this more or less represents the actual for research spending on this subject and it would therefore not have been reasonable to undertake the research without having in view the marketing of a whole series of reactors (e.g., 10,000 MWe), that is to say, if it was only to be regarded as worthwhile - and paid off - within the ORGEL context.

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[1] See p. 28, Section 7.2

[2] For a high-polymer level held at 30% by means of one of the "physical" processes researched by Euratom, which does not alter the constituents of the fluid but removes certain compounds. "Chemical" processes altering the fluid constituents were studied in the USA (reducing the heavy compounds into substances of lower molecular weight by hydrocracking, and recycling the new fluid thus obtained in the coolant circuit), but were never confirmed with a pilot plant, still less with a reactor.

2.5 Reactor physics

2.5.1 Reactivity problems are particularly important in the field of heavy-water reactors, which have to be designed to allow the longest possible irradiation of the unenriched fuel. An economic optimization demands exact knowledge of how the reactivity balance varies with the geometrical characteristics of the lattices and with the evolution of the fuel. This knowledge cannot be obtained solely by theoretical paths, because the geometry of a heavy-water reactor cell is very complex (fuel element divided into "clusters" of a number of pins; possible presence of a calandria tube, a pressure tube, also of a coolant which absorbs and slows down at temperatures and/or is of a nature differing from the temperatures or nature of the moderator, and so forth). Consequently, numerous experimental plants were built very early in different countries[1].

The 1959 knowhow appeared to be solidly established in regard to fresh cold lattices moderated and cooled with heavy water and fuelled with metal uranium or uranium oxide in the form of plates, rods or, better still, clusters of "pins". For the last-named, the ZEEP, Aquilon and Zebra results provided the means of establishing codes fitted to the experiments which showed

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[1] in Canada: ZEEP (critical 1943), ZED (critical 1960)

in USA: SE (exponential 1956); PSE (exponential); PLATR (critical 1958); PDP (critical 1960) PRCF (critical 1962)

in Sweden: Zebra (exponential 1955)

in France: Aquilon (critical 1956), then Aquilon-2 (critical 1960) etc.

good general agreement[1] in a restricted range. The number of fuel-element geometries and the range of lattice pitches studied was too limited, however, to meet the full needs of the optimization studies (Geneva Conference, 1958; A/CONF 15, p. 336, France; Heavy-Water Lattices, IAEA, Vienna, 1960).

Under these conditions, the uncertainties in 1959 basically concerned:

a) the effect of using organic liquid instead of heavy water as the coolant;

b) the trend of lattice parameter changes at temperatures over 80°C;

c) the trend of lattice parameter changes with irradiation of the fuel, chiefly at high burn-ups;

d) the effect that enrichment of the fuel would have;

e) in 1962 these four uncertainties were, for ORGEL, joined by a fifth, when uranium carbide was chosen as the fuel.

2.5.2 Uncertainty a) was cleared up very soon by the buckling measurements done under contract in Aquilon-1 in March 1960 with a metal uranium fuel, and then in Aquilon-2 in June 1961 with clusters of uranium oxide pins. The French correlation, adjusted to a heavy-water coolant, could not justifiably have been applied directly to an organic coolant. As regards the nature of

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[1] For instance, the differences between the lattice buckling values studied on ZEEP and those calculated by the French code on Aquilon did not exceed 0.2 m^{-2}.

the fuel (uncertainty e)), Fig. 10 shows that the Caroline heavy-water/organic code (1962) adjusted to uranium oxide[1] underestimated the reactivity of the carbide lattices as determined from the experiments conducted later on EXPO (1964), ZED-2 (1965) and ECO[2] (1966), for it gave values which fell outside the experimental margins of error.

Nevertheless the deviations are acceptable for feasibility and optimization[3] studies; it can be concluded therefrom that studies of types a) and b) on new, cold lattices are only justified for thermal reactors in special cases and where they do not cost very much.

Thus, in the context of a specific development project, high capital investments such as ECO are not justifiable; the decision to build ECO was a consequence of the decision to fit out the Ispra Centre with ORGEL-slanted equipment[4].

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[1] The seven tonnes of uranium carbide needed for the physics experiments were not delivered until 1964, owing to the time required to develop and fabricate this new fuel.

[2] p. 25, Section 6.2.

[3] According to the IAEA Report "Heavy-Water Lattices", 1960, the desirable margin of accuracy on the buckling values would be 0.3 m^{-2} for optimization studies and 0.8 m^{-2} for the feasibility studies.

[4] For the reasons that led up to the building of ECO, see p.25, Section 6.2.

2.5.3 As regards the elucidation of the unknowns of types b) and c) in the ORGEL context, a multi-channel loop which can be used for lattice studies with organic temperatures up to 300°C came into operation in 1969 just when the programme was closed down; these studies are to be pursued, however, since they are of general interest. Here, too, the future will show whether the gap between the calculated and the experimental values is really significant.

2.6 Safety

2.6.1 The use of an organic coolant substantially reduces the hazards connected with activation of the coolant or cladding failures. Activation is due solely to the impurities, which are kept at a very low level for other reasons (p. 70, Section 2.4); hence it is negligible, thus greatly facilitating maintenance work, as was confirmed by OMRE, Piqua and WR-1 operating experience. As to cladding ruptures, a crust of polymerized organic forms and stops up the cracks, as was seen in the Canadian irradiation experiments, so that they have only limited, slowly-developing consequences and the necessary action can be taken without haste.

On the other hand, the use of an organic coolant demands certain precautions, which were revealed or specified after 1959; at that time, the major unknown factors were:

a) the toxicity of the coolant;

b) the hazards of fire and explosion of the organic dust, liquid and vapour.

To these must be added two hazards linked with both the reactor structure (pressure tubes) and the organic coolant:

c) the risk of a reactivity insertion too rapid to be controllable, as a result of accidental dumping of the coolant out of the core (rupture of primary circuit);

d) the possibility of chain rupture of the channel tubes that traverse the reactor, initiated by accidental failure of one of them.

The 1959 knowhow came from operating experience with the OMRE reactor during the previous year and from the preliminary studies done on that type of reactor; hence it only related to points a) and b). The introductory report on a 150 MWe OMR power plant, prepared in 1959 by Atomics International[1], concluded that the coolant could only catch fire in the presence of an igniting agent (electric arc, spark) and that the few fires resulting from work on OMRE had been extinguished quite easily with carbon dioxide. Under normal reactor operating conditions, the usual industrial fire precautions ought to suffice; there was no question of risk of an explosion[2], other than that of a cloud of solid organic dust, which was considered unlikely to occur provided that certain precautions were taken.

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[1] Very similar to the one submitted by Atomics International for KBWP (AKS power plant) (p.28, Section 7.2).

[2] Leaving out of account the danger represented by the accumulation of highly combustible gases (produced by coolant radiolysis) in certain tanks of the degassing system. This hazard was eliminated by using a nitrogen cover gas, a procedure followed by all subsequent designers.

In regard of toxicity, the same report described the diphenyl and terphenyl as pharmaceutically inert, to the extent that workers needed no mask or special clothing. Nevertheless it recommended that for continuous work, the diphenyl vapour concentration in the air should not exceed 0.2 ppm.

All this information shed no light on uncertainties c) and d), of course, since these had nothing to do with an organic cooled and organic-moderated reactor.

2.6.2 The last uncertainty, d), was the first to be tackled, owing to the seriousness of the potential accident and the lack of knowledge at that time regarding the reliability of the SAP channels.

Experiments were run on a rig constructed for the purpose, which reproduced in full scale the experimental zone of the ESSOR core, assumed to be loaded with SAP channels.

The first set of tests investigated the behaviour of the calandria tube; the SAP pressure tube was artificially weakened along a generatrix over a length of about 1.5 m and the organic liquid was injected at the maximum temperature and pressure prescribed for a prototype ORGEL reactor (425°C, 30 atm.abs). In the first tens of seconds following the rupture of the SAP tube, stresses distinctly higher than the normal working stresses appeared in the Zircaloy tube; nevertheless the

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[1] The toxicological data and industrial experience, however, essentially concerned diphenyl and certain of its compounds used as industrial fluids.

latter not only never ruptured, but did not even exhibit any plastic deformation[1]. It was therefore considered to be highly unlikely that the rupture of a pressure tube would be followed by that of a calandria tube.

Nonetheless, a second set of tests was carried out to investigate the behaviour of the channels and control rods adjacent to a bursting channel, and to study the pressure waves in the reactor vessel; for this purpose the calandria and pressure tubes of one channel were artificially weakened. No shock waves were observed in the vessel, and no rupture or dangerous deformation of the adjacent channels. When a fuel element was included in the weakened channel, there was no projection of missiles.

These results were very reassuring and argued strongly in favour of organic cooling in a pressure-tube reactor, and uncertainty d) was regarded as solved after some four years' work.

2.6.3 Uncertainty c) concerned the reactor control system: accidental draining of the organic liquid from the core led to a reactivity insertion of some thousands of milliniles in a time which the most pessimistic calculations assessed as two or three tenths of a second. It was thus to be feared that the safety rods would not work fast enough. This uncertainty was solved by theoretical and experimental studies of the draining mechanisms, and also by developing fast-insertion safety rods using poisoned liquid.

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[1] This result was very important, because it provided grounds for assuming that an irradiated, and therefore more brittle, calandria tube would likewise have a considerable margin of safety with regard to the accident in question.

2.6.4 The fire and explosion hazards vary according to the nature of the organic coolant, its physical state (solid, liquid, vapour), its temperature, its pressure and the nature of the gaseous medium surrounding it.

2.6.4.1 In the solid state, an explosion may occur: a leak of hot coolant through a small hole acting as an atomizer may create a cloud of solid particles in suspension in the atmosphere. If, in a certain region of the cloud, the organic concentration exceeds one-tenth of a gram per litre, an explosion is liable to occur in that region if a sufficiently "hot" spark (over 600°C) is present. Nevertheless, since a leak of the type described above is quickly detectable and involves only small quantities of organic, this type of explosion cannot be regarded as a major risk.

2.6.4.2 In the liquid state, a fire may break out: spontaneous combustion resulting from a leak through a pipe-burst is ruled out, since the maximum envisageable temperature for an organic coolant (about 400°C) is generally[1] far below the temperature for self-ignition at atmospheric pressure. Spontaneous

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[1] This is always the case with the OM-2 type of non-hydrogenated organic coolants, for which the self-ignition temperatures are 500-600°C. In the case of pure hydrogenated coolants of the HB-40 type, the self-ignition temperature decreases with the percentage of hydrogenation, down to values below 400°C (Fig. 11). The coolant temperature must therefore be limited accordingly.

ignition is also ruled out inside the circuits on account of the nitrogen cover gas, although at their pressure value the self-ignition temperature may be in the vicinity of the coolant temperature.

A fire can only be caused by a big leak of coolant at the operating temperatures, in an atmosphere not rendered inert and in the presence of a source of ignition. This danger is reduced, where the reactor block is concerned, by filling or sweeping with nitrogen and as regards the organic circuit rooms, by a temporary or permanent oxygen depletion (a few percent). The electrical material is in both cases explosion-proof.

In addition to these safeguards there is general provision for a fire-fighting system, which reduces the consequences of any accident.

2.6.4.3 In the vapour state, there is a risk of fire and explosion. A major escape of coolant to the atmosphere can lead to instant vaporization or slow evaporation of the escaped coolant, depending on the conditions. In either case, if a certain volume of the cloud reaches an organic-vapour concentration lying within a certain range (0.48 - 3.7% for ON-2 vapour in air), both fire and explosion may occur if a source (electrostatic discharge, electric arc, etc.) is present. This hazard can be countered, as shown in Section 2.6.4.2, p. 81, by creating an inert atmosphere in the vulnerable places and using explosion-proof fittings.

Under these conditions a decision to take into account a major accident due to an explosion of organic vapour depends on the view of the safety experts regarding

the probability of the following events occurring simultaneously:

i) accidental flashing of an ignition source;

ii) malfunctioning of the alarm, fire-fighting, inerting, etc., systems;

and on the intrinsic uncertainty as to whether there is a significant volume of organic vapour at a dangereous concentration surrounding the flash-point.

Although this accident was not regarded as credible for the Piqua, EOCR and WR-1 reactors[1], its potential severity[2] for a power reactor and its heavy incidence on the costs of the leaktight containment led to its being taken into consideration for the HWOCR[3] project and for the ORGEL prototype competition.

A study was launched under contract, to clear up the uncertainty mentioned above. Organic vapours were to be injected into an enclosed space of 100 m^3, the conditions governing their ignition were to be studied, and the pressure rise in the enclosure to be recorded. The study was stopped at the same time as the ORGEL programme and no light has been thrown on the subject since then.

2.6.5 Toxicity of organic coolants

Although the American studies carried out in connection with OMRE produced the conclusion that the toxicity of diphenyl (and terphenyl) is very low, the question of the toxicity of organic coolants came up again when work started on the experimental organic rigs for the ORGEL programme.

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1 It was considered credible for ESSOR. The decision was then taken to render the upper and lower reactor rooms inert with nitrogen and to carry out the explosion effects study in the bunkers of the experimental organic circuits. This study shows that the bunkers withstand the accident envisaged.

2 In particular as regards the release of fission products if the leaktight containment bursts.

3 Heavy Water Organic-Cooled Reactor; name of the American project.

Research to clear this uncertainty was started for two reasons: the first, of a psychological nature, was the difficulty of establishing convincing safety standards for the staff on the basis of experiments conducted elsewhere; the second related to the use in the various test circuits of different organic mixtures[1] (p. 61, Section 1.3.3) the toxicology of which had not been studied.

Special attention was paid to the possible consequences of chronic inhalation of organic vapours; a rotating chamber enabling 48 rats to be exposed simultaneously was used to study this question.

The conclusions, based on animal studies, were as follows:

i) The chemical toxicity of all the commercial polyphenyl mixtures tested depends essentially on the toxicity of the individual components and their relative concentration in the mixture.

ii) All mixtures, except HB-40, are slightly toxic after chronic inhalation at high doses; to do any harm, over 20 g terphenyl a day would have to be absorbed over an appreciable period. HB-40 is practically non-toxic after ingestion.

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[1] The mixtures tested were: OM-2 (Progil, France), DOM (Monsanto, USA), both containing diphenyl and isomers of terphenyl, HB-40 (Monsanto, USA), containing hydrogenated compounds, Thermip (ESSO, France) and Solvent 200 (ESSO, France), both of them petroleum distillation cuts composed of diphenyls and alkylnaphthalenes in varying proportions.

iii) OM-2 and DOM are moderately toxic; HB-40, Thermip and Solvent 200 are slightly toxic after chronic inhalation of strong concentrations in the atmosphere, causing, very particularly, receptivity to infections of the respiratory passages.

iv) All the mixtures are virtually non-toxic for intact skin and slightly toxic for open wounds.

It must be remarked that these conclusions refer to mixtures of commercial coolants which have not been altered through operation in the reactor; their toxicity under operating conditions thus remains to be defined.

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APPENDIX 1

ESSOR, which is equipped for testing heavy-water reactor subassemblies in a representative environment, has a core moderated entirely with heavy water. A ring of cylindrical enriched-uranium fuel elements[1] of the MTR-type, cooled by a special heavy-water circuit, provides the neutron flux for the zone inside this ring, where there are twelve experimental sites able to receive channels passing vertically right through the reactor vessel. These channels, surrounded by heavy water, can have various coolants flowing through them; thus ESSOR reproduces the real environment found in a heavy-water power reactor. The unperturbed mean thermal neutron flux in the irradiation zone is of the order of $3 \cdot 10^{14}$ neutrons/cm^{2}sec. In connection with the development of the ORGEL Project, three organic loops were built, two serving a single experimental channel and a third (called the MK-5 multiple loop) designed to cool a cluster of 5-8 channels.

Another experimental site at present contains a channel assembly for the Italian Cirene programme (heavy-water moderated, boiling light-water cooled reactor).

The ESSOR complex also comprises a storage pond for active components and two high-activity laboratories: in one, irradiated fuel elements are studied and in the other, large-scale devices such as channels eight metres high.

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[1] The fuel elements, known as "feeders", are mounted in thimble circuits.

Thus, with its large available volume under flux, and backed up by its adjoining laboratories, the ESSOR complex is a really convenient tool for irradiating fuel-scale channels and fuel elements for the heavy-water reactor types and for studies of such components after irradiation.

APPENDIX 2

The Scientific and Technical Committee having been consulted at its meeting of 28 April 1959, the Commission submitted a communication concerning its programme to the Council (Journal Officiel of 6 June 1959, pp. 664-665/59), which included the following text:

"Energy Applications

"The Commission's programme must, as far as possible, complement the national programmes. Furthermore, the sums allocated under Annex V of the Treaty for the first five years (sums of only the same order of magnitude as France's annual nuclear budget) permit only a limited effort.

"The Community has no access to enriched uranium on economic terms, apart from what it can procure under the Euratom-US agreement[1].

"Certain choices therefore have to be made.

" The graphite/natural uranium reactor system forms the basis of vigorous programmes being run by France. The United Kingdom, with which the Commission has an agreement for cooperation, uses this system and Italy is also working on it.

. "With due regard to the Community's own resources, the basic system must use natural uranium and the natural uranium/heavy water system is the best choice.

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[1] The reactors built under the Euratom-US programme totalling 1,000 MW) will give the Community's industrial firms experience in the use of enriched uranium; and the Commission's share in the relevant research and development programme amounts, in five years, to 50 million dollars.

"In order to define the Commission's course of action more clearly, it is necessary to bear in mind that:

a) heat extraction by pressurized heavy water in pressure tubes is under study in Canada and Germany is doing research on these lines;

b) France is designing a prototype heavy-water reactor cooled with pressurized gas (EL-4).

"Hence it appears that the Commission must study extra carefully the natural uranium/heavy water variant cooled with organic liquid.

"Furthermore, organic-cooled reactors qualify to come under the Euratom-US agreement, and the studies relating thereto can be carried out in the joint research programme covered by that agreement.

"Moreover, owing to the European shortage of uranium-235, it is important for the Community to use artificial fissile elements or isotopes (uranium-233 and plutonium). The Commission has therefore included in its programme research on fast plutonium reactors in preparation for the breeder system (though not overlooking the promise offered by the use of the thorium/uranium-233 chain). It will likewise study the possibility of re-using plutonium in slow neutron reactors[1].

"Lastly, the Commission must coordinate the marine propulsion reactor projects currently envisaged in the Community (in France, Germany, Italy and the Netherlands). The Commission's effort might extend to the development of a prototype on land.

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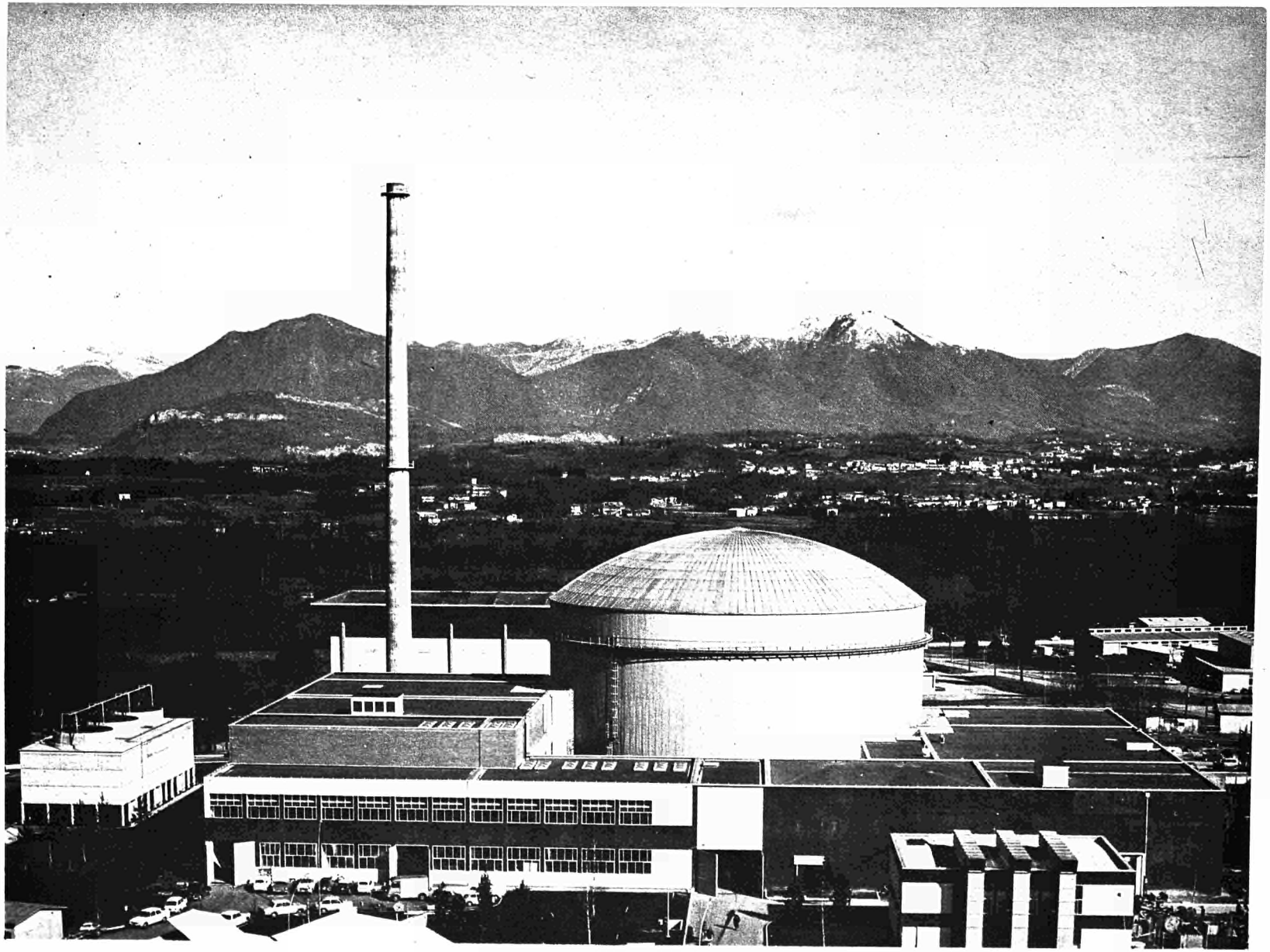
[1] In the field of uranium enrichment, however, original methods are being studied in the hope of devising a more economic process than diffusion. The Commission has no intention of disregarding these methods.

"In view of the manpower and money demanded by this prototype programme, it must be the pivot around which the Commission's priority research schemes will develop. Nevertheless the Commission will not systematically refuse to consider any other line of research and will, in particular, consider to what extent it can assist the national programme."

APPENDIX 3

The core of the ORGEL Project organization consisted of a small number of engineers responsible for special questions (Messrs A. Bahbout, N. Cadelli, F. Lafontaine), a Project Design Studies office headed by Mr J.C. Charrault, and an office responsible for constructing the ESSOR complex, of which Mr C. Garric was the director and Mr G. Hess the deputy director.

The ESSOR Operating Division is directed by Mr P. Bonnaure, with Mr W. Kranert as his principal assistant.



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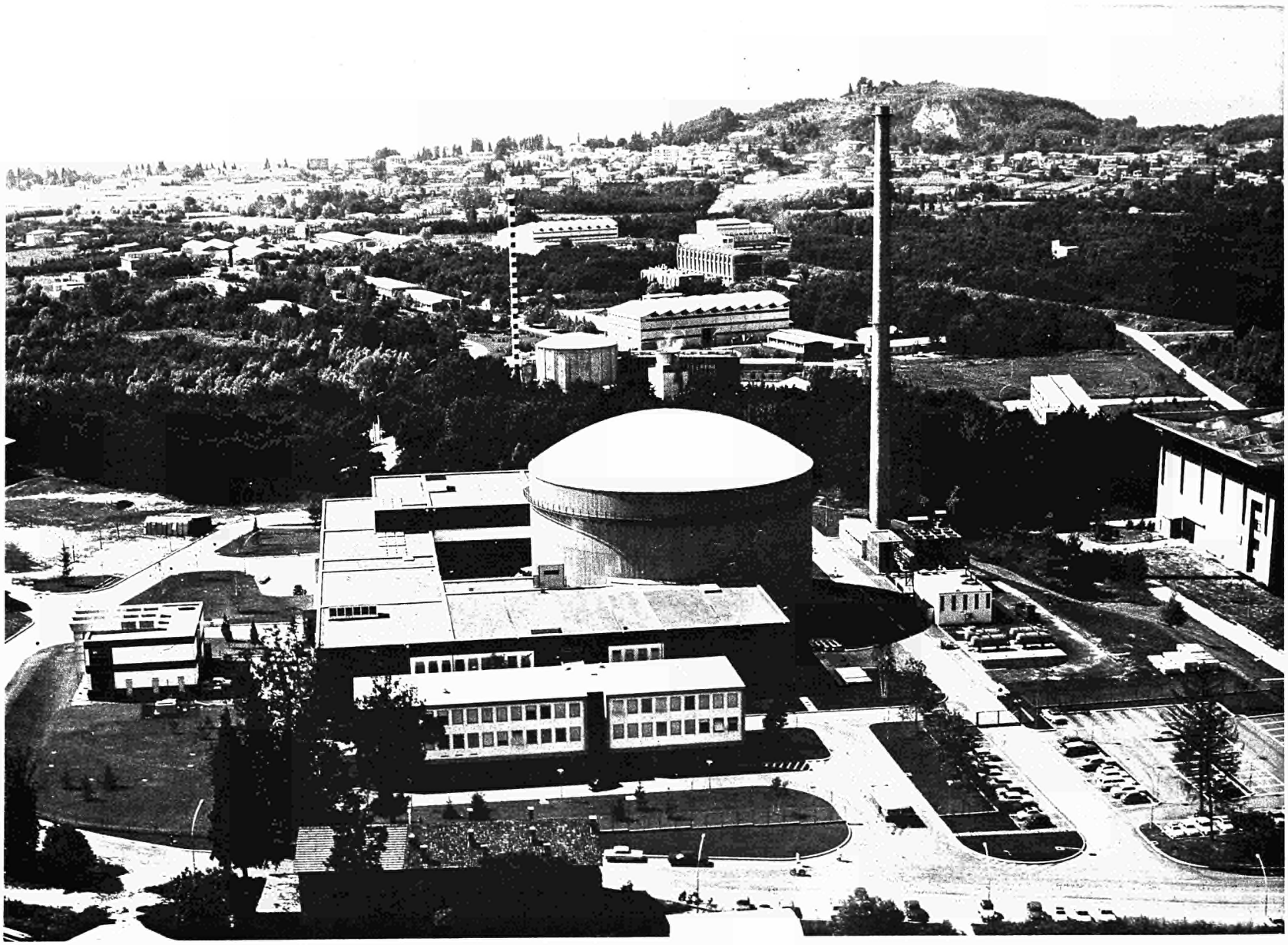

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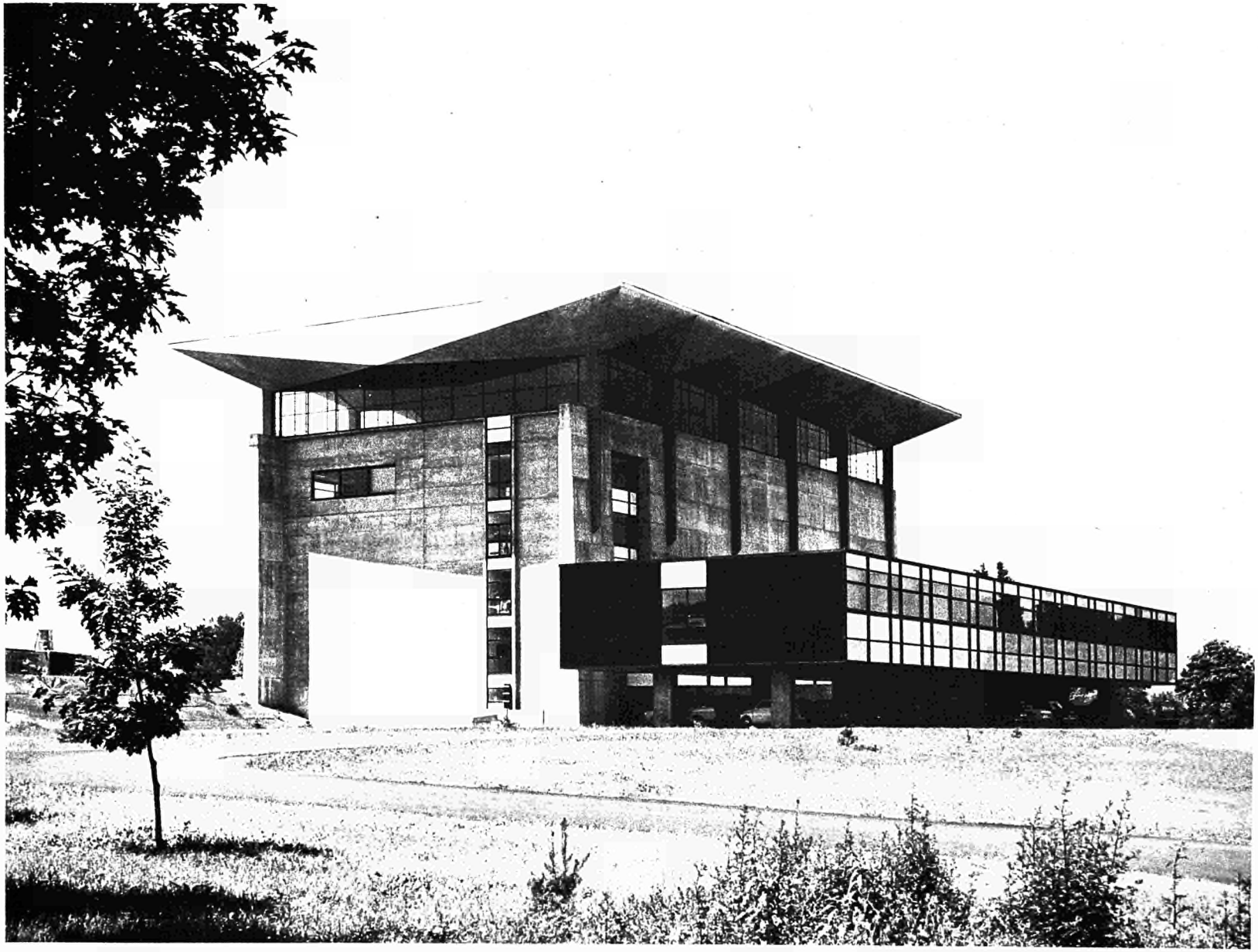

ECO: Photo 3

ORGEL PROGRAMME: MANPOWER

(EURATOM staff: personnel who worked under contracts signed with private or State concerns are not included)

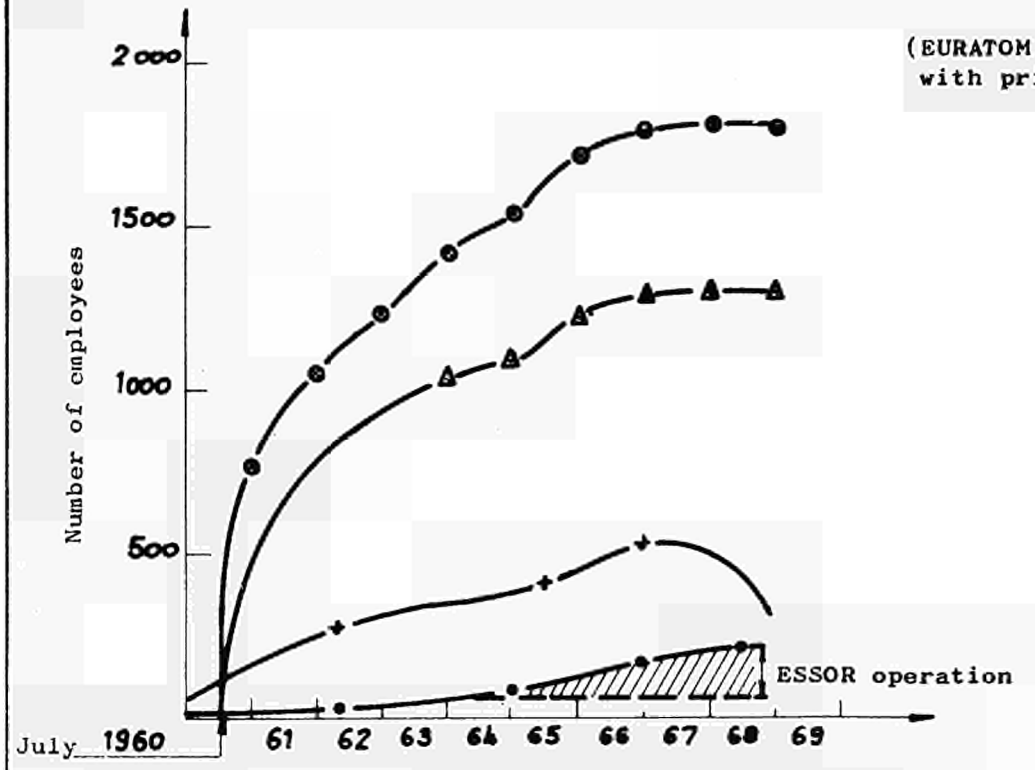

FIG. 1a - Growth of Joint Research Center Ispra staff and of staff working on ORGEL programme

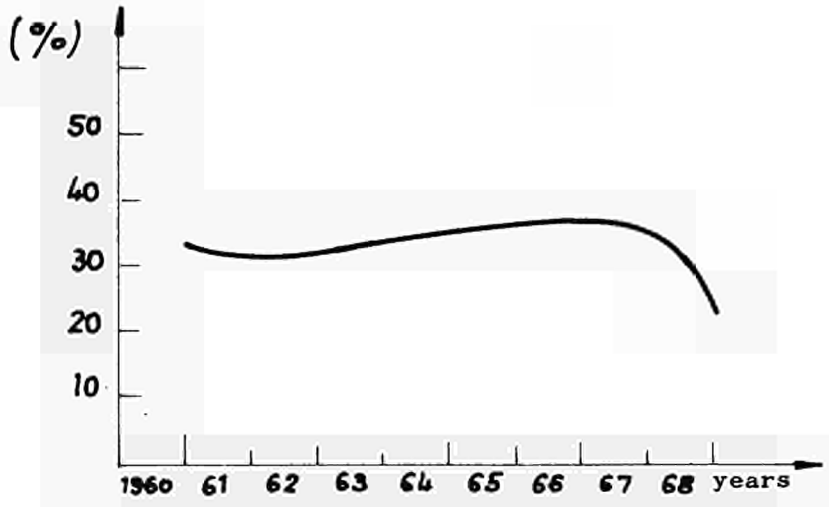

FIG. 1b - Percentage of Ispra Establishment's scientific and technical staff who worked on the ORGEL programme (including project doordination and operation of ESSOR)

- ● Total staff of JCR's Ispra Establishment (employees of every status - Ref. Personnel Division)
- Δ Scientific and technical staff of JRC Ispra Establishment (Ref. Personnel Division)
- \+ Scientific and technical staff working for ORGEL Project
- • Project coordination + ESSOR (construction and operation

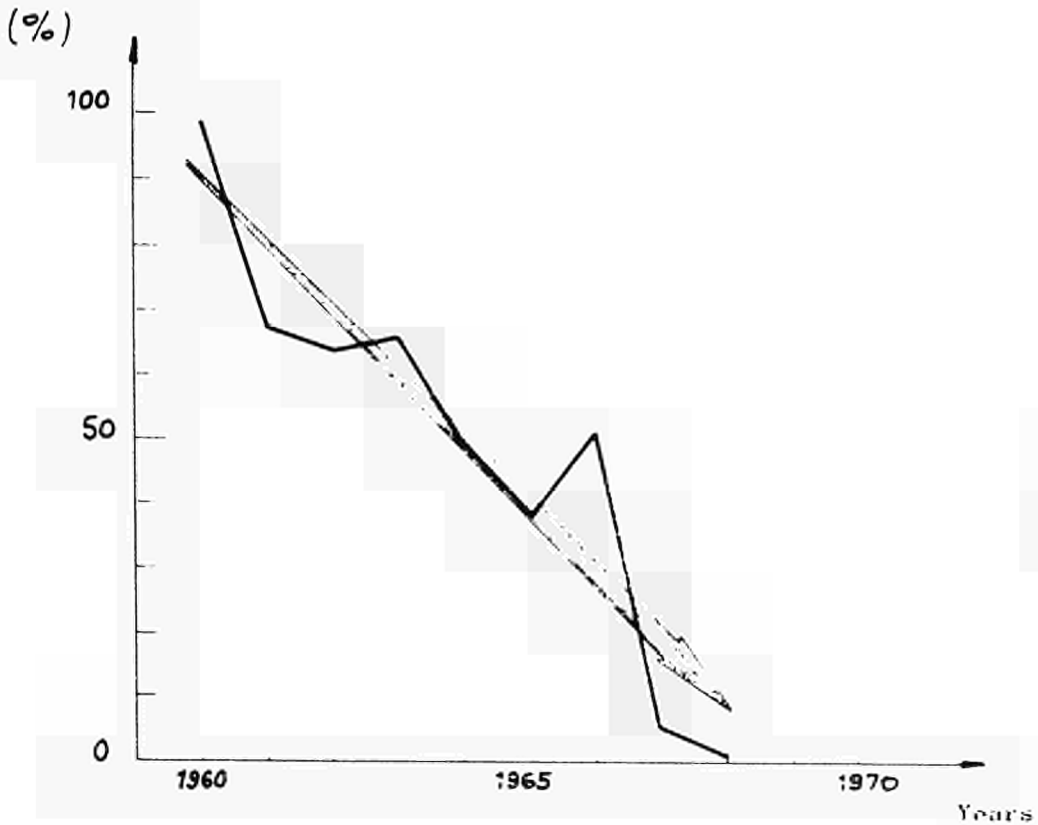

FIG. 2 - Percentage of ORGEL research budget allotted to indirect action (contracts) plotted against time

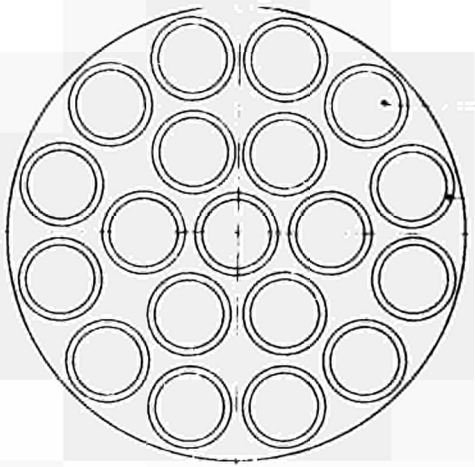

FIG. 3a - Metal uranium fuel element

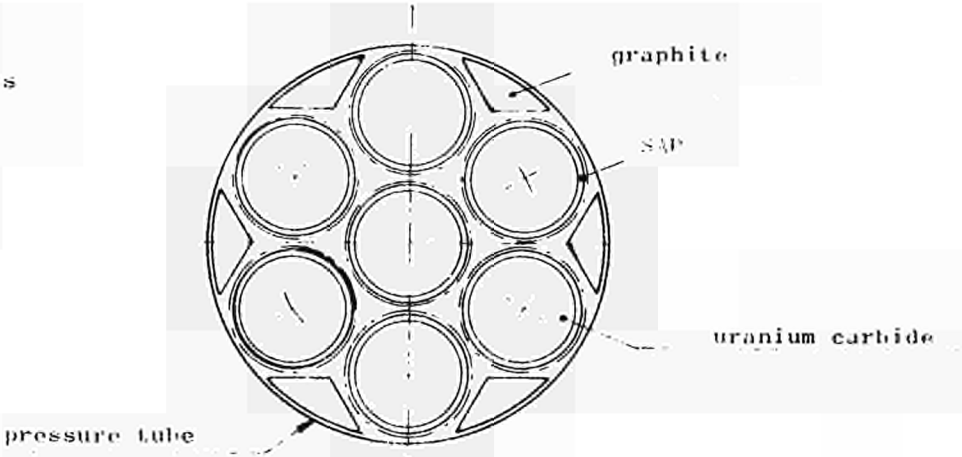

FIG. 3b - Uranium carbide fuel element

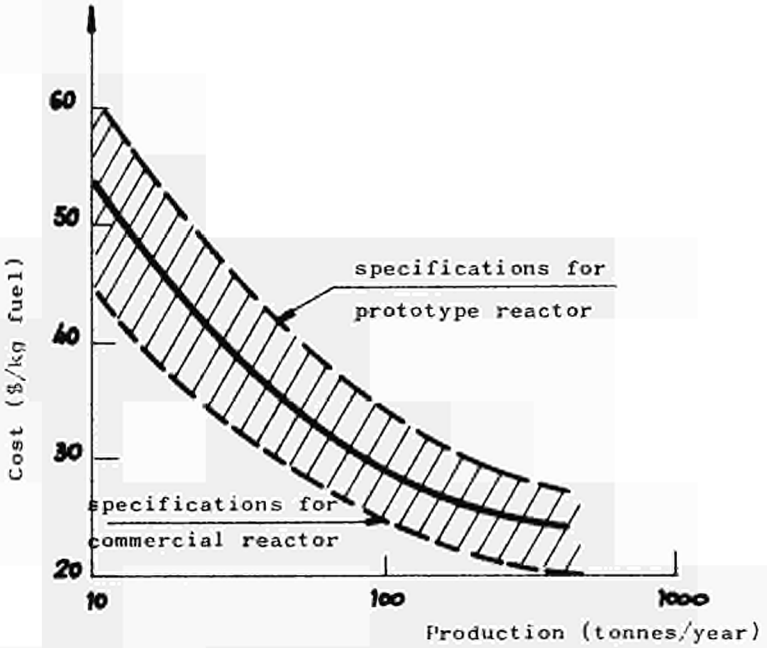

FIG. 4 a - Fabrication cost for natural uranium carbide pins (diameter 18 mm; cost of uranium not included)

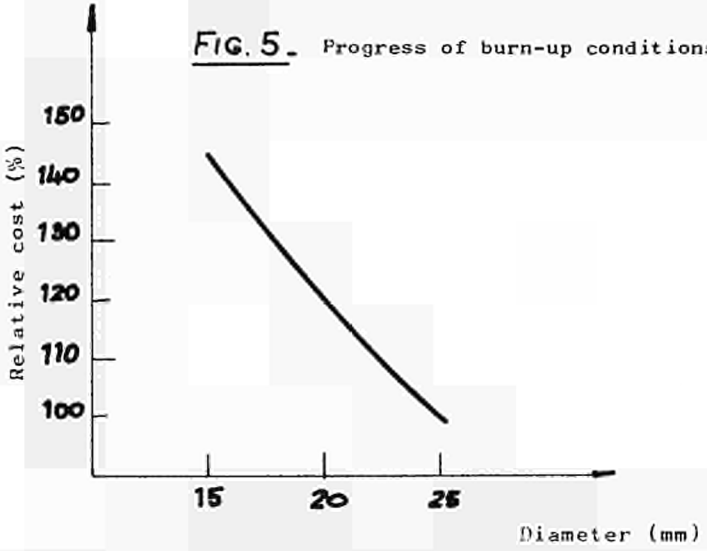

FIG. 4 b - Influence of pin diameter on the cost per kg of uranium carbide pins

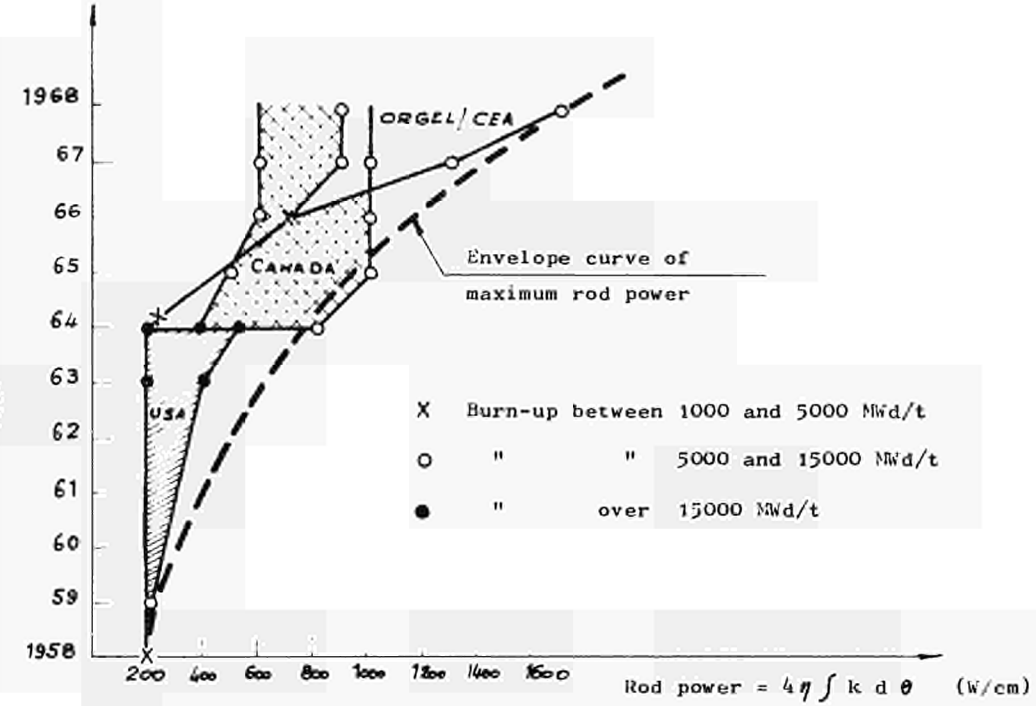

FIG. 5 - Progress of burn-up conditions for uranium monocarbide pins

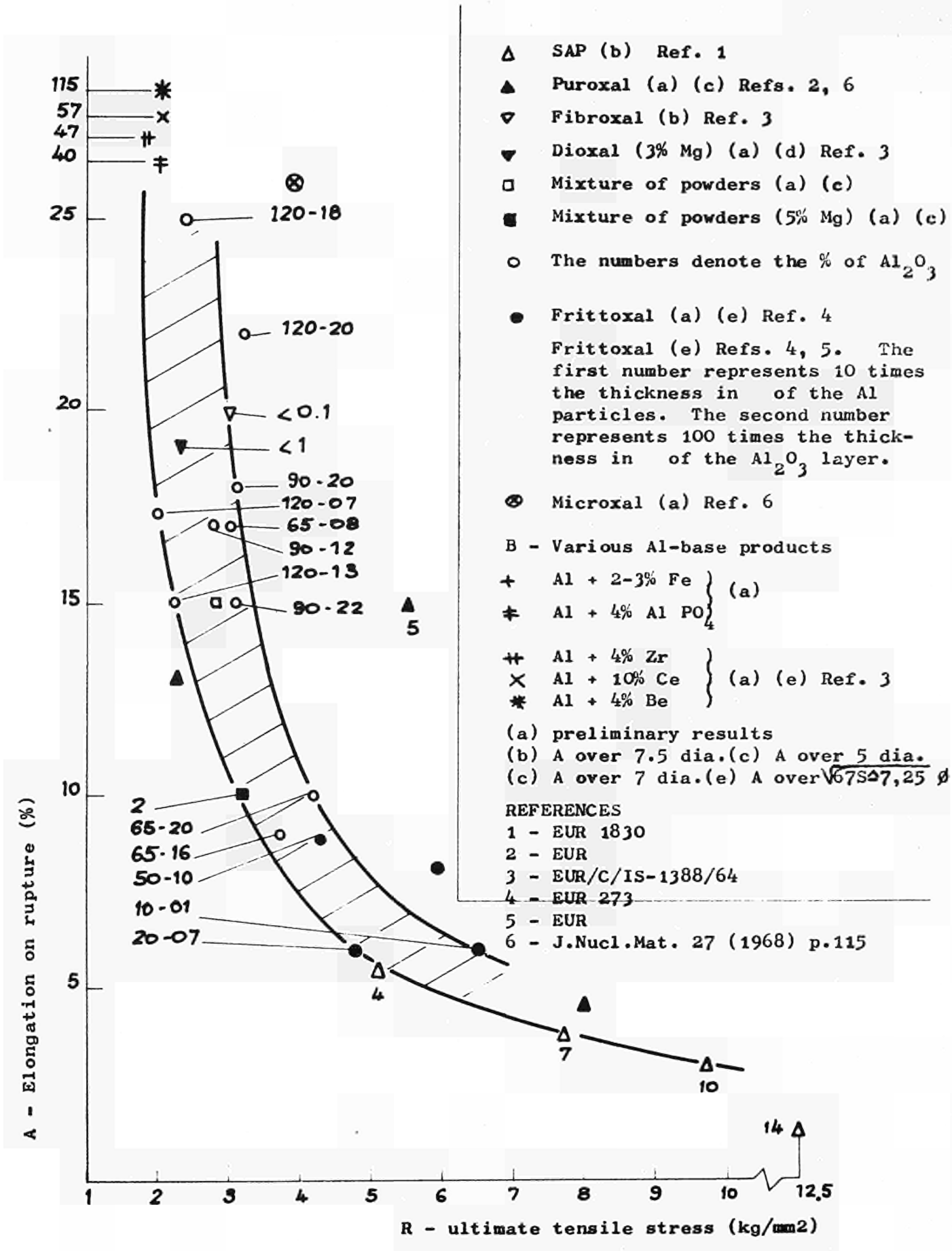

FIG. 6 - Aluminum-base materials
fast tensile test at 450°C - R/A relation

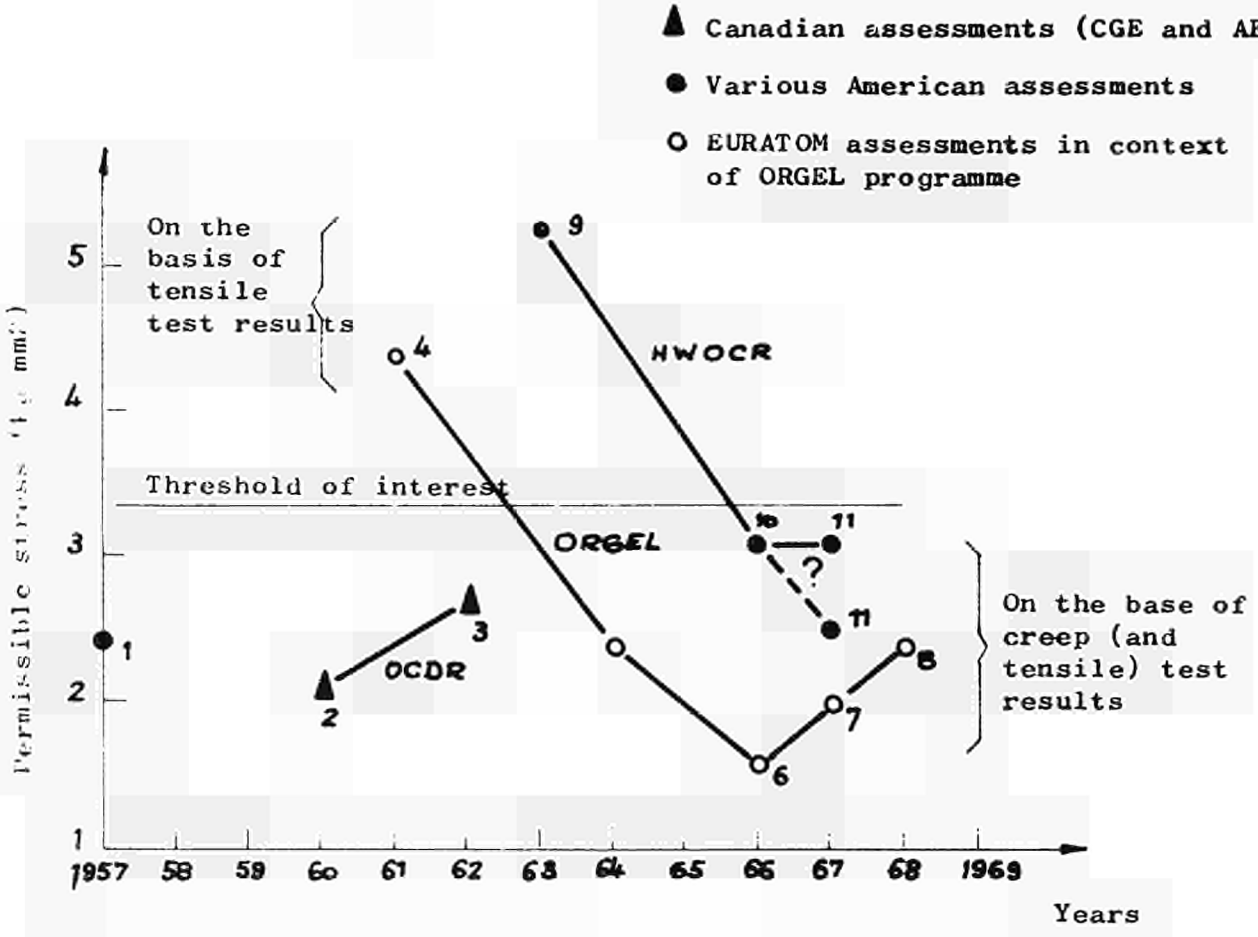

FIG. 7 - Progress of assessment of the permissible stress in a sintered Al - Al_2O_3 pressure tube, plotted vs time

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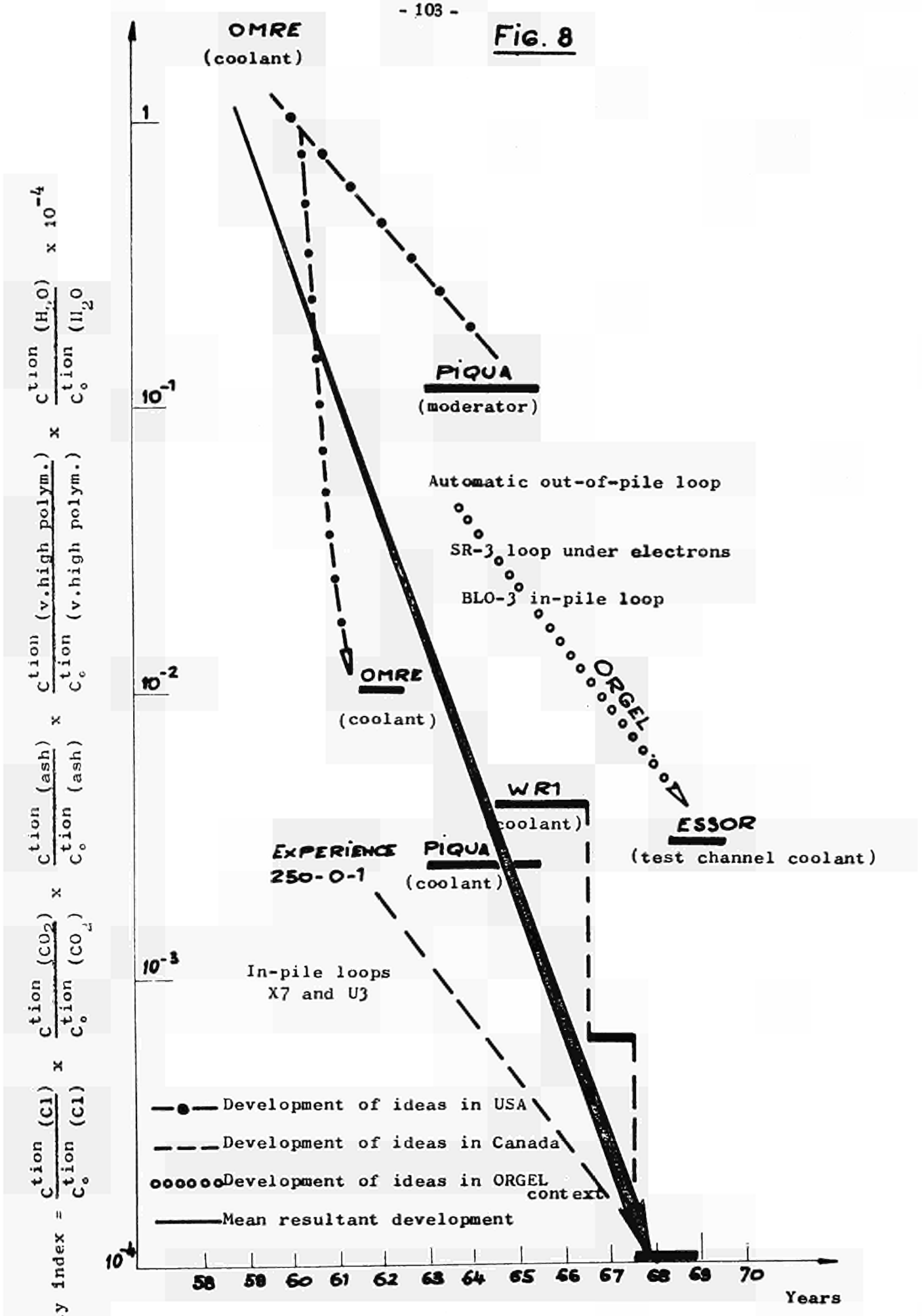
FIG. 8


OMRE
(coolant)
PIQUA
(moderator)
Automatic out-of-pile loop
SR-3 loop under electrons
BLO-3 in-pile loop
ORGEL
OMRE
(coolant)
WR1
(coolant)
ESSOR
(test channel coolant)
EXPERIENCE
250-0-1
PIQUA
(coolant)
In-pile loops
X7 and U3
Development of ideas in USA
Development of ideas in Canada
Development of ideas in ORGEL context
Mean resultant development
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
58 59 60 61 62 63 64 65 66 67 68 69 70
Years
Purity index = $\frac{c^{tion}(Cl)}{c_o^{tion}(Cl)} \times \frac{c^{tion}(CO_2)}{c_o^{tion}(CO_2)} \times \frac{c^{tion}(ash)}{c_o^{tion}(ash)} \times \frac{c^{tion}(v.high\ polym.)}{c_o^{tion}(v.high\ polym.)} \times \frac{c^{tion}(H_2O)}{c_o^{tion}(H_2O)} \times 10^{-4}$

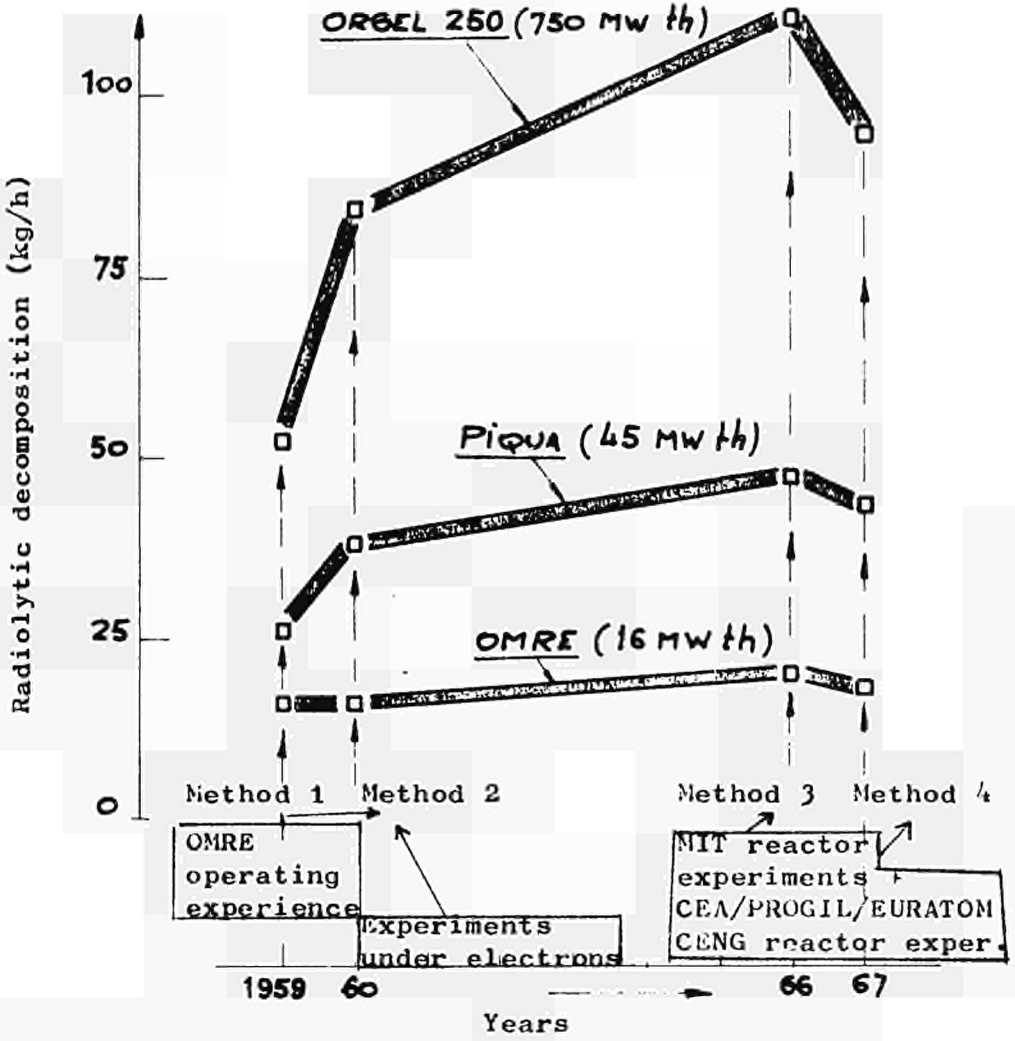


FIG. 9 a – Development with time of the estimate of the hourly radiolytic decomposition of the organic coolant, for various reactors

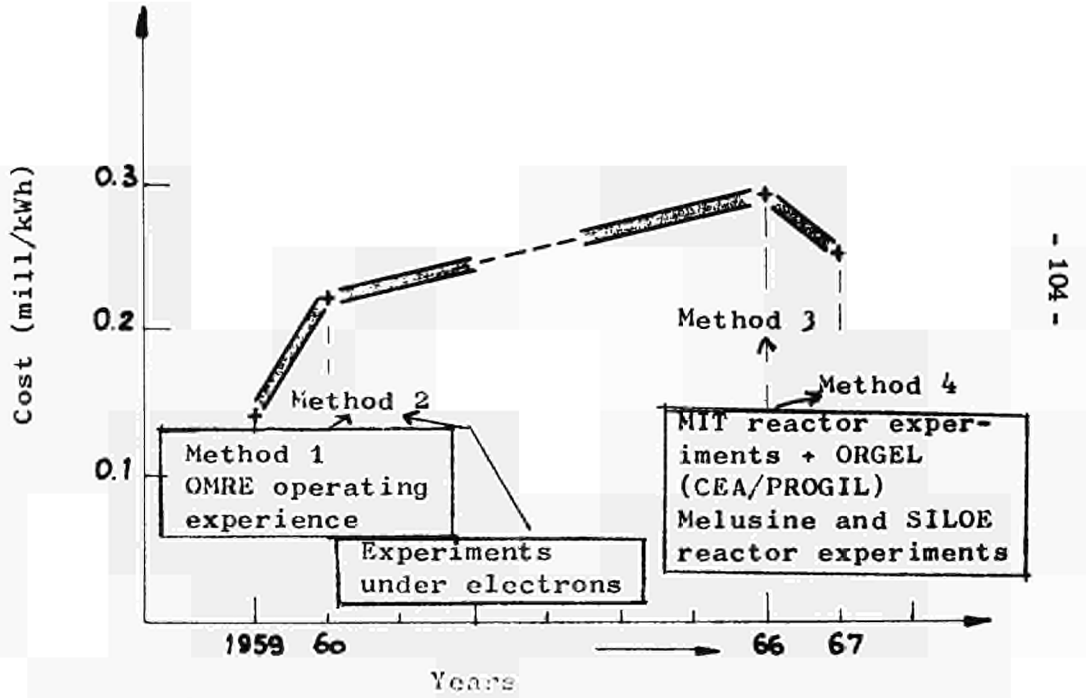


FIG. 9 b – Development with time of the estimate of the cost of replacing organic coolant destroyed by radiolysis, for a 250 MWe ORGEL reactor

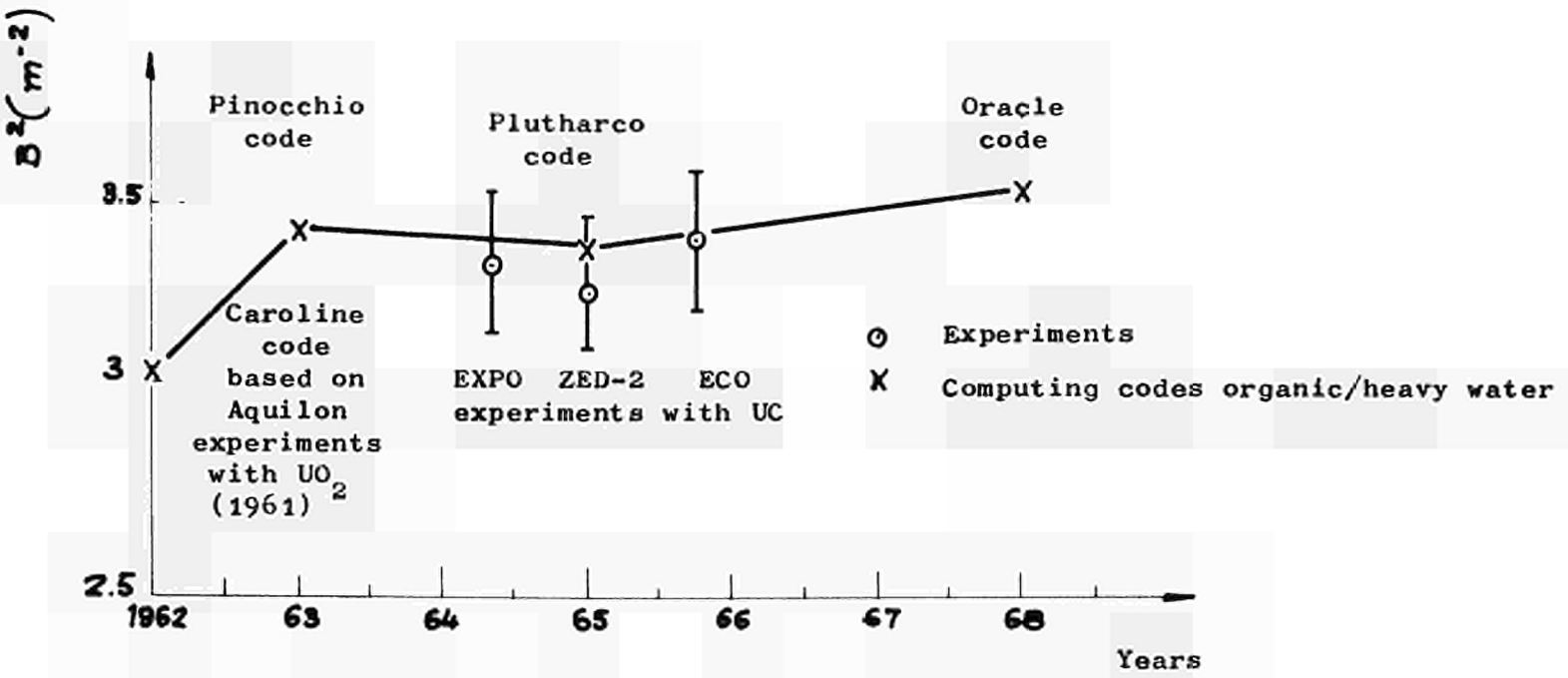


FIG. 10 - Progress of the assessment of buckling of an organic/heavy water lattice with cluster-type of fuel element containing seven UC pins (rod diameter 25.2 mm; lattice pitch 240 mm)

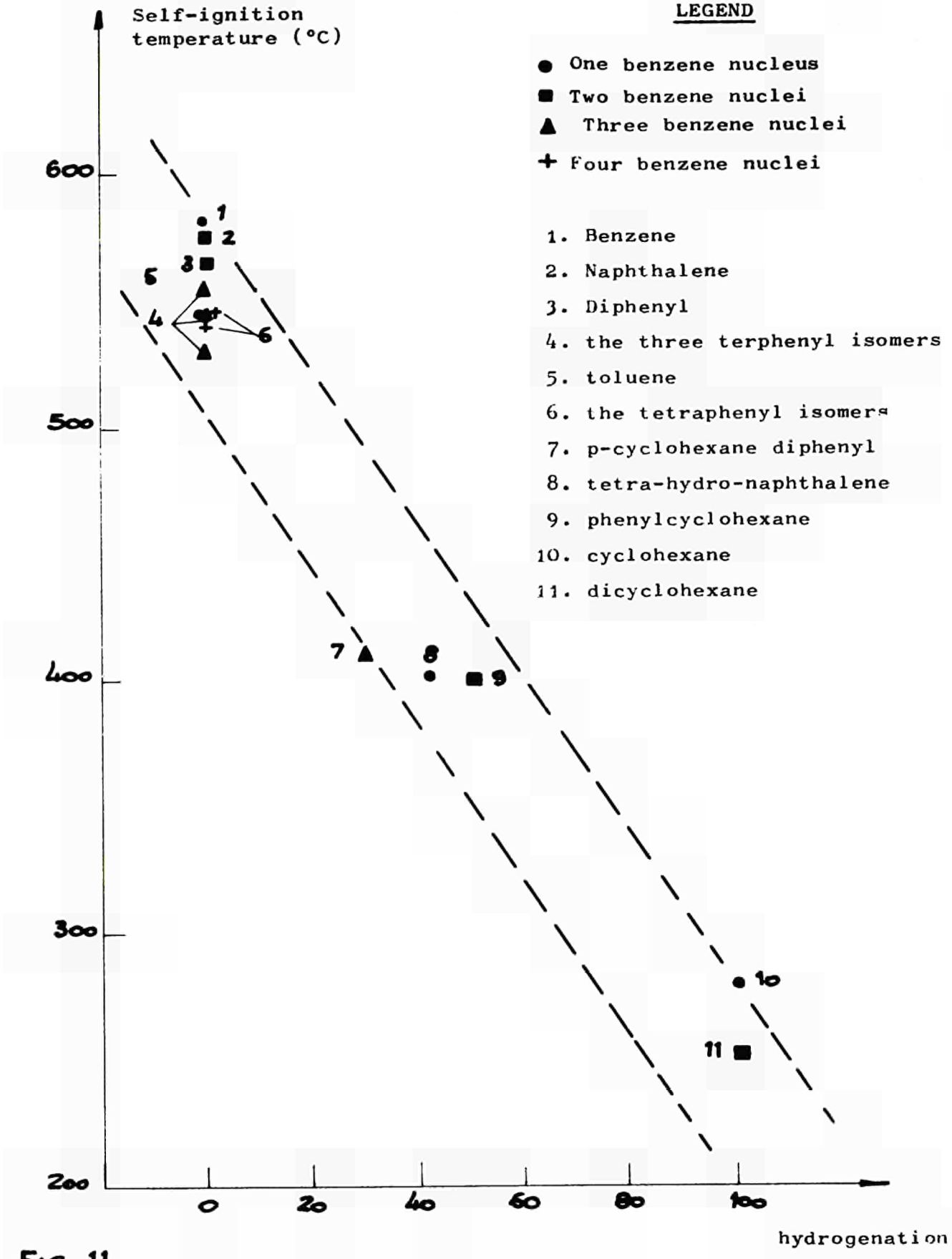
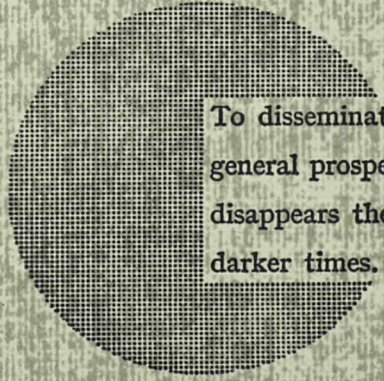


FIG. 11 - Variation of self-ignition point of certain aromatic derivatives vs the percentage of hydrogenation (from Geiss and Kuhlbörsch)

The self-ignition point falls when the hydrogenation percentage rises; most of the hydrogenated derivatives considered were detected by analysis in either OM2 or HB40 after irradiation.



To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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