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REACTOR BLOCK AND FUEL HANDLING

(Bloc reacteur et manutention)

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SUMMARY

Preliminary studies of the reactor block and fuel handling of a high power reactor lead to the comparison of different designs leading to a choice using technological knowledge acquired with Rapsodie and Phenix.

Since then, studies have been done concerning the following decisions: the number of pumps and heat exchangers, number and function of vessels, upper closures, and transfer and discharge systems. Several designs for integrated primary circuits have also been developed.

After these studies, an adequate number of elements were touched upon in order to recommend a system with: four pumps and eight heat exchangers, a major vessel lined with a security vessel, upper closures comprised of low heat insulation which is completed by a transfer system with three rotating plugs, and the discharge crossing the base. The results of studies of the design of the primary circuit allow mainly for the choice of a solution of a low step relay or a siphon pump. The choice cannot be made, since additional studies are necessary.

In addition, the adoption for Super Phenix of 1200 MWe power and the decrease of core Δt of about $20^{o}C$, which may not be considered, since preliminary studies indicate a strong increase in primary flow, so pump dimensions require new designs with a wider selection.

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I. REACTOR BLOCK

A. Design of the Primary Circuit

Two primary circuit designs have been examined: the Phenix type (separated pumps and heat exchangers, internal vessel) and the type with pump-heat exchanger systems and no internal vessel (figure 1).

The type with no internal vessel has two styles: the first, with internal structures greatly reduced with a possible gain in the price of the reactor block; the other, the possibility of facilitating the extrapolation of higher power, since the size of each pump is smaller than in those with an internal vessel and the ring-shaped heat exchangers present fewer problems with thermal asymmetry or discharge.

However, a certain number of difficulties have shown up. In effect, this design is characterized by the absence of any cold collector. Thus, the sodium contained in the main vessel will be, essentially, at the termperature of the core outlet (520 - 530°C). The cool sodium flow necessary for the thermal protection of the main vessel, which may not exceed 500°C, will be restored in hot sodium, and will reduce the temperature sensitivity and therefore the performances of the power plant.

The pump-exchanger system design does not allow for supplying the pumps with non-relay rectifiers. Any stopping of a primary pump therefore causes a cold shock on the heat exchanger. Any stopping of a secondary pump is followed by a significant cold shock to the framework and the corresponding primary pump. Since the cold collector is no longer present, there is very little absorption of these shocks. Furthermore, from the aspect of the general safety of the installation, the absence of any significant amount of cold sodium is not favorable.

Studies undertaken regarding this design have indicated neither a substantial economic gain, nor a technological advance. It has, therefore, been rejected because of the diverse possibilities offered by the internal vessel, for which there is the benefit of technological continuity.

B. General Arrangement and Number of Components

The design may be such that the core is approximately centered on the axis of the main vessel, or that the core is completely off-center. This last design, which does not permit the use of two pumps and four exchangers but which evidently causes an increase in component size and asymmetry of charge and temperature, has been abandoned. On the other hand, an equal number of secondary loops, which are identical and symmetrically located, are necessary. Also, taking flow into account, four pumps are needed so that the extrapolation factor is not too significant. It has been held to, therefore, leading to a smaller vessel diameter and smaller extrapolation factor, meanwhile keeping a good symmetry (Figure 2). The upper arrangement is conditioned by the maintenance of the sodium level of the handling assembly, by the non-pitting of the exchanger apertures, and by the aspect of the NPSH of the pumps.

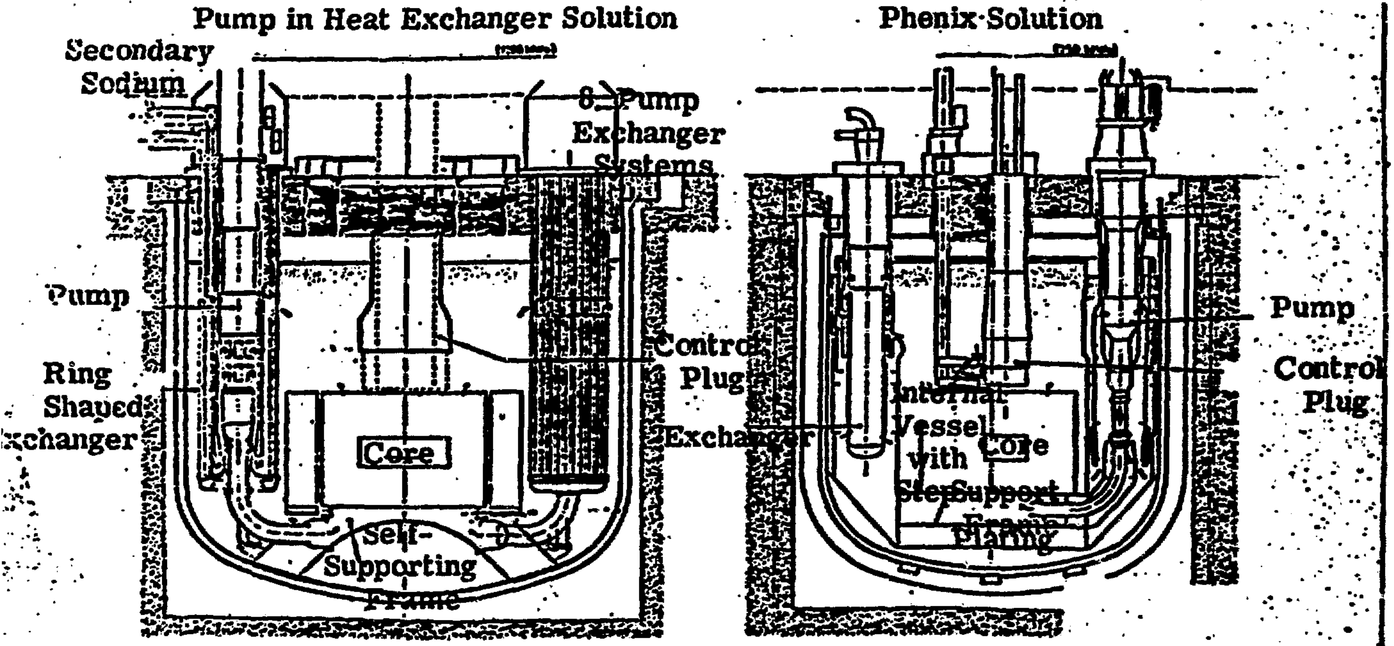


Fig. 1.- Comparison of Position of the Sodium Pump in a 1200 MW Reactor and in Phenix

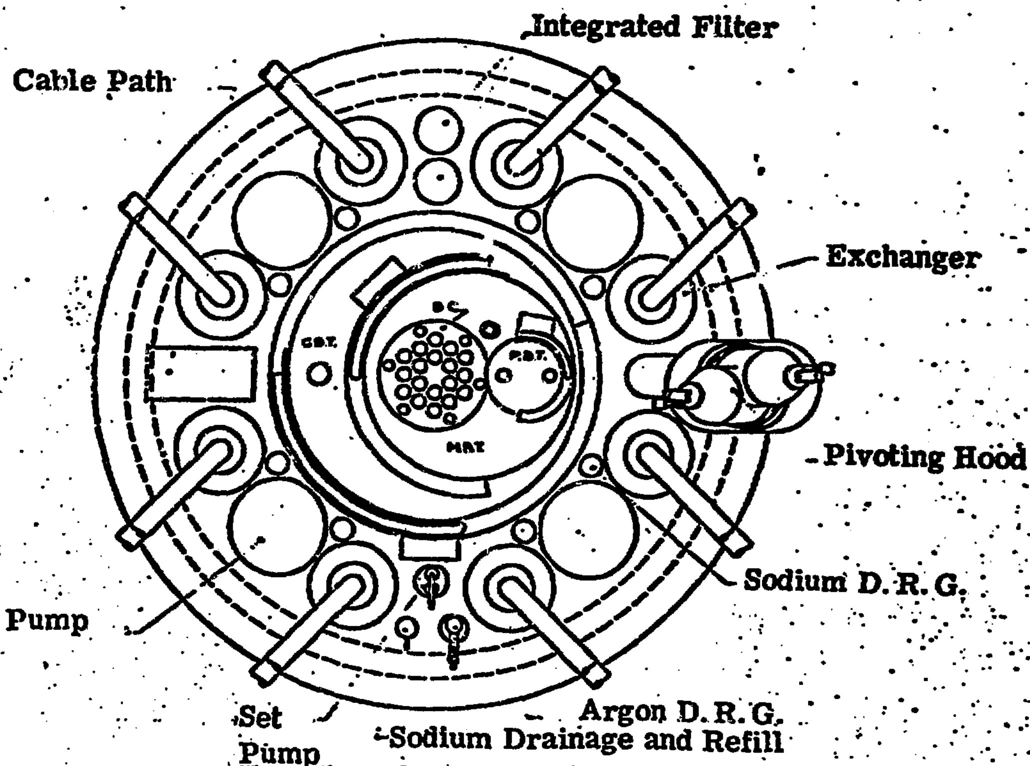


Fig. 2.- Top View Showing the Arrangement of 4 pumps and 8 Exchangers

C. Roof and Upper Closures

Whereas, for most other sections of the reactor block, the extrapolation of options taken for Phenix may be used in order to assure technological continuity, it is almost mandatory to find other solutions for the "roof" of the reactor studied.

In effect, the roof of the Phenix, which is flat and dense, embedded at its extremity to the junction of the main vessel, has a high temperature, about 525 °C, at nominal power, in addition to its sensitivity to variations in pressure in the argon top layer and the nitrogen in the primary confinement, which poses problems in respect to mechanical holding. This creates a surpassing of allowable constraints, especially on the main vessel, in transition operations, especially startup, and necessitates an electrical reheating system to decrease it. Regarding the functions demanded from this structure, the solution used for Phenix is difficult to extrapolate, and other answers must be researched quickly.

Three other solutions have therefore been examined:

- A flexible and hot roof, which has bellows, the feasibility of which has not been clearly established.

- A conical roof, cooled by a sodium flow, which also uses bellows. Hot sodium flow naturally creates a significant lowering of the temperature of the core outlet.

- A roof with a base heat insulation which eliminates these problems, but demands heat insulation in argon charged with sodium aerosols. Also, it presents the problem of connection of the main vessel to the roof-floor.

Tests and studies which have been performed have been sufficiently promising for the use of the last solution. The pumps and the exchangers are then attached to the base which are not mobile as in Phenix.

It is necessary therefore to develop a non-watertight heat insulation in order to present a good behavior with sodium. It is preferable that the thermal characteristics of this heat insulation are not a function of time.

Therefore, the design is oriented toward a metal heat insulation directly inspired by the heat insulation used in the Bugey reactor (metalisol heat insulation designed by Creusot-Loire). It consists of a stack of metallic layers separated by anti-radiation and anti-convection filters, all of it supported by resistant sheet-metal forming a non-watertight "case." The main problem created by this heat insulation is that of the penetration of sodium aerosols and vapors to the interior of the metallic layers; in the "cooled" areas, where the temperature is less than 97°C there is condensation and partial warping of the heat insulation, which increases thermal conductivity. This trapping of sodium in these areas equally depends on the capillary action presented by the heat insulation. The work in progress has as its primary objective the understanding of this phenomenon as a function of the size of the mesh of the metallic layers (which is equally significant to the convection motion between the elementary cells of the layers), and the use of protective sheet metal as a casing.

As another difficulty, the heat insulation of singular points of the floor may be mentioned such that: crossing equipment with diverse diameters, protection of the walls of the main vessel at the level of its connection with the base, etc. ... which goes against the definition of a general procedure to put this equipment into service. All these problems are presently being studied and are the object of a large amount of preliminary testing. A general verification of the behavior of this heat insulation will be performed on a large mock-up (about 8 m in diameter) representative of a portion of the base of the reactor and the "ceiling" of the reactor.

D. Sheathings and Ultimate Recourse

The confinement of primary sodium in the reactor Phenix is assured, in all cases of more serious accidents by three sheaths:

- the main vessel, for normal phases of operation;
- the double lined vessel in case of leakage on the main vessel or its open rupture;
- the lined primary vessel in case of maximum accident.

Taking experience with Phenix into consideration and in accord with safety criteria, it is hoped to assure confinement of primary sodium of 1000 MWe by way of only two sheaths. These sheaths will be:

- the main vessel
- the security vessel, seen to serve the functions of a double lined vessel (or anti-leak) and the lined primary vessel, according to the terminology of the Phenix projects.

The suppression of one sheath poses problems concerning safety and ultimate security.

The significant separation which exists between the main vessel and the security vessel causes, in the case of a rupture of the main vessel, a lowering of the sodium level. This leads to suggestions concerning inlet apertures of the exchangers being higher, but a solution with no vessels makes it possible to decrease this type of occurrence.

The idea of the implantation of an ultimate security system inside the security vessel has been rejected. In effect, in case of a significant accident, the integrity of this vessel is assured, but not its container. The circuit permits the maintenance of its temperature to a reasonable value when placed at the outside since on the inside there is no guarantee of operation after an accident. Therefore, this circuit consists of a network of tubes of water circulators, separated from the security vessel.

E. The Organization of the Primary Circuit and Core Support

The structures of the reactor block, other than the components, basically serve the function of core support, separation of hot and cool sodium, and the general capacity of sodium and argon. The structure supporting the core must also assure its accurate positioning, in order to eliminate the creation of insurmountable management problems during operation phases. Problems raised by these functions concern the main vessel as well as the internal vessel. Concerning these problems, the following may be cited:

- conditions of usage of structural materials;
- thermohydraulics of the internal vessel, of which analysis will furnish the elements of calculation of the internal and main vessels (use of leakage flow at the bottom of the assemblies, transmitted power of hot and cool Na, temperature variation between the two sides of the internal vessel);
- compatability with other functions to assure: handling, purification, etc....;
- mechanical holding of the internal vessel;
- mechanical holding of the main vessel;
- behavior in transition phases;
- safety;
- difficulties of fulfillment and hazards of operation.

Possible solutions have been classified into two groups:

- step solution, where the heat exchangers cross the internal vessel (Figure 3);

- cylindrical solutions, where the heat exchangers cross the independent cylinder with the internal vessel positioned on a Phenix type flat surface.

All other solutions have been eliminated, especially the Phenix type of step or cylinder with the internal vessel suspended from the base, since there was a recurrence of difficulties with Phenix because of the increased size and also because the use of the equipment led to too significant subjections.

The solution of cylinders and an internal vessel has three variations, due to the type of hydraulic joining between the internal vessel and the cylinders:

- a polished cuff, which presents delicate maintenance problems;

- argon cover, with no polished connection, but significant obstacle;

- hydraulic cuff, with problems at the operational level.

As a result of study, the step relay has been chosen as the basis of the solution. Although calculations are still necessary, this solution presents the fewest hazards or operational problems and no testing seems necessary. Among the cylinder solutions, that of the polished cuff manifests the necessity of endurance testing for long periods, and the certainty of easily providing a replacement mock-up may be abandoned. On the other hand, the solution of the argon cover and the hydraulic cuff eliminating all contact between the internal vessel and the cylinders merits a more thorough examination operation in various phases, safety, and testing of the principle.

II. FUEL HANDLING

A. Principle

The definition of fuel handling relies on three essential economic criteria, proven techniques, ease of operation:

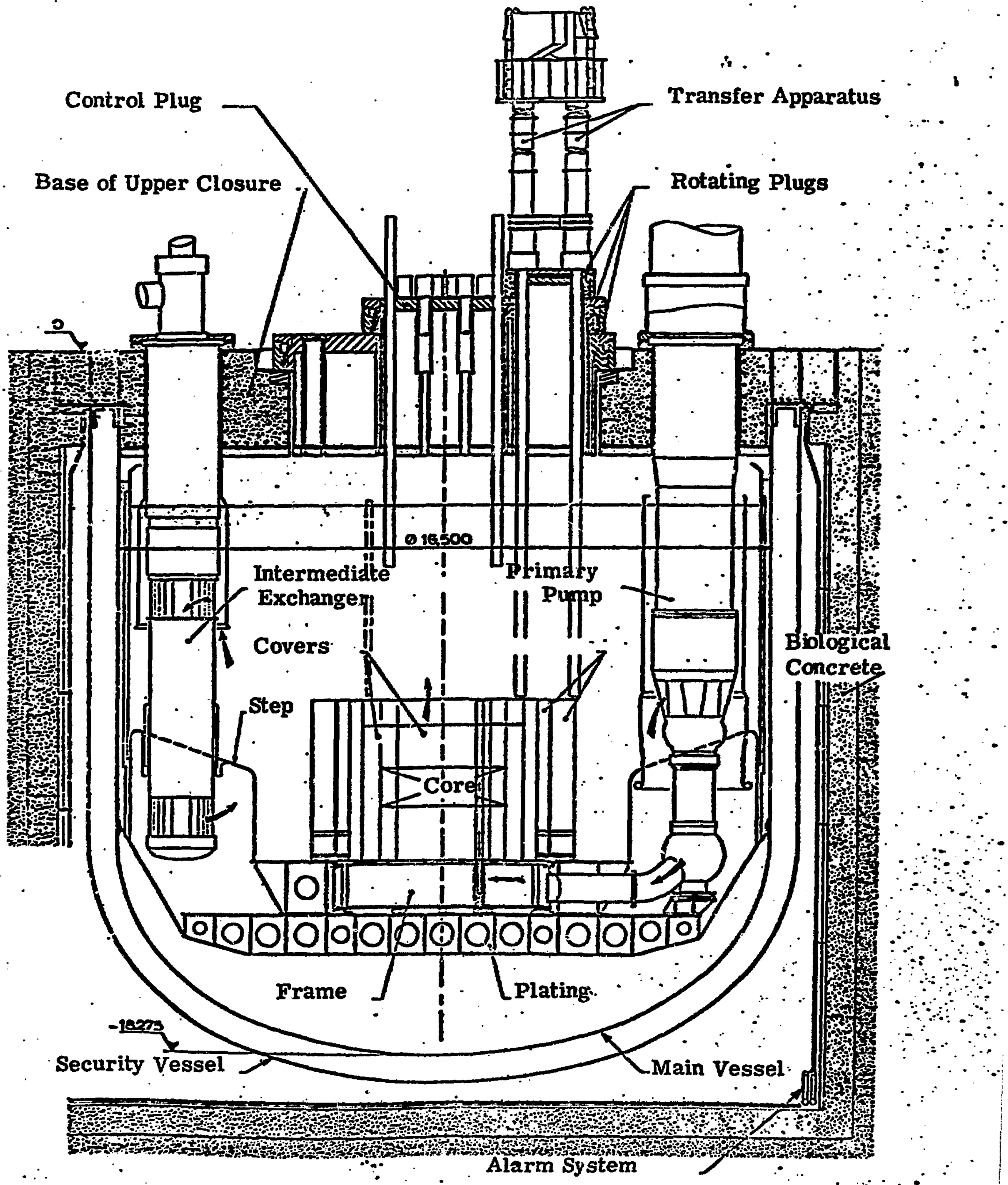
- economy of the fuel cycle, investments (not the cell for examining irradiated elements), the charge-discharge time;

- proven techniques using known technological solutions;

- ease of operation by the ability of dismantling mechanical elements.

B. Storage

Internal storage, to which the discharge in operation is attached, presents the major inconveniences of necessitating a larger diameter of the



Vertical Cross Section of the Reactor Block Step Solution

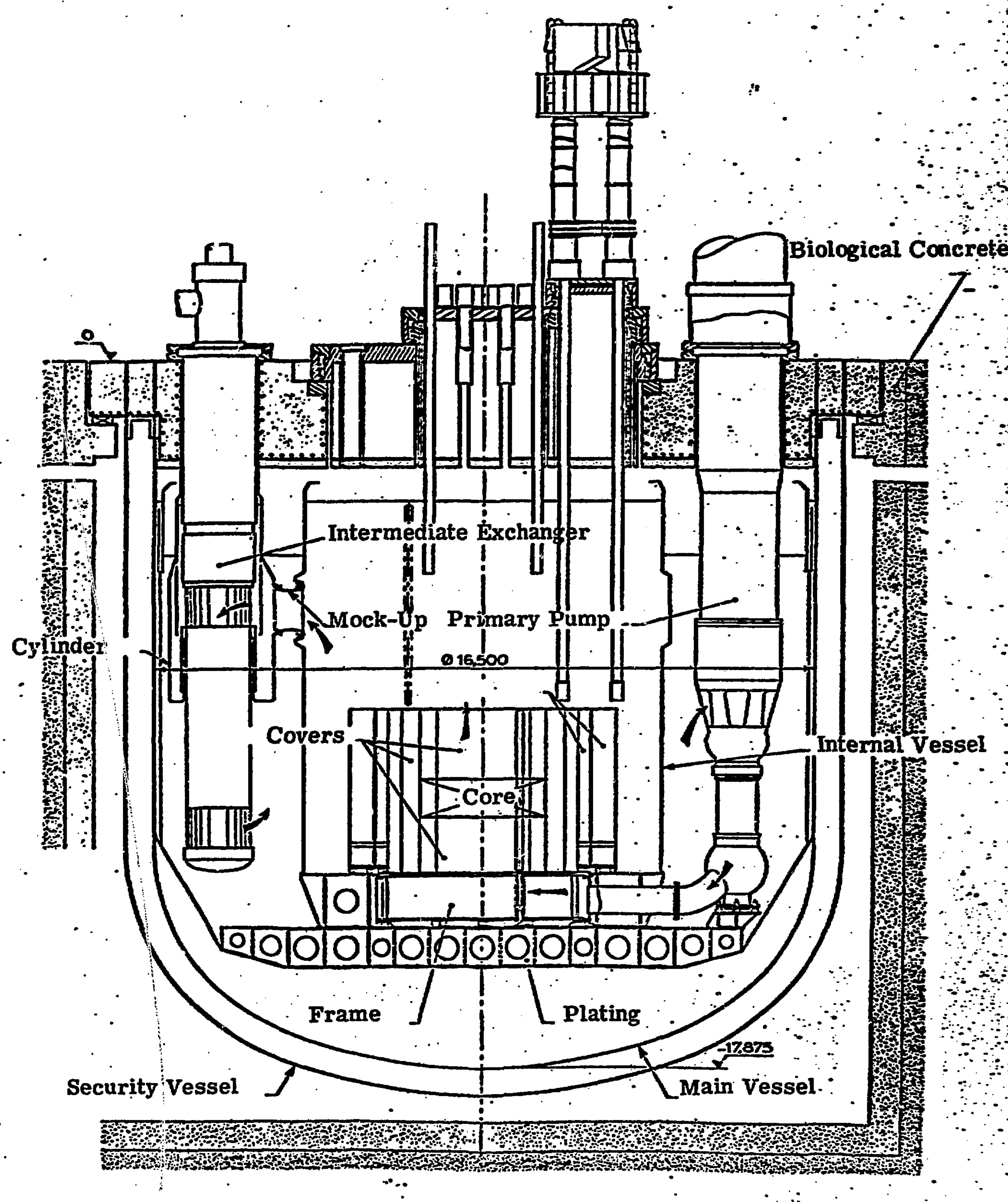


Fig. 4. Vertical Section of the Reactor Block: Solution with Mechanism Mock-Ups

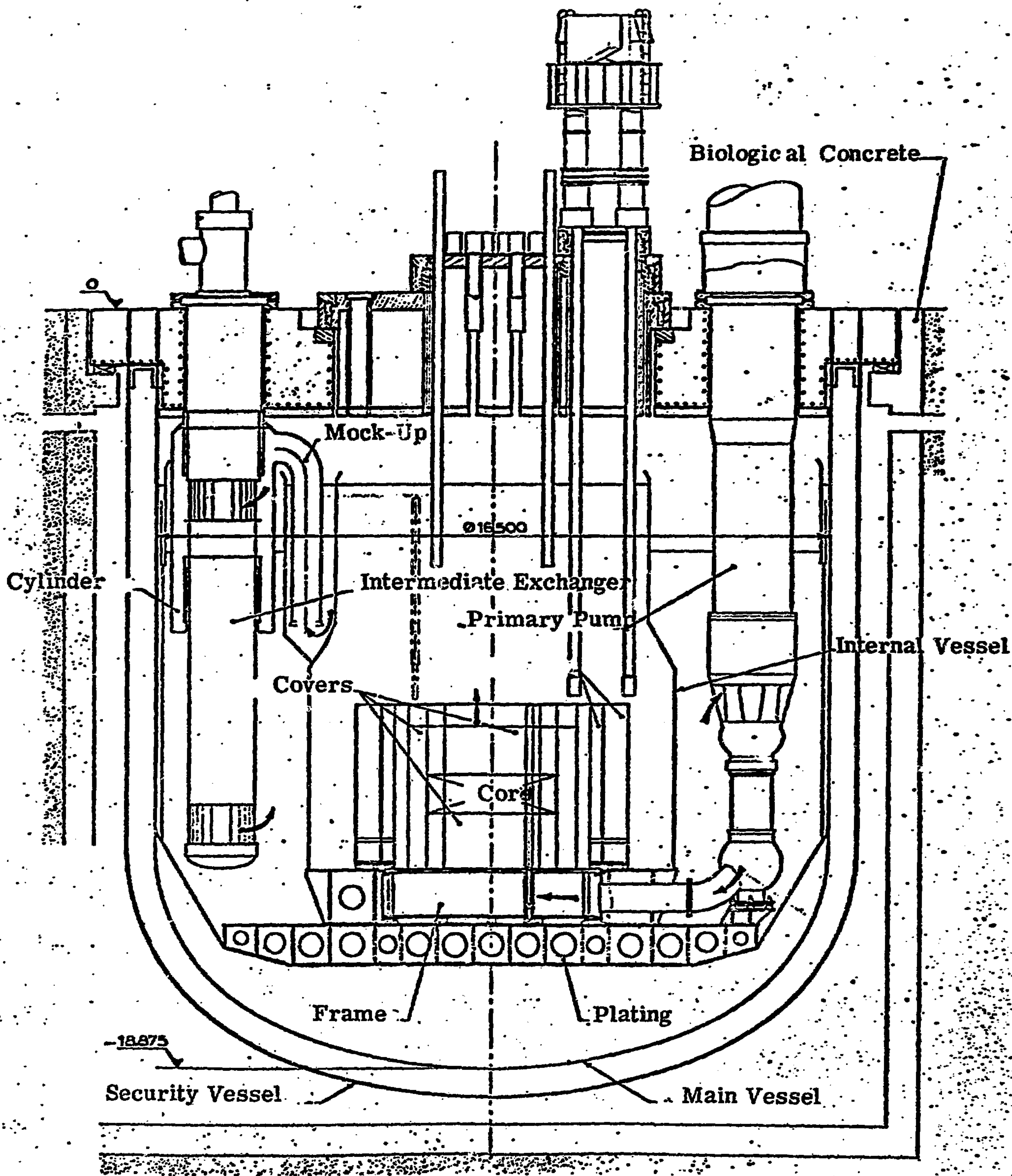


Fig. 5. - Vertical Section of the Reactor Block: Solution with Hydraulic Mock-Ups

internal vessel, an increase in the number of mechanisms in the reactor, and the opening of the primary containment while the reactor is running, which is incompatible with the presence of a dome.

External storage seems to require a higher investment and implies the ability to discharge assemblies having a residual power which is still elevated (greater than 20 KW) for the charge-discharge phase which begins 24 hours after reactor shutdown. Equipment foreseen to this effect leads to storing plain assemblies.

The technological continuity and operating security indicates strongly in favor of the study of external storage.

The storage capacity is fixed by the renewal frequency and the residual power value when the assembly is extracted. It is not opportune to foresee complete core storage, as the probability of this operation does not seem to compensate for the increased investment.

Concerning the storage method, a study of installation, ease of access and time of operation, the solution of storage in rims on a treadmill (cylinder) with manipulation by ring guards on a rotating plug is recommended.

The presence of a small internal storage (several assemblies) must also be studied in relation to the possibility of replacing an assembly when there is a failed fuel element during a simple week-end shutdown of the power plant.

The choice of external storage implies the placing of a fuel handling container able to drain residual power only a few days after reactor shutdown (about 30 KW).

Dimensions of such a container are about 6 m in length and close to 400 mm in diameter. In order to have the chance to drain this power without passing a temperature level in the assembly which is too high, the conditions of thermal exchange by the wall of the container is improved and favors a sodium circulation at the inside of the assembly. In order to do this, tests have been performed on the emission capacity of samples taken from various surfaces, having been in sodium. Successive testing has been done on samples of stainless steel which has received an appropriate surface treatment, and on samples facing radiation surfaces of various geometries.

A reduced scale prototype has been built and is presently in the course of testing.

C. Transfer

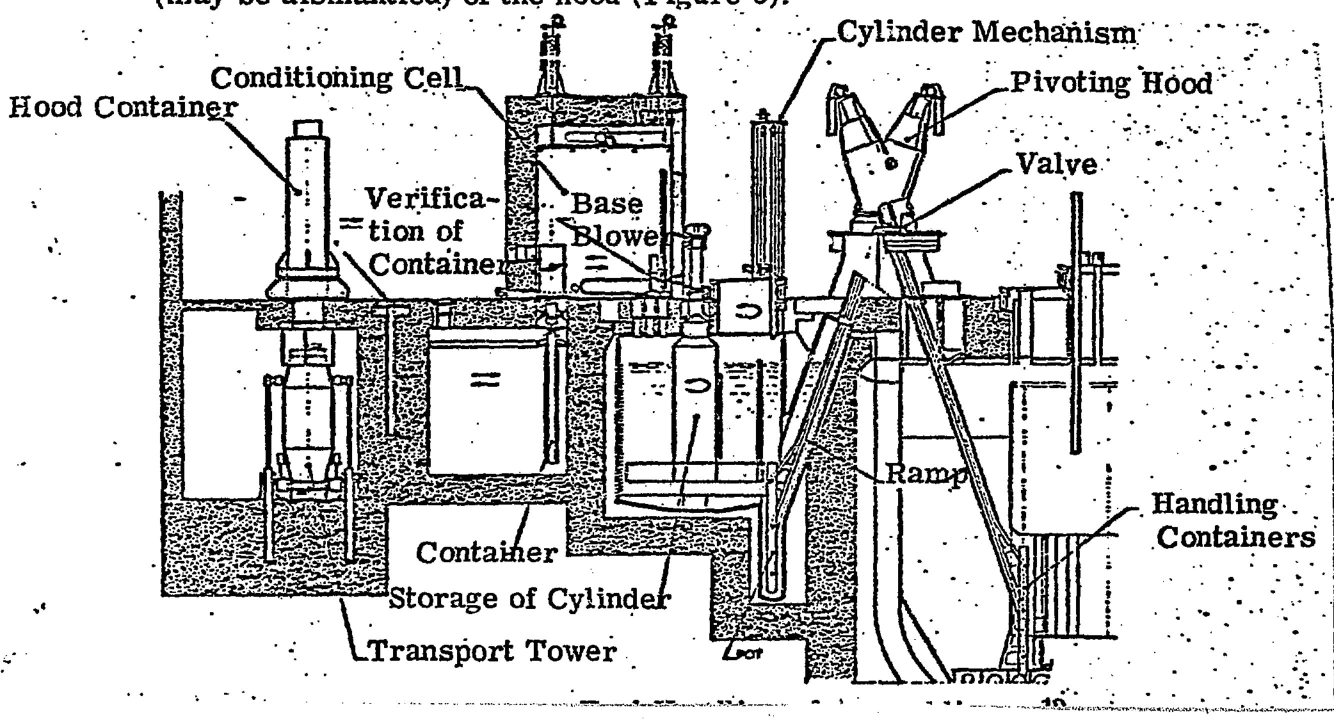
The choice of a transfer system may be made between: two rotating plugs and an arm or a poker, three rotating plugs and one or two pokers.

The susceptible efforts to be engendured between assemblies by their deformation under neutron fluxes leads to the choice of a system which permits vertical intervention with an assembly, that is, a ring guard. The comparison of fuel handling time, which is a function in particular of the placement of a discharge channel at the floor, or the plug, shows significant advantage in favor of a system with three plugs and two pokers with passage across the floor. The duration of the replacement of an assembly is about one hour.

D. Discharge

The choice of a discharge system depends, in the first place, on the placing of the discharge channel. The advantages of continuity of atmosphere and discharge of the container carrying the assembly necessitates passage across the floor. The obligation to carry out discharge operation in times concealed by transfer ratio imposes the doubling of the parts of reactor-storage connection. The corridor connections, of the Phenix sieve or hood type, present inconveniences which are averted.

In particular, the corridor is too close to one cell and does not allow a rigid command for the hook; the sieve is greatly complicated by the doubling of mechanisms and associates poorly with a dome: the hoods imply a vertical crossing of the floor, thus a ramp cut in the reactor, the addition of a rotating plate assures their intersection, which, carried to the outside of the dome, lengthens their distance. The solution adopted, by a pivoting sieve, combines the functional advantages of the sieve (continuity of atmosphere, oblique ramps) and the maintenance advantages (may be dismantled) of the hood (Figure 6).



E. Removal of Assemblies (Figure 7)

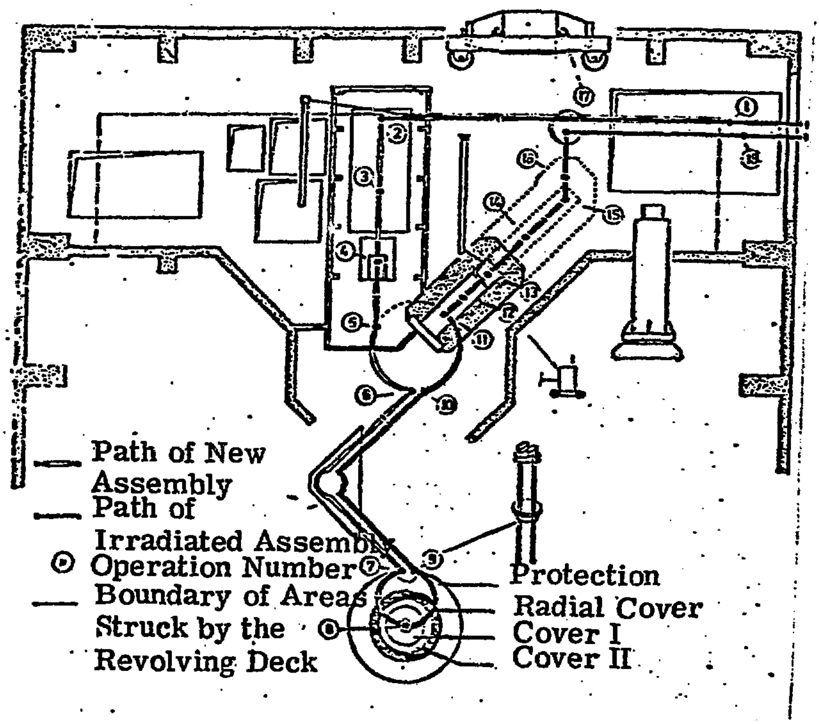
On an electricity-producing power plant, it does not seem justifiable to use washing, cutting, and detailed examination of assemblies. This choice, added to research on the reduction of the fuel cycle, therefore presents these options:

- to drain the assemblies for retreatment with a residual power of 5 kW;
- to transport them in a group (about six) in liquid metal (one assembly per sheath).

The first stage of the drainage of an assembly begins at the storage outlet and ends with the placing of a sheath with a watertight closure. In order to do this, it seems that the corridor is preferable to a hood. In effect, the corridor assures the continuity of atmosphere, seems favorable to the positioning and control of the sheath, allows general observation of the assembly, whereas the hood introduces regular contamination. In order to facilitate the sequence of storage drainage, direct access to each ring of assemblies has been chosen.

The second stage of drainage concerns the transport of the sheath containing the assembly during the positioning of the closure onto the container.

During the preliminary study stage, it seems preferable to adopt the solution which allows the most liberty to the general design of the power plant. Such is the case of the hood (only γ protection) contrary to the corridor.



No.	Premises	Function
(1)	Sieves	Taking assemblies in their transport sheaths to the deck.
(2)	Location of new assemblies	Disposal of sheaths into a receptacle.
(3)	Storage of new assemblies	Taking each element in its sheath and placing it in a storage receptacle.
(4)	Control equipment of the new assemblies	Transport of assemblies by the rotating deck. Control.
(5)	Insertion of new assemblies	Charging of the assembly by an insertion hood.
(6)	Cylinder	Transfer of the assembly from the cylinder to the ramp carriage.
(7)	Charge and discharge equipment	Taking the assembly and transferring it along the arms and rotating plugs.
(8)	Core	Irradiation after transfer of the assembly by the arms and the rotating plugs.
(9)	Charge and discharge equipment	Removal of the irradiated assembly to the ramp carriage.
(10)	Cylinder	Transfer of the irradiated assembly from the ramp carriage to the cylinder.
(11)	Outlet of the assemblies of the cylinder	Assemblies removed by the circular by a ventilating poker.
(12)	Transfer machine at the ventilating base	Transfer of assemblies to be placed in the transport container.
(13)	Setting the sodium level and plugging the containers	Setting the assembly in the transfer container by the ventilating poker. Setting the sodium level and plugging the container.
(14)	Transfer path of containers	Transfer of the containers by carriage for the hood.
(15)	Outlet path for container transfer	Taking of the containers by the hood.

(16)	Control equipment	Transfer of containers by hood control.
(17)	Charging equipment for transfer area	Transfer of containers by the hood. Positioning in the transfer area.
(18)	Sieves	Charging of the transfer area.

F. Charging of New Assemblies

For new assemblies, which arrive by groups to the power plant, the choice must be made between special storage and the direction introduction into storage of irradiated elements. The non-contamination of new assemblies have their insertion into the reactor excluding the possibility of a prolonged stay of these assemblies close to those which are irradiated. This determines the choice of special storage for new assemblies.

The reactor discharge system leads to the idea of the insertion of new assemblies in the fuel handling sequence at the level of storage of irradiated assemblies. For this insertion, the use of a hood seems to be the most convenient.

III. CONCLUSION

This article has set forth the numerous solutions being examined during the preliminary study phase of the 1200 MWe project. The choices described result in part from safety criteria or economic criteria and mainly from experience gained from the operation of Rapsodie and the construction of Phenix. These choices are not definitive and they depend greatly on the evolution of studies and testing which will be undertaken during the phase of establishing the plans of a high power reactor.