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THE SAFETY REASSESSMENT OF RESEARCH REACTORS IN FRANCE

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ABSTRACT

Since 1948, the first criticality year for ZOE reactor, about thirty research reactors have been built in France. They largely contribute to nuclear science development and were keystones for the French nuclear energy program. Today, the CEA operates research reactors for all the applications connected with nuclear energy, as well as for research, radionuclide production and other applications.

The Safety Reassessment of these reactors follows strict guidelines in terms of methodology, requirements and rules.

After a brief review of these operating research reactors (10 research reactors from neutron physic studies to Material Testing Reactor such as the Jules Horowitz Reactor under construction), the paper describes, as an example, the safety reassessment methodology of the MASURCA reactor.

1 INTRODUCTION

Research reactors are major research infrastructures to cope with scientific, industrial and public bodies' needs. They are costly facilities, both from the point of view of investments (up to several hundred of M€) and operation. The timeframe for managing facilities is the decade (reassessment period, construction time, …). The safety objectives for research reactors are in some way similar to industrial reactors.

These figures altogether make of particular importance the building of a comprehensive strategy for research reactors in order:

- to fulfil the permanent needs for up-to-date and high performance experimental capacities in support to the development of a safe and reliable nuclear energy
- to maintain the availability of these experimental capacities by refurbishing and renewing the required facilities; this rationalisation implies also shutting down facilities facing ageing issues or lack of programs.
- to provide an efficient and flexible operation conditions, implying international collaboration and special care for the training of the new generations.

The following chapters illustrate the CEA management for research reactors.

2 RESEARCH REACTORS IN FRANCE: A HISTORY OF ABOUT 60 YEARS

December 15, 1948, three years after the creation of the French Commissariat à l'Energie Atomique (CEA), ZOE, the first French nuclear reactor, reached criticality. ZOE was a small reactor, using uranium oxide fuel and moderated with heavy water, built in Fontenay aux Roses near PARIS. ZOE was stopped on April 6, 1976 after twenty-six years of activity and since, more than thirty research reactors have been built and operate in France.

As soon as it was proved that nuclear fission start-up and control can produce energy, scientific needs for research for the nuclear energy development were very strong. Everything had to be studied: neutron science, the material science for nuclear fuel and structural materials under irradiation, as well as the operation of reactors and the specific problems of nuclear safety… So, the Fifties and Sixties saw the realization in France of a large number of facilities and research reactors, from Zero Power Reactors (also called critical mock-up) to the 70MW irradiation test reactor, intended to meet these needs and to test the various nuclear systems.

In the Seventies, the rate of the research reactors realizations strongly decreased in France. Indeed, the most important choices for the industrial reactor types were fixed and the number of research reactors existing in Europe was sufficient to satisfy the technological irradiation needs.(as an example, the table 1 shows the majority of the reactors which have been shut down between the 60's and today)

The realizations from this decade concerned especially :

- High flux neutron sources dedicated for fundamental research on matter,
- Research reactors designed for safety experimentation
- Prototype for sodium fast reactors

3 RESEARCH REACTORS IN OPERATION TODAY

Eleven research reactors (see table 2) are presently operated in France by CEA (except for ILL-HFR). They offer a comprehensive experimental capacity to address major fields of interest for the nuclear energy implementation.

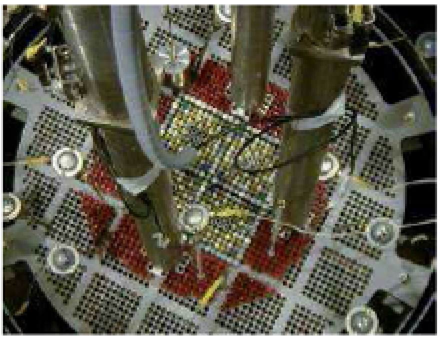
3.1 The Zero Power Reactors (critical mock-up facilities) for reactor physic studies

Three ZPR called EOLE, MINERVE and MASURCA located at the CEA/CADARACHE centre are the CEA experimental facilities for reactor physics studies.

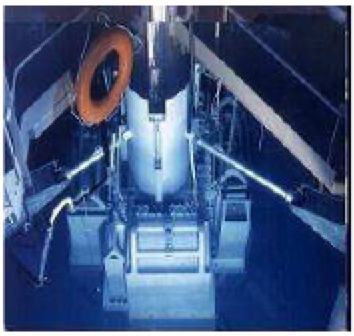
EOLE is dedicated to the neutron physics studies of moderated lattices such as those of industrial Pressurised or Boiling Water Reactors (PWR-BWR). EOLE is a pool type reactor operating at a maximum power of 100 W. This facility is very easy to use, it is mainly constituted by a cylindrical vessel in aluminium with an upper structure in stainless steel, able to contain various types of core (UOX, MOX with various plutonium content), related structures and instrumentation. Since its first criticality in 1965, EOLE has never been shut down and has always been used for the qualification of LWR core calculation. As examples we can quote the EPICURE program at the end of the 80's dedicated to the qualification of 30% MOX core loading for French PWR or, more recently the FUBILA program performed for a Japanese consortium of Operators for the qualification of 100%MOX core in ABWR. The present programs in the EOLE facility are dedicated in support for the lifetime extension project of the French operator of PWR (EDF) and for neutron studies in support to the EPR development (Generation III power reactors) The role of EOLE as a research reactor for the improvement of neutron physics computer codes for future industrial applications leads to its identification as a key structure for CEA R&D programs.

MINERVE is also a pool type facility with a maximum power of 100 W designed to be able to reproduce various neutron spectra, from a fast reactor to light water reactor and even a heavy water reactor spectra. As a key feature, MINERVE provides a very precise measurement of the reactivity effect by the oscillation of well characterised samples. This reactor is dedicated to nuclear data evaluation (integral cross sections) in order to reduce the uncertainties of this data and consequently improve the quality of the international Databank such as the JEFF3 bank from OECD/NEA. Like EOLE, MINERVE has never been shut down since its first criticality. The present programs are linked to the optimisation of the fuel cycle for the utilities (high Burn-up Programs) and to the improvement of actinides data knowledge (Neptunium, Americium, Curium…) The final goal of such measurements is the reduction of uncertainties in industrial numerical schemes.

Due to the importance of these two reactors for the neutron physics codes, the CEA strategy is to maintain these facilities in operation. Consequently a safety reassessment is just starting and refurbishment works are planned at the beginning of next decade.



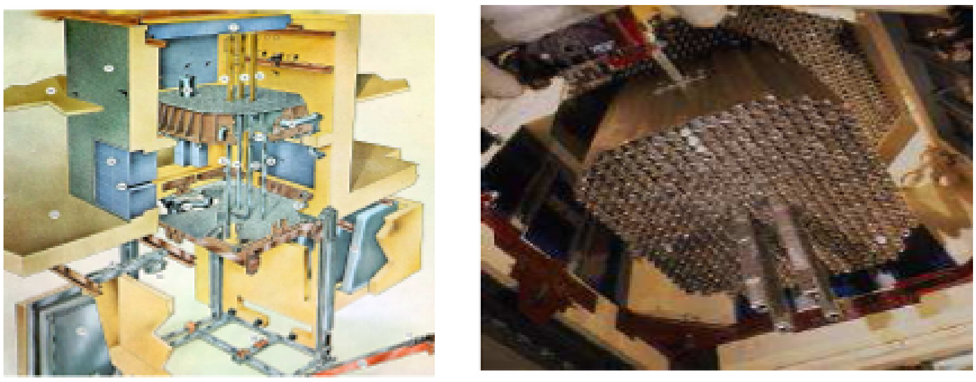
View of EOLE reactor



View of MINERVE reactor

MASURCA is a low power research reactor dedicated to experimentation in support to the qualification of neutron core calculation for fast reactors.

The various programs performed since its first criticality in 1966 allows the validation of different Uranium-Plutonium core concepts. The future of MASURCA has been assessed in depth versus international scientific and industrial needs and versus its technical status. With its large core, a large variety of available nuclear materials offering the capacity to build up dedicated configurations, MASURCA is and will be a major experimental tool for fast neutron reactors developments, as identified by the Generation IV forum. Consequently, CEA has decided to maintain the facility and has launched a safety reassessment project followed by a refurbishment program which will be detailed in the § 5.



The MASURCA reactor

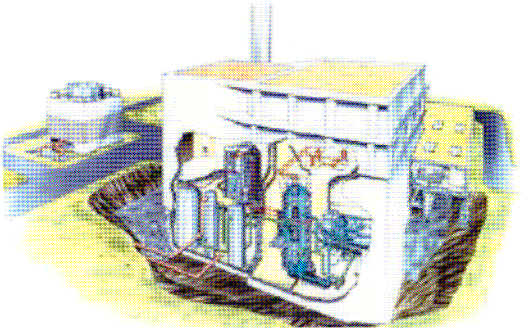
3.2 Dedicated reactors for Safety experimentation

Harnessing against risks is compulsory for the nuclear energy development. CEA contribution on experimental studies of severe and/or dimensioning accidents is performed through two research reactors PHEBUS and CABRI located at CADARACHE centre.

They allow the implementation of complex experimentations from the design of the test to the interpretation and analysis of the experimentation.

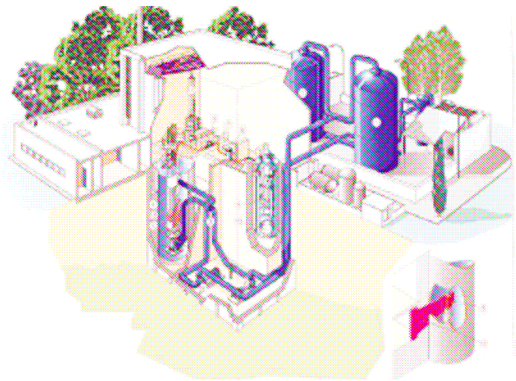
The safety tests and the scientific programs are lead by the French Institute for Radioprotection and nuclear Safety (IRSN) within large international collaboration.

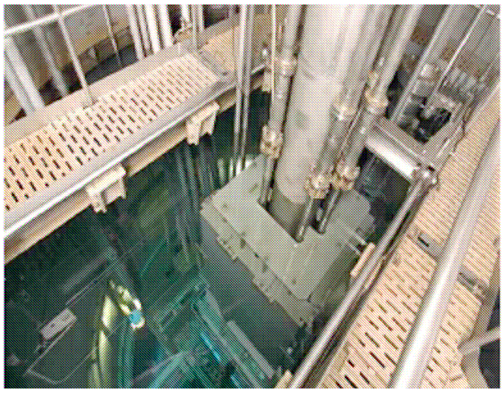
The PHEBUS Reactor started operation in 1978 with Safety experimentation on LOCA (Loss Of Coolant Accident) type accidents. PHEBUS is a pool type reactor of 40 MW maximum power with a driven core and an experimental loop which contain the fuel to be tested. After an extension of the building in the 90’s, a large international program PHEBUS PF was launched by IRSN. After the last test of this program (2004) an international expert group was set-up to assess potential future experiments in PHEBUS (severe accident, LOCA, GENIV concepts). The discussions pointed out that the scientific interest for PHEBUS, as a worldwide unique facility, is sustainable; nevertheless the operation will have to accommodate long periods without experiment. The operation will be optimised according to the need of the international community.



PHEBUS, schematic view and fission product analysis

The CABRI Reactor is dedicated to the study – at the level of fuel rods- of Reactivity Initiated Accidents (RIA). It is also a pool type reactor with a driver core at a maximum power of 25 MW; an experimental loop which contains the fuel rod to be tested and control rods in helium gas, allowing to carry out a fast injection of reactivity so as to pass from 100 KW to 20,000 MW of power in a few milliseconds and fall down as quickly. The program under preparation now is the CABRI water-loop program; it requires the implementation of a specific loop which creates the conditions of a PWR. In parallel a complex and comprehensive refurbishment is being carried out in order to reach the most recent safety standards (in terms of seismic risk, fire risk, flooding…) so that, the reactor can be operated for a few decades more. The first test of this new program is planned for the end of 2009 and the water-loop program will be performed until 2013 (notably with high burn-up MOX fuel rods).





CABRI, schematic view and view of the core

3.3 Neutron source reactors for fundamental research

Neutron applications for fundamental research have been developed in the world from the sixties for the study of the matter at the atom or molecule scale, with an increasing need for intense neutron sources.

France hosts two major high flux neutron source reactors:

- The High Flux Reactor (HFR) located near to Grenoble, of a power of 57 MW and a "thermal" neutron flux of $1,5.10^{15}$n/cm2.s. This reactor is operated by the Laue-Langevin Institute (ILL) to which contribute mainly England, Germany and France. This reactor started in 1971 and has been recently refurbished in order to reach the most recent safety criteria.

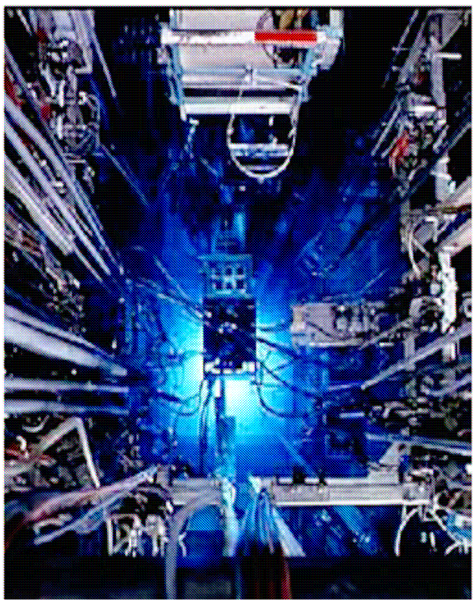
- ORPHEE reactor located on the CEA/Saclay centre, of a power of 14 MW and a "thermal" neutron flux of $0{,}3.10^{15}$n/cm2.s. ORPHEE is operated by the CEA in the framework of a joint laboratory between CEA and CNRS (French national scientific research centre) and is largely open to international collaboration.

ORPHEE

These reactors have a very compact core with strong density of power. Around the core, a heavy water reflector is used to obtain "thermal" neutrons and tangential beam tubes to drive neutron beams towards the matter samples and the associated scientific instruments (scattering instruments such as diffractometers, gamma and neutron spectrometers …).

3.4 *OSIRIS, a reference Material Test Reactor (MTR)*

OSIRIS is a pool type reactor with open core of 70 MW power established at the CEA/SACLAY centre; it is cooled and moderated with light water. With a first criticality in 1966 it is now 41 years old



OSIRIS

OSIRIS is mainly dedicated to material and fuel tests, but it also produces radioisotopes for medical applications, doped Silicium for micro electronic industry and irradiated samples for neutron activation analysis.

The design of OSIRIS reactor was optimised to obtain power density and neutron flux as large as possible with an open core and to allow easy operations with the experimental devices. Up to fifteen experimental devices can be set up in OSIRIS at each irradiation cycle (about 8 cycles per year). They are supporting scientific programs carried out for utilities and makers.

3.5 *MTR Strategy, from SILOE and OSIRIS to the JULES HOROWITZ REACTOR (JHR)*

In 1963, CEA started the operation of a 40MW flexible MTR: SILOE in Grenoble. Three years later, OSIRIS was also in operation. During 30 years, CEA operated in parallel two MTRs, as a key facilities to implement a reliable and effective nuclear fleet of power reactors.

Due to a decrease of industrial needs at the beginning of the 90's, SILOE has been shut down in 1997 and the competencies have been maintained in Saclay and in Cadarache

Due to its ageing, it is planned to shut down OSIRIS at the beginning of the next decade. An internal safety and performance assessment has shown that even a major refurbishment would not allow to secure and to guarantee the availability of the irradiation experimental capacity for the industry and the public bodies.

The question of the future and the availability of a state of the art reliable irradiation capacity was then set-up.

Following a broad survey, the international community agreed that the need for Material Test Reactors in support of nuclear power plant safety and operation will continue in the context of sustainable nuclear energy:

- In support to the current generation of power reactors (GEN II reactors), in particular, in connection with safety and plant lifetime extension, increased performance and safety of the fuels for competitiveness of nuclear fission energy.
- For the optimisation of the power reactor design and operation in the framework of the renewal of the fleet (GEN III reactors)
- For assessment and validation of more innovative designs for future power reactors (GEN IV concepts, hybrid systems, …)

In the same time, existing European MTRs, dedicated to the industry support, are ageing[1] and face an increasing probability of shut down due to their obsolescence , both from the point of view of operational and safety performances. For example, R2 reactor in Sweden has been shut down mid 2005.

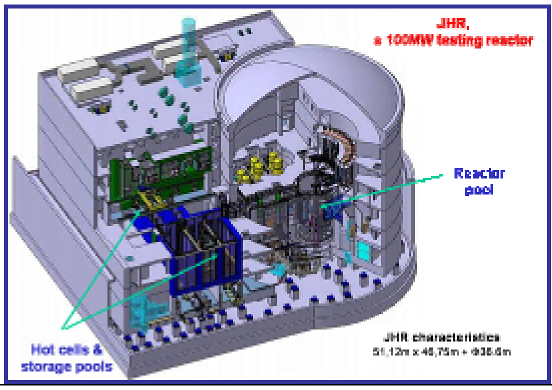
The history of research reactors was mainly driven within national policy. As a major new trend, the implementation and access to international research infrastructures is an effective way to manage the rationalisation & optimisation of the research reactors fleet meeting both requirements of safety, scientific and economic efficiency as well as training and competences management. Like in fundamental physics for decades, the access to up-to-date high performance research reactors should be considered as an opportunity for several countries to get a top level expertise, as an alternative to keep in operation outdated domestic facilities.

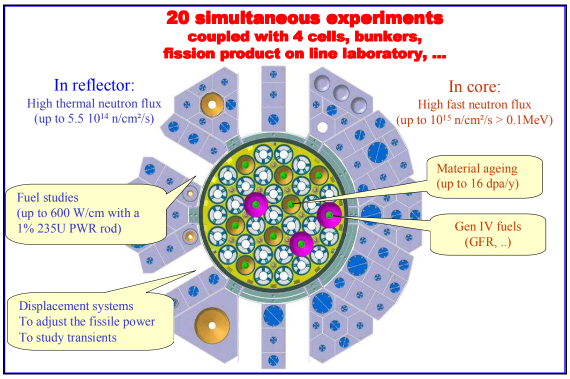
The Jules Horowitz Reactor project (JHR) copes with this context. This project is driven and funded by an international consortium gathering vendors, utilities and public stakeholders. JHR is designed as a user-facility reaching the needs of the international community. This means:

- flexibility with irradiation loops able to reproduce the operation condition of the different power reactor technologies,
- high flux capacity to address both Generations II, III, IV needs.

The JHR consortium has been set up in March 2007. On site excavation is under process and start of operation is scheduled in 2014.

[1] LVR15 in Czech Republic (1957, 10 MWth), Halden in Norway (1960, 19MWth), R2 in Sweden (1960-2005, 50 MWth), HFR in Netherland (1961, 45 MWth), BR2 in Belgium (1961, 100MW), OSIRIS in France (1966, 70MW)





In order to comply with the evolution of safety requirements and to guarantee long term operations, the construction safety standards of JHR have been significantly improved compared to MTR built in the 60s.

- The safety approach of JHR takes into account a systematic assessment (and the implementation of necessary design modification) of external or internal hazards on the nuclear buildings.
- Furthermore, the JHR confinement is designed to face severe accident conditions. The so-called "Borax accident" (hypothetic beyond design reactivity accident with explosion and core melt) is taken into account in the design of the containment and the water bloc.
- In addition, the JHR safety approach will focus on irradiation devices as a potential aggressor of the facility. This problematic involves potentially energetic experiments (PWR loops, safety tests) and/or tests with significant radio isotopic content (eg. Tests on minor actinides).

4 The Safety Reassessment of research Reactor in France and the CEA strategy

In France, all the research reactors are subject by law to periodic safety reassessment which is necessary to maintain them in operation.

These safety reassessments follow strict guidelines in terms of methodology, requirements and rules, similar to the ones used for Nuclear Power Plants. Compulsory, they are made every ten years. The objectives of such reassessments are:

- To check that the facility is in conformity to its safety system of reference in use,
- To perform an inventory of the nuclear safety of the facility related to present rules.

This process is in fact based on two separate steps:conformity exam and safety reassessment. It takes into account feedback experiments, obtained during the operation of the reactor and on other similar nuclear facilities. It allows us to identify the gap between the present situation and the requirements due to the current rules and to check the possibility of implementation.

At the end of these safety reassessments, refurbishment work is defined (seismic reinforcement, fire protection, command/control upgrade …) according to the life expectancy forecast for the facility. In this way, the safety level of the research reactor increases.

These Safety Reassessments can give also the opportunity:

- To upgrade the experimental capabilities of the reactors, the impact of such modification being included in the new Safety Analysis,
- To solve problems linked to the obsolescence of materials even if these materials are not linked to the safety level of the reactor.

A Safety Reassessment Report is examined by the French Nuclear Safety Authority and its technical supports (IRSN: Radioprotection and Nuclear Safety Institute). The French Nuclear Safety Authority:

- expresses its needs which represent a significant amount of studies and work,
- gives its formal approval to the modifications of the reactor,
- and, finally, gives its authorisation to continue the operation of the reactor.

The definitive Safety Report is then produced in order to take into account all the modifications of the facility.

The most sensitive points which appear on these safety reassessments in the French Research Reactors concern:

- The dimensioning of the confinement barriers,
- The treatment of internal risks (fire, flood…),
- The treatment of external risks (earthquake, airplane crash…),
- The incidental and accidental situation analysis and their radiological impact according to the new rules.

All the CEA reactors described above are subject to this periodic safety reassessment process. As a key preliminary step, a strategic assessment on the future of the facility is performed by answering the following major questions:

- What are the needs in terms of international scientific and/or industrial interest for maintaining the reactor in operation?
- What is the level of difficulty in terms of refurbishment work in order to meet safety requirements?
- What is the overall cost/benefit of the refurbishment.

This process allows consistent decisions on the life-time of the facility, the level and schedule of refurbishment, possibly the renewing of the facility.

For example,

- OSIRIS reactor safety level will be improved to be operated for a limited period consistently with its replacement by JHR.
- For Zero Power Reactors (see § 2-1), major refurbishment are planed in order to maintain them in operation for a few decades.

5 EXAMPLE OF SAFETY REASSESSMENT: THE MASURCA REACTOR

As described in §3-1, MASURCA has been subject to a safety reassessment from 2002 to 2006. The main items studied during this process were:

- Feedback experience of operation and position of the safety level of the facility according to present rules
- Definition of new general safety objectives
- Safety-criticality analysis
- Electric supply analysis
- Command/Control analysis
- Confinement /Ventilation analysis
- Radioprotection analysis
- Fire/Explosion risk analysis
- Hydrogeology and Flooding risk
- Human factor analysis
- Seismic Risk of the Reactor building and of the fuel storage building.

An independent expert group on Reactor Safety has been requested by the French Nuclear Safety Authority in order to get approval of:

- the refurbishment program proposed by CEA,
- The new safety report of the renovated facility including new operating rules.

Following this Safety Reassessment, CEA had the approval to go ahead on the following refurbishment works :

- Electric supply (complete modification of the architecture, no common modes…)
- Command/Control (brand new one qualified in parallel with the present one-new control room)
- Fire protection (anti-fire wall, wire protection…)
- Ventilation (design and implementation of an emergency system for post-earthquake monitoring of the reactor- the cooling of the core must be maintained whatever the situation)
- Loading machine (new command/control)
- Seismic reinforcement: this point leads to important building work especially for the nuclear fuel storage building where a concrete extension of 60 cm all around the building will be performed.

After the refurbishment works, the restart of the reactor and its experiments will need the formal approval of the French Nuclear Safety Authority .This Authority will check the conformity of the renovated facility with the CEA 2006 agreements .

Table 1 Research Reactors operated and shut down in France

Name	First criticality	Shut down	Power
ZOE	1948	1974	100 KW
EL2	1952	1965	2 MW
EL3	1957	1965	18 MW
EL4	1966	1985	267 MW
MARIUS	1960	1983	0,4KW
CESAR	1964	1977	10KW
MELUSINE	1959	1988	8MW
TRITON	1959	1982	6,5MW
PEGASE	1963	1974	30 MW
RAPSODIE	1966	1983	40 MW
SCARABEE	1972	1982	100 MW (pulse)
HARMONIE	1963	1995	2 KW
SILOE	1963	1997	40 MW
SILOETTE	1964	2002	100 KW

Table 2 Research Reactors in operation in France (2007)

Name	Power MWth	Critical Date	Fuel Reactor type	Utilization								
				Training	Basic/applied research	Testing irradiations	Qualification			Production		Gamma scan
							Reactor physic	Safety	Prototype	Isotopes	Silicon	Neutronography
Zero Power Reactors												
EOLE Cadarache	0,0001	1965	UAL Pool				X LWR					
MINERVE Cadarache	0,0001	1959	UAL Pool	X			X LWR/FR					
MASURCA Cadarache	0,005	1966	(U, PU)O2 In air				X FR					
Material testing reactor and experimental reactor												
OSIRIS Saclay	70	1966	U3SI2AL3 Pool			X				X	X	X
PHENIX Marcoule	300	1973	UO2 Na-Fast reactor			X			X			
Safety test reactors												
PHEBUS Cadarache	40	1978	UO2 Pool					X				
CABRI Cadarache	25	1963	UO2 Pool					X				X
Education & training reactors												
ISIS Saclay	0,7	1966	U3SI2AL3 Pool	X			X Osiris					X
ULYSSE Saclay (planned to be stopped in 2007)	0,1	1961	UAL	X								
Basic research, high flux neutron source												
ORPHEE Saclay	14	1980	UAL/H2O-D20 Pool		X					X	X	X
RHF Grenoble Operated by ILL	58	1971	UAL/H2O-D20 pool		X							