Seismic Reinforcement of the High-Flux Reactor

2002 - 2007

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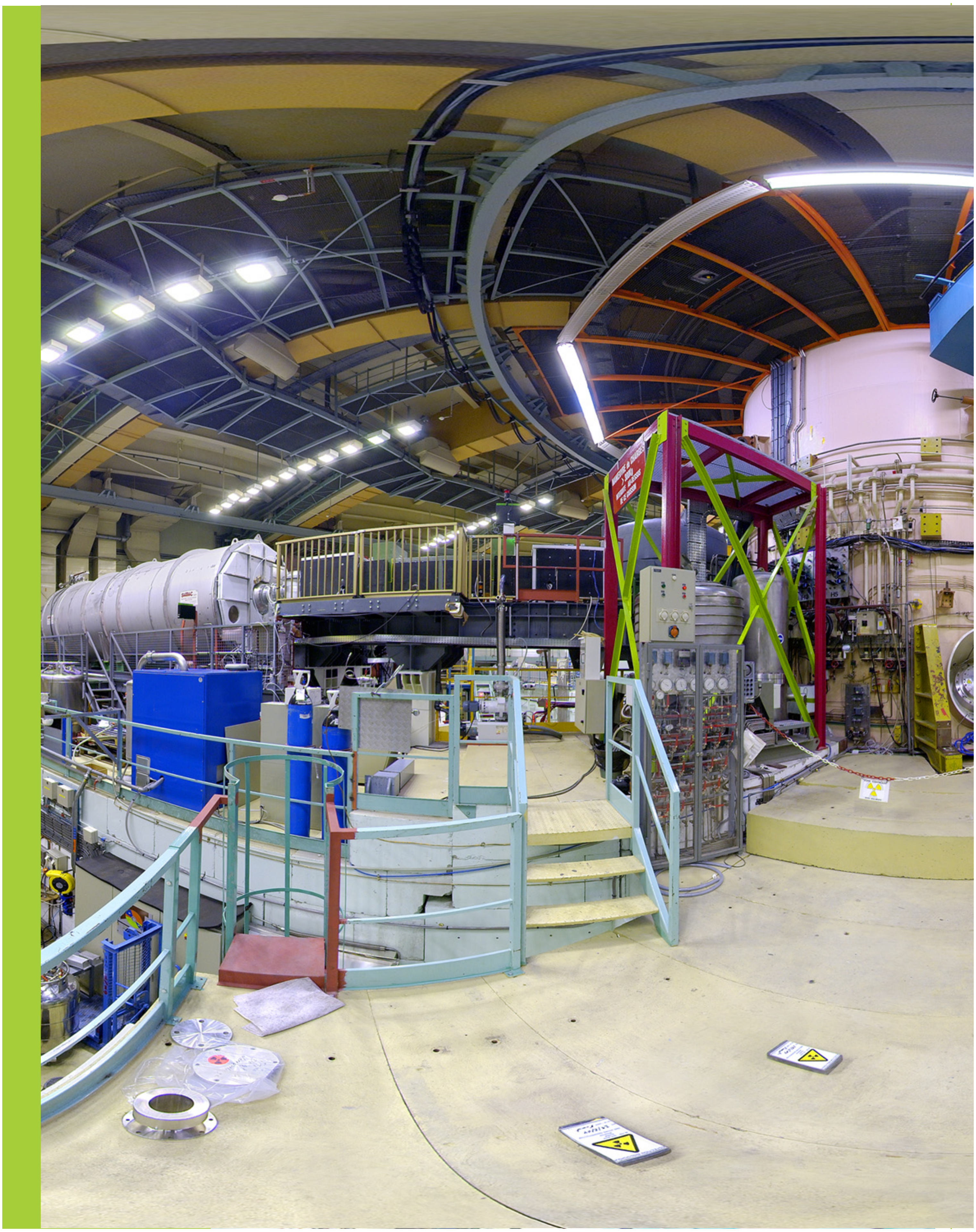
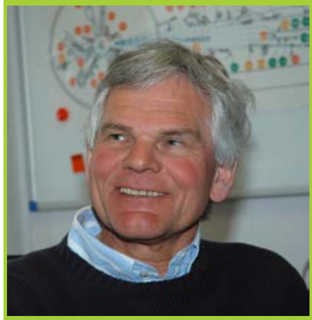
Institut Laue-Langevin



Foreword



In October 2007 the French nuclear safety authorities officially signed off the Refit Programme, a major initiative by the ILL to ensure the seismic stability of its High-Flux Reactor. This signature confirmed the successful conclusion of almost six years of intensive renovation work. The period placed a heavy burden on both the staff and wider user community of the ILL, but we can today be sure that our neutron facilities, the local environment and the neighbouring population are better than ever protected from the highly improbable but nevertheless serious possibility of an earthquake.

Under the Refit Programme several key reactor components were subjected to non-destructive testing; these tests have confirmed the complete integrity of the reactor system after 35 years of operation. This, together with the ongoing modernisation of ILL's instrument suite – the Millennium Programme – will help secure the Institute's position at the forefront of neutron science well beyond the coming decade.

This brochure records the tremendous challenges faced by our staff during the course of the Refit Programme. I would like here to pay tribute to all the staff members who have so admirably contributed to the final achievement. A special word of appreciation is also due to the Expert Advisory Committee for its invaluable analyses during the work, and the recommendations it made on the operations required. I would also like to thank our Associates for their continued support throughout the programme. Their special contribution of some 30 M€ towards the Refit Programme has reinforced not only the ILL's facilities, but also staff and users' confidence in a splendid future.

Richard Wagner
Director of the ILL

Context

Following the safety authorities' 10-year safety review of the High-Flux Reactor in May 2002, the ILL set out on a wide-ranging programme to upgrade and reinforce its nuclear installations.
One of the main aims of this Refit Programme was to guarantee compliance with recent changes in seismic regulations.

As a consequence, between 2002 and 2007 a vast programme of renovation work was undertaken, particularly with regard to the ILL's ability to withstand an earthquake without significant radiological consequences.
This included a major reinforcement of the reactor building and the associated facilities:
• new operational and instrumentation-and-control systems to ensure reactor shutdown in the event of an earthquake
• a new water circuit to feed the reactor tank and transfer canal, now considered leak-tight in the event of an earthquake
• the removal of 1500 tons of concrete structures within the reactor building
• the separation of the guide halls from the reactor building and the reinforcement of the main office building
• new spent fuel racks
• the non-destructive testing of the heavy water pipe welds (with no signs of defects or ageing detected).

This renovation work was carried out in such a way that it fitted in with the routine maintenance work on the High-Flux Reactor and caused minimum disruption to the operation of ILL's experimental facilities.

Project Organisation

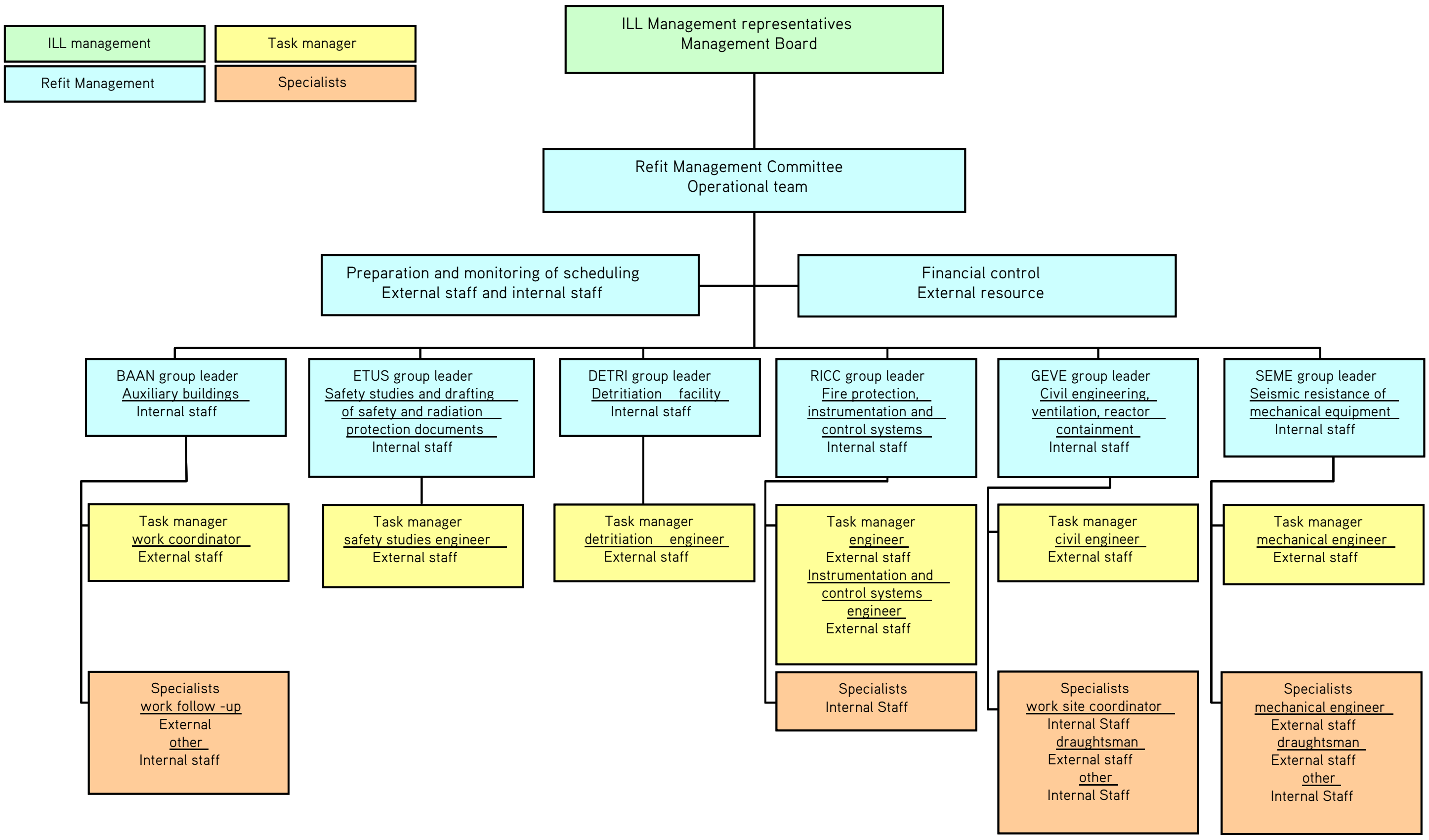
The Refit Programme, which began in 2002 for a duration initially estimated at 5 years, involved setting up a temporary structure (the Refit Management Committee) in addition to the existing divisions in the ILL organisation chart, bolstered by extra staff with skills and experience which did not necessarily exist within the ILL.

The Refit Management Committee (RMC) was made up of a team representing ILL Management (ILL Director, Head of the Reactor Division, Head of the ILL's Finance Service, Chairman of the Millennium Programme Management Committee) and of an operational team comprising a unit with managerial, organisational and control functions and six task groups with specific areas of operation.

Group BAAN responsible for the auxiliary buildings ILL4, ILL7, ILL22 and the air-intake building, and for modifications to the areas immediately surrounding these buildings.
Group ETUS responsible for safety studies and the drafting of safety and radiation protection documents.
Group DETRI responsible for the detritiation facility.
Group RICC responsible for the instrumentation and control systems and protection against the risk of fire.
Group GEVE responsible for the ventilation and confinement system of the reactor building (containment and equipment), as well as for seismic civil engineering work and studies.
Group SEME responsible for the mechanical equipment inside the reactor building.

Concerning technical decisions, the RMC was advised and monitored by the Expert Advisory Committee (EAC), a group set up by ILL Management and made up of experts from outside the Institute. Twice a year, the RMC presented a progress report on the status of the project and the EAC delivered an opinion on this report.

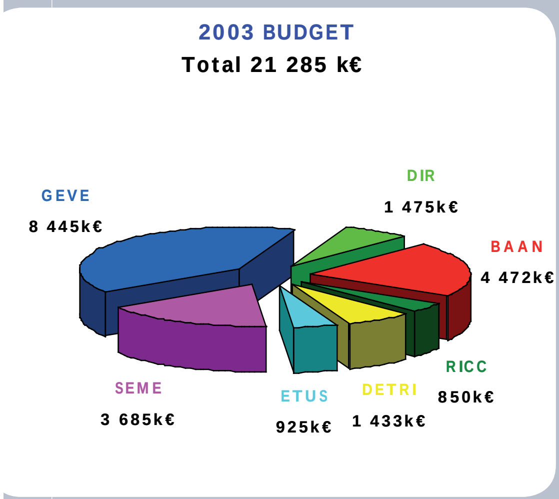
Refit Programme Organisation Chart

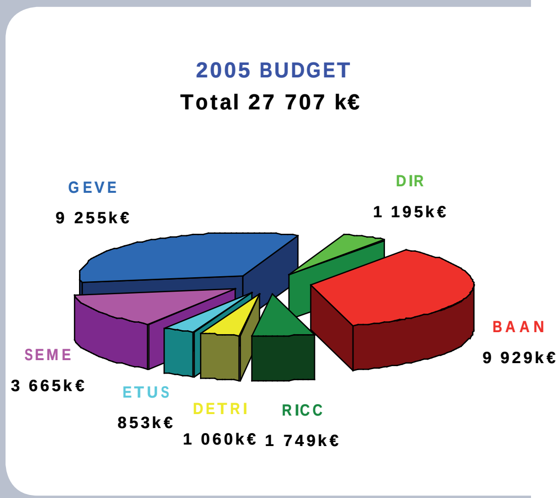


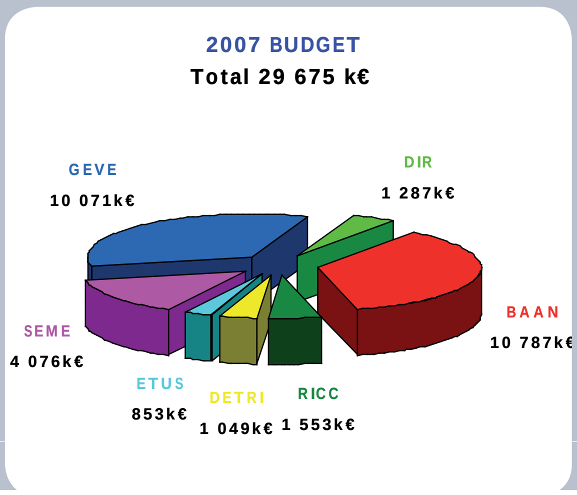
Budget

At the start of the Refit Programme, the overall budget for external expenditure (excluding taxes and ILL staff costs) was drawn up at a time when the technical solutions had still not been defined : it was estimated at 20 M€ ± 20 % (without indexation), over a period of 5 years (2002 to 2006).
The final budget figure is approximately 29.7 M€ (without indexation) over a 6-year period (2002 to 2007).

Budget progression by group between 2002 and 2007 (without indexation)







Work accomplished

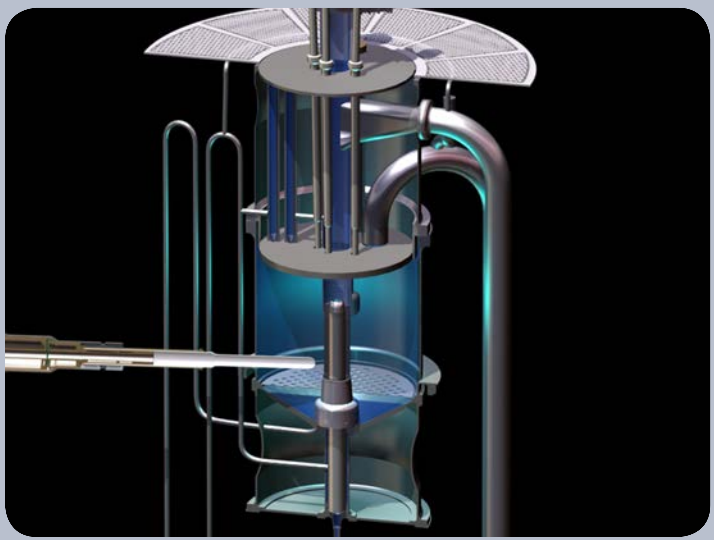
The major part of the work accomplished was associated with the ILL's ability to withstand an earthquake, with quantified objectives in terms of radiological impact.

In order to obtain additional margins with respect to these objectives, the ILL decided to make the necessary demonstrations and carry out the necessary work to guarantee the main safety functions. These are described below.

Controlling the fuel reactivity

In order to control the reactivity of new and spent fuel elements, the **civil engineering structures** of the reactor building and the various **metal support structures** (e.g. fresh fuel element storage boxes, reactor block in the reactor pool, spent fuel element storage rack in the transfer canal) must be stable.

Other prerequisites for controlling the reactivity of the reactor are the **proper functioning of the safety rods** and the **early detection of seismic signals**, so that the automatic shutdown of the reactor can be triggered before the strong phase of the earthquake.



View of reactor block - Fuel element

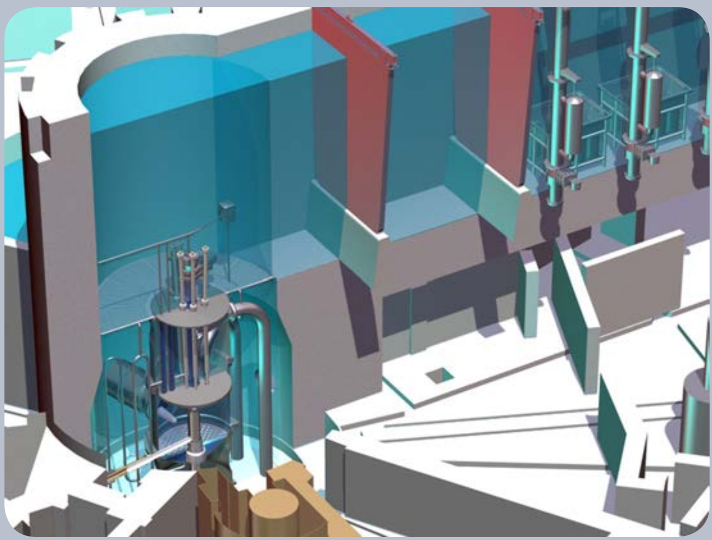
Cooling of the fuel elements

The non-release of the fission products contained in the spent fuel elements is guaranteed by the presence of water. The three most penalizing cases have been considered:

• Reactor shutdown transient in the event of an earthquake: **no major breach of the reactor block or the main part of the primary cooling system,** including primary pumps and heat exchangers;

• Cooling of the spent fuel element in the reactor block: **stability of the reactor block**, operation of at least one of the natural convection valves, **leak tightness of the reflector tank and the reactor pool;**

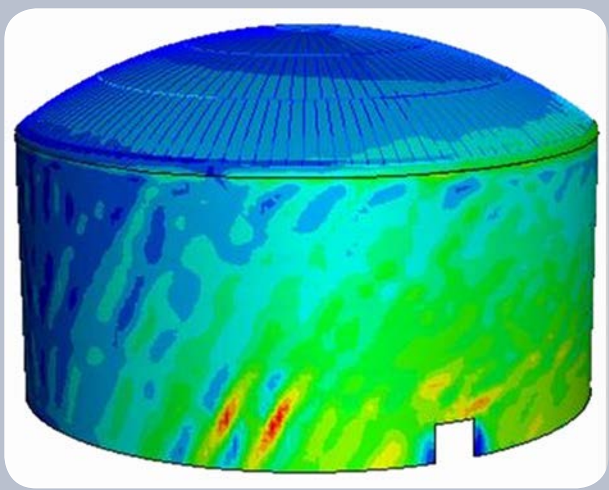
• Cooling of the spent fuel element in the transfer canal: **stability of the fuel handling cask, leak tightness of the transfer canal and the reactor pool gates.**



View of the reactor pool and the fuel element handling devices in the transfer canal

Controlling the efficiency of the reactor containment

Following an earthquake, air from inside the reactor should be filtered and only be released through the exhaust stack. Therefore the main openings in the concrete containment wall (**air locks, doors, isolation valves of circuits** which penetrate the containment) must be **leak-tight** and the **containment walls and exhaust stack** must be stable.



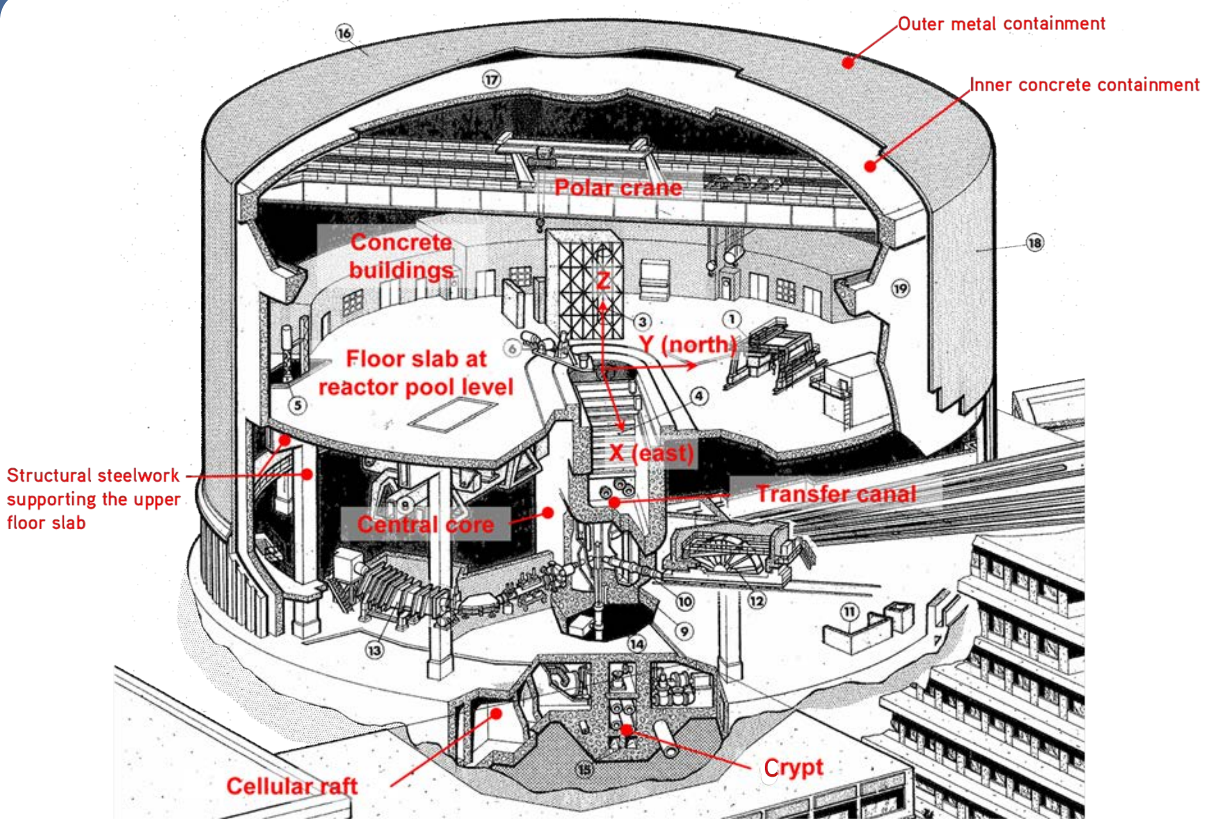
Work accomplished

Civil Engineering

THE REACTOR BUILDING

To guarantee the main safety functions, the following structures must be stable:

- Outer metal containment
- Inner concrete containment
- Internal concrete structures

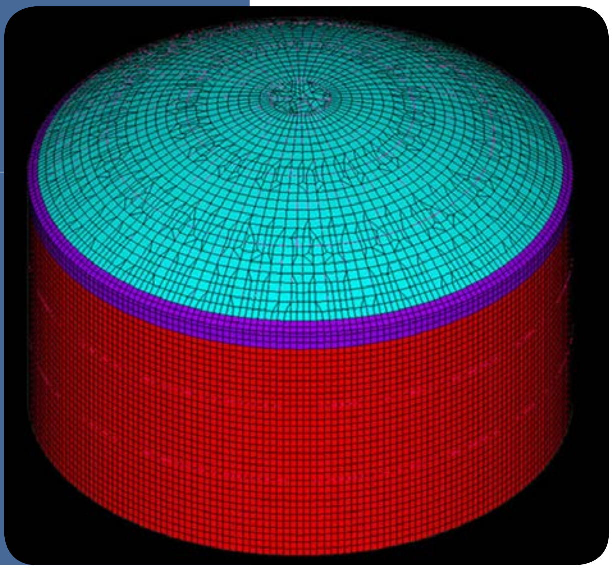


Sectional view of the ILL reactor building

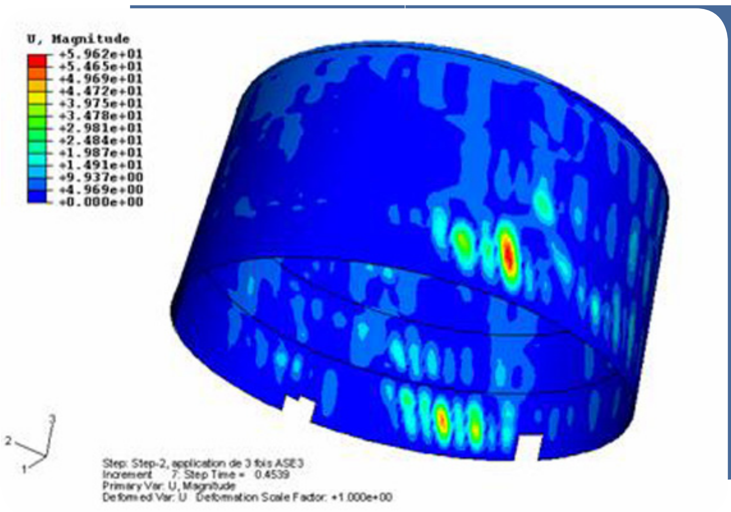
Stability of the outer metal containment wall

The overall stability of the outer metal containment wall was verified by studies.

The outer metal containment wall



Mesh description of the outer metal containment wall

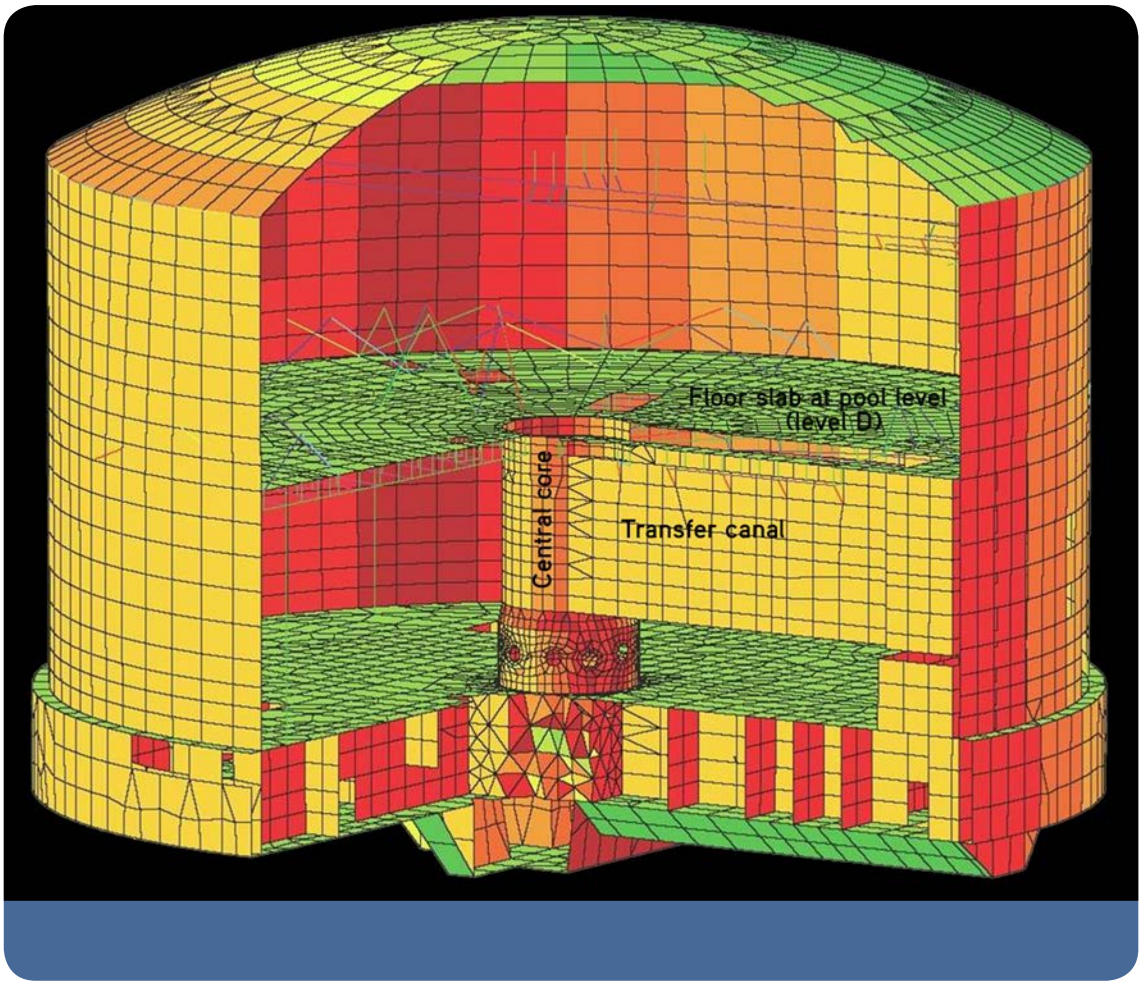


Buckling calculations on the outer metal containment wall

Stability of the concrete structures of the reactor building

Studies on the concrete inner containment wall demonstrated its overall stability during a safe shutdown earthquake. However weaknesses were detected in the transfer canal, the central core and the floor slab at reactor pool level. Therefore the following reinforcement work was carried out:

- Reinforcement of the rear block of the transfer canal
- Dismantling of the concrete buildings on the floor slab at reactor pool level (1500 tons removed)
- Reinforcement of the central core by transferring the efforts to the concrete inner containment wall through the floor slab
- Local reinforcement of the floor slab



Finite-element model of the reactor building

• Reinforcement of the rear block of the transfer canal

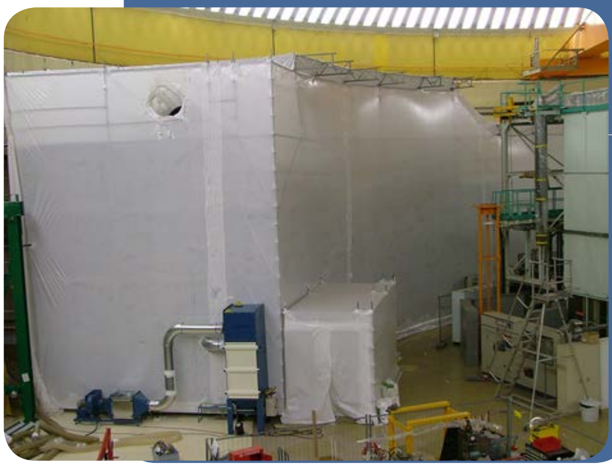
New cogs between level C (experimental hall) and level D (pool level)

Reinforcement of concrete column under the back wall at level B (basement)

Concrete back wall at level C (experimental hall)

• The internal concrete buildings situated at the periphery of the reactor level D (pool level) were dismantled for three main reasons:
- Instability of the structures during an earthquake
- Easing the strain on the concrete floor slab at level D
- Permitting access to the connection between the level D floor slab and the inner containment wall

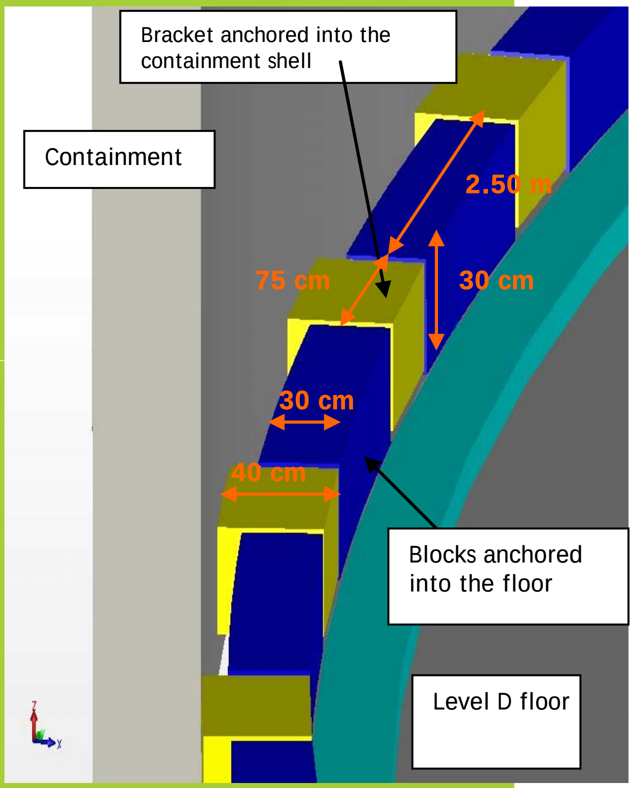
Before work
2003



During work
2004-2005

After work
2006

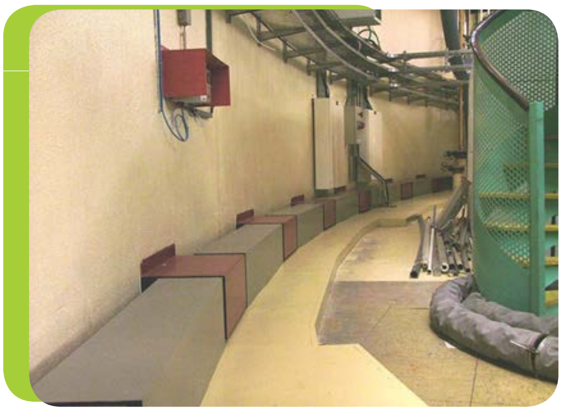
• Strengthening of the floor slab at the reactor pool level (level D)



Orthoradial liaison between the floor slab and the containment wall (so-called 'comb')

Steel framework for the 'comb'

Concreting the steel framework



The finished 'comb'

• Local reinforcement of the floor slab on level D (reactor pool level)

with concrete ground beams

with carbon fibre

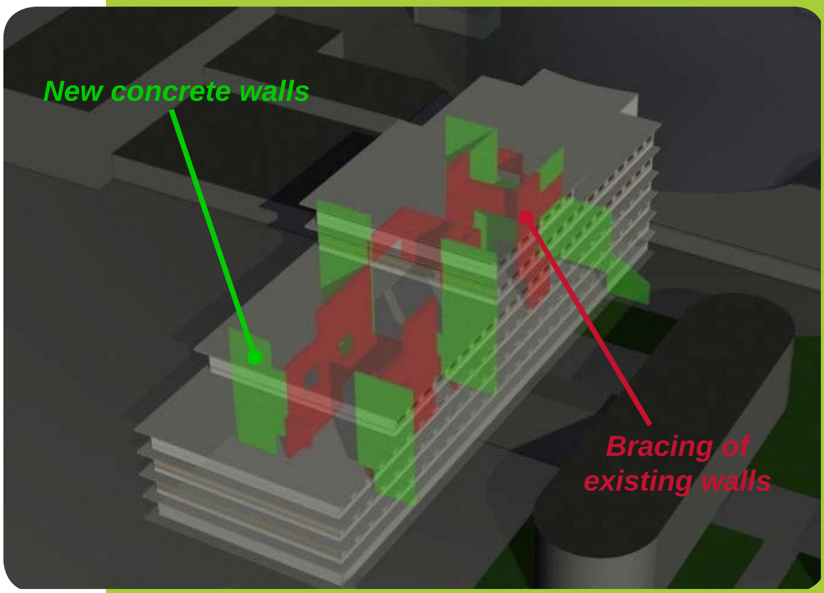
Laying and pasting of the fabric

Protection of the fabric with metal panels

Finished work

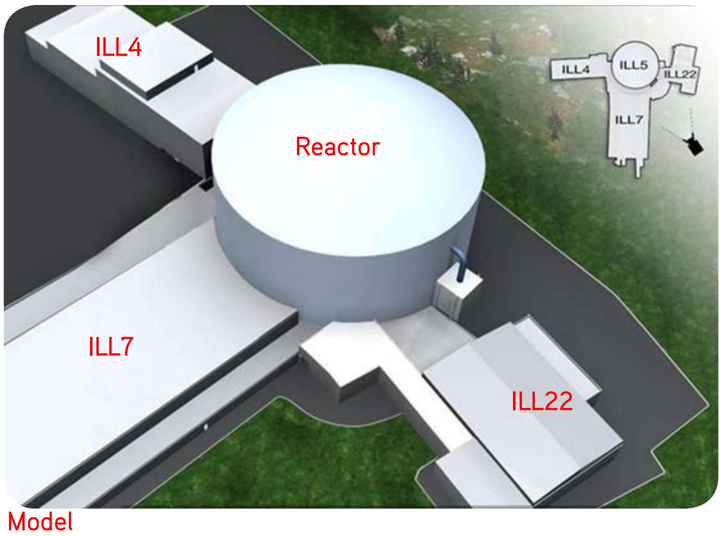
OFFICE BUILDING – ILL4

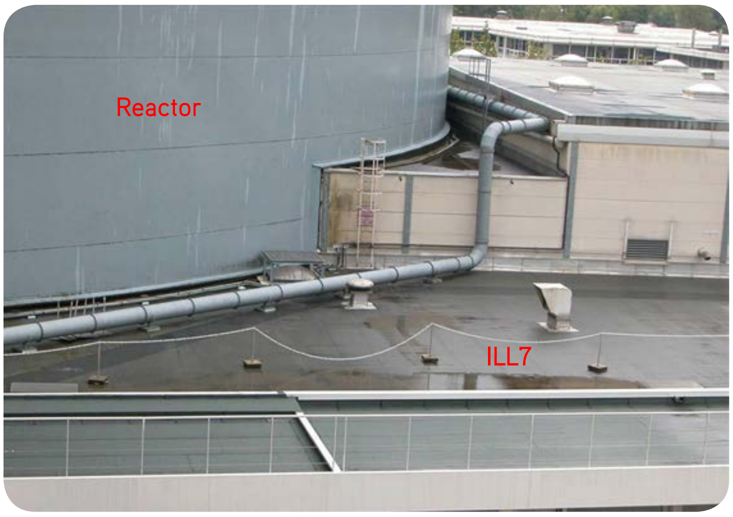
To avoid any interaction between the office building and the reactor containment during an earthquake, the office building ILL4 was stabilized by creating new cross-bracing walls and reinforcing the existing walls.



ILL7 & ILL22 - NEUTRON GUIDE HALLS

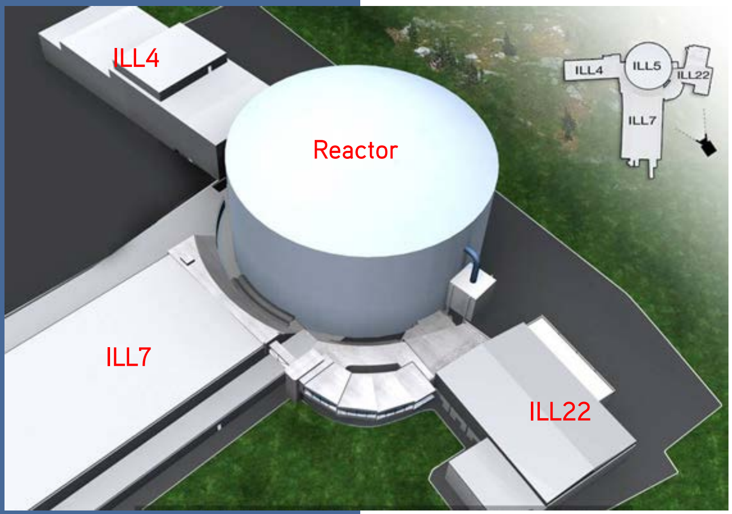
To avoid any interaction between the neutron guide halls - ILL7 and ILL22 - and the reactor containment during an earthquake, the front parts of these buildings adjoining the reactor containment were dismantled at a 45˚ conical angle.





General overview of ILL buildings before work

Connection between the reactor and the neutron guide hall ILL7 during work



Model

General overview of ILL buildings after work

REACTOR AIR INTAKE BUILDING

To avoid any interaction with the reactor containment during an earthquake, the reactor air intake building was reinforced.

Adding micro foundation piles under the reactor air intake building

Mechanical engineering

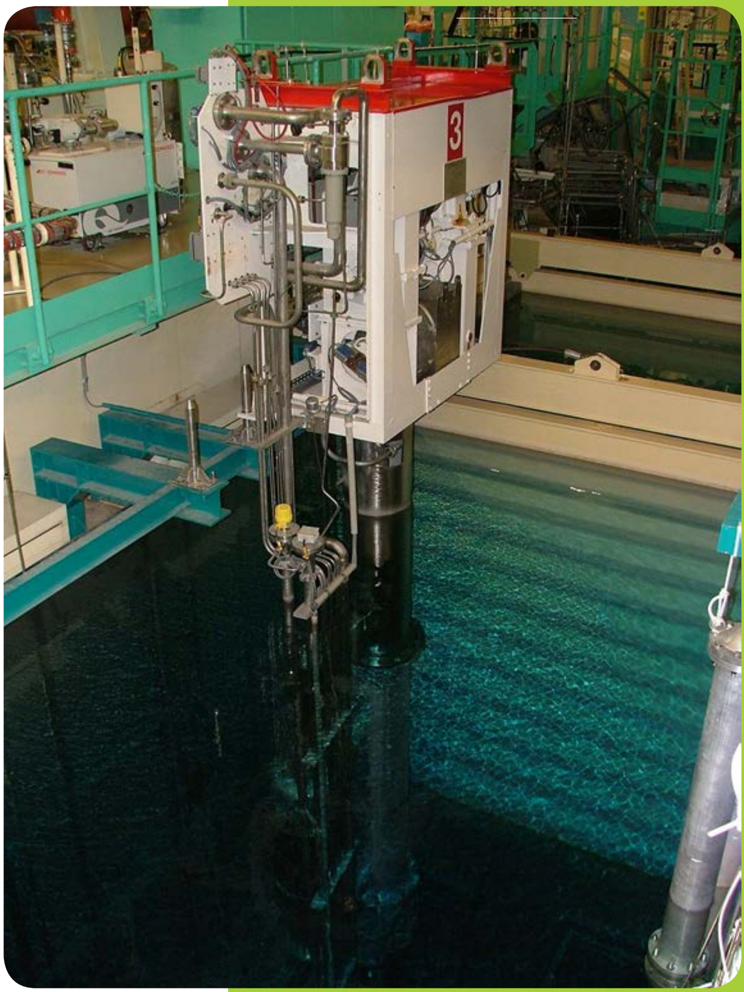
COOLING OF FUEL ELEMENTS AND REACTIVITY CONTROL

Mechanical studies and non-destructive tests were carried out and showed no weakness on the **primary heavy water circuit.**

Model of the water circuit in the basement of the reactor building, including the primary water circuit

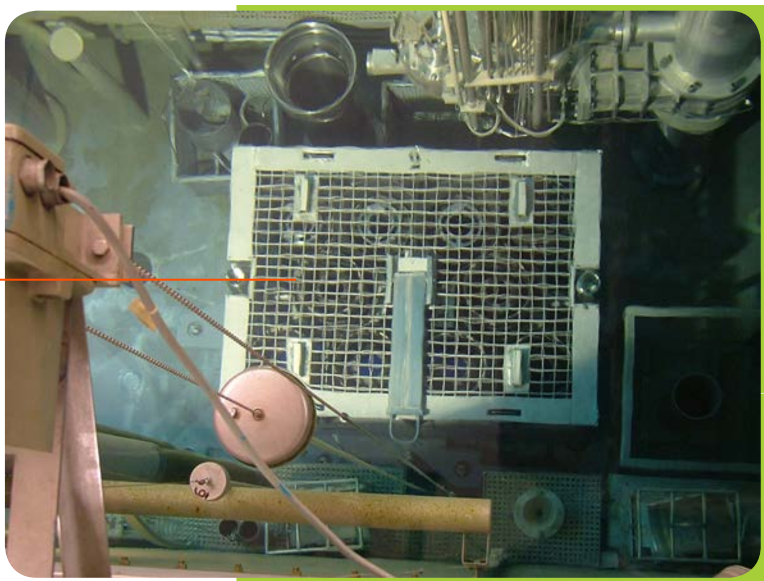
Renovation of pipe supports

The seismic resistance of the **fuel handling casks** was demontrated by studies

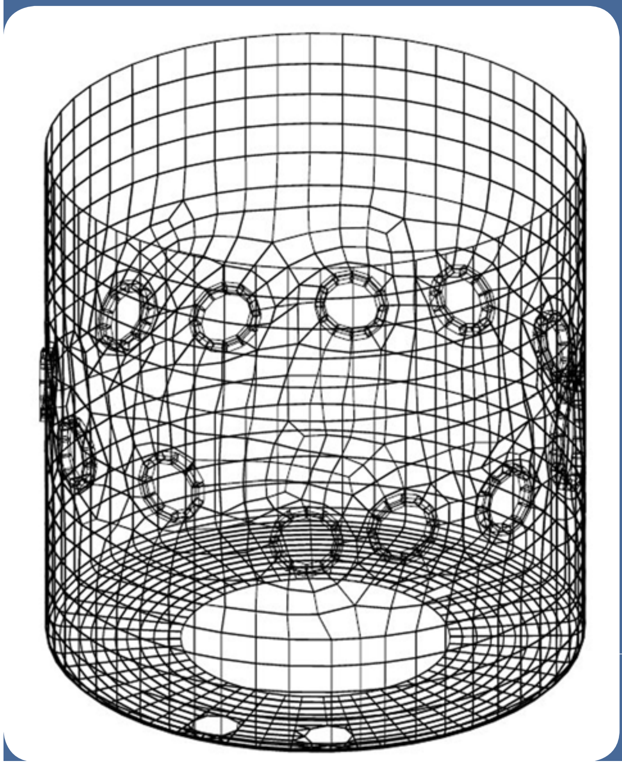


The studies revealed that the **racks for spent fuel** would not be stable during an earthquake. New ones were therefore designed and manufactured.

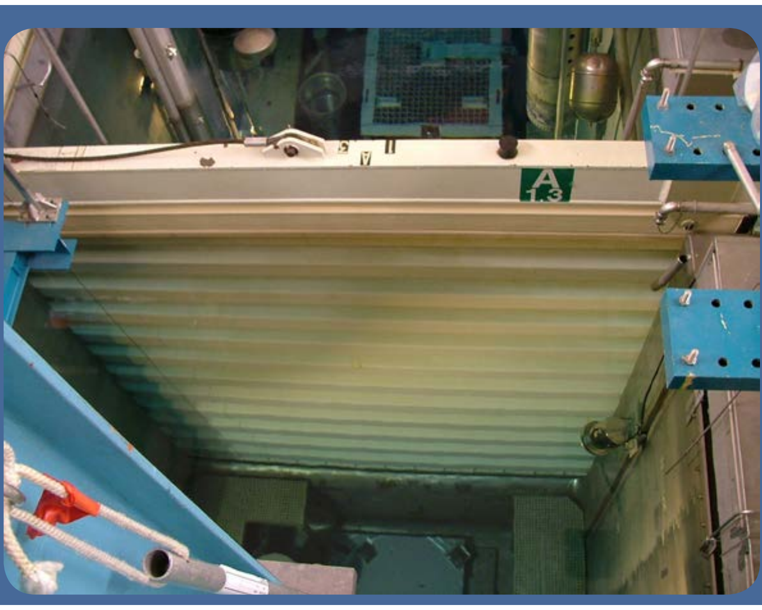
New rack for spent fuel



Mechanical studies were performed on the **pool**, **transfer canal** and **gates** to demonstrate their leak tightness during an earthquake.

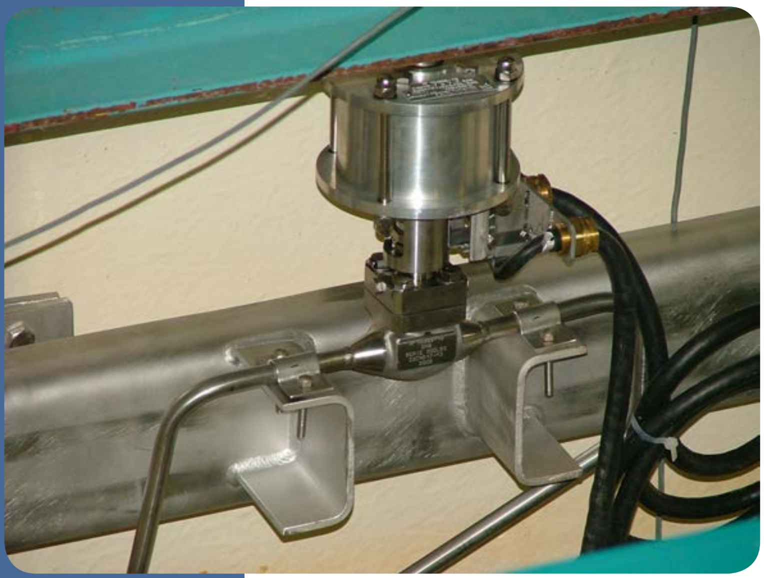


Finite-element model of the reactor pool



Gate between canal 1 and 2

New seismic air-operated valves were installed on **pool penetrations**



... and the **beam tube flanging** leak tightness was verified.

An emergency **water make-up system** was created to avoid the core dewatering during or after an earthquake.

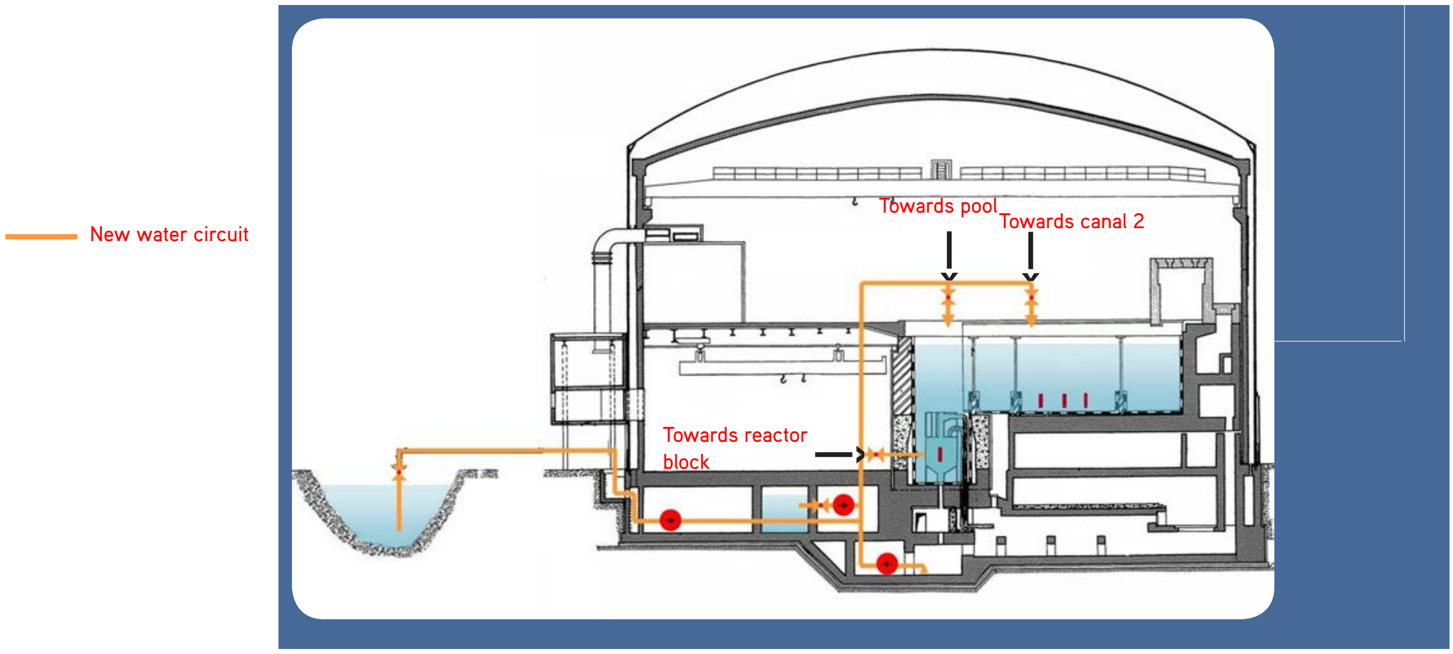


Diagram of water make-up system

New pump on level B (basement)

Emergency filling of the canal 2 containing spent fuel elements on level D (reactor pool level)

REACTOR CONTAINMENT

Containment penetrations were studied and reinforced when necessary.

Before work

After work

The seismic resistance of **air locks and doors** was verified by studies.

Air locks

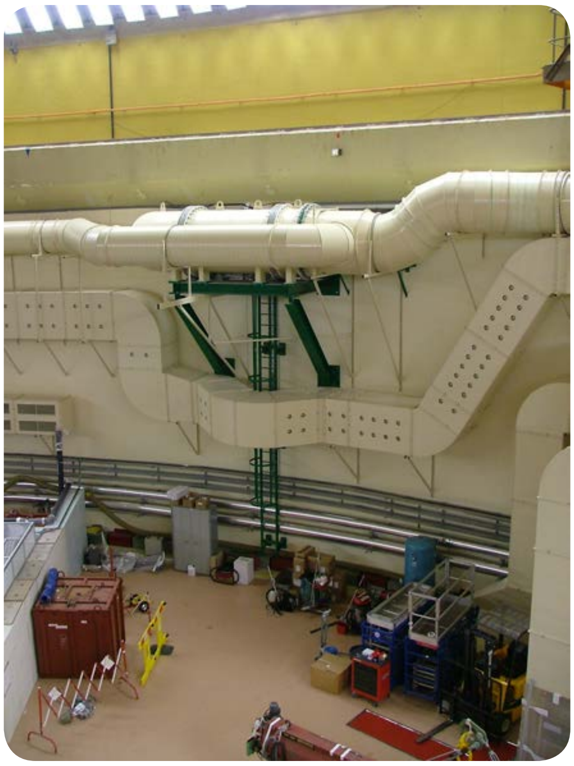
Reactor basement entrance

Truck entrance into the reactor building, level C (experimental hall)

To increase their seismic resistance, the **inlet and outlet structures** for the reactor building ventilation system were reinforced.

After work

Before work



Air inlet of the reactor building ventilation system

Air outlet of the reactor building ventilation system

Other safety-related work

AIR CONDITIONING AND VENTING SYSTEM

The air conditioning and venting system was an integral part of the concrete buildings situated on reactor level D.
The dismantling of these buildings (see p. 14) involved the renovation of the reactor ventilation system.

CONTROLLED ACCESS TO THE REACTOR BUILDING

For security purposes, an **exclusion zone** was set up around the reactor building to prevent unauthorized vehicles from accessing the vicinity of the reactor.

The control room for site security

Retractable bollards near the reactor building

DOUBLING OF THE REACTOR SAFETY CIRCUIT

This second safety circuit operating the protection relays has been installed in a new cabinet. It is powered independently of the other safety circuit.

The new independant safety circuit

PHYSICAL SEPARATION OF THE NEUTRONIC SAFETY SYSTEMS

The cabinets were reorganised to ensure a physical separation between the three neutronic safety systems.

Reorganised cabinet for neutronic safety systems

LIGHTNING PROTECTION SYSTEM

A lightning protection system for the buildings that present radiological risks was installed.

Lightning protection system

ILL4 building façade

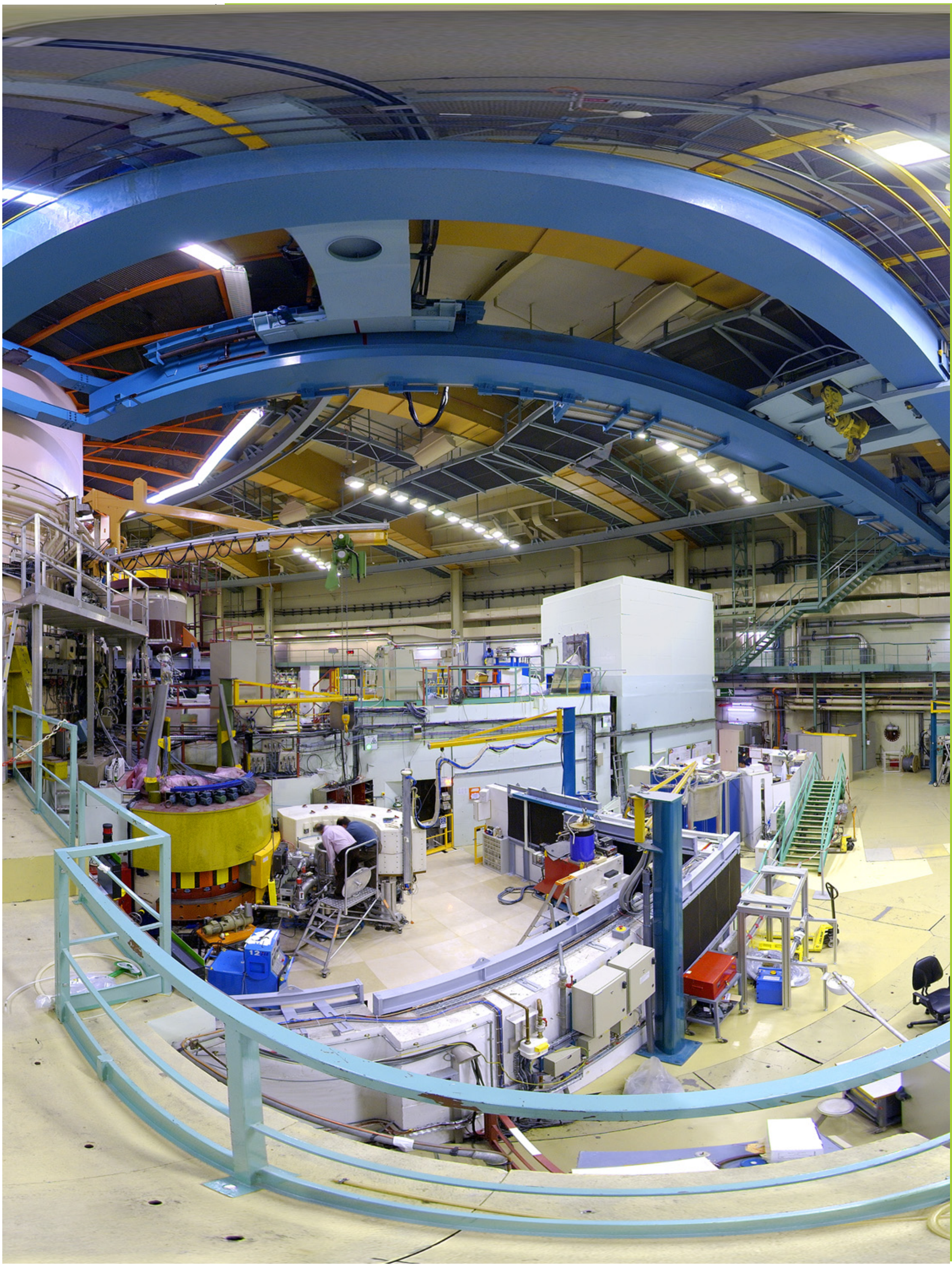
EARLY AUTOMATIC SHUTDOWN IN CASE OF AN EARTHQUAKE

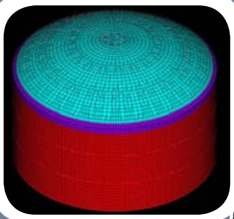
In the event of an earthquake, the reactor is shut down automatically in 2/3 logic as soon as the earthquake is detected. This also triggers the automatic cut-off of power supplies.

This early automatic shutdown of the High-Flux Reactor is possible thanks to new highly sensitive seismic sensors.

The newly installed seismic sensors

Notes





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