FROM PHENIX TO SUPER PHENIX: MECHANICAL STRUCTURES ASSURING REACTOR VESSEL TIGHTNESS AT MAIN SODIUM PUMP PENETRATIONS

Structures mécaniques assurant le confinement du bloc réacteur à la traversée des pompes principales à sodium

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SUMMARY

Introduction

It is shown how the mechanical problems concerning the tightness of main sodium pump penetrations through the deck of a pot type reactor have been solved in joint SNECMA — HISPANO-SUIZA/CIRNA studies.

The main primary components (primary pumps, IHX) are contained in a single vessel. The top of this vessel is closed by a deck from which the pumps are suspended. These pumps feed sodium into the core and are thus connected to structures fixed to the bottom of the vessel. Reactor operating conditions require that both joints permit differential displacements so that slight shifts in the position of the pump will not affect either tightness with the deck at the top of the vessel, or the continuity of the hydraulic channel at the bottom of the vessel.

Super phenix joints

1. *Special conditions*

Even though the components of SUPER PHENIX are larger than those of PHENIX, there is no corresponding increase in available vessel height. Furthermore the SUPER PHENIX vessel does not possess a roof. For these reasons, original and patented solutions, which, nevertheless, take advantage of the experimental results and operating experience acquired with PHENIX, were sought.

The most important parameters to be taken into consideration are: weights and sizes of various components; stresses transmitted to the structures differential displacements between the top and bottom positions of components; inclinations due to deformation of the deck; preservation of containment at places where components penetrate the deck.

2. *Studies and solution adopted*

Extensive general studies have been performed and a comprehensive dossier of different possible solutions compiled. Wherever appropriate, information has been extrapolated from PHENIX experience. In the solution finally adopted, an elastic torus shaped ring, which forms a ball-and-socket type joint is used. A thin shell structure connects the bottom to the reactor internals in such a way as to permit both vertical and rotational displacements.

The upper joint consists of: 1) a bolted double flange system; 2) flanged component; 3) a torus with a gear tooth shape profile made of elastic material; 4) leaktight bellows attached to both flanges. The elastic ring is specially designed so as to permit ball-and-socket joint type motion of the pump without introducing any severe reaction on the internal structures of the reactor. The ring is sufficiently stiff to avoid any unwanted vibrations. The upper ball-and-socket joint, which accomodates the differential displacements experienced, and the restricted reactor height criterion, led to the choice of a thin shell structure with a spherical bearing for the lower joint. The technique adopted has been extrapolated from PHENIX.

3. *Tests before putting into service*

Studies and calculations have been completed with the realization of a 1/5 scale model of the upper torus ring. Displacement, and angular and axial stiffness measurements have confirmed the validity of the hypotheses.

Moreover, even though the lower part is an extrapolation of PHENIX, full scale experimental tests have been carried out in sodium, reproducing the real displacements and forces that will be experienced in the reactor.

Finally, the pumps will be tested with water; the suspension will be studied (investigation of relevant mechanical parameters, measurement of leaktightness with respect to the outside).

1 - INTRODUCTION

A paper dealing with French design sodium pumps for Super Phénix [8] was presented at the 1975 Nuclex in Bâle.

A brief recap of the work conducted over the past 20 years (fig.7), by, in particular Hispano Suiza, Bergeron Inc. and the French Atomic Energy Commission was given. This work led to the development of a third generation of pumps.

Today, we will describe how the complex containment problem posed by the primary pump/roof penetrations of Super Phenix has been solved.

Leak tightness integrity assurance is one of the prime considerations to engineers concerned with designing and constructing large components located (like the pumps) inside the reactor vessel. Leaktightness integrity assurance criteria have led to solutions which are more complex than those merely sufficient to guarantee the functioning of the component under good operating conditions within the limit imposed by the reactor internals.

Different types of roof/pump connection have been investigated in the framework of the French fast reactor programs (Rapsodie, Phenix, Super Phenix) (fig. 1,and also of several foreign programs.

2 - GENERAL PROBLEMS RESULTING FROM THE GEOMETRY OF POOL-TYPE REACTORS

2.1. Description (figures 2 and 3)

In pool-type reactors, the core and components are placed in the same vessel. The uppermost part of this vessel is closed by a roof from which the pumps are suspended. The core, fed by these pumps, is located in the hot collector. The pumps themselves are located in the cold annular collector ; their axes are vertical.

2.2. Reactor operation

The pumps (currently between 2 and 4) operate in parallel, pumping sodium whose temperature may vary between 200 and 500°C, depending on the operating conditions imposed.

Because of the large temperature difference (∿ 300°C) between the upper and lower parts of these pumps (which are some fifteen meters high), large differential displacements occur in different directions. It is important that the pumps follow these displacements while retaining their leak-tightness both at the pump/core and pump/roof connections.

2.3. Parameters influencing the design and options retained for connections

In addition to the conditions just recalled, it is also possible to cite : the amplitudes of the relative displacements between the top and the bottom of the pump, the internal and external forces to be taken into consideration, the sizes and weights of components, the dimensions of the vessel, dismantling possibilities and finally criteria to assure the reliable and correct functioning of the primary pumps.

3 - DIFFERENT TYPES OF CONNECTION

The pump connections studied and developed for test loops and pool (or loop) type reactors over the past 20 years fall into the following three categories : rigid, mobile, universal joint coupling.

3.1. Rigid connection (fig. 4)

This type of pump assembly was adopted to test loops, loop-type reactors (Rapsodie, Indian F.B.T.R., Italian PEC) and for secondary circuits. In all cases, the pumps are installed inside a tank and relative displacements are of the order of a few millimeters. This solution is applicable to all pumps with elastomer seals.

The pump is bolted directly onto a flange, the continuity of the hydraulic channel being assured by a system of baffles or sealing rings.

3.2. Mobile Phenix type connection

The increase in size and the larger differential displacements (of the order of a few centimeters) in comparison with preceeding realizations, have led to a solution in which the pumps are supported by the roof via sliding supports ; in this way, displacements can be followed, leak-tightness being assured by a metallic compensator.

As far as the lower part of the pump is concerned, the continuity of the hydraulic channel between the pump and diagrid is assured by articulated piping.

Details are given about these systems in references [3, 4 and 5].

3.3. Universal joint Super Phenix type coupling connection

The limited increase in available cold collector height in comparison with the increase in vessel diameter, has led to the use of an original upper universal joint type coupling connection and a lower Phenix type connection. Details about these connections are given hereafter.

4 - SUPER PHENIX PUMP CONNECTION

4.1. Generalities

Phenix was used as a starting point for general studies which have been conducted over the past several years. An extensive documentation covering solutions involving elements directly extrapolated from Phenix and completely new elements has been compiled. The basic principles and techniques developed and tested for Phenix, for which several tens of thousands of reactor hours of operational experience is available, have been retained.

Particular attention is given here to studies involving two mutually dependent and important elements : the pump/roof connection ; the pump/diagrid connection.

The general dimensions of Super Phenix primary pumps are given in figure 1. These pumps are of the free-surface centrifugal type and operate at speeds varying from 75 to 500 revs per minute ; the sodium (400°C) flow rate is 4.8 m^3/s, the manometric height being 70 meters of sodium.

The total weight of the pump without its motor is 120 tons ; a 4000 kW electric motor is used to operate this pump.

4.2. Upper pump/roof connection

a) Description (fig. 5)

The pump is fixed to the reactor roof and can follow the relative displacements between the roof and the diagrid. The connection consists essentially of :

- a supporting flange (1) welded to the roof (2) and constituting the plane upon which the pump rests ; the pump flange (3) is tightened up against this supporting flange by means of bolted counter flange part (4),
- the motor support (5) and the motor itself, supported by the flange (3) and thus rigidly fixed to the roof,
- an elastic torus (6) with an inner gear-tooth profile,
- leak-tight bellows (8) fixed to the elastic joint (6) on one side, and to the component's flange on the other.

b) Main functions

The upper connection enables :

1 / the assembly to be inclined in any direction with respect to the roof,
2 / forces to be absorbed (in particular vertical forces)
3 / sufficient angular and vertical stiffness to be obtained to avoid vibrations, but not too much stiffness as this would be detrimental for the lower structures of the reactor,
4 / handling operations to be performed with a special flask,
5 / leak-tightness between the active argon atmosphere of the reactor and the space above the roof to be assured.

Particular emphasis is given to this leak-tightness which is assured by an external flange rigidly attached to the bellows. The system incorporates a double seal and is fed with argon at a pressure always in excess of that in the reactor. The bellows' internal flange is welded to the pump which constitutes a leaktight plug. A sealing ring on the air side forms a second barrier behind the bellows.

It is recalled that Hispano-Suiza friction type oil seals are used to assure the leaktightness of the shaft penetration [3 and 6].

4.3. Lower pump/diagrid connection

If a double sleeve concept similar to that of Phenix were adopted, it would lead either to a prohibitively large increase in the height of the reactor, or to an increase in the height of the pump wheel, having a detrimental effect on the hydraulic characteristics of the system, as a result of a reduction in the available NPSH (and thus the margin relative to cavitation). Furthermore, the upper connection just described no longer renders such a concept indispensable. Thus we are moving towards a simpler solution permitting :

1 / a relative leak-tightness between high pressure sodium leaving the pump and the lower pressure sodium in the vessel,

2 / the centering of the pump with sufficient guiding to avoid vibrations,

3 / handling with a special flask,

4 / external forces to be transmitted without deteriorating bearing contacts,

5 / freedom of movement in all directions.

In order to accomplish these functions, many solutions were possible. Phenix experience [5 and 7] was used as a basis for the extrapolation and development of different types of joint (elastic sleeve ; ring, cylindrical ans spherical bearings).

The following solution has been retained (fig. 6) :

- the bottom of the diffuser (1) constitutes an external guide ; it is provided on the inside with an elastic sleeve (2) plated with hard alloy ; in this way a semi-rigid leak-tight joint is formed ; this last part has a large influence on determining the critical speed of the rotor and the self-resonance frequencies of the pump assembly.
- both parts are spherical in order to permit universal joint type movement around the torus.
- the facing part, which is fixed to the diagrid but can be remotely dismantled from the reactor roof after removal of the pump, incorporates two elements :
  - . an internal hard alloy plated sleeve (3) which constitutes the female part of the leak-tight joint.
  - . a large nonplated part (4) provided with a cone for a push fit with the pump ; this cone also facilitates the centering of the pump and the transmission of forces.

A sleeve (6) assures the leak-tightness of this assembly with the piping (5) of the diagrid connection.

5 - STUDIES AND TESTS

5.1. Extensive studies of the various possible solutions have been conducted. Attention is drawn to the following studies :

- calculation of bending and torsional stresses,
- calculation of angular axial stiffnesses,
- evaluation of the effect of pump inclination of the load capacity of the hydrostatic bearing and experiments with a full scale bearing in a water test facility,
- effect of stiffness on the dynamic stability of the pump assembly (vibrations, seismic response, critical speed of the rotor),

Hispano-Suiza and the French Atomic Energy Commission jointly submitted an international patent on connections [9].

5.2. These studies were concluded by series of experiments aimed at verifying the behavior of the elements proposed and confirming calculated values for stiffnesses and forces.

A 1/5 scale model of the elastic torus and corresponding flanges was constructed. Displacement and force measurements enabled the validity of the calculations performed to be verified.

A full scale mock-up of the lower construction is currently being tested in a facility of the Cadarache Nuclear Research Center. The temperatures and pressures of the sodium are reproduced in this facility, together with the relative displacements taking place. The tests carried out fulfill two main purposes : they confirm the feasibility of large hard alloy plated parts ; they enable friction coefficients and leaks to be measured. In addition, they can be considered as endurance tests.

5.3. All the pumps will be full scale tested in water testing facilities of the French Electricity Generating Authority (EDF). During the very long foreseen period, the mechanical, vibratory and hydraulic behavior of the pumps will be verified. Particular attention will be given to studies of the two subassemblies that we have just described (force, stiffness and stress measurements).

When these tests are over, the pumps will be installed in the reactor. Before starting up, tests will be carried in sodium at appropriate temperatures in order to ascertain that the pumps operate correctly in conjunction with the other reactor structures.

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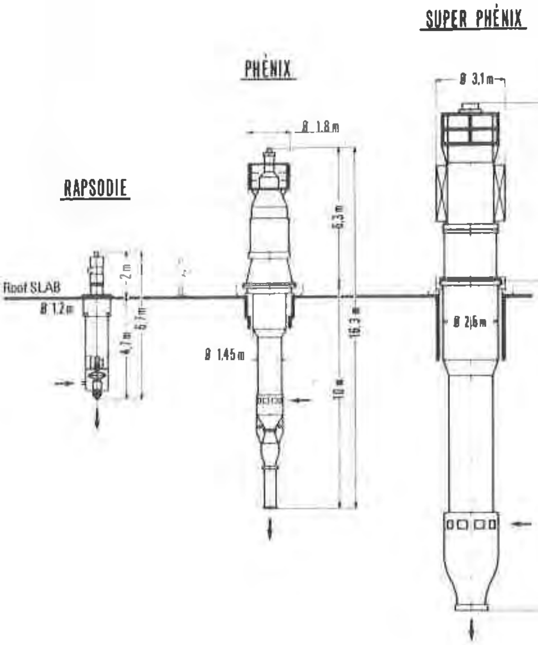
   Dispositif de liaison d'un appareil dans un système possédant des structures soumises à des mouvements relatifs.

FIGURE 1



PRIMARY PUMPS

FIGURE 2

REACTOR BLOCK

bloc réacteur

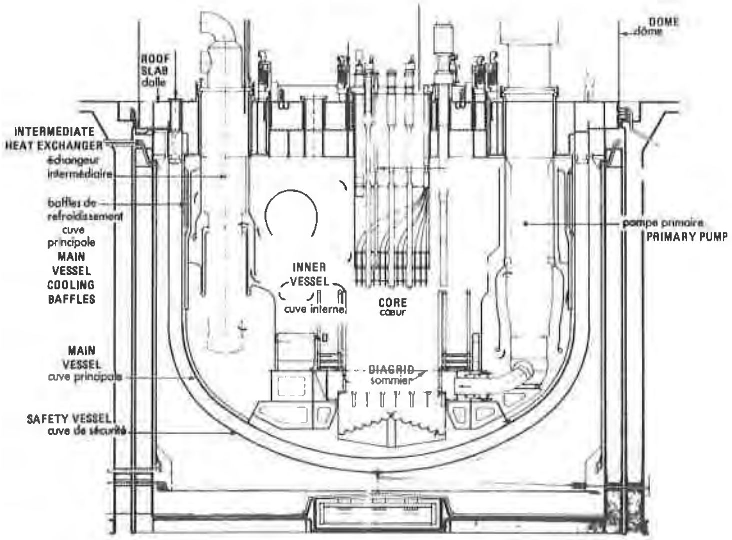
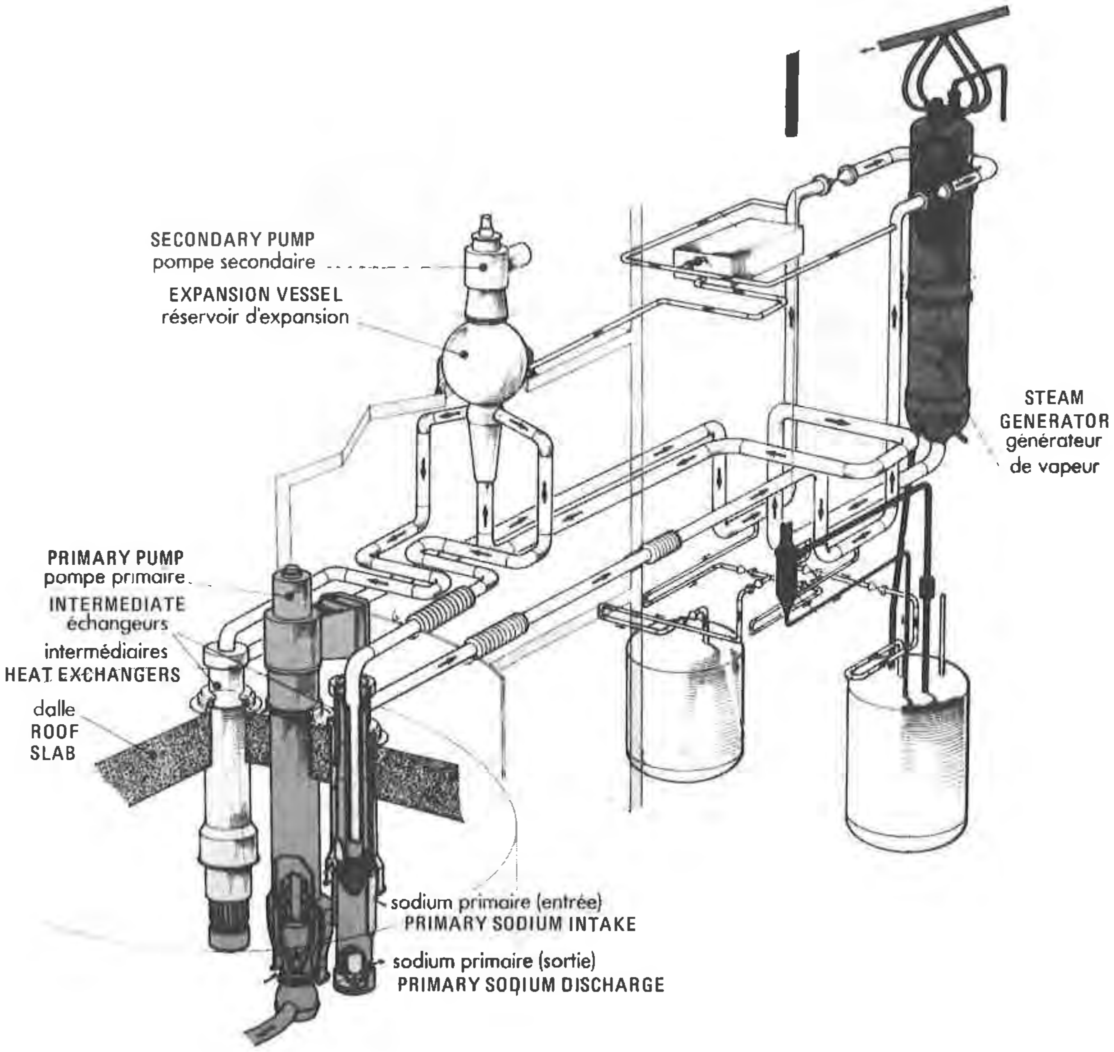


FIGURE 3

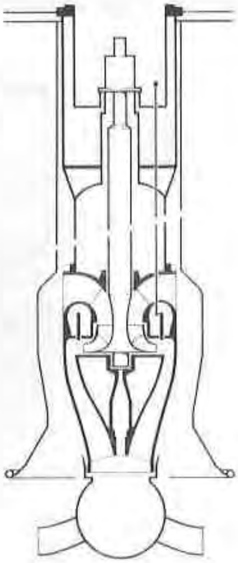
SECONDARY HEAT TRANSPORT LOOP

circuits secondaires principaux

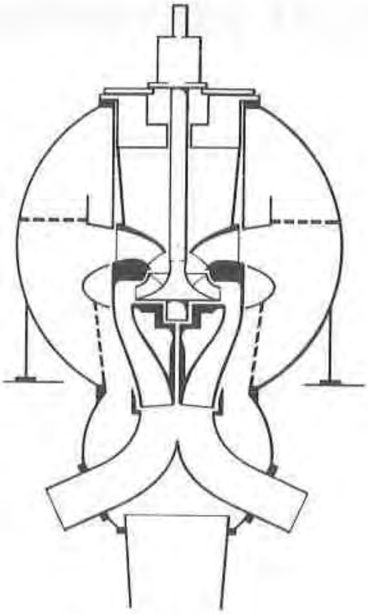


SUPER - PHENIX

FIGURE 4

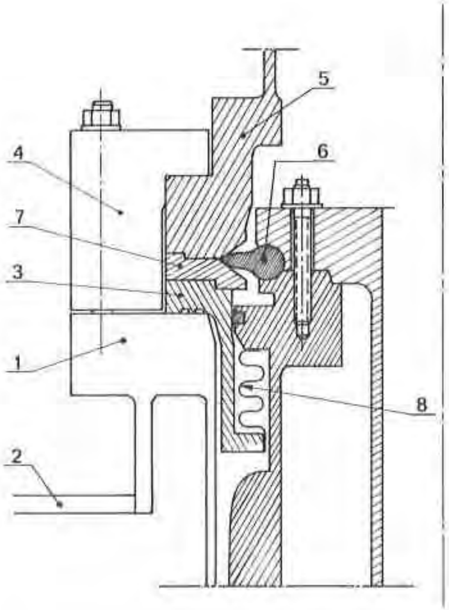


Primary pump
Pompe primaire



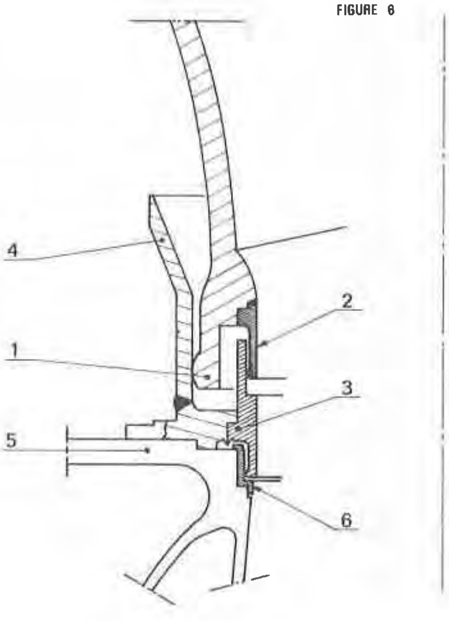
Secondary pump
Pompe secondaire

FIGURE 5



Apper Connection
Liaison supérieure
SUPER-PHENIX

FIGURE 6



Lower Connection
Liaison inférieure
SUPER-PHENIX

HISPANO-SUIZA
Division de la SNECMA

Figure 7

CARACTERISTIQUES APPROXIMATIVES DES POMPES A SODIUM

Année	Destination	Q m3/h	Hm	Ntr/mn	P kW	Temp. nominale °C	Masse T	Hauteur m	Ø m	Lieu d'utilisation	Qté
1959	Essai générateurs de vapeur sodium eau	120	40	1 400	30	600	0,25	1,6	0,34	Grand Quevilly	1
1961	Expérimentations diverses	350	20	900	50	550	6,5	5,60	0,85	CEA CADARACHE	1
1961	Expérimentations diverses	480	20	950	55	550	2,2	3,10	0,85	CEA CADARACHE	1
1965	P.P réacteur RAPSODIE	380	32	1 100	54	540	6	5,5	0,8	CEA CADARACHE	3
1965	P.S réacteur RAPSODIE	380	18	875	54	540	1,8	4	0,8	CEA CADARACHE	3
1967	EDF boucle d'essais de matériaux	36	13	2 600	5	780	0,17	1,1	0,25	EDF Centre des Renardières	1
1967	EDF boucle d'essais d'équipements	12	40	3 200	6	780	0,17	1,1	0,25	EDF Centre des Renardières	1
1966	Boucle d'essais d'échanges thermiques	45	63	3 000	20	650	0,36	1,8	0,35	Chatou	1
1967	Boucle d'essais d'échanges thermiques (SAEB)	30	30	3 000	6	600	0,25	1,10	0,25	Pélindaba (Afrique du Sud)	1
1968	Boucle d'essais réaction sodium eau INTERATOM	120	75	3 000	40	550	0,35	1,80	0,35	Bensberg (West Germany)	1
1969	P.P pour réacteur RAPSODIE version FORTISSIMO	640	54	1 380	120	540	6,5	5,5	0,8	CADARACHE	3
1969	P.S pour réacteur RAPSODIE version FORTISSIMO	650	34	1 200	54	540	1,8	4	0,8	CADARACHE	3
1971	CNEN Boucle d'essais ESPRESSO (*)	120	120	3 000	65	650	0,25	1,8	0,35	Brasimone (Italie)	1
1971	P.P pour réacteur PHENIX	4 250	76	1 000	1 200	540	20	10	1,2	Marcoule	4
1971	P.S pour réacteur PHENIX	3 200	65	1 000	700	420	8	5,5	1,2	Marcoule	3
1974	P. pour circuit expérimental d'endurance CEDI (*)	320	175	3 000	170	600	0,35	2,5	0,5	Brasimone (Italie)	1
1975	CPC1 pompe d'essai pour réacteur PEC (*)	35	150	2 100	60	600	0,8	3,40	0,6	Brasimone (Italie)	2
En étude	P.P réacteur SUPER-PHENIX	18 000	75	500	4 000	400	120	14	2,5	Creys Malville	5
En étude	P.S réacteur SUPER-PHENIX	14 000	32	600	1 200	350	35	6	2	Creys Malville	4
En étude	P.P réacteur PEC (*)	1 300	65							Brasimone (Italie)	2
En étude	P.S réacteur PEC (*)	1 300	18							Brasimone (Italie)	2
En étude	Pompes de canaux réacteur PEC (*)	35	150							Brasimone (Italie)	2
1977	Pompe de circulation Pivoterie en sodium (*)	500	70	1 600	170	450	1,8	4	0,8	Brasimone (Italie)	1
1977	FBTR P.P	650	57	1 400	150	400	6,5	5,5	0,8	(Inde) Kalpakkam	3
1977	FBTR P.S	375	32	1 000	50	300	1,8	4	0,8	(Inde) Kalpakkam	3

(*) En coopération avec FIAT - ITALIE -