The irradiation test program for transmutation in the French Phenix fast reactor

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Abstract *– Put on commercial operation in July 1974, the French fast reactor PHENIX reached a 100 000 hours operation time in september 2003. When the French law relative to long lived radioactive waste management was promulgated on December 1991, priority was given to PHENIX to be run as a research reactor and to carry on a wide irradiation program dedicated to study transmutation of minor actinides and long-lived fission products. After a major renovation program required to extend the reactor lifetime, Phenix power buildup took place in 2003. Experimental irradiations have been loaded in the core, involving components for heterogeneous and homogeneous transmutation modes, americium targets, technecium 99 metal pins and isolated isotopes for integral cross-sections measurements. Associated post–irradiated examination programs are already underway or planned. With new experiments to be loaded in the core in 2006 the PHENIX reactor remains to be a powerful tool providing an important experimental data on fast reactors and on transmutation of minor actinides and long-lived fission products, as well as it will contribute to gain further experience in the framework of the GENERATION IV International Forum.*

INTRODUCTION

Built on the Marcoule nuclear site, Phenix is a sodium fast breeder prototype reactor (FBR) which was coupled to the grid in December 1973. The objectives were to demonstrate that FBRs are safe and reliable reactors producing electricity, as a powerful tool for improving knowledge for further development on fast reactors.

Initially, Phenix plant provided a 563 MW thermal power, using sodium as a coolant. The reactor was equiped with a 250 MWe GTA. The plant operates until 1990 with a highly satisfactory load factor.

More recently, successive safety upgradings involving massive renovation work and in-depth inspections of the components and structures have been performed. In the same time, Phenix has been devoted to an R&D program for transmutation, in the framework of the French law of December, 1991.

The plant is run now at 2/3 of the initial nominal power, i.e. 142 MWe. An important research program for the transmutation is currently underway.

THE PHENIX POWER PLANT [1]

The Phenix reactor is the only breeder reactor currently in operation in Europe. The flux provided by the core is approximately 10 times greater than those reached in the other research reactors being used in Europe (Osiris, HFR, BR2, R2, HALDEN, REZ, .) and different neutron spectra conditions are possible. As a result, Phenix is a very powerful experiment tool, with unique possibilities compared to other reactors, in particular in the field of transmutation where high epithermal flux are required.

High atom displacement (dpa) rates (18 dpa per cycle) also enable research on innovative materials and fuels research programs. Today, 30 different experimental assemblies are located in the Phenix core during the 51st cycle currently underway.

In addition, within the framework of the Generation IV International Forum, fast sodium cooled reactors are one of the six reactors projects selected for NPPs future development.

EXPERIMENTAL CONDITIONS

The flux

Phenix differs from other experimental reactors by its high neutron flux, which is over 10 times greater, with a characteristic relatively hard spectrum of fast breeder reactors and higher dose rates, as shown in the following table :

Reactor	Fast flux ($n/cm^2/s$)	Dose rate
PWR	$1.3\ 10^{14}$	2 dpa/y
Research reactors (Osiris, HFR, BR2, .)	2 to 4 10^{14}	3 dpa/y
Phenix		
Fast spectrum	$4.4\ 10^{15}$	18dpa/6-month cycle
Moderated spectrum 1*	$3.6\ 10^{15}$	12 dpa/ cycle
Moderated spectrum 2*	$1.5\ 10^{15}$	4 dpa/cycle

* : depending on the carrier used

Temperatures

Phenix provides a 380 °C-530°C temperature range corresponding to the temperatures in core inlet and outlet. Although it is impossible to carry on irradiation experiments at lower temperatures, possibilities are offered to higher temperatures through technological solutions combining insulating gas layers and gamma heating, etc.

EXPERIMENTAL DEVICES

Phenix has two types of experimental devices :

Experimental sub-assemblies

These are quite similar to the Phenix core driver fuel sub-assemblies, showing slight modifications :

- structure materials (cladding, wrapper, etc.),
- fuel composition,
- geometry of rods or pellets,
- component manufacturing process, etc.

Most of these sub-assemblies are fissile, but fertile ones and control rods are also used. These devices provides characteristics for irradiation very close to real operations.

The irradiation rigs

As part of the experimental sub-assembly, the irradiation rigs generally consists of a 40 mm-diameter tube equipped with a sodium feed base and a handling head respectively to the lower and the upper end. A wide range of experimental objects can be introduced in the rigs, such as the following :

- fuel pins in various geometries,
- absorbers,
- specimens of materials for mechanical tests (traction, resilience, tenacity, fatigue, creep, etc.),
- transmutation targets, etc.

For irradiation, the rigs are placed in the central channel of special sub-assemblies called “carriers”. Various types of carriers are used, depending on the required irradiation conditions. More particularly, new carriers have been designed to provide a moderated zone around the rig, in the core or core periphery, in order to improve the transmutation performances in some experiments.

A wide range of irradiation conditions can be reached, with respect to both the neutron flux, the neutron spectrum and the temperature. In addition, as the rigs can be assembled and dismantled on site, successive periods of irradiation and following examinations are possible on the same pins.

TRANSMUTATION EXPERIMENTS [2]

Pursuing the purposes defined in articles L542-1 and following, in the Environmental Code (former law of 30 december 1991) on the management of long-lived and highly radioactive waste, transmutation is the main research objective underway at Phenix.

Incineration of Minor Actinides in heterogeneous mode : the ECRIX, CAMIX-COCHIX and MATINA experiments

The heterogeneous mode consists of irradiating an incineration target containing an isolated minor actinide.

The so-called ECRIX-B, ECRIX-H refer to the incineration of americium in heterogeneous mode in the scope of the monorecycling strategy in fast breeder reactors. Two identical experimental pins were loaded in the reactor under different irradiation conditions. Each pin consisted of a column of pellets containing fine particles of americium oxide uniformly distributed in an inert magnesia matrix. In order to increase the transmutation rate, these experiments took place inside a device providing a local moderated neutron flux. The experiments benefits from the high level of neutron flux combined with high cross sections, that made

possible to reach a 30 % fission rate and a transmutation rate over than 80 %.

Continuing the ECRIX experiments, the CAMIX-COCHIX program is relative to the behavior of optimized incineration targets. Changes involve the particle dispersion microstructure in the inert matrix and the stabilization of the americium oxide. This experiment will be irradiated under moderated spectrum in the similar conditions considered for the ECRIX-H experiment.

In parallel, the MATINA series (1, 1A, 2-3) will add other results about the irradiation of new inert matrixes and new optimized concepts of targets.

Incineration of Minor Actinides in homogeneous mode : the METAPHIX experiments

In the homogeneous mode, small quantities of Minor Actinides mixed with a driver fuel are irradiated.

The METAPHIX experiment is devoted to the transmutation of neptunium, americium, curium and rare earths in homogeneous mode. Three rigs containing three experimental pins were placed in the reactor for different periods of irradiation. This experiment differs with the use of a metallic UPuZr fuel , similar to that used in the American fast neutron reactors.

Some segments of the experimental pins also contain rare earths to provide knowledge on their influence on the fuel's behavior during irradiation.

Transmutation of long-lived fission products : the ANTICORP-1 experiment

Irradiation of fission products reduces their radiotoxicity by transmuting the radioactive elements into stable or short-lived elements.

The aim of the ANTICORP-1 experiment is to demonstrate the feasibility of transmuting Technecium 99 into stable Ruthenium 100. Three pins, each containing two ingots of technecium 99 in metallic form are irradiated under moderated flux till reaching a 25 % transmutation rate.

The basic PROFIL-R and PROFIL-M experiments :

In addition to the experiments described above, the basic PROFIL experiments aim at acquiring basic data to be used for transmutation calculations.

The PROFIL-R set up in a nearly standard fuel sub-assembly in which two experimental pins replaced the bundle pins. Each of the two experimental pins contains 55 containers filled with very small quantities of minor actinides isotopes or fission products to be studied.

With the PROFIL-M experiment, new data will be obtained, in order to complete those got through the PROFIL-R experiment. Six pins, containing similar containers than those used in PROFIL-R, will be irradiated in a slightly moderated spectrum.

Support experimentation for reactors of the future : the FUTURIX experiment

The FUTURIX experiment is linked to the studies on reactors of the future. It consists of three stages :

- The FUTURIX-FTA experiment involves fuels dedicated to incineration with high contents of minor actinides. Several types of fuels such as metallic, nitride and oxide fuels with and without uranium will be compared.

- FUTURIX/MI aims to study the behavior of inert materials intended for use in gas-cooled reactors fuel and irradiated under high temperature conditions.

- Lastly, the FUTURIX/Concept experiment is designed to investigate several different fuel concepts, for use in gas-cooled reactors.

These experiment programs come within the scope of the international collaboration between The Unites States, the European Union and Japan.

CONCLUSIONS

After more than 100 000 hours operation time, the PHENIX reactor remains to be a very powerful tool providing an important experimental data on fast reactors and on

transmutation of minor actinides and long-lived fission products, as well as it will contribute to gain further experience in the framework of the GENERATION IV International Forum.

REFERENCES

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