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TOWARDS COMMERCIAL FAST BREEDER REACTORS THE FIRST 1200 MWe UNIT

(Vers les Reacteurs Rapides Industriels: La Premiere Unite de 1200 MWe)

By

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Summary

The public thinks of the line of fast breeder reactors as consisting of the RAPSODIE and PHENIX reactors, soon to be joined by the new 1200 MWe power plant. It is true, without playing down the essential importance of the research and testing what went into these reactors and made their construction possible, that the reactors themselves are the concrete evidence of the results achieved.

The public probably thinks of these units in terms of their rising unit capacity: RAPSODIE 20 MW (thermal), raised to 40 MW, PHENIX 25 MWe, and now 1200 MWe. However, the framework of construction and the purposes of the project have been fundamentally different in each case.

To say that RAPSODIE confirmed the validity of the principle, PHENIX the technique, and the new 1200 MWe reactor the economic comperitivity of the approach is oversimplified. RAPSODIE was a large scale model designed and built by research engineers, and the stages in the transition to a commercially competitive plant constructed using industrial techniques cannot be plotted in a one-dimensional time graph: many dimensions operated, some with unforescable variables, and the choice of the path and the stages along the way that would optimize the economic data within a

reasonable time-scale was a delicate problem that goes beyond the scope of this report.

The purpose here is to show that although the technical options are common to RAPSODIE and its successors, there have been substantial changes in the conditions in which successive projects were executed. The 1200 MWe unit comes as closely as possible to true industrial-style methods. RAPSODIE was a starting point that made the rest possible, and PHENIX was the first model of an industrial scale unit. It would have been hard to get to where we are now without them.

RAPSODIE has been described at length in many publications and all that need be said of it now is that is remains an enormously valuable tool, that can be used to carry out endurance testing of sodium technology at the same time as studies are made of the irradiation in a fine approximation to actual working conditions of that essential component, the mixed plutonium and uranium oxide fuel. Its excellent availability must be acknowledged as one of the primary factors responsible for the subsequent development of this reactor family.

1. THE PHENIX STAGE

It was in 1966 that the study of the project-plan Phenix began and the decision for its construction was made in 1968.

To build a power plant large enough to represent all the industrial problems without a very high investment, the power level agreed on to be was 250 MW. This would represent the advantage of the utilization of the classic turboalternator set of the French Electricity system and the characteristics of steam supplied by a reactor very similar to them at the same time.

In this decision, France followed the route taken by Great Britain with the PFR, and URSS with BN 350, more recently the RFA with its project SNR and finally the USA with its decision to build a "demo plant".

Let us recall briefly the main characteristics of Phenix:

- Power: 250 MWe (563 MWth) turboalternator set, tested.
- Sodium cooled reactor using mixed fuel: plutonium and uranium oxide encased in stainless steel.
- Integrated concept: The main primary circuit with its three pumps and six intermediary exchangers surrounding the core is entirely contained in a stainless steel casing filled with 800 tons of sodium. This concept has been essentially retained for its advantages concerning the safety of the installation.
- The fuel monitoring is accomplished with the reactor stopped (one run every two months) by means of a system consisting of a loading

plug, a maneuverable arm and a ramp-lock system that allows the transfer into an outside station.

- Operation with the basic power system.

Finally, besides the capability of producing electrical energy it has to be emphasized that the experimental operation of Phenix will be a valuable tool during the following years.

Since the beginning of the construction in 1968, it was hoped that general tests could be started in 1972 and the full power operations could begin by 1973. Despite some slip-ups that are quite understandable in the case of such a prototype this program is still valid.

Let us summarize briefly the principal phases of construction:

- From 1968 to 1971 project studies, experiments on mock-ups (hydraulic and thermal engineering of the reactor) tests of the main components prototypes (main pumps, driving rod mechanism, arm, ramp and lock system of the fuel monitoring.

- At the same time the construction of the buildings, the positioning of the pressure shell in November 1970, the roofing of the main vessel (roof) in August, and the upper protection block in September 1971; rigging up the steam generators from May 1971.

- In the first half of 1972 the other components have been installed - the loading plug, pumps, intermediary exchangers, maintenance. The turboalternators were set up in the fall.

After minimizing the risks involved with a prototype of such installation, gaining the greatest amount of information and at the same making the best necessary improvements, tests were prepared in 1970. They were as complete and exhaustive as possible, their purpose: the methodical testing of all parts of the installation in four successive phases.

- Thest before the loading the sodium into the principal circuits, terminating in 1972.

- Sodium testing before fueling which began by the loading of the sodium into the reactor and the secondary circuits finished on the 10th of January 1973. During this very important phase all the circuits of the plant functioned as close to the noraml conditions as it was possible (nominal yield, temperature up to 450°C). At the same time the turboalternator set was put on in November 1972 and tested in February 1973 on auxiliary steam.

- Loading of the fuel assembly and neutronic tests with divergence before the start up of the power.

In fact we could draw our first conclusions from now on from what we have learned during the construction of Phenix and what we hope to find out by its operation.

a) In planning and design as well as project studies, the Phenix project helped to evaluate and master the problems inherent to this type of integrated reactor (hydraulic, distribution of thermal gradients and associated stresses as well as the entire functioning of the power plant.)

b) On the actual construction plan the advantages connected to this type of reactor have been confirmed:

- Civil engineering will not present any particular difficulties;

- The absence of high pressures in the circuits allows the construction of the thin, but very large, components such as the pressure shell, on site.

Correspondingly, there would be no delays in the manufacturing of the components, stretching the time of construction such as the traditional case with the turboalternator. We hope still to make some improvements in this area in comparison with the Phenix project where the delays are evidently caused by the inherent risks associated with this prototype.

c) As far as the maintenance is concerned, the sodium experiments made possible to define the way to manipulate the components for maintenance and in case of emergency operations, and the crew is well in position to master the problems of operation with active sodium.

d) There is one particular problem that we must elaborate on, and that is the fuel.

For the manufacturing of the first core of Phenix, the irradiations in the Rapsodie experiment supplied us with very valuable experience concerning the behavior of the fissionable pins on elevated irradiation levels, most importantly the deformation of the plutonium oxide mixture and the uranium due to swelling under irradiation. The same problem concerns the steel casing containing the fuel elements.

It is quite obvious that the study alone on the general behavior of the first core of Phenix will present enough information statistically and globally to determine the average attainable level of irradiation.

Based on anticipated, continuous observations it will be possible to proceed in two directions at the same time:

- Improvement of the fission material in the succeeding cores.
- Definition of improvements contributing to the conception of monitoring materials, specifically, the eventual deformation caused by swelling.

Here, Phenix demonstrates its double function: a reactor for the demonstration of the system; an experimental reactor allowing significant irradiation for the fuel arrangement for the fast breeders.

e) - Finally, in its industrial concept, the manufacturers seem to have mastered the problems particular to the fast breeder reactors concerning the particular difficulties, and have the knowledge sufficient in construction methods and the necessary means in work force and work tools at the same time.

On the other hand we should remember that the project managers at CEA and at EDF cooperated in this project combining their skills for the promotion of the necessary basis for the development of the fast breeder. This has been particularly clear as far as the engineering of the plant is concerned since the construction and the starting of Phenix have been managed by a combined team of the project managers of CEA and

EDF under the direction of CEA and a private company long associated with our work in the fast breeder line - the Alsacienne and Atlantic Atomic Company.

One cannot emphasize enough the importance of such cooperation of effort and experience in solving the particular problems of a new product. This experience could immediately help in the development of the fast breeder reactor and most of all for the studies and construction of the Super Phenix.

2. SECOND STAGE: SUPER PHENIX - TECHNICAL PROBLEMS

The objective of the Super Phenix project is the construction of an industrial scale prototype of fast breeder reactor. The goal is to build a plant capable to produce electricity superior to power plants equipped with so called "tested" reactors, specifically power plants built on water power from the aspect of economy, safety, feasibility and construction without difficulties.

The first important step was to settle the question of power level. To lessen the burden of investment on the cost of produced kWh, the size took on a particular importance. The power level of 1200 MWe was thus selected in analog to light the water power plants built in the same period of time as Super Phenix. It had to be made certain by a systematic examination of the components that there will be a reasonable expansion in relation to Phenix. At the same time the studies carried out on higher power level than 1200 MWe proved that the choice made for Super Phenix was the right one from the point of view of the future.

The studies of Super Phenix were in continuity with Phenix, profiting from the knowledge gained during the conception and construction of the demonstration plant, a knowledge that is being completed little by little with the experience coming by its operation. The significant options kept are: primary integrated circuit, refueling at reactor stops, and most of the important components are in close similarity to that of the Phenix.

The chief modifications were motivated by economic considerations or by technological improvements. We should mention the following modifications in particular:

- In order to guarantee the rate of combustion of the fuel - while diminishing somewhat the performance - the steam had to be produced on a little lower temperature (490°C instead of 510°C).

- The handling arrangements have been modified for the purpose of reducing the time of work stoppage of the central for refueling.

- The elmination of the "roof" of the main pressure shell that caused the problems of temperature variations necessitating as insulation of argon atmosphere for unlimited operations.

- In the steam generators, the diameter of the low power units of Phenix (17 MWth) were replaced by much larger ones whose exact measurements (125 to 750 MWth) are yet to be defined during the testing operations.

- Finally, the ever growing concern for the safety and the protection of environment lead us to observe more keenly the safety measures retained from the Phenix project in many areas. The most typical example is the tight enclosure (Dome) placed over the reactor constituting as additional barrier against the consequences of an eventual accident.

Briefly, the general distinctions of the plant are the following:

In the first place, the nuclear boiler consists of a reactor unit very similar to that of Phenix, whose diameter was appreciably increased and which contains four main pumps and eight intermediary exchangers.

Coupling the intermediary exchangers two by two we have four secondary sodium rings symmetrically positioned around the reactor, which are identical. The steam generators are placed into special housings on both sides of the reactor housing, where the secondary pumps have also been placed.

The handling arrangements of the fuel elements and components are also housed in the reactor. The fuel monitoring assembly involves a series of installations allowing their deactivation stockage and their loading into the transport towers.

The engine room is organized to utilize the steam from the generators in a superheating thermodynamic cycle, the necessary calories supplied for this by the steam accumulated during expansion.

The essential characteristics of the primary circuit of the energy discharge are approximately the following:

- Thermal power (pressure) of the reactor 3000 MW

- Electric power	1200 MW
- Water at steam generator entrance:	
- Flow	1350 kg/sec
- Temperature	235°C
- Pressure	230 bar
- Superheated steam at the steam generator outlet:	
- Temperature	490° C
- Pressure	180 bar
- Superheated steam:	
- at the entrance of the superheater drying apparatus	165°C and 7 bar
- at the outlet of the superheater drying apparatus	290°C and 6.5 bar

The steam delivered by the steam generators will be used by a set of turboalternators, one of 1200 MW electric power or two with half of that power. The decision concerning these units has not yet been made. Presently there are studies undertaken as to the best solution based on the actual knowledge to take advantage of the availability of meterials and the investment cost of the installations.

Regardless of the eventual decisions, the water-steam circuit studies are conducted with concern to retain most of the already proven solutions from the classical thermal power plants and to choose materials that have already proven their worth avoiding as much as possible the technical innovations.

The previously described water steam principal circuit is connected to a stop and start circuit of the power plant whose essential functions on normal operation are the following:

- Discharge of the residual power from the reactor core,
- Supplying water for the steam generators.

3. SUPER PHENIX - INDUSTRIAL PROBLEMS

The relative autonomy with which the program development of fast breeder reactors had been conducted evoked some criticisms in the big European countries. It could be stated, that Europe had to invest a considerably higher amount for the establishment of these techniques than at the same time the United States has spent on the same project. On the other hand the dispersion of the studies did not hinder in Europe by any means the very good exchange of information of the basic problem, the favorable effect of competition and moreover, perhaps the simplicity of the procedures, just when the choice of technical option had to be made appealing mainly to intuition.

The disadvantages of the prularity of the program are actually outweighed and become the advantage of, predominantly influencing the realization of the industrial prototypes. First of all, the field of technical options becomes less open due to the effort to lean of the previous experiences.

On the other hand, the amount of money ventured in a single operation becomes quite considerable. The 1200 MW unit by itself will cost more than half of the expenses consecrated up to this day in France for the fast reactors. The attained experiences thus are particularly important, but the hesitancy to use them becomes bigger and bigger, because the question becomes more acute by every moment not only "what to do" and "how to do it" but also "who is going to do it".

To have several techniques developed paralelly witnout profiting one or another, or even having to discard one or possibly all is a great risk, and might result in making ineffectual many of the already agreed on participations. The associations are necessary and although the electricity producers are not the most affected by them, they might have to bear the risk of a prolonged anarchic situation and do in any case all they can to avoid them.

With this in mind, three principal West European electricity producers, EDF, ENEL, and RWE got together on the initiative of UNIPEDE and with the support of the Commission of European Communities for the coordination of the development of fast neutron breeders by building together two of these plants:

- One, built in France, which is the subject of this report
- The other, to be built in Germany.

Since the project has been made public in July 1971, the three partners have been working for the solution of the administrative, legal and similar problems for France and Italy legislatures that would set up this agreement.

These problems are going to be solved shortly, and the agreements will probably be signed while this report is being presented at S.E.E. Congress.

Without entering into details of this agreement, let us remember that the figures below represent not only the participation of the three partners in the expenses and products, but the work force under the project heads and manufacturers who provide the supplies and work for their respective countries.

	Power Plant France	Power Plant Germany
EDF	51%	16%
ENEL	33%	33%
RWE	16%	51%

As soon as the company will be set up to represent the French power plant it will head the operations for its construction and operation.

Who will be the supplier and particularly who will manufacture the parts of the most important component, the nuclear boiler? The comlexity of this problem presented for the electro-mechanical industry in France is clear to everyone.

Beside the CEA, who is responsible for the reasearch and development and who is the inventor of the "system" there should be not just one but a group of companies working on this project, who are, if their proposal is accepted by the head of the project, should be responsible for the construction.

Already, the agreements have allowed the recruiting of the engineering force, which constitutes a very important part in the success of the whole undertaking. Created from the staff of the Alsacienne Atlantic Atomic Company, just as the Phenix project had been, and of an engineering affiliation of CEA recently formed and named Technicatome, the group now conducts the studies and should coordinate the construction when the time comes joined by the representatives of the Italian Engineering.

Important negotiations are being conducted presently to form an industrial group (from which would come the previously described engineering force); and it should be ultimately extended by the Italian industry.

All these decisions must be made without delay; the proposal is expected by the project head in 1974 for the opening of the work site in 1975 and completion of the construction in 1979-80.

CONCLUSION

French contributions in the fast breeder reactor series are firmly continuous.

The efforts displayed and the money spent in this area place us into the group of leading industrial nations.

There is no time yet to lessen our efforts. We have to proceed vigorously to reach our goals. Our main tool at this time is the Super Phenix; it is this project that must demonstrate our technical capabilities and prove our economical competivity.

If all proceeds as we could reasonably expect, we could take a favorable place in the group of industrial nations playing a role in the world market of electro-nuclear power plant line, whose ultimate purpose is to utilize, better than any other installation, the potential energy of the uranium reserves.