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Development of the Second French Reactor

By integrating the technical chronology with the philosophies underlying construction of the Saclay reactor, the director of the project paints the best available picture of the French advance towards nuclear power

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THE FRENCH AEC started its activity early in 1946. Its first goal was to produce a low-power reactor sufficient to exhibit the nuclear chain reaction in its simplest form and free from all preoccupation as to what to do with its energy output. This first reactor, called Zoe, came to life at the end of 1948; this was, for French reactor designers, the end of the first stage and the beginning of the next.

The *second* reactor, in the opinion of its originators, had to supply a substantial amount of scientific and operating data that would provide the designers a base on which to face, in a concrete way, the problem of nuclear power on an industrial scale. Behavior of metallic uranium and other materials under irradiation, maximum temperatures tolerable inside a reactor, effect of cooling pipes on the nuclear process and vice versa—none of these questions could be answered properly without actual observation on an experimental prototype in which as much power as possible was developed in a minimum possible volume. Whatever ambitions we could cherish to go far in this direction had to be weighed in these early days of 1949 against two hard facts of life: the necessity for speed and the total absence of technical information from abroad. (The first Anglo-American declassifications of reactor information did not become effective until late in 1950.)

Choice of Reactor Design

The French production of metallic uranium was just getting into its stride. It was reasonably certain enough would be available in time to fuel a heavy-water pile, but hardly enough to envisage a graphite-moderated reactor, which would require at least ten times more metal. For cooling, a choice had to be made between four variants.

1. Circulation of heavy water in bulk. This system, already well known from CP-3 (Argonne National Lab.), was later on used in JEEP (Oslo) and SLEEP (Stockholm). It raises no serious mechanical difficulties and can be built quickly. The power yield per ton of uranium is of the order of 100, possibly 200 kw. The temperature stays appreciably below 100° C. Generally speaking, operating conditions differ radically from those foreseen as likely in an industrial nuclear plant.

2. Circulation of low-pressure air along uranium rods. Compared to **1**, this method promises no important gain in power yield per ton (a factor 2 or so), but it is of vastly greater interest as an introduction to industrial applications. Low-pressure air cooling has been used in America and especially in Britain in connection with graphite-moderated reactors containing vast masses of uranium and reaching well into the two-figure megawatt region.

3. Circulation of compressed gas along the rods. It was natural to think of air first; since it is advisable to remove ingredients that, at a high temperature and under irradiation, may become corrosive (oxygen) or highly radioactive (argon), one comes naturally to the idea of using nitrogen. Other gases (in particular CO_2) were envisaged later on.

Compressed gas is a much more efficient coolant than a low-pressure one. The only limit is that imposed by the mechanical strength of pipes that can be lodged conveniently in a reactor.

This cooling method can evolve directly into an economically interesting way of producing motive power. A prototype of this description is, however, obviously more difficult to build than a low-pressure one.

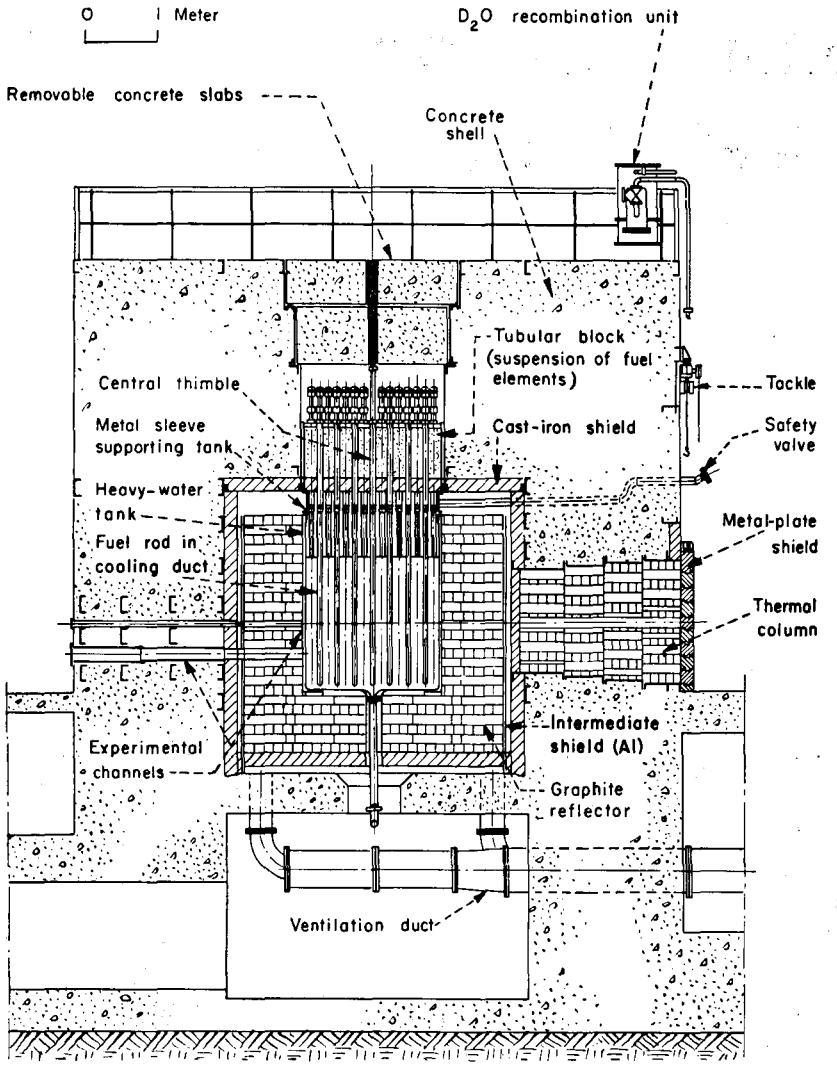
4. Circulation, under pressure, of a liquid along the rods. As long as natural uranium is the only fuel available, the choice of liquid is practically limited to natural and heavy water; the former is cheap, but the latter absorbs no neutrons and therefore requires a smaller quantity of uranium.

Water cooling, as used in the U. S. and Canada in conjunction with natural uranium, permits the highest rates of power extraction per ton of uranium. Its difficulties, notably metallurgy and precision mechanics, are many.

The four preliminary projects were

* PRESENT ADDRESS: European Council for Nuclear Research, Geneva, Switzerland.

The Saclay Reactor: Construction and Operation



CONSTRUCTION of reactor is shown by cross section. Criticality can be achieved with about 5¾ metric tons of heavy water in reactor tank; in practice about 6½ tons are used to maintain a reserve reactivity. Total uranium mass of slightly under 3 metric tons is divided among 136 rods. Each sheathed rod is suspended inside aluminum tube about twice rod's diameter; annular space surrounding rod is divided by another tube into two concentric tubular ducts. Compressed gas travels downwards in outer duct, enters inner duct at lower end of rod and returns upwards, in inner duct, in direct contact with rod sheath. During downward journey gas helps cool heavy water, from which it is then separated by only one thickness of aluminum tubing. When going upwards, gas picks up heat from uranium rod. Each of the 136 double ducts is individually gastight; reactor tank itself is not built for high pressures. Cadmium plates move vertically between tank and reflector for control; two safety rods can be dropped along tubular channels into central part of reactor

EXPERIMENTAL FACILITIES (three channels, thermal column, and central thimble shown) are not as numerous as is desirable in a laboratory reactor, since this reactor is primarily a cooling experiment. 21 horizontal channels, 10 to 14 cm square, lead up to tank wall through biological shields and reflector; 37 vertical channels are located just outside graphite reflector; one central thimble, 6 cm in diameter, reaches reactor core. Single fuel elements can be replaced by more complicated structures such as uranium sleeves for fast-neutron irradiation, or experimental cooling devices

examined in August, 1949, by the High Commissioner and his advisors. The third variant was chosen because of its importance for future reactor technology; its power yield was judged reasonably high, taking into account the level of specialized knowledge (in particular as regards metallurgy) reached at that time in France. We were well aware of the interest previously shown by American and British specialists in compressed-gas cooling, and we knew that, in the conditions of their own atomic development, the building of a reactor of this type was provisionally postponed. We did *not* know that this provisional state of things lasted well into 1952, at which time the British decided to build a gas-cooled pile. Our earlier initiative was original to a much greater degree than we realized then.

The performance of an entirely novel device cannot be foreseen with any degree of accuracy. The project's authors ventured the hope that the power yield per ton of uranium would be somewhere between ⅓ and ½ Mw. This latter figure was considered as a ceiling; safety components, such as the concrete shell, were designed accordingly. The weight of uranium invested in the reactor was kept to its strict minimum of about 3 tons, corresponding to a total output between 1,000 and 1,500 kw.

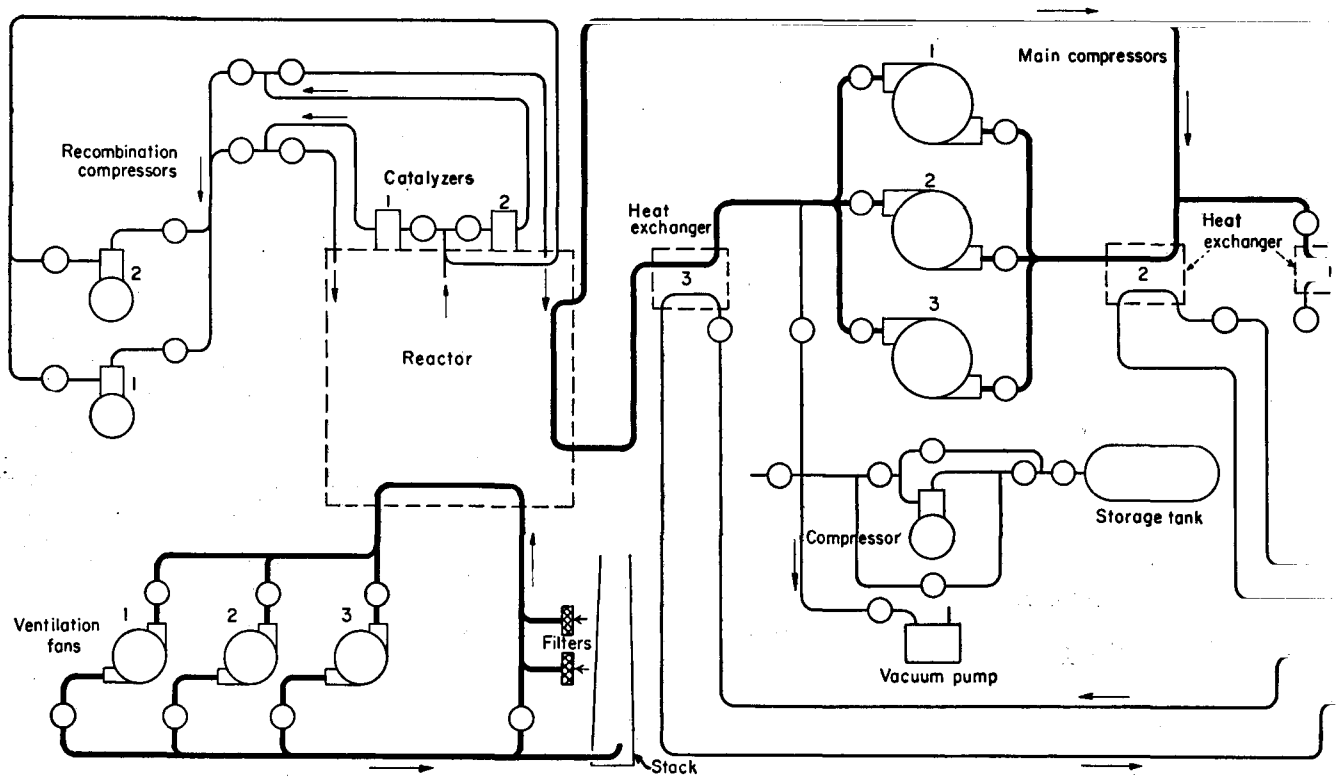
With its novel cooling system (see reactor description above), the Saclay reactor* was intended to open a new chapter of nuclear technology; its main purpose was to give useful information for designing bigger reactors free of whatever imperfections were found in the Saclay reactor itself. After having fulfilled its experimental role as regards the cooling system, the Saclay reactor could be assigned a permanent role as a source of radiations and radioisotopes.

Construction and Testing

After adoption of the project's main lines, a Commission headed by the High Commissioner was set up to control detailed design and construction. Its permanent executive body was the Project Office comprised of L. Kowarski as chairman responsible for the carrying out of the project; E. Le Meur, chief engineer; J. Stohr, special problems concerning the use of metals; and J. Yvon, calculations and theory. M. Surdin (electrical plant and electronics) joined the office at an early stage and a close contact was kept with

* The reactor is so known at present. Neither the nickname "Cyrano," given in the Zeep-Bepo tradition, nor the Argonne-style symbol "P2" seem to have stuck.

Five Piping Circuits Are Needed for Operation



1. PILE COOLING CIRCUIT (heavy lines) uses two blowers, with third as standby, drives gas towards reactor at maximum absolute pressure of 170 lb/in² for nitrogen. Each blower handles flow of 30–35 metric tons of gas per hour, uses 400 kw. Exchanger 3 cools gas to 20–30° C before entering reactor. Gas leaves reactor at about 70° C (higher temperatures will be possible shortly), gives up its heat to exchanger 2 (exchanger 1 not used at present), returns to blower, and is recycled through reactor.
2. WATER CIRCUIT (right) delivers cooling water to exchangers at about 15° C; temperature varies with atmospheric conditions. Heated water is pumped to top of cooling tower. Flow rate is about 200 metric tons/hr.
3. AUXILIARY GAS CIRCUIT (center) can be used to prime main circuit or to introduce additional gas. Storage gas tank is filled directly from delivery bottles; compressor raises gas pressure to main-circuit level. Vacuum pump removes gas from main circuit if change of gas is necessary.
4. RECOMBINATION CIRCUIT (top left) includes catalysis chamber to remove radiation-produced deuterium and oxygen gases from D_2O gas above heavy-water level in reactor tank. These gases are potential explosion hazard.
5. VENTILATION CIRCUIT (bottom left)

other participating divisions, especially with applied chemistry (under B. Goldschmidt) and physical chemistry (J. Gueron).

Chronologically, the work proceeded as follows:

1950: Detailed plans completed, main orders placed, building erected.

1951: Main mechanical and electrical components assembled, uranium rods manufactured and ready to be sheathed.

1952, first half: Assembly, sheathing of rods, completed.

At the project's earliest stages, our knowledge of metallic uranium and of its behavior under the influence of the relevant mechanical, chemical, and thermal factors, was very incomplete. An experimental inquiry into these topics was carried out parallel to reactor construction.

By the fall of 1951 our researches had shown clearly the necessity of inserting certain definite steps in the rod manufacturing process to insure their future satisfactory behavior. This meant that the set of rods nearly completed at that time would have to be replaced by another before the full design power could be reached.

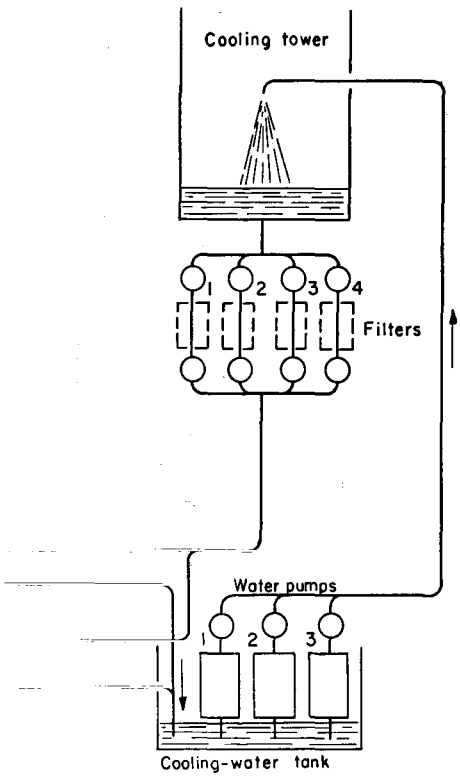
In the spring of 1952 the same provisional set of rods exhibited an unforeseen kind of corrosion; a quick study showed what preventive measures had to be taken in the future. The provisional set itself had to undergo a "curative" treatment that delayed its use by about 3 months.

Criticality was reached on October 27, 1952. After a few weeks' physical studies at a low power, the output was gradually raised in a series of tests completed in March, 1953. The main conclusions were:

1. Compressed-gas cooling in a closed circuit is basically satisfactory. There is no unforeseen radioactivation of the gas, by dust or otherwise. Blowers of an unusual (in French conditions) type work satisfactorily; the behavior of their gastight joints is good. Heat-transfer efficiency is rather better than expected.

2. In our 1949 ignorance of the behavior of the metallic uranium, we hoped that the surface temperature of our rods could reach 250° C at the hottest point. In the light of our increased metallurgical knowledge, however, we felt it advisable to go slow to avoid the risk of warping, which would endanger not only the functioning of the reactor but even the possibility of its repair. A surface maximum of 115° C was therefore imposed, pending replacement of provisional rods.

3. Gas-flow distribution between the 136 individual ducts, established at



removes air possibly contaminated with radioactivity from spaces adjoining coolant gas lines and reactor, exhausts it through stack. Supervised zone, in particular the graphite reflector, basement housing exchangers, hoods surrounding compressors, and trunk gas lines, is constantly monitored for atmospheric radioactivity. Recirculation of coolant gas may make impurities in it dangerously radioactive, and circuits are never 100% gastight.

first on theoretical grounds, had to be adjusted gradually in the light of our measurements on the spatial distribution of neutrons inside the reacting space. Suggestions as to the desirable machinery and accuracy of such adjustment have been derived for the benefit of our future installations.

4. The motion of the gas in the aluminum pipes lodged in the reacting space generates vibrations; this phenomenon was expected, but some of its manifestations, culminating in a succession of jerks and blows, were not. It was decided to insert in these internal pipes a set of metal pieces suitably shaped to attenuate the vibrations; and, on the other hand, to strengthen the joints between the "nuclear" (aluminum) and the "outer" (steel) region of the gas circuit.

After a period devoted to low-power physics, mechanical alterations and a detailed study (mechanical and metallurgical) of the second set of rods, full-power operation of the reactor was resumed in September, 1953, on an intermittent schedule, allowing for full-power runs, variable power, and shutdowns for inspection and adjustments. The limitation of rod temperature set a maximum for the full power, kept between 850 and 1,050 kw, that varied with the weather. Meteorological fluctuations have a direct effect on cooling efficiency of the water circuit.

All minor disturbances and stoppages during the subsequent half-year not only were easily remedied, but added to our understanding of this new kind of mechanism and prepared our engineering personnel for its much more arduous future task of running bigger and less approachable nuclear plants.

On the whole, our experience has shown that dismantling, repair, and reassembly operations seem to be less drastically precluded, even in the most active regions of the reactor (provided it is not operating), than we had expected. It seems that a similar conclusion, on a higher level of reactor technology, can be derived from the Canadian experience with the NRX accident.

In March, 1954, the provisional rods were taken out of the Saclay reactor; when insertion of the second set is completed, we expect much higher rod temperatures and (approximately) double the power output to be possible.* This stepwise rise towards design power and then beyond it, parallels the history of some earlier reactors The British "Bepo" stayed a few years at about 60% of its design power until an essential forward step in metallurgy had been made. The necessary progress is in such cases usually due to observations made with the help of the reactor itself.

Results to Date

The contribution already brought by the Saclay reactor, at its 1,000-kw level, to French atomic development can be summarized under three headings:

1. As a "testing bench." Practical proof has been given for the first time that a reactor can be used, steadily and reliably, to heat a compressed-gas current, thus opening one way towards economic production of motive power. This way is, at present, being explored by the British.

In addition to this demonstration of feasibility, a number of smaller problems (interchange of gases, distribution of gas flow, vibrations, gastight joints) has been solved.

2. As an object of physical research. Numerous physical aspects of the chain reaction have been studied: spatial distribution of radiation in and around the reacting core; effect of different gases on the reactivity; kinetics of transient states; fission-product poisoning; propagation of neutron waves. Some of this work, notably by V. Raievski and J. Bernot, has been reported at the Oslo Conference of August, 1953, or published in the *Journal de Physique* (Paris).

3. As a source of radiations. At 1,000 kw, the Saclay reactor offered a higher central flux (about 4×10^{12}) than the British laboratory reactors and was comparable with Brookhaven. Its radiations were used for cross-section measurements, for study of neutron-induced displacement in crystalline lattices ("Wigner effect"), and for occasional radioisotope production. The Saclay reactor is not much of a plutonium producer. This production is proportional to the total uranium mass present in the reactor, whereas the designers aimed precisely at keeping this mass as low as possible. A few dozen grams already accumulated will serve, however, to increase our knowledge of this element.

Future Prospects

France's present atomic "Five-Year Plan" aims at enlarging the industrial scope of the national atomic effort and at bringing France to the threshold of a paying power production. Reactor development is directed simultaneously at the production of plutonium in "cold," Windscale-like structures, and the building of high-temperature and high-flux prototypes.

The Saclay reactor, even after having transcended its "provisional" stage is, then, soon to lose its prominent position in the vanguard of French atomic progress. The gropings of its adolescence having yielded their expected harvest of knowledge, the reactor will soon reach its quiet maturity, as a steady source of radiations and radioisotopes. END

* NOTE ADDED IN PROOF: This operation, ably directed by J. Robert and R. Uguen, was completed in June. Early in July, steady operation was resumed at 1,500 kw with the hot point provisionally at 200° C. Higher temperatures and outputs will be attempted shortly.

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