Some special operating experiences in the French LMFBR Phenix from 1982 to 1986

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ABSTRACT

From 1982 to 1986, the load factor of the French LMFBR Phenix was good (61,48 %) especially for a demonstration prototype plant. However during these five years some special operating experiences were necessary. This paper gives an analysis of the most significant experiences and explains how it was possible to operate with all the necessary safety for the structures and components.

INTRODUCTION

Phenix is the first industrial French fast breeder reactor. It is a prototype of 563 thermal MW and 250 electrical MW, that was brought into industrial operation on July 14/1974 Fom this date to the end of 1986, the load factor was 60,27 %.

MAIN OPERATING PARAMETERS

Phenix is a pool-type reactor. This pool design includes a primary vessel 12 meters diameter and 10 meters high, known as the reactor block, containing the entire primary system : core, primary pumps, heat exchangers, etc...

In nominal operation the core is cooled by liquid sodium with inlet and outlet temperatures of 400 and 560° C. Three primary pumps ensure the primary sodium circulation with a nominal speed of 820 rd.min. The hot sodium is then cooled through six heat exchangers by the sodium of the secundary loops. There are three secundary loops, with for each loop - one secundary pump, two heat - exchangers and one steam - generator. The nominal speed of the secundary pumps is 800 rd/min. The thermal power is then conveyed by the three steam - generators to the classical part of the plant.

SPECIAL DESCRIPTION OF THE HEAT - EXCHANGERS

We will see later that the difficulties in the special - operating experiences are especially due to the thermohydraulic problems in the heat exchangers. So these components need a special description of their conception and configuration. The figure 2 gives a view of this component. He is hanged under the roaf-slab and connects the hot and clod plena inside the pool through the internal vessel. The secundary sodium enters at the top of the component and flows downwards through a central downcomer. At the lower part of the heat exchanger the secundary sodium flow is reversed upwards through the tubes fixed between two tube - plates. Then it is collected above the upper tube - plate in an annular chamber, surrounding the central downcomer and leaves the exchanger through a lateral outlet - nozzle. For the primary sodium an aspiration skirt is surrounding an inlet window and, a lower part of the component, the primary sodium emerges directly in the cold plenum through the inlet window. An annular space, filled with argon, separates the cold secundary sodium of the central downcomer and the circulation of hot sodium.

After the sodium leaks in 1976, modifications were made on all the heat-exchangers in 1976, 1977 and 1978 [réf. 1 and 2] the main reason of this problems was that the hydraulic circulation of the primary sodium was not uniform in the bundle and was bigger, in the bundle, near the external shell that near the annular space. So there were differencies of temperature of the secundary sodium outside of the upper tube-plate. These differencies remain in the vertical circulation and between the internal and external shells. So the stress were too important, on the uper welds of the colder internal shell [ref. 2] and sodium leaks appear at this place.

So, even with the new modifications on the heat exchangers, the ratio primary/secundary sodium flows remains a very important and sensible parameter for the utilisation of these components. For exemple it appears that variations of primary or secundary flow rate of five per cent, give variations of the T of secundary sodium above the upper plate, of more than twenty per cent. A decreasing of the primary sodium flow-rate of only three per cent, increases the stress on the weld of the internal shell of more than ten per cent.

So it appears that even a few per cent variations could give a big increase of the stress and the cumulated damage on the heat-exchangers.

OPERATION RESULTS FROM 1982 TO 1986

The figure n° 1 gives the main operating results of the plant between 1982 to 1986.

The more important events are the following.

1982 : First reaction sodium/water on april 29 th. Second reaction on décember 17 th. Long operations at two/third of the power. Load factor of 49,45 % [réf. 1].

1983 : Third and fourst reactions sodium/water End of the reparations of the steam-generators. Load facto of 55,64 % [réf. 1]

1984 : A sodium leak in the annular space appeared on the heat - exchanger n° 31, that was replaced in june and jully. But the new heat - exchanger shows also a leak in his annular space in december. A special operating experience is made in this situation. The load factor is 70,07 %.

1985 : We hod to change this exchanger, but we have no spare component. So we operate a long time at two/third of power with two "false exchangers" (two special components that only isolate the cold and hot sodium in the primary vessel) A special test was made in this situation with only two primary pumps operating. The load factor was 57,21 %.

1986: A leak of sodium on the steam generator n° 1 in june, imposed an operation at two/third of nominal power with two heat - exchangers obturated. The load factor was 75,05 %.

To resume these five years of plant operatings it appears that four operating experiences seem especially interesting to discuss.

. The definition of the operating parameters of the plant in 1982 with two heat exchangers obturated.
. The special operating experiences in 1984 with a leak of sodium on an heat - exchanger.
. The definition of the operating parameters in 1985 with two "false exchangers".
. The special test of operation with two secundary loops and two primary pumps in 1985.

DEFINITION OF THE OPERATING PARAMETERS IN 1982 WITH TWO HEAT - EXCHANGERS OBTURATED

The main problem in this case is to avoid big stresses on the heat exchangers due to a bad ratio of the primary/secundary sodium flows. Indeed a part of the primary flow is going under the obturators of the two heat exchangers of the secundary loop out of order. Then, if the level of the hot sodium is too high, it is also possible to have another circulation of primary sodium above these obturators.

At this date it was possible to measure the levels of hot and cold sodium and, with special thermocouples the T sodium above the upper plate. But the measurement of the flow rate is made on the primary pumps and doesn't permit to discriminate the flows of sodium circulating in the four heat exchangers in operation and in the two heat exchangers obturated.

With all these measurements, a special test was made to determinate the optimal parameters. In first the pumps speed was increased at the maximal level authorised for the primary pumps (540 rd/min) and at 800 rd/min for the secundary pumps. The T core was of 150° C. In second we increased the core T two degrees by two degrees until 170° C. The results are shown in the annexe I . It's clear that the level of the hot sodium is increasing with the core T. When the core T is bigger than 164° C, it appears the first signs that the sodium beginns to flow above the obturators :

- The hydraulic head loss in the heat exchangers in operation is decreasing (calculated with the levels of sodium).
- The secundary sodium differencies of temperature above the upper - plate increases and reaches 19 and 20° C.
- The difference of temperature inlet/outlet of one of the obturated heat - exchanger, that was bigger than 50° C reaches 40° C, then 30° C and then 15° C. This value is the most sensible due to increasing of the sodium flow - rate through the obturated component.

In third we choosed the definitive parameters : we came back to the last value of core T without flow of sodium above the obturators : 164° C and we decreased the secundary pumps speed to 790 rd/min, to decrease the sodium T above the upper - plate.

SPECIAL OPERATING EXPERIENCE IN 1984 WITH A LEAK OF SODIUM ON AN HEAT EXCHANGER

When a leak of sodium appeared on the heat exchanger 31 in june 1981, it was soon replaced by the heat exchanger F. But another leak of sodium appeared on this heat - exchanger F in december. In this case no replacement unit was disponible and we tried with the measurements in place to continue the operations at nominal power.

The leak of secundary sodium was inside the annular space of the heat exchanger and was seen in first by a leak detector (spark - plug) inside a guide tube. We deposed the spark - plug and used the guide tube to send argon bubles inside the sodium of the leak. With a differential pressure measurement it was then possible to know the level of sodium inside the annular space with a precision of one millimeter. When the level of sodium reached a too high value, this sodium was drained with the same guide - tube. The figure 3 gives à view of all the measurements and possibilities used during this time. In order to minimise the leak we took the maximal level authorised of argon pressure inside the annular space and we decreased the secundary pump speed to operate at reduced secundary sodium pressure. However, the draining became too frequent.

The figure 4 shows the evolutions of the cumulated level of leak - sodium and of the draining frequency. It was clear that the leak was in evolution and then we decided to stop the plant at the end of december.

DEFINITION OF THE OPERATING PARAMETERS IN 1985 WITH TWO "FALSE HEAT - EXCHANGERS"

In this case all the primary sodium in circulation is going through the four heat - exchangers in operation. Therefore the hydraulic head loss in the operating heat - exchangers (estimated with the level measurements) showed that there was a primary flow in the heat - exchangers lower than during nominal operations.

It was due to three reasons :

- The speed of the primary pumps is not exactly at two/third of the nominal speed (540 and not 547 rd/min).
- The hydraulic head - loss of the core is not exactly proportional to the square of the flow (P = aQ with = 1,9). So the flow - rate is a little lower than two/third of the nominal flow.
- The hydraulic head - loss of the heat - exchangers in operation remains the same as at nominal power. Even if this head
- Loss is very less important than in the core it is another reason to have a lower global nominal flow.

So, to respect the nominal ratio secundary/primary sodium flows, we started the operations with the speed of the primary pumps at 540 rd/min and the speed of the secundary pumps at 760 tr/min.

Then a special test was made to determinate the optimal parameters that were : 565 and 800 rd/min. In those new conditions it was possible to produce several MW more. An authorisation was asked, with the results of this test, to increase the rotation speed of the primary pumps from 540 to 565 rd/min.

SPECIAL TEST WITH TWO SECUNDARY LOOPS AND TWO PRIMARY PUMPS IN OPERATION

In august 85, during the operation at two/third of power, with the loop 3 stopped, we made a special test.

We stopped the secundary pump n° 2 and increased the speed of the two others pumps to 640 rd/min, to maintain the primary flow rate in the core. The final state was two primary pumps at 640 rd/min (maximal value without cavitation) and two secundary pumps at 760 rd/min, with an electrical power only six MW lower.

All the measurements were made in this state to be sure that there was no hydraulic difficulties and no thermal - dissymetries on the vessel : after all these verifications we came back to the initial state.

The target of this test was to demonstrate the possibilities of operation of a pool type LMFBR with one secundary loop and one primary pump together out of order.

CONCLUSION

This paper explains briefly the operation results of the Phenix plant from 1982 to 1986. it is shown how through any measurements (thermocouples, sodium level gauges, spark-plug with tube-guide, etc...) it was possible to operate a fast breeder reactor in various situations, with all necessary safety. In all cases it bas been possible to measure the hydraulic situation of the plant by tests and to obtain an estimate of the mechanical consequences on the structures and the components. This experience demonstrates also all the operation - possibilities of a pool - type reactor.

REFERENCES

Réf. 1 : MM. GELEE, GUIDEZ, MOREAU
"Safety related aspects of Phenix nuclear plant after ten years of industrial operation"
Knoxville 1985

Réf. 2 : MM. GUIDEZ, MARCELLIN
"Hydrothermic behaviour of intermediate heat - exchangers in a pool - type fast breeder reactor"
OXFORD April 1984

ANNEXE I - MAIN RESULTS OF THE TEST IN 1982

PRIMARY PUMPS SPEED rd/min	SECUNDARY PUMPS SPEED rd/min	CORE T °C	HOT SODIUM LEVEL (mm)	T SECUNDARY SODIUM ABOVE THE UPPER PLATE °C	T INLET/OUTLET EI 21 °C	H HYDRAULIC HEAD-LOSS OF THE HEAT EXCHANGERS mm
540	800	152	2 015	13/17	54/59	734/745
540	800	154	2 016	14/18	55/59	728/741
540	800	156	2017/2019	14/18	59	724/742
540	800	158	2 023	14/18	58/60	730/741
540	800	160	2026/2027	14/18	58/62	731/744
540	800	162	2 028	15/18	58/62	727/742
540	800	164	2 034	16/18	52/58	730/740
540	800	166	2036/2037	14/19	43/52	727/738
540	800	168	2040/2042	15/19	28/32	715/735
540	800	170	2 047	16/20	12/15	714/722
540	790	164	2 039	14/18	48/50	742/759

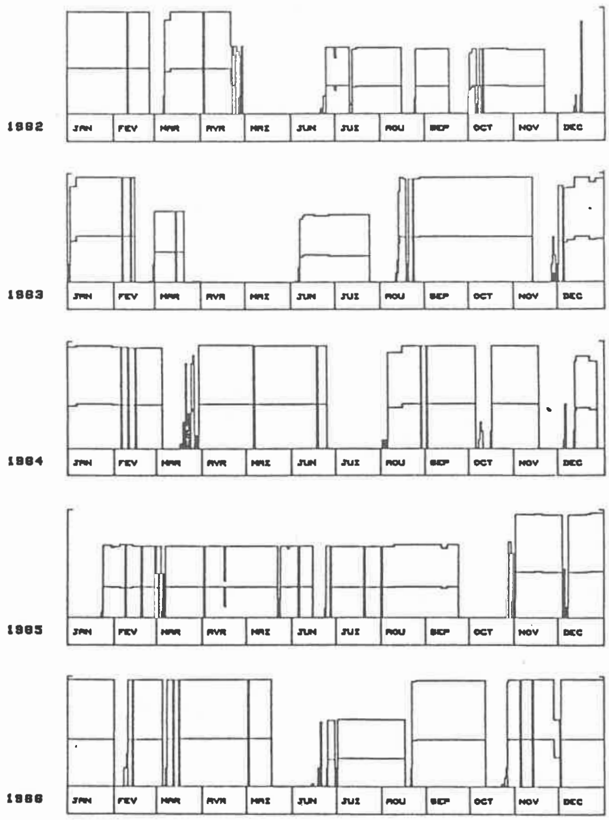

Figure N°1 - MAIN OPERATING RESULTS OF THE PLANT FROM (1982 to 1986)

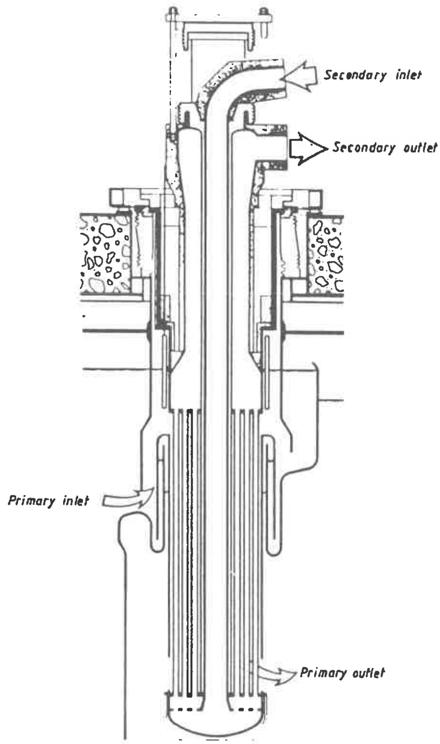

Figure N°2 - **DIAGRAM OF AN INTERMEDIATE EXCHANGER**

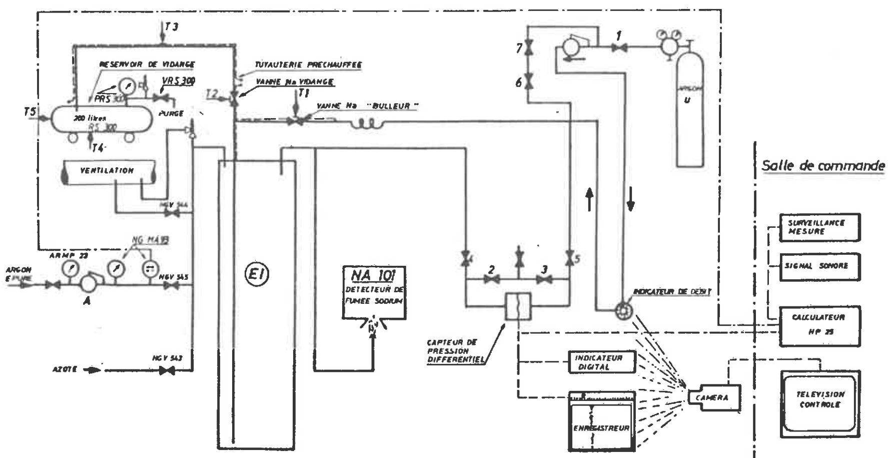

Figure N°3 - **ANNULAR SPACE MEASUREMENT USED TO SURVEY THE LEAK AND DRAIN THE SODIUM (Decembre 84)**

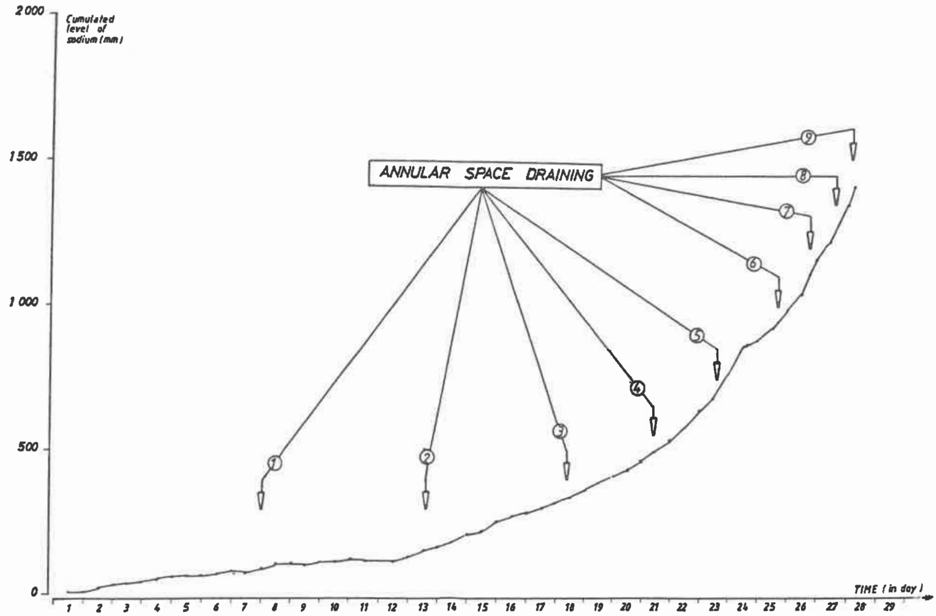

Figure N°4 - CUMULATED LEVEL EVOLUTION OF LEAK SODIUM IN THE ANNULAR SPACE OF THE HEAT EXCHANGER.