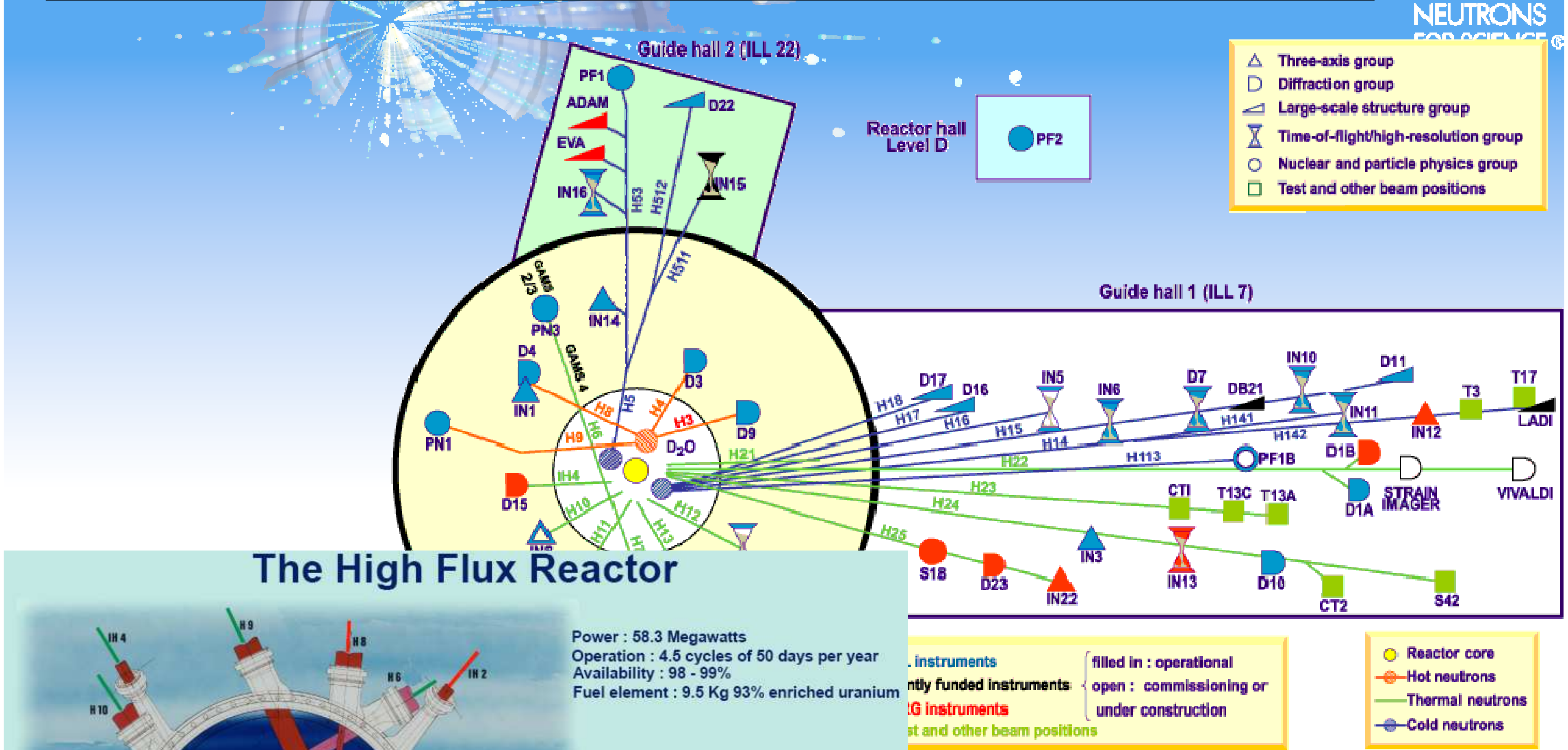
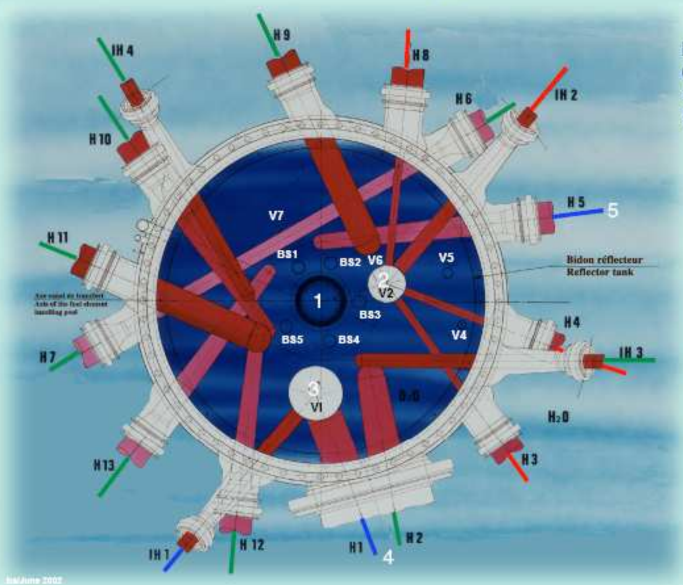
Refurbisment and Upgrade of ILL reactor and instrument suite

The joint ILL – ESRF – EMBL site

15 beam ports and 40 instruments



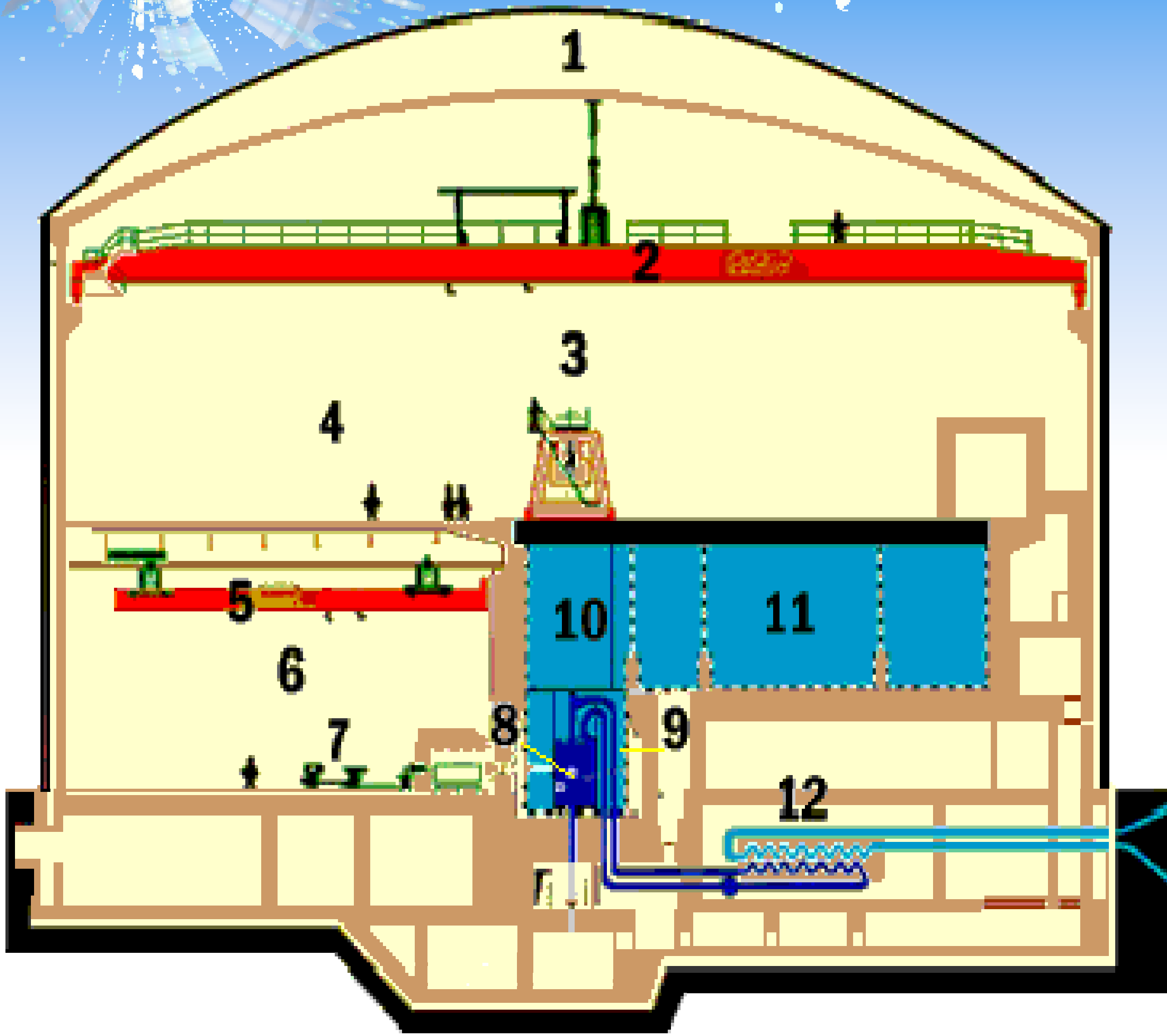
The High Flux Reactor



Power : 58.3 Megawatts
Operation : 4.5 cycles of 50 days per year
Availability : 98 - 99%
Fuel element : 9.5 Kg 93% enriched uranium

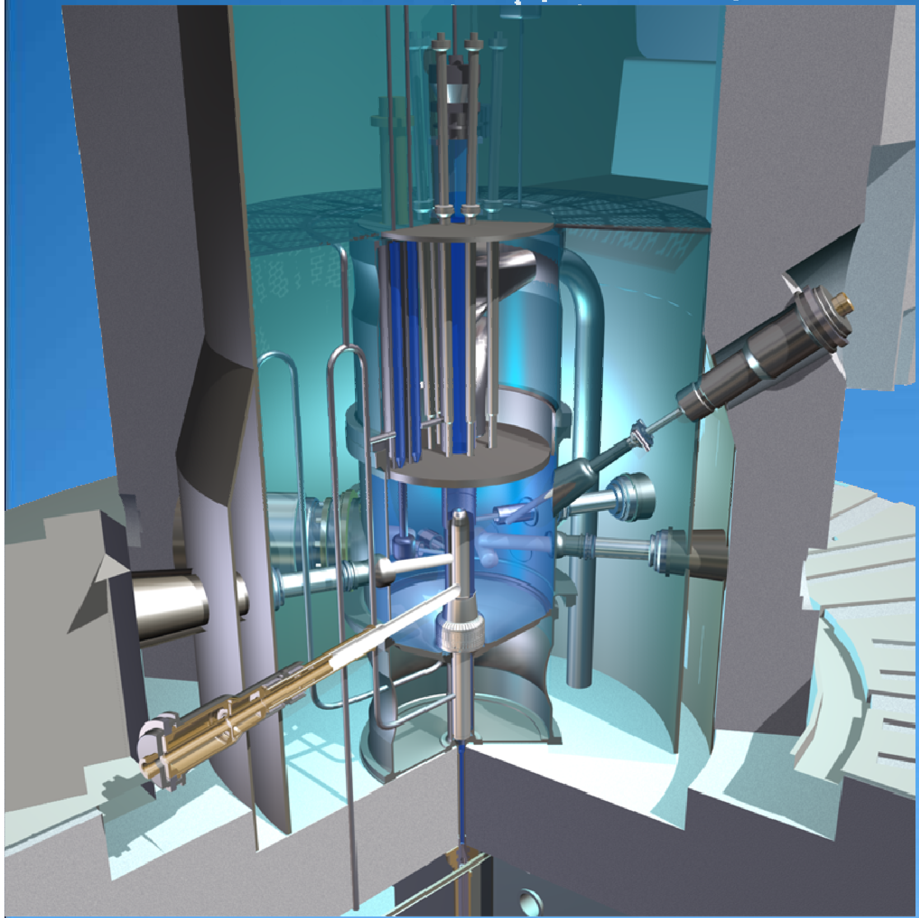
1 - reactor core
2 - hot source
3 - cold source
4 - neutron guides
5 - horizontal cold source
— Cold neutrons
— Thermal neutrons
— Hot neutrons
H - Horizontal tube
IH - Inclined tube

NEUTRONS FOR SCIENCE®

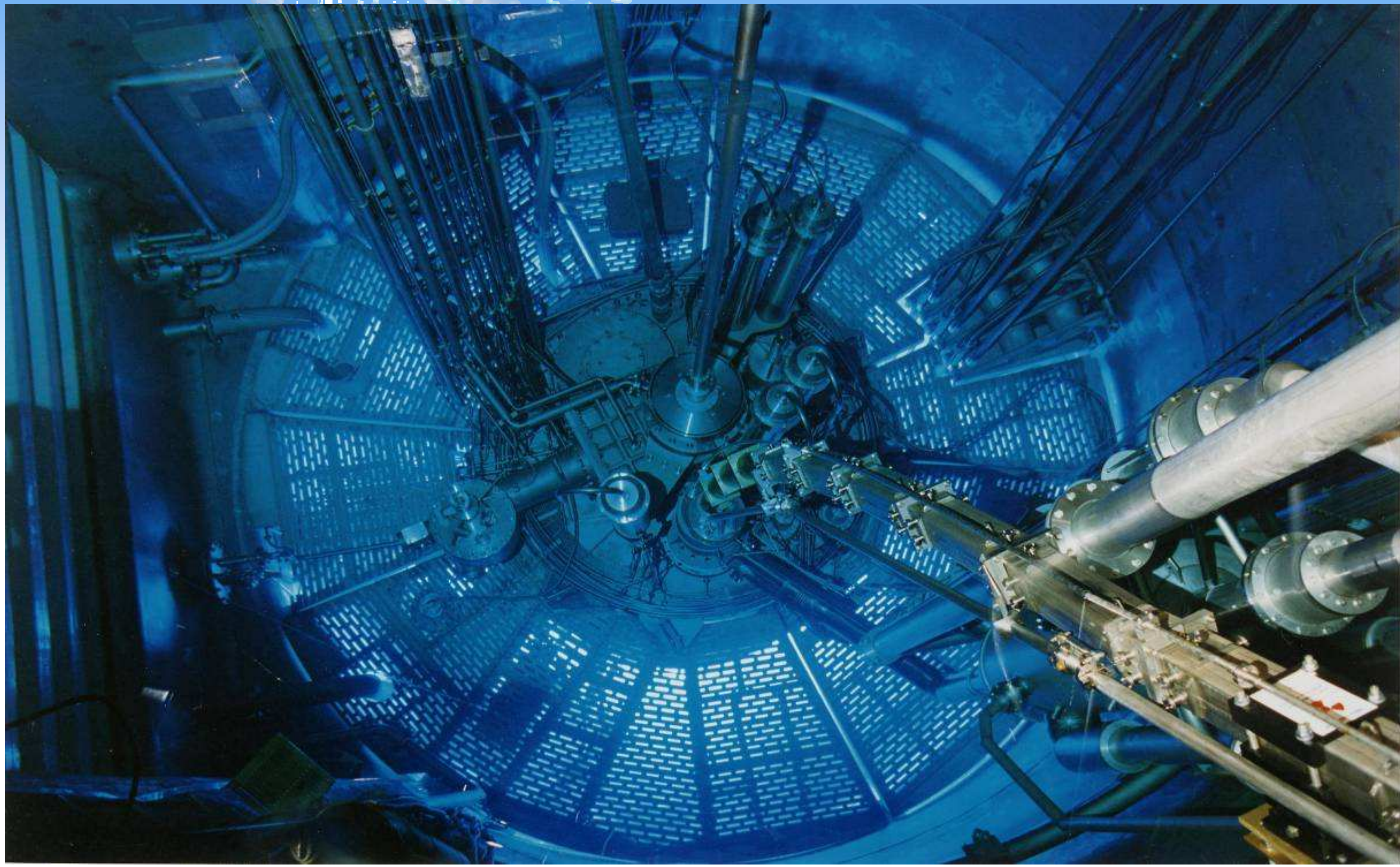


"RHF": the ILL reactor

5 x 10^{18} fast neutrons per second at 58.3 MW



200 days of operation per year
4 cycles – 58.3 MW



Through 4 consecutive decades, continuous refurbishment, upgrade and modifications have been carried out, on

- the reactor,
- the scientific instruments,
- the civil installations,

to maintain the ILL’s position at the forefront of international science

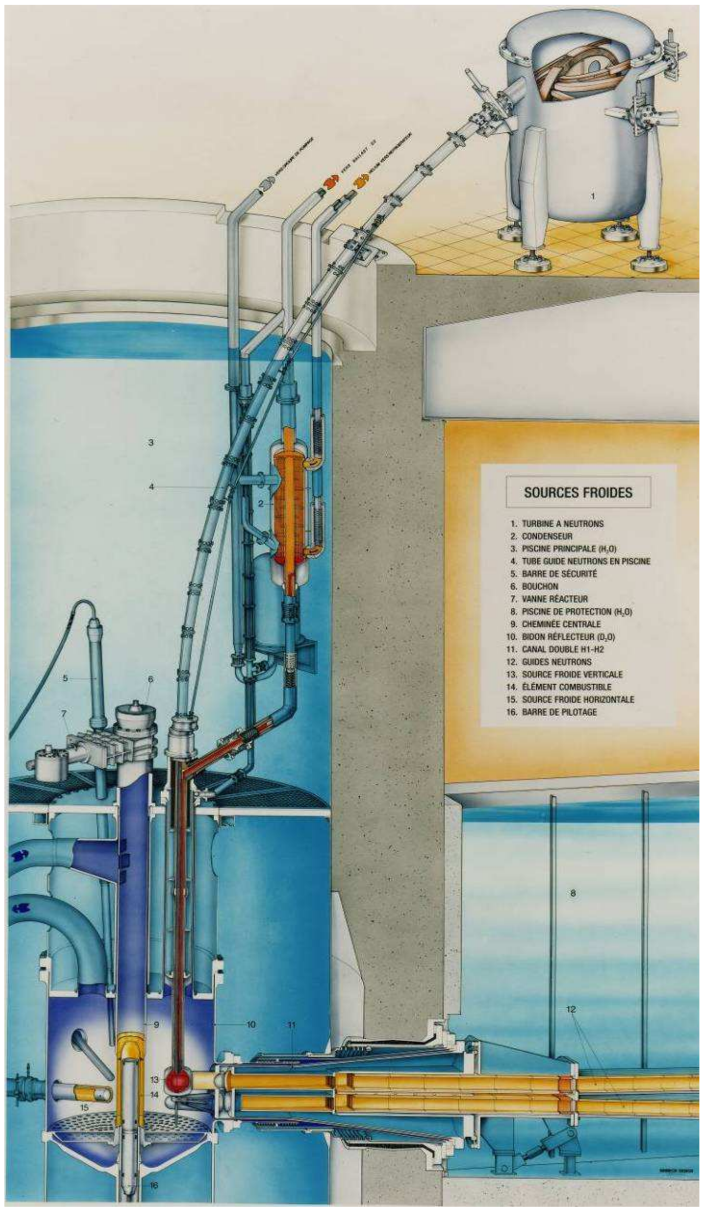
THE REACTOR:

1971	Start-up of the reactor
1985	a new Vertical cold neutrons source
1987	an additional Horizontal cold source
1991-1994	Replacement of the reactor vessel
2002-2007	REFIT program (seismic work)
2005-2017	Key Reactor Components program

RHF modernization and refurbishment: past

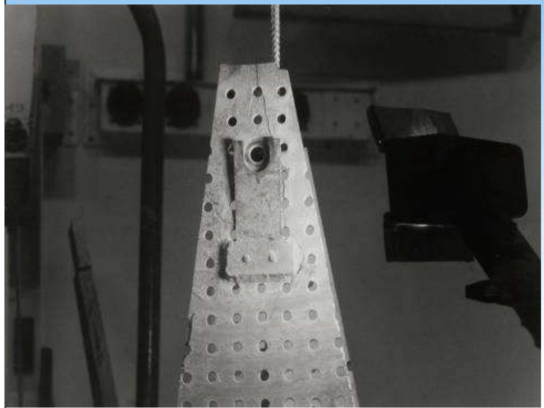
- **<u>1971</u>**: start-up of RHF, the world most powerful High Flux Reactor dedicated to neutron science

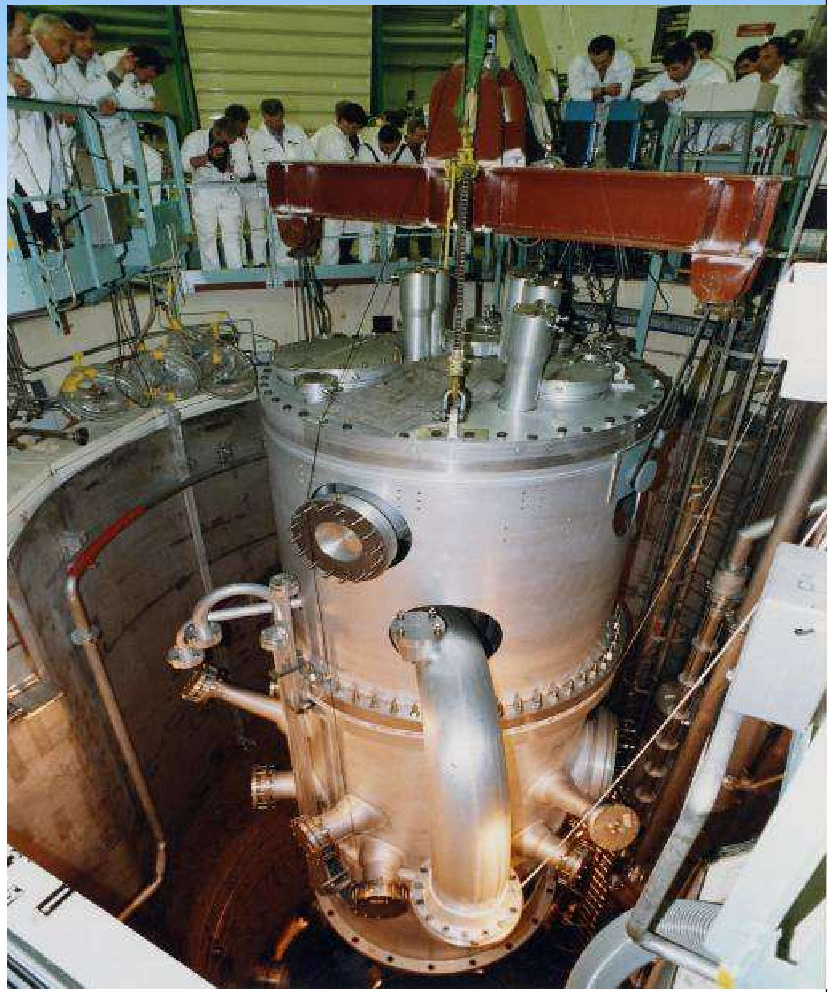
- **<u>1985</u>**: A new vertical cold source equipped with a vertical and curved guide tube connected with a turbine. This device feeds ultra-cold neutrons to the experimental instruments.
- **<u>1987</u>**: a second (horizontal) cold source. It is positioned at the front of a horizontal beam tube. It feeds the second guide hall, ILL 22.

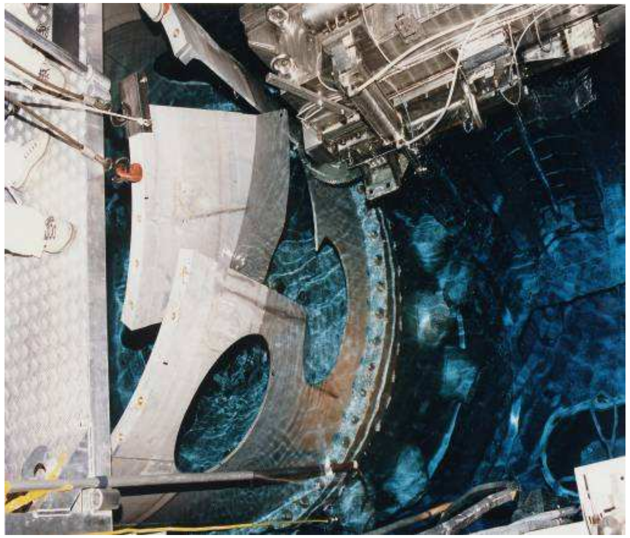


The Reactor

•From 1991 to 1994: replacement of the reactor block; observation of unusual marks on the upper antiturbulence grid.







The Reactor

•**2004:** replacement of the aluminium beam tube H9 by a zircaloy tube. This has extended its service life, allowing extended reactor operations and reduced radiation exposure for workers.

REACTOR OPERATIONS

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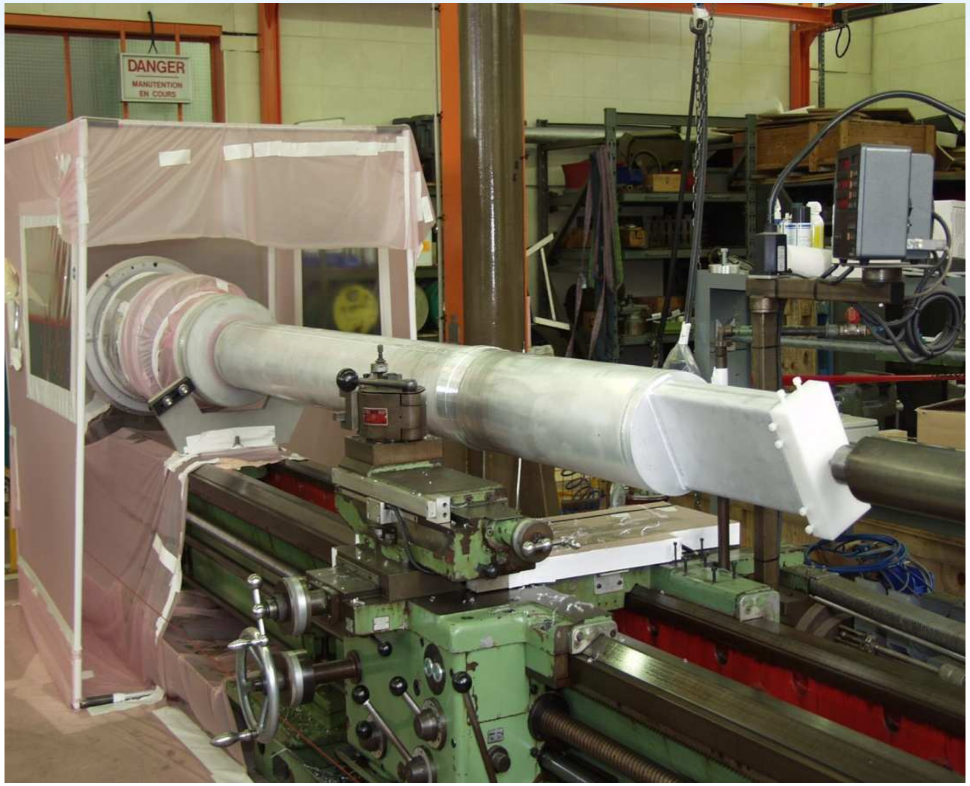
The H3, H4 and H8 beam tubes were installed, opposite the hot source.

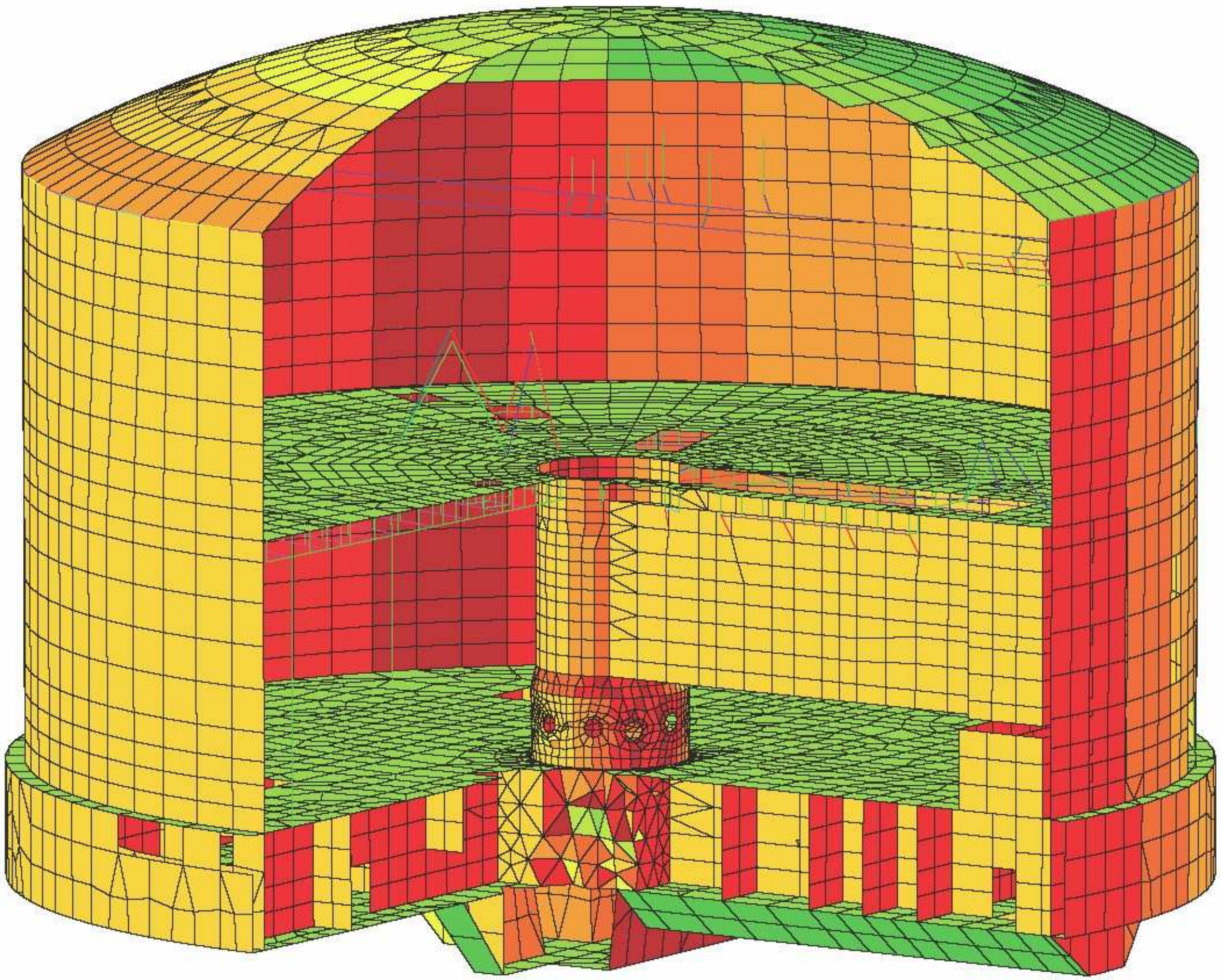
A new contract with the CEA is being signed, in order to examine the properties of irradiated aluminium.
The cost of these studies is being shared.



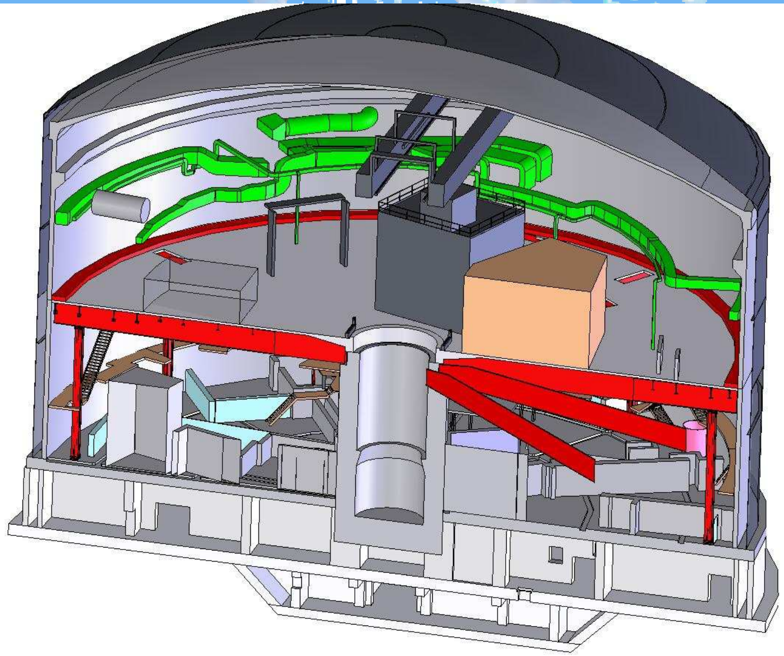
2002 - 2007
REFIT Program

2002 safety review led to the "REFIT program"

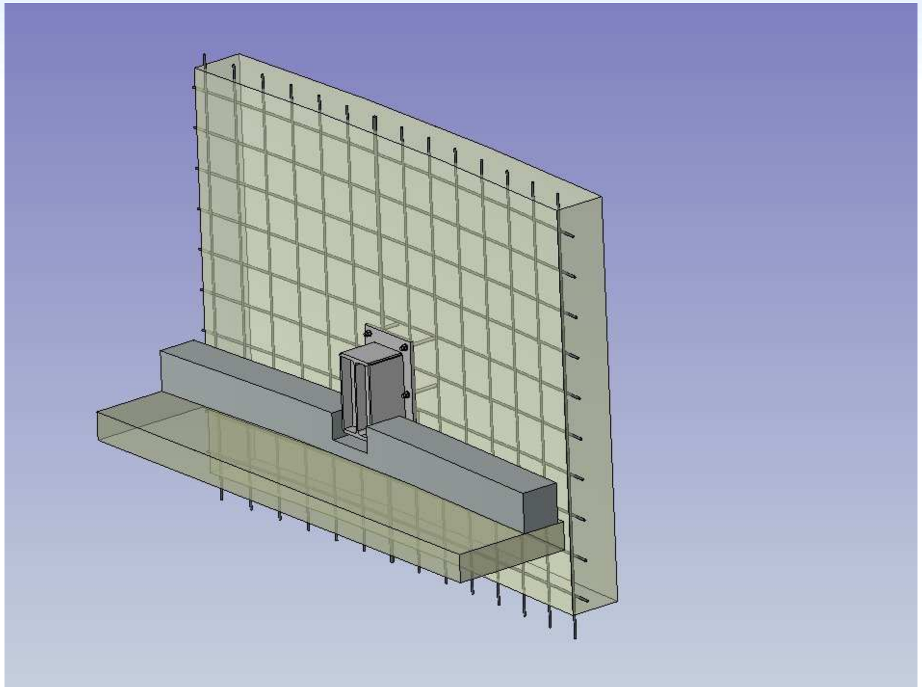
Modeling for seismic studies



Refit programme



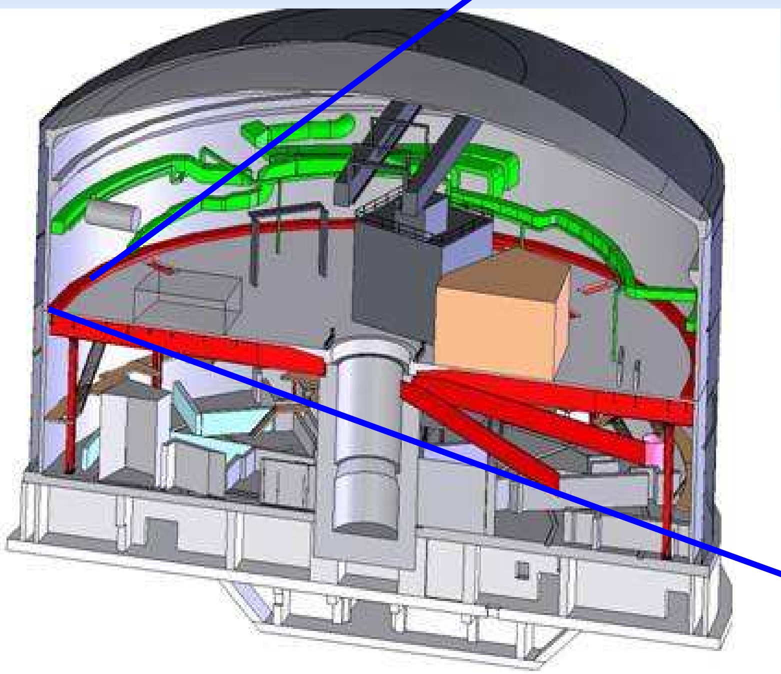
Removal of the buildings located along the periphery of the floor on level D



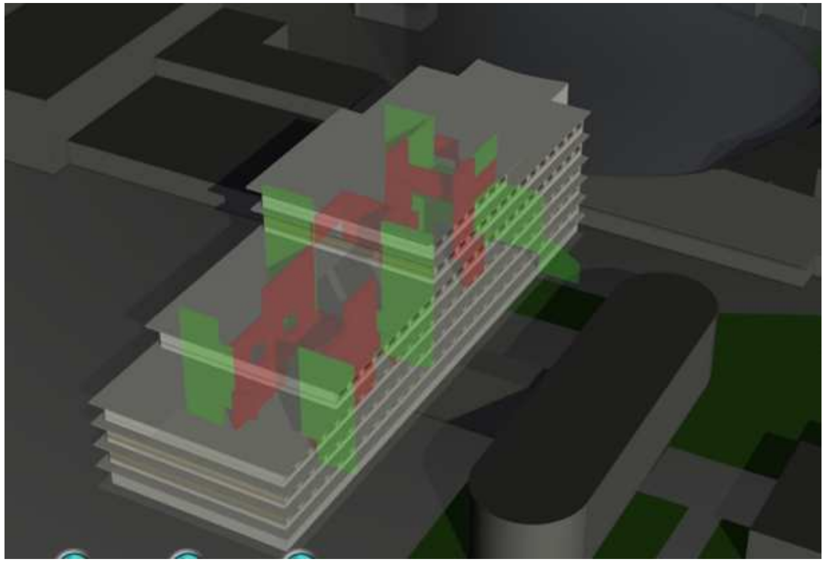
Reinforcement using the so-called "comb" solution

Seismic reinforcement of ILL5

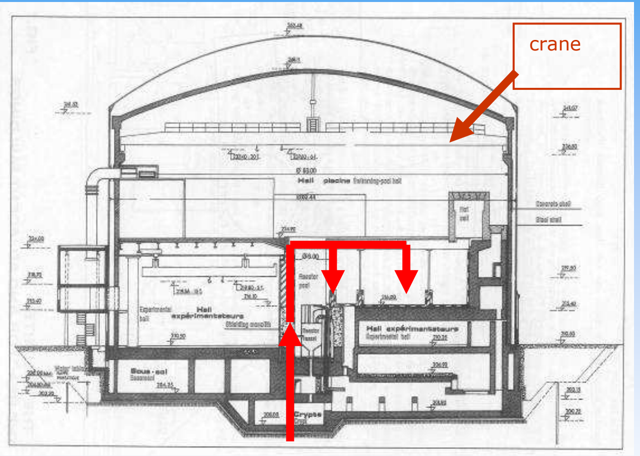
Reinforced reactor building:
- without its inner buildings on level D floor
- with orthoradial links between level D floor and the inner shell



Reactor : Refit Program from 2003 to 2007



Reactor : Refit Program from 2003 to 2007



REFIT Program

NEUTRONS FOR SCIENCE

2002 | 2003 | 2004 | 2005 | 2006 | 2007

Budget overview

Safety studies and EISS

Transfer canal rear block reinforcement

New storage room for fuel elements

Studies on the reactor block

Water tightness of reactor pool

ILL4 reinforcement

Studies on the stainless steel pool liner

ILL7-ILL22 modifications

29,6 M€

Studies on leaktightness of transfer canal

ND ex... water

27,2 M€

...calculations on heavy

Containment penetrations reinforcement

Emergency control room upgrade

Studies on polar crane

New rack for the water gates

Air intake building reinforcement

18,9 M€

Studie... thimbles

H1/H2 « carter pink » strengthening

Studies on canal handling gantry

Water makeup system

11,0 M€

...onic safety system physical separation

Automatic reactor shutdown system

Studies on outer metallic shell

Air intake valves seismic reinforcement

Ventilation renovation

4,6 M€

Studies on fuel transfer casks

0,7 M€

ILL5 internal buildings dismantling

Air outlet valves seismic reinforcement

Seismic strengthening of ILL5

New racks for spent fuel

Linear seismic analysis of ILL5

2002 | 2003 | 2004 | 2005 | 2006 | 2007

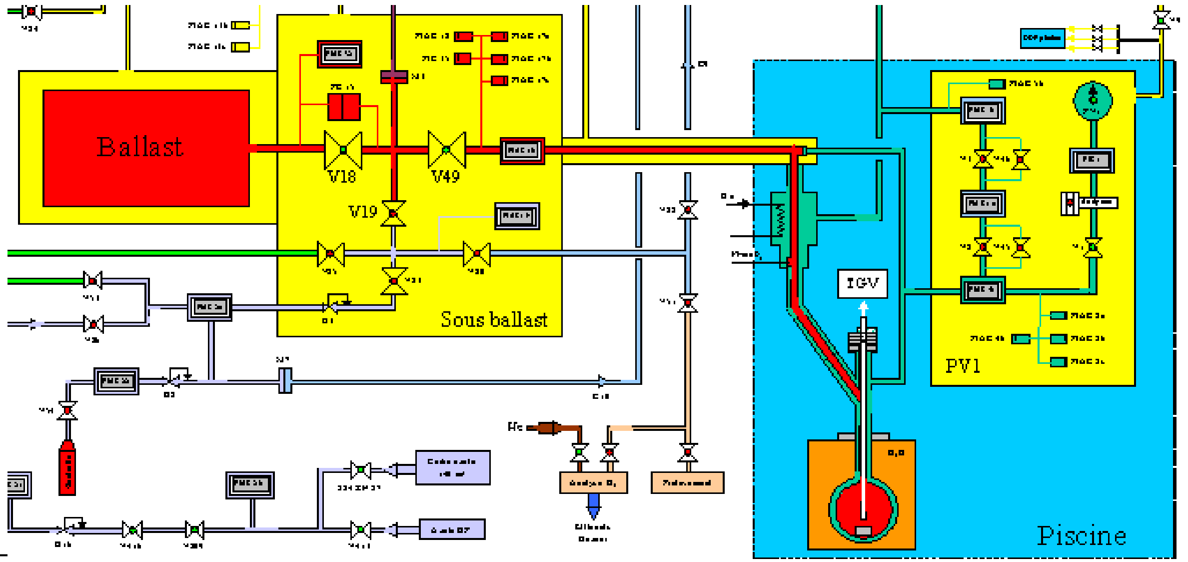
2005 - 2017
Key Reactor Components Program

NEUTRONS FOR SCIENCE®

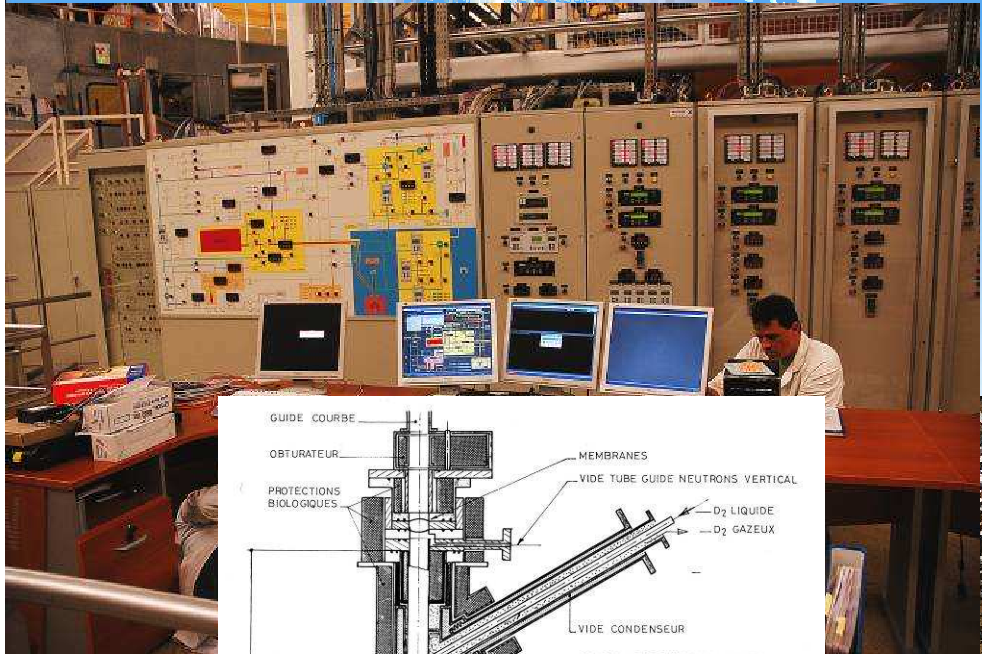
Key Reactor Components

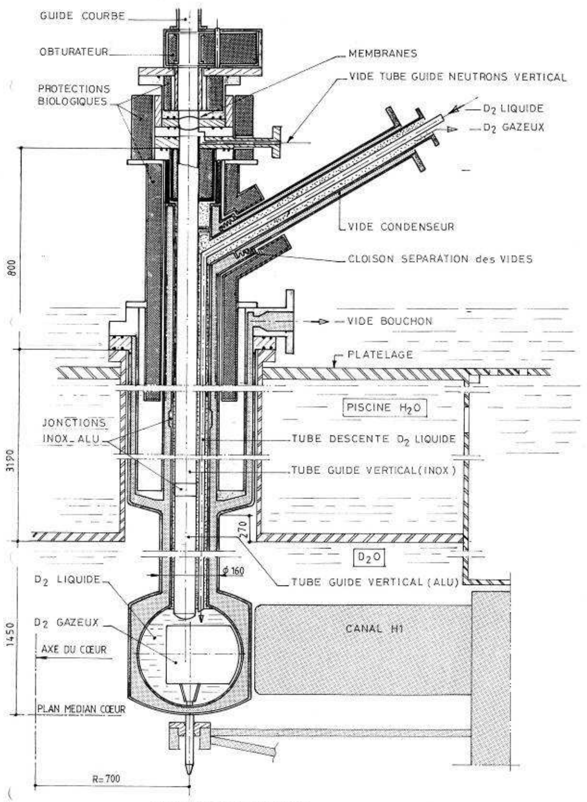
The aim of the **Key Reactor Components programme** is to guarantee reliability until 2024. Indeed several important systems have been operating for 35 years. The main focus of this programme is on:

- Safety rods, 12 new safety rods, project for a new design **(on-going)**
- **Vertical cold source: renewal of the instrumentation and (digital) control system, and renewal of the pressure-resistant housings; (accomplished during the Refit Programme, taking advantage of the long 2005-2006 shutdown)**



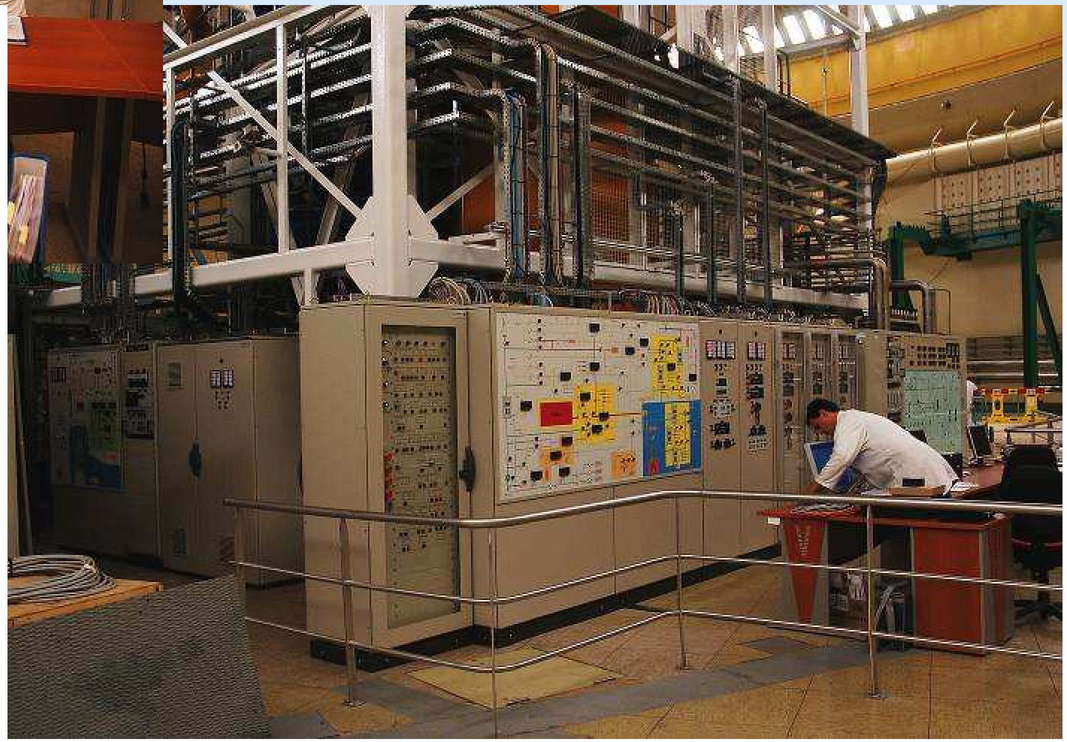
Key Reactor Components





SOURCE FROIDE

Schéma du bouchon SFV3 avec tube guide



Key Reactor Components

Fuel handling devices: Renewal of the instrumentation and control system with a digital one (done during the Refit Programme, taking advantage of the long 2005-2006 shutdown)

RHF modernization and refurbishment: KRC

Key reactor components

- <u>High-tension facility</u>: high-tension antenna, cells and transformers have been replaced with a conversion from 15 to 20kV (carried out in 2007)

RHF modernization and refurbishment: KRC

Key reactor components

- ❖ <u>Overhead polar crane</u>: part of the seismic reinforcement of the facility (planned for completion in November 2009)

RHF modernization and refurbishment: KRC

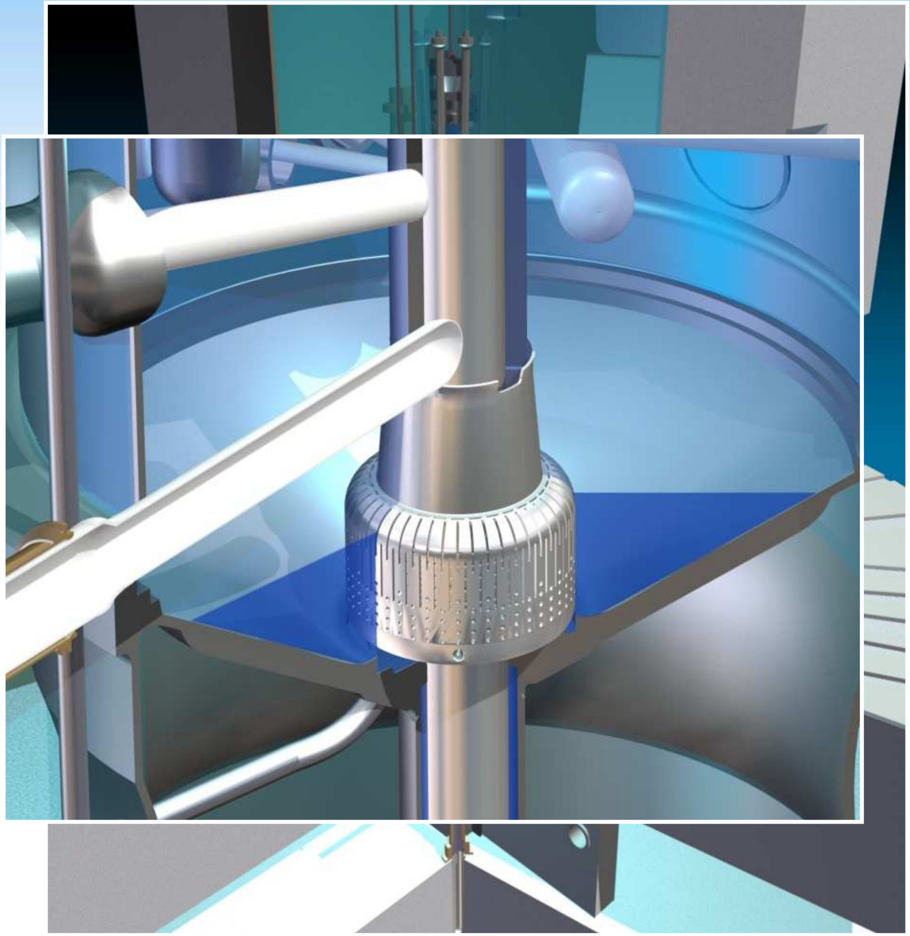
Key reactor components

- <u>Beam tubes</u>: many will have to be replaced in the near future and some of them will be manufactured in zircaloy instead of aluminium

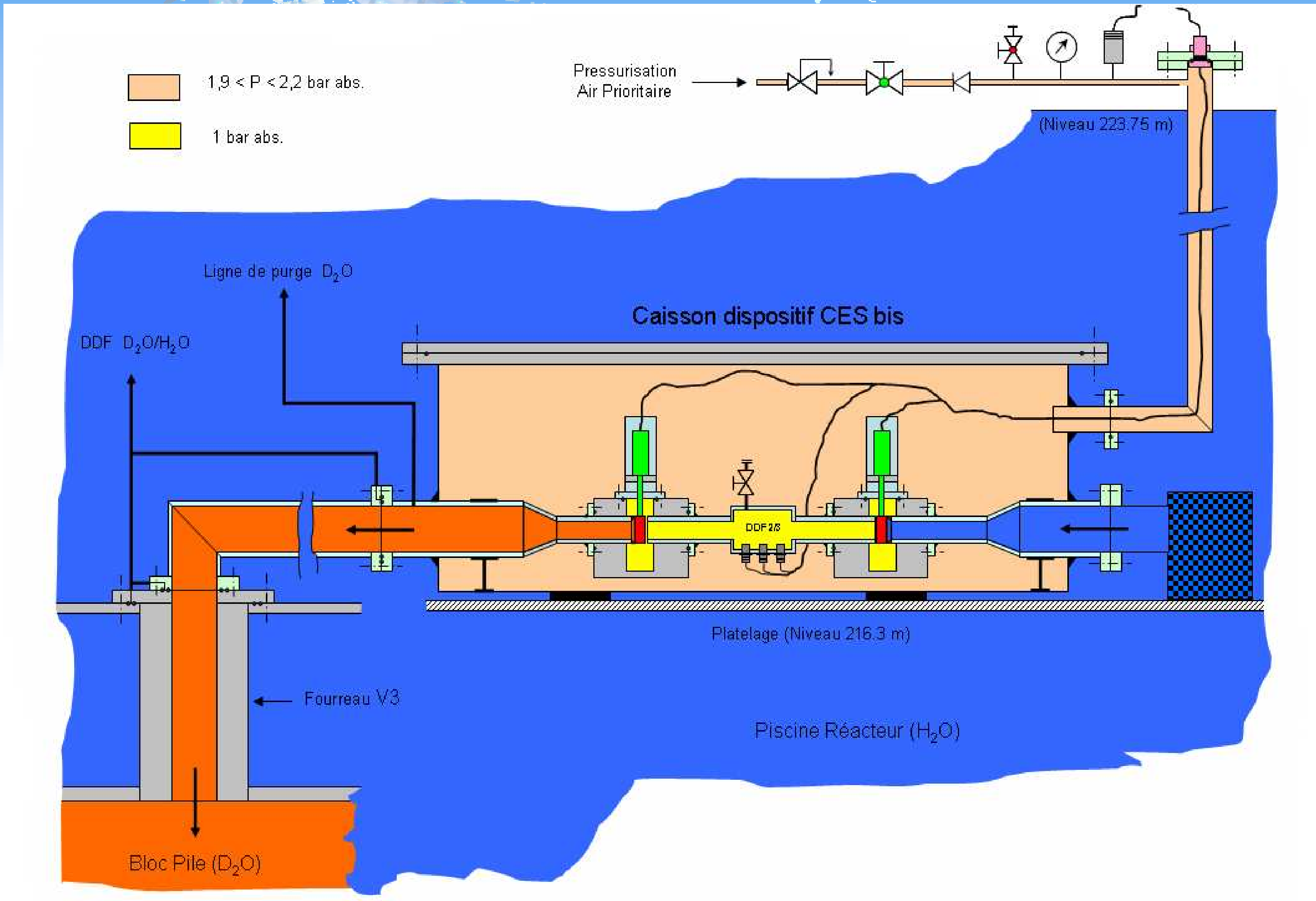
RHF modernization and refurbishment: KRC

Key reactor components

- ❖ Reactor vessel: anti-turbulence grid periodic replacement (early 2010)



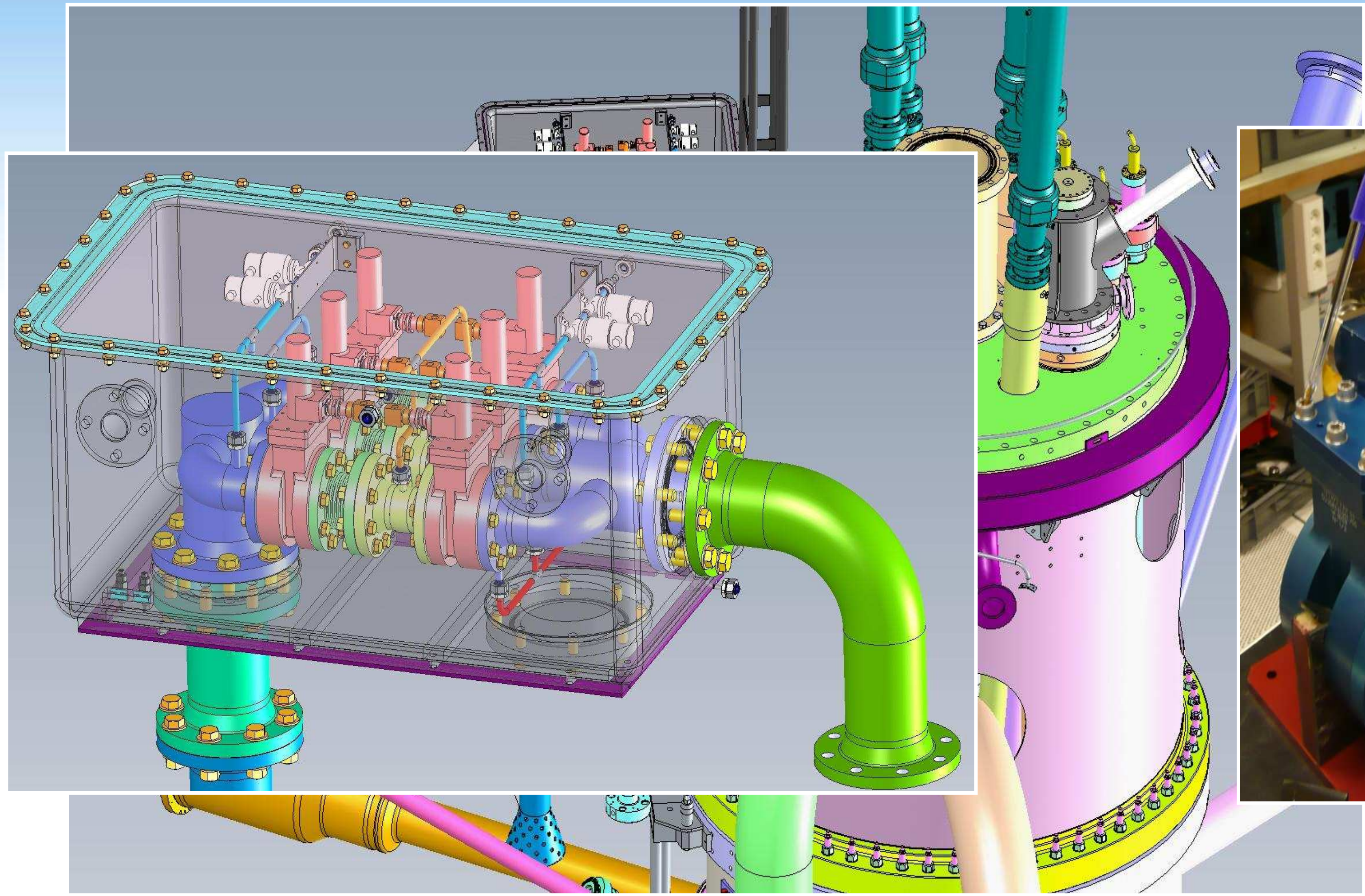
Emergency reflood circuit



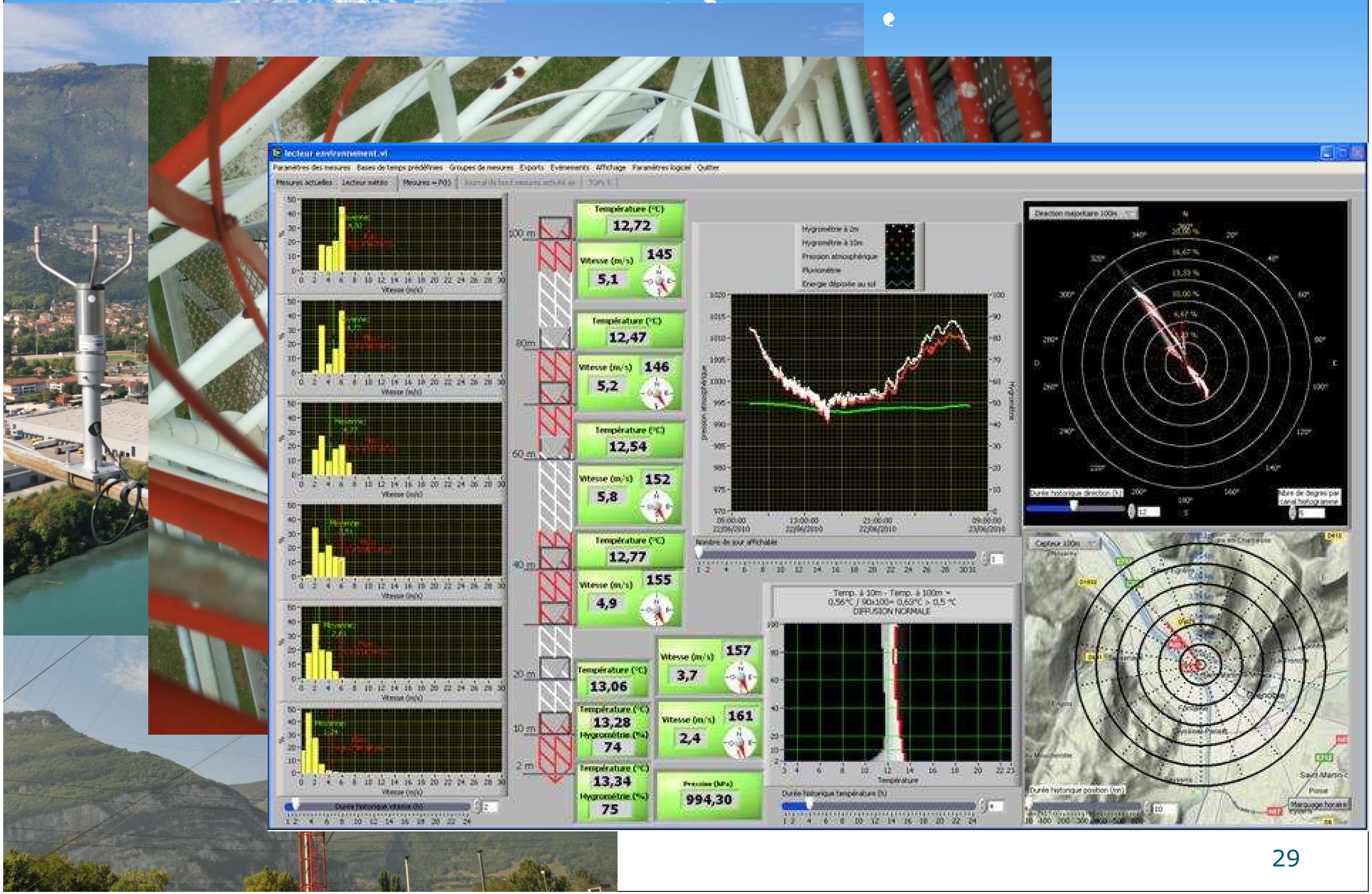
RHF modernization and refurbishment: KRC

Key reactor components (continued)

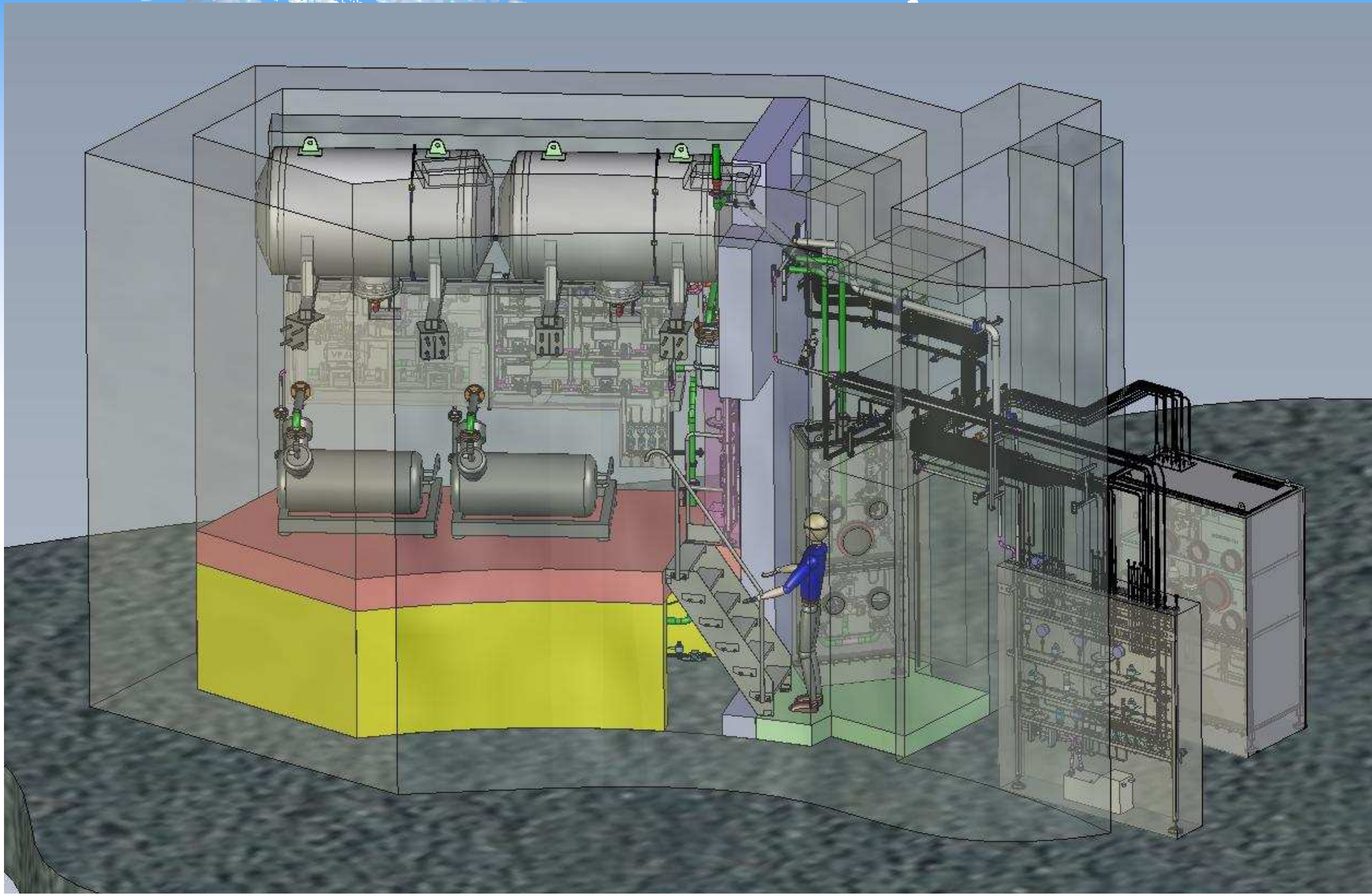
- <u>Primary circuit</u>: the emergency core reflood circuit using pyrotechnic valves (work carried out in 2010)



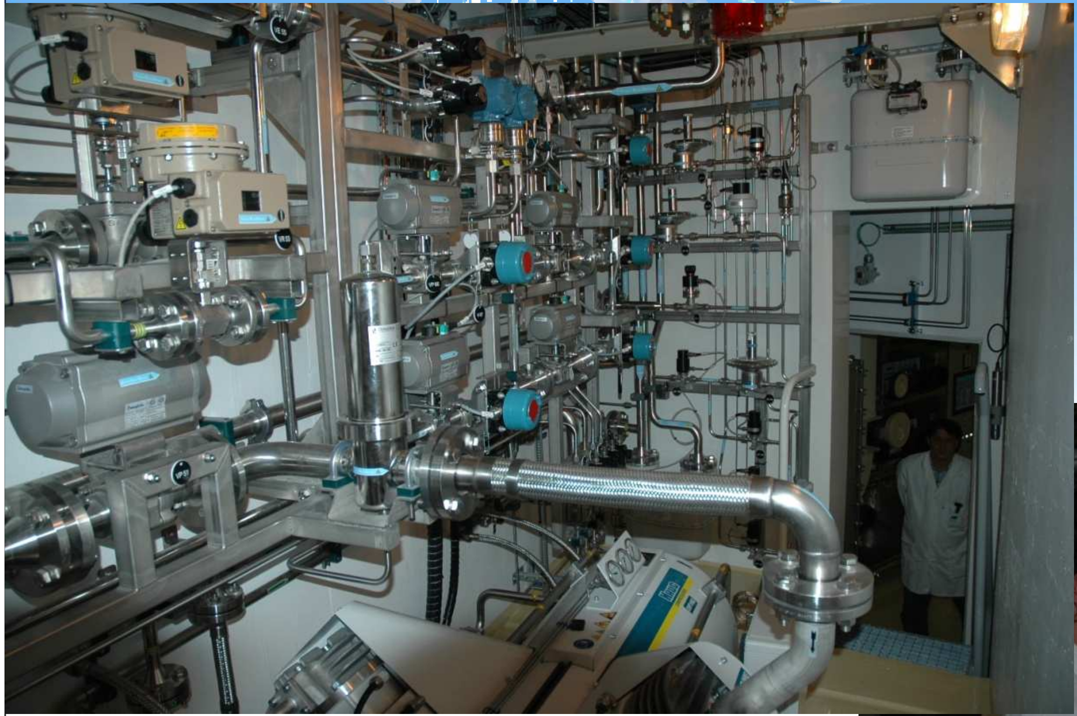
Winter Shutdown 2009/2010



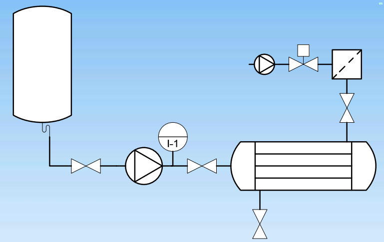
Gaseous decay tank



Gaseous decay tank



Info flash Groupe Fluides de la DRe



11/03/2010

Drac river filters replacement

Ces derniers jours, TB 38 a agrandi l'ouverture dans le plancher et effectué les arases nécessaires en fond de fosse

Fond de fosse nue avec bonde de dessablage

Hier, mercredi 10 mars, nous avons reçu et mis en place le nouveau filtre Beaudrey.
Son installation va continuer pendant quelques jours…

RHF modernization and refurbishment: Heavy water management

Key reactor components

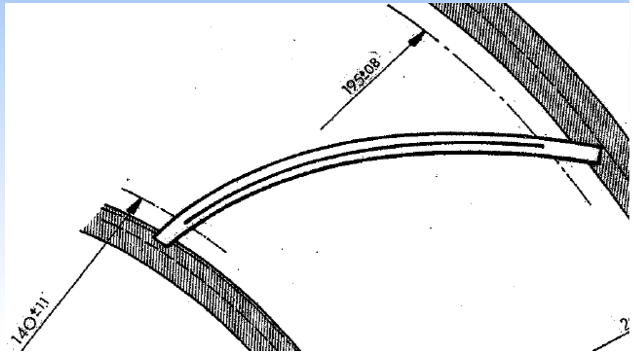
- Heavy water management: The decision not to refurbish the detritiation facility (2008) implies new facilities for sending the reactor's heavy water for processing and re-importing treated heavy water (studies in progress)

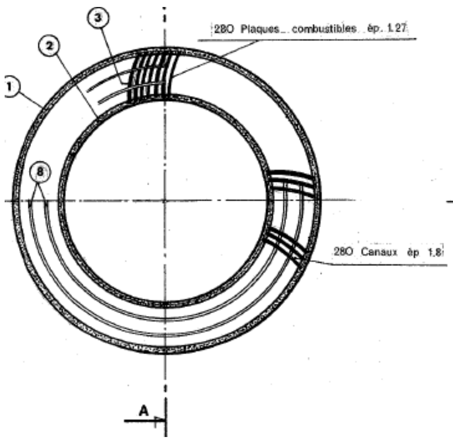
Fuel conversion from HEU to LEU

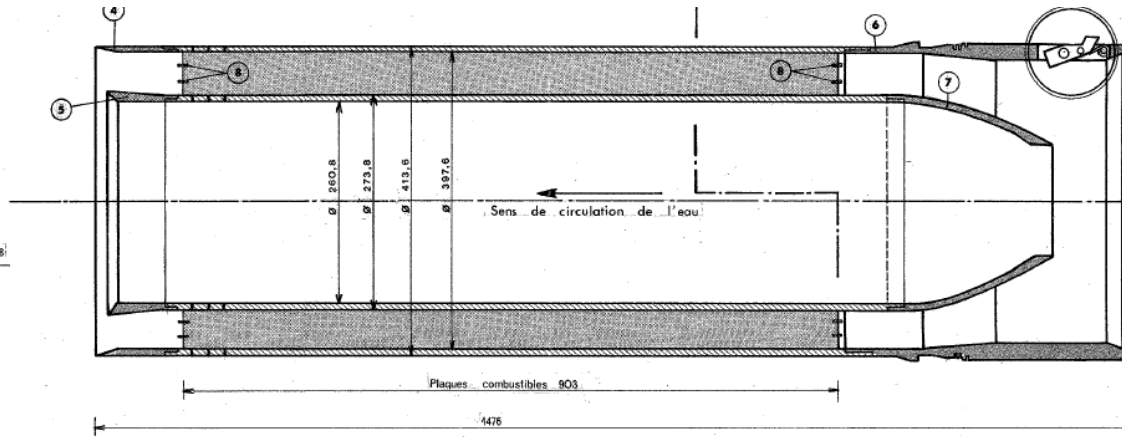
The ILL neutron source

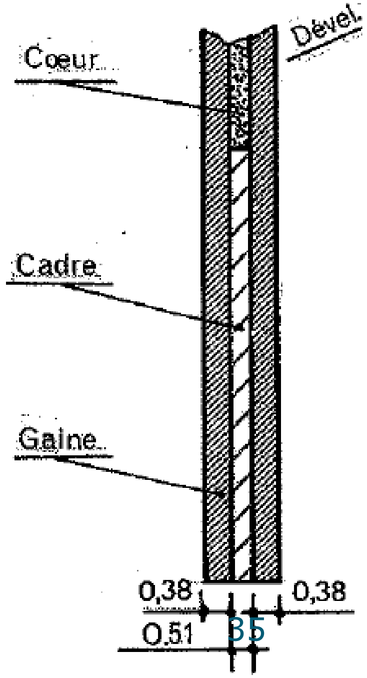
10 kg of uranium 235 inside the single fuel element:

- 1.2 g/cm3 with 93% enriched uranium UAlx in an Al matrix
- 6 g/cm3 > 20% U3Si2 / Al matrix
- 8 g/cm3 20% UMo / Al matrix
- 16 g/cm3 20% monolithic UMo

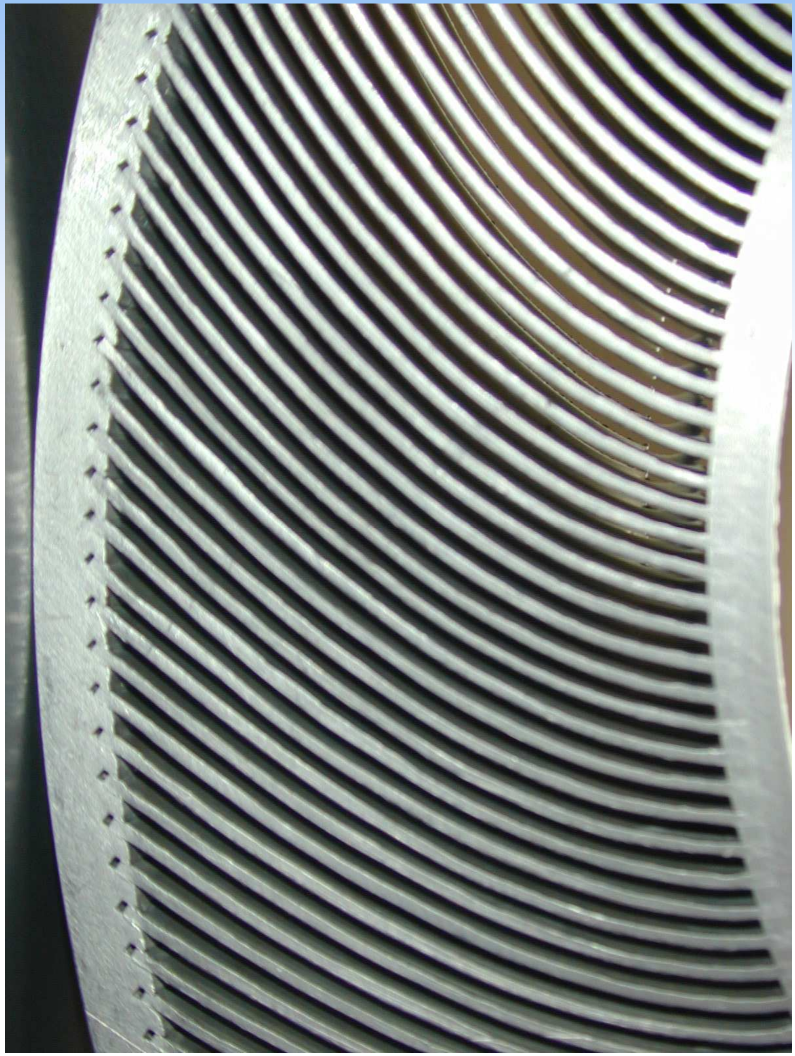


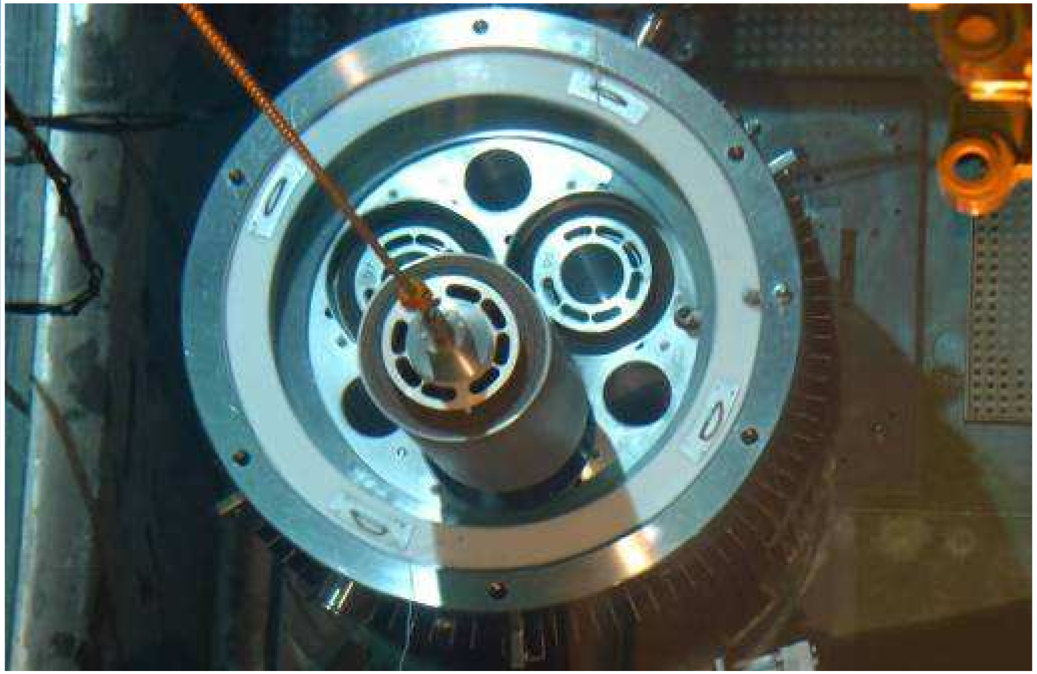


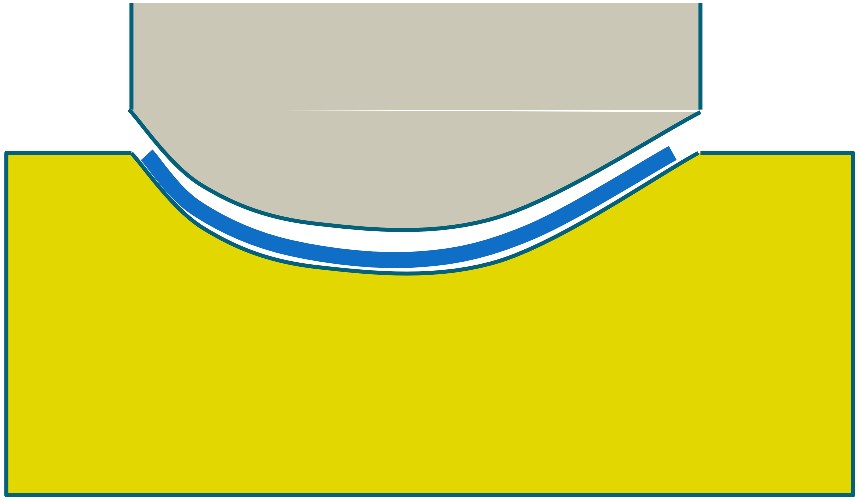




Consequences on fuel-plate fabrication







Safety analysis

- Neutronics studies
- Thermo-hydraulic studies
- Mechanical studies
- Fuel qualification
- Standard and accidental behaviour & impact
- Mock-up
- Inspection after first irradiation (visual, gamma-scanning, thickness ...)

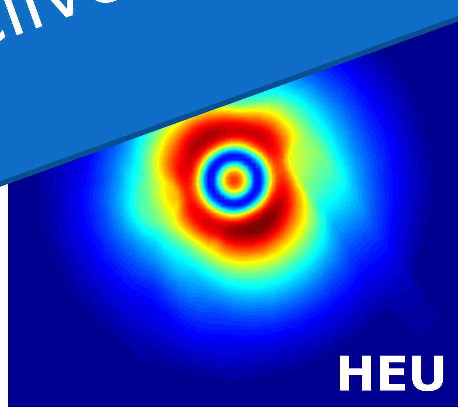
Long-term perspectives for ILL's neutron source

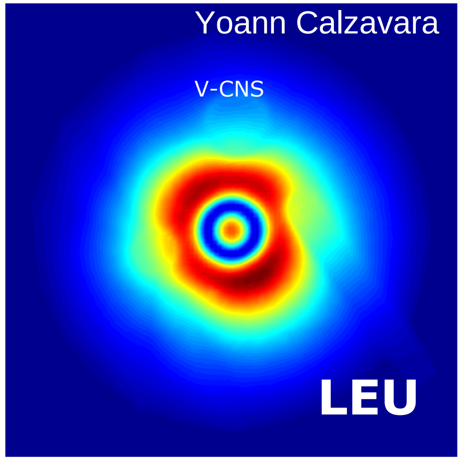
- External detritiation of he…
- Conversion fr…
  - (MoU 8 g/…
  - …

- Supply of HEU fuel

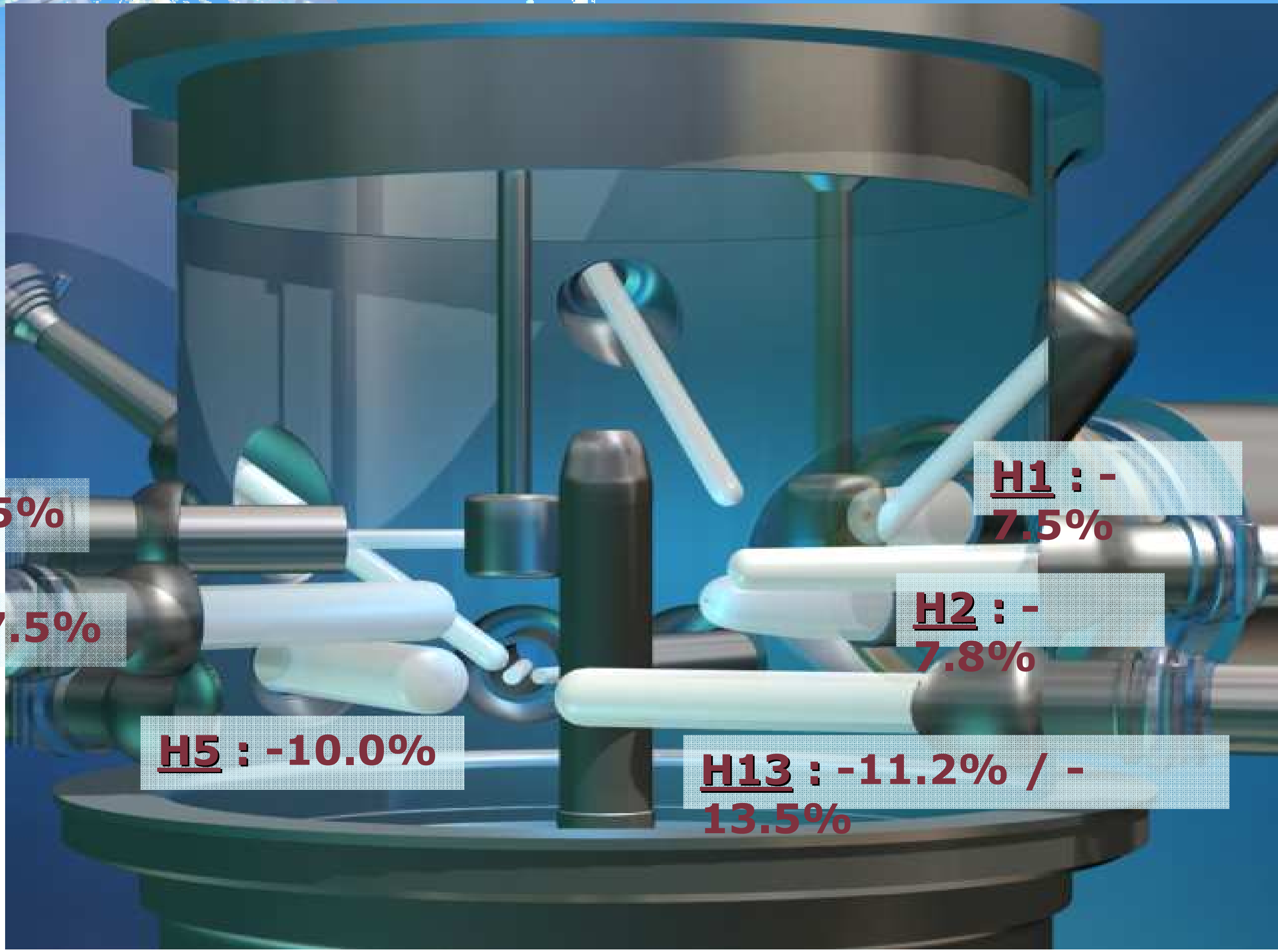
HEU export licence submitted to DOE in 2010 .

Delivery in 2012

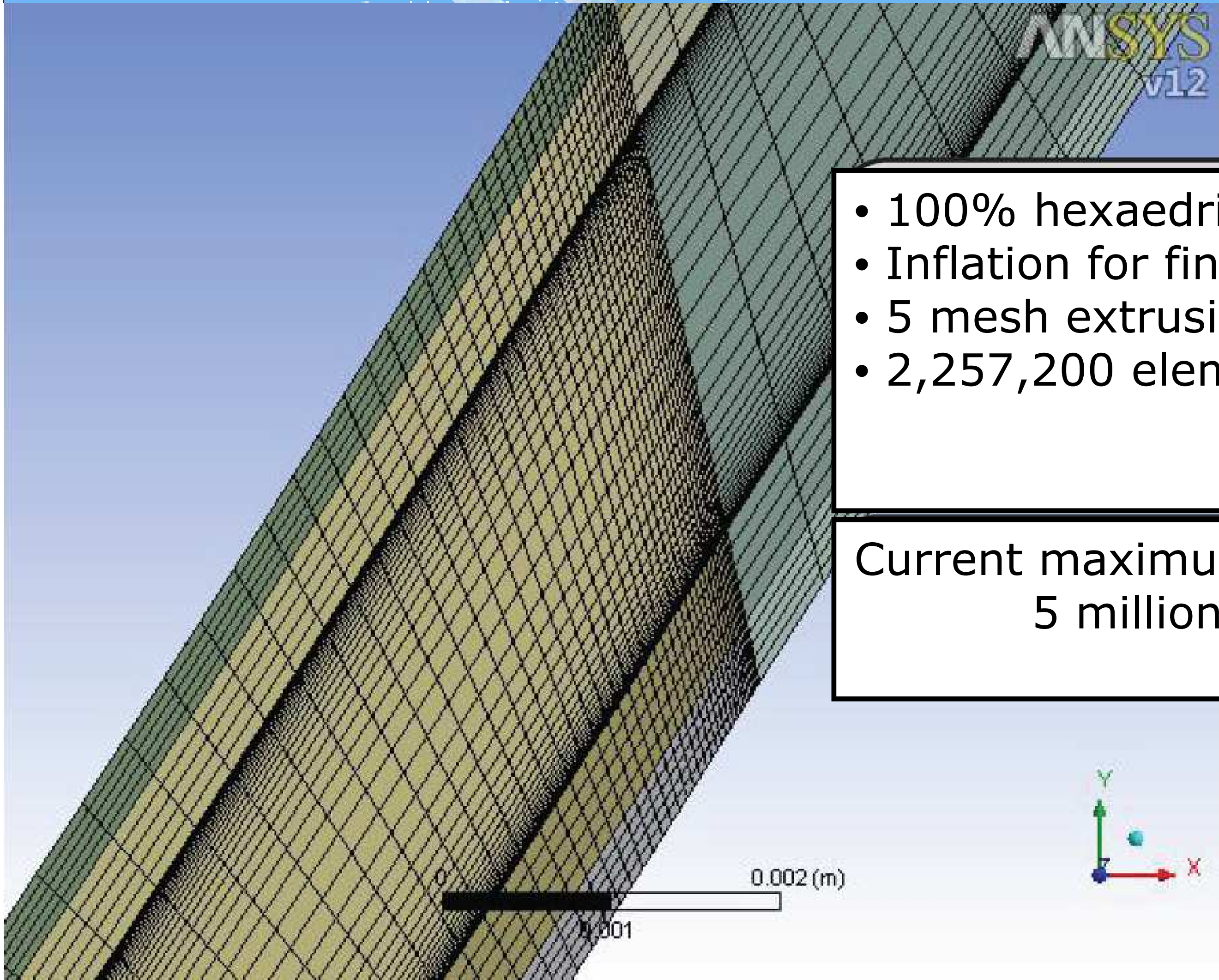




Fuel management : LEU conversion



Calculation mesh



- 100% hexaedric
- Inflation for final levels
- 5 mesh extrusions
- 2,257,200 elements

Current maximum calculation :
5 million elements

$$\overline{y}^{+} \approx 8 \text{ à } 9$$

$$y \approx 10 \mu m$$

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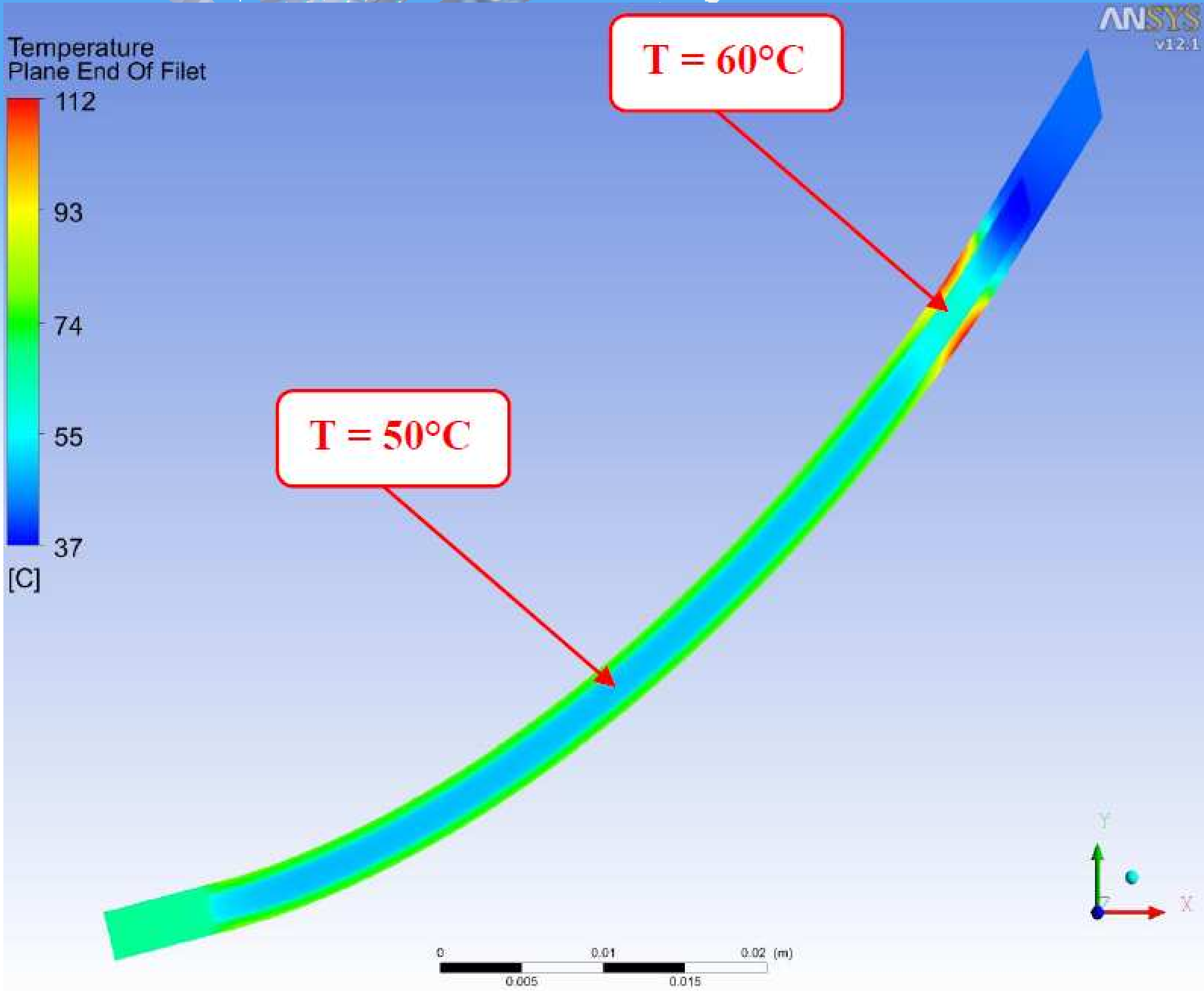
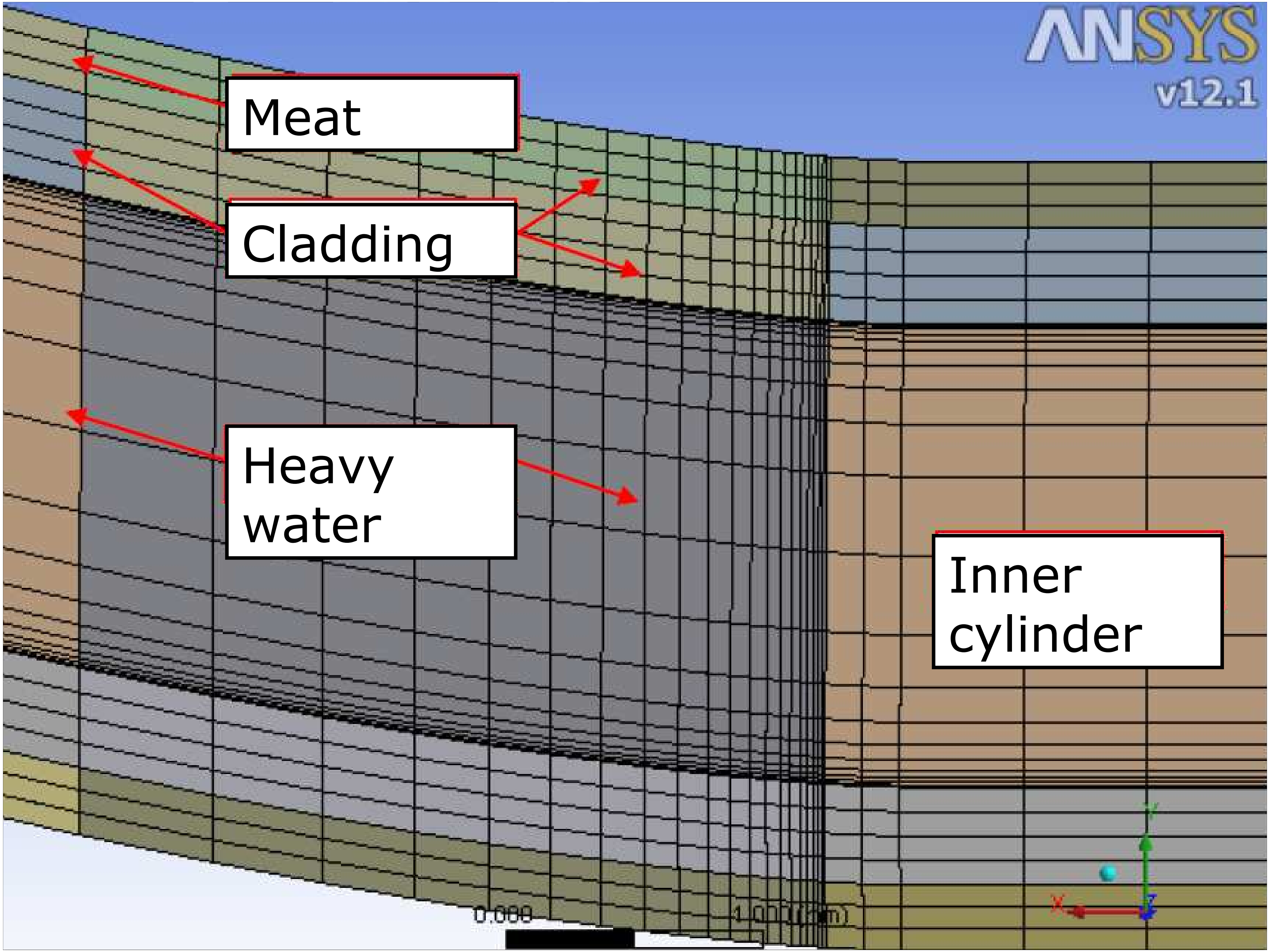
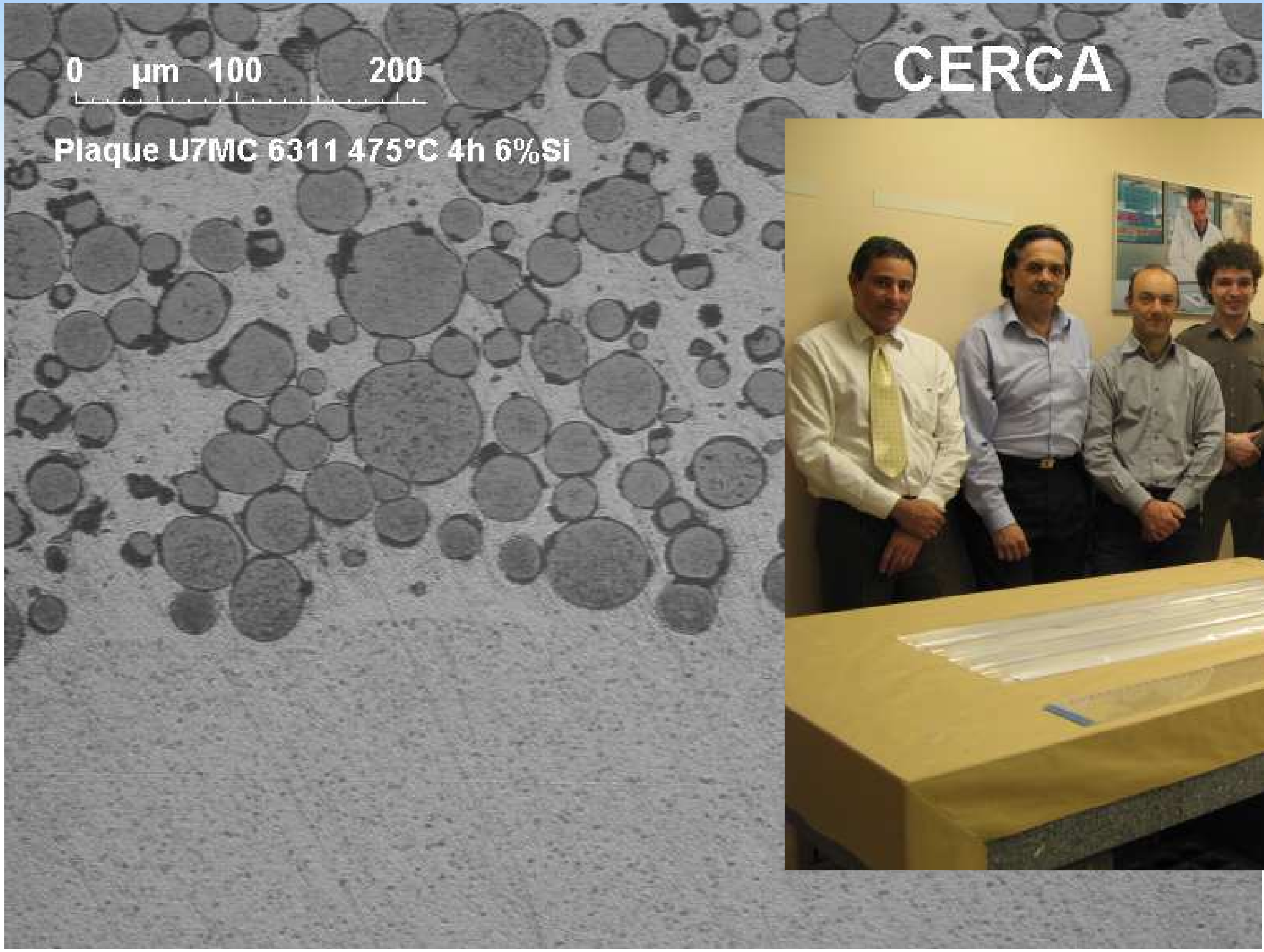


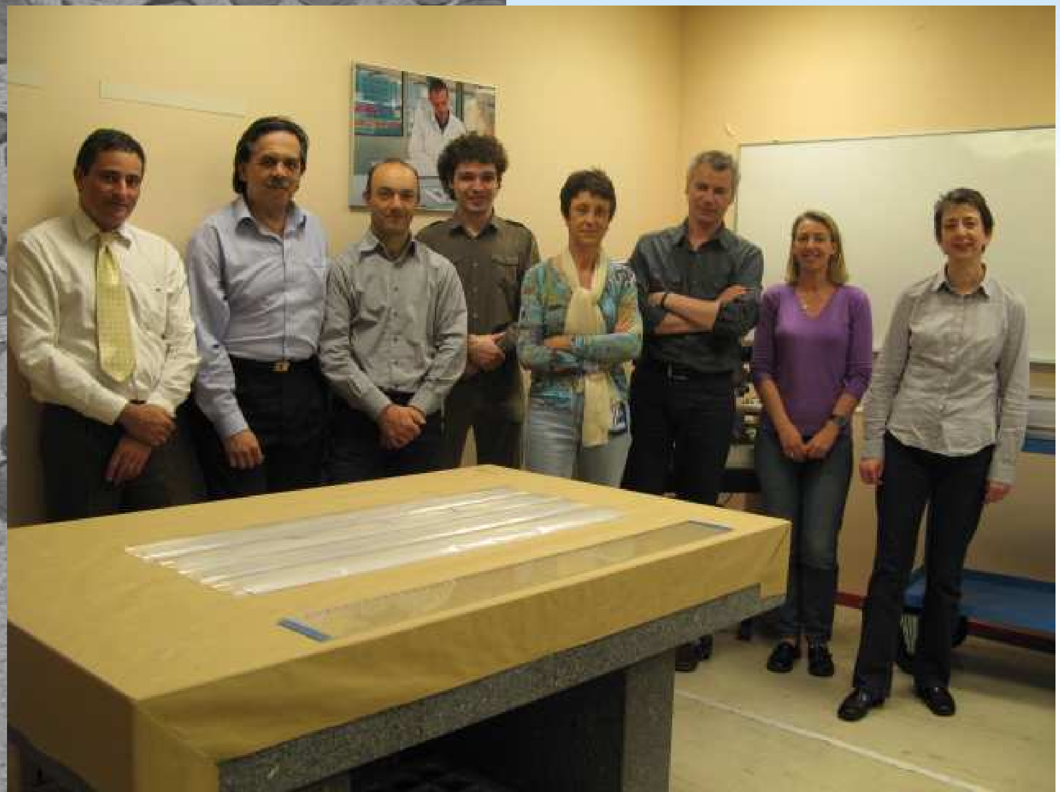

ANSYS
v12.1
Meat
Cladding
Heavy water
Inner cylinder
0.000
1.000 (m)

Fuel management

Lowly Enriched Fuel Element

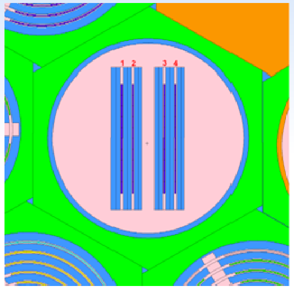
- **LEONIDAS programme : E-Future test in BR2**





LEONIDAS Experimental Program

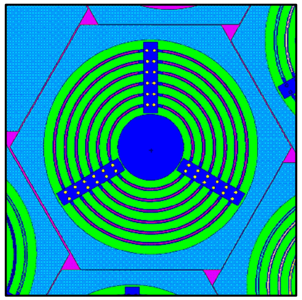
- International results show that the addition of Si to the matrix stabilizes growth of the interaction layer between UMo and Al matrix



- But last fuel parameters, as Si content in Al matrix & final thermal treatment, have to be carefully chosen in close correlation with the high power operating conditions, and then validated under irradiation

➔**This is the objective of the 1st LEONIDAS Irradiation test**

« E-FUTURE »



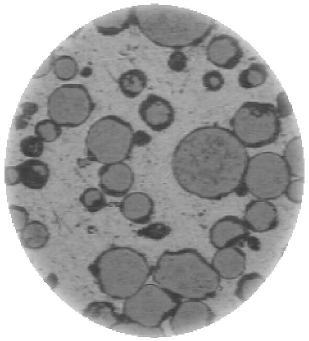
- Therefore, there is an absolute necessity to test the best combination of these parameters under representative conditions of high performance research reactors (470 W/cm², 11 m/s for BR2; 500 W/cm², 17 m/s for RHF)

➔**This is the objective of the 2nd LEONIDAS Irradiation test**

BR2 « Mixed Element »

Test Matrix of E-FUTURE

- Fuel parameters chosen for the E-FUTURE test (September 2009 with GTRI Reactor Conversion program representatives) :
  - Si content : 4 & 6%
  - Final TT : Std (425°C-1h) to very high TT (475°C-4h)



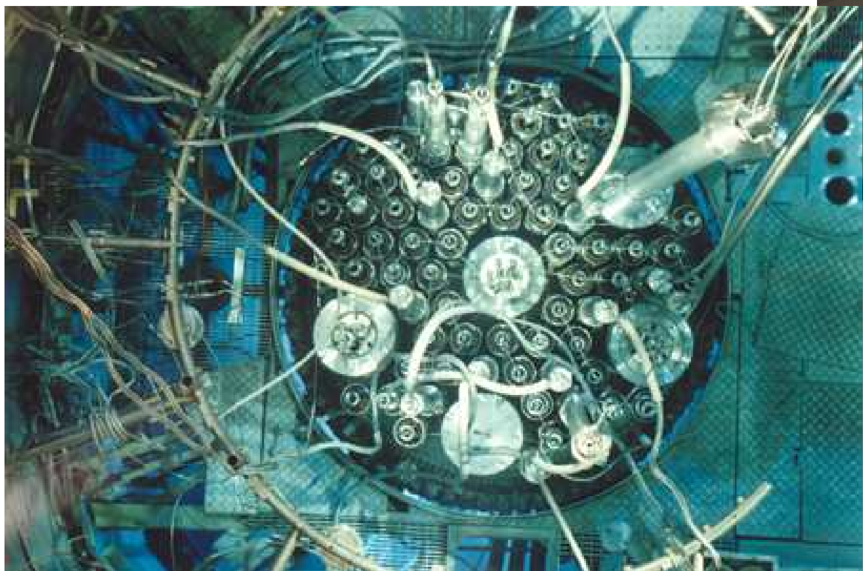
Si content	Final Thermal Treatment
4%	425 °C x 2h
	475 °C x 2h
6%	425 °C x 2h
	475°C x 4h

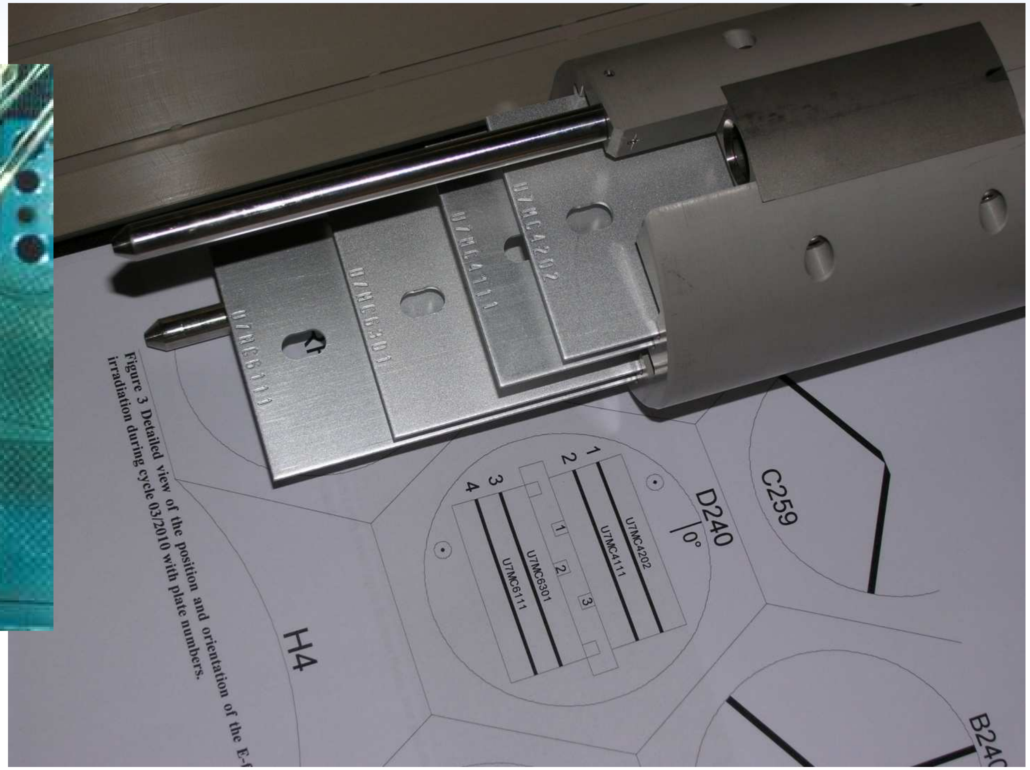
E-FUTURE Irradiation in BR2

- E-Future basket

E-FUTURE Irradiation in BR2

- Irradiation objectives
  - Pmax ≥ 450 W/cm2 during at least 10 % of the irradiation time,
  - Mean burn-up of the 4 fuel plates of at least 55 %



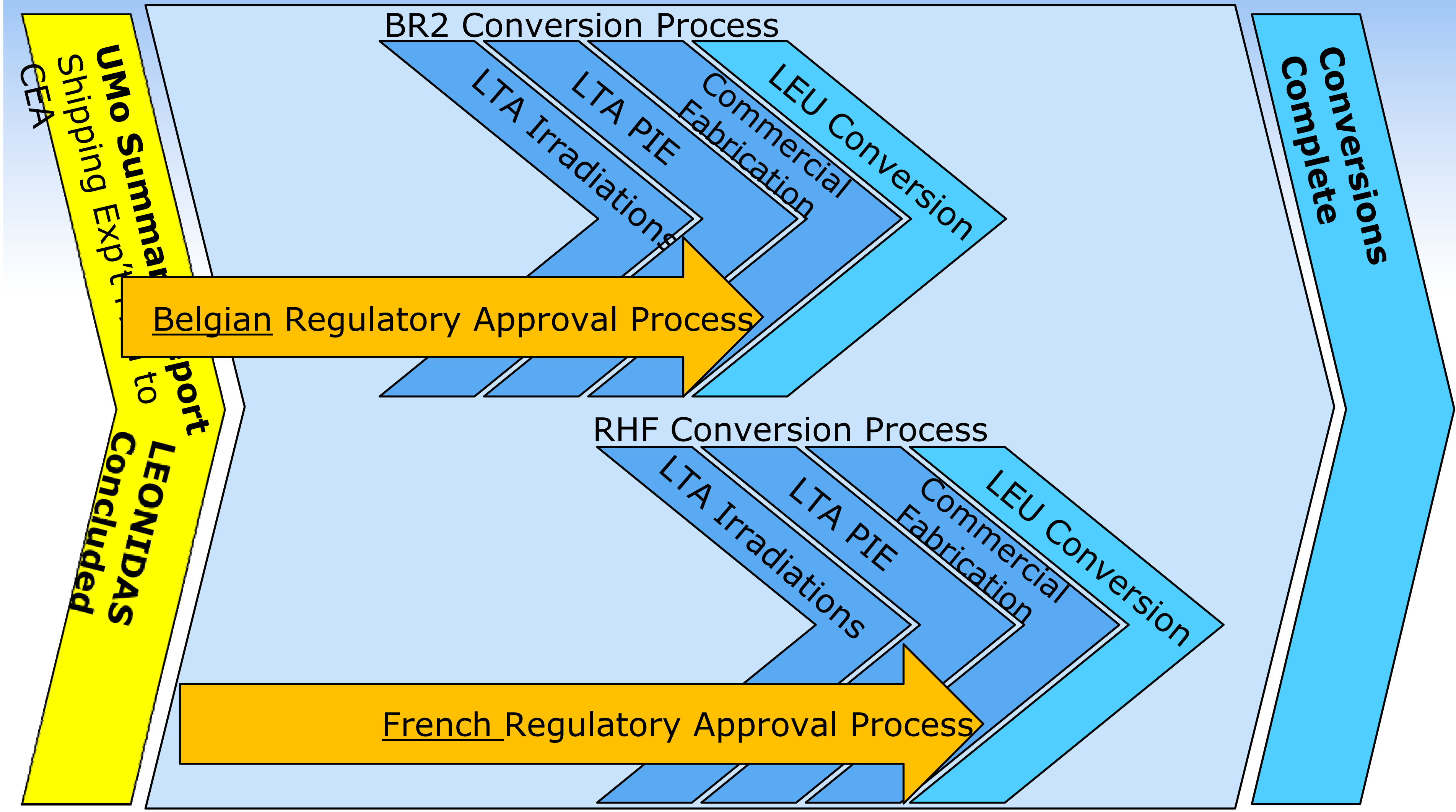


E-FUTURE Irradiation in BR2

- First two irradiation cycles completed, on-going third cycle
- No fission products detection so far → no clad failure

Cycle	1	2	3 (forecast)
Dates (2010)	June 1 – June 29	July 20 – August 17	*Sept 29 –*
Length	28 EFPD	28 EFPD	*21 EFPD*
Mean Burn-up	19 %	36 %	*50 %*
Max Burn-up	32 %		
BOC max heat flux	470 W/cm²	350 W/cm²	*240 W/cm²*
EOC max heat flux	340 W/cm²		

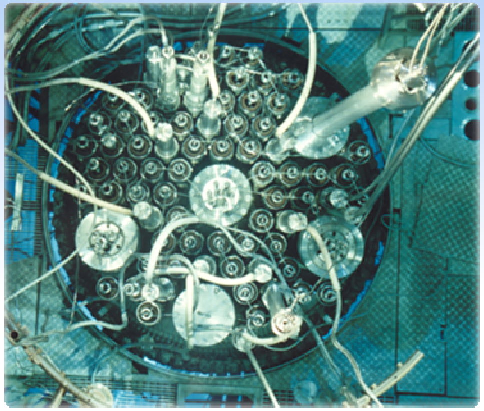
The Conversion Roadmap
After LEONIDAS
A Shared Goal of Participants

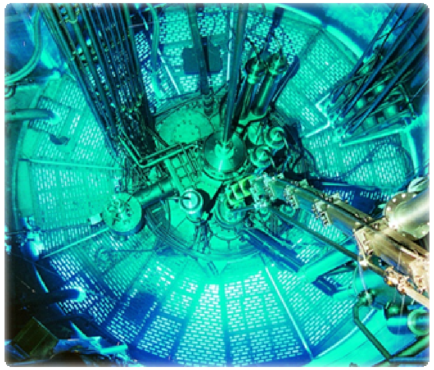


Roadmap to Actual Conversion After the LEONIDAS Program

- **After completion of the LEONIDAS program**

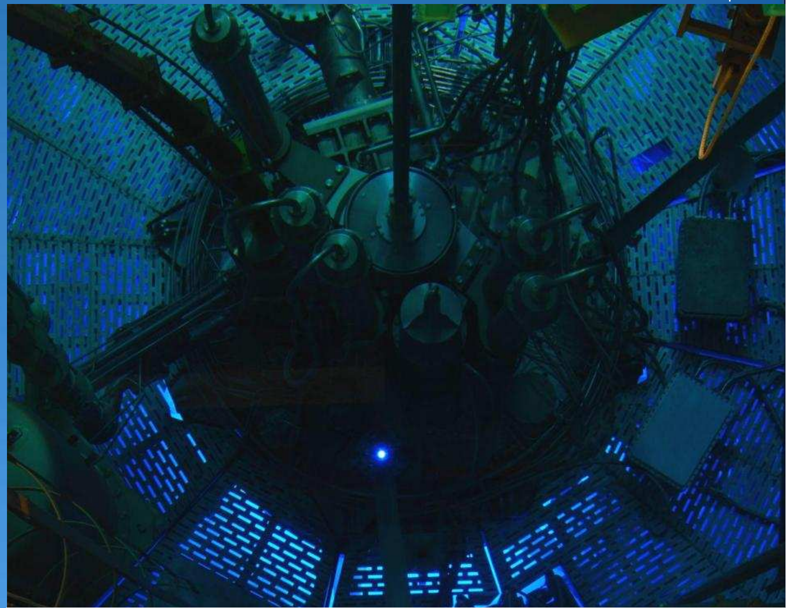
  BR2 and RHF will have to
  - Irradiate some Lead Test Assemblies (LTA's) at the required element geometry with the qualified burnable absorbers
  - Start the conversion process by loading a 1st batch of fresh LEU fuel elements ➔ no more HEU needed from this point on





- **This requires**
  - That the **fuel manufacturer** can produce the fuel on industrial scale
  - Approval by the **Safety Authorities** (French / Belgian)
    - the establishment of the safety case (including an updated version of the SAR) has to start in due time
- The **back-end of the fuel cycle** must be preserved
  - SCK•CEN, ILL and CEA send their spent fuel to La Hague

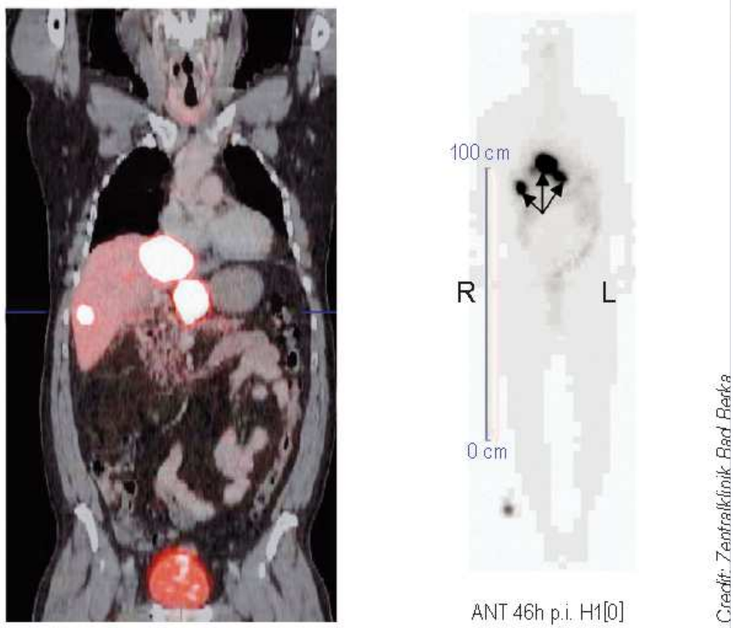
Radio-isotopes for medical application



Production of ^{188}W with high specific activity (>3 Ci/g) by double-neutron-capture requires a thermal flux >1E15 n/cm^2/s. With its present authorization ILL can provide about 5 TBq ^{188}W per year.

Emerging isotopes and R&D isotopes profit from the high neutron flux in V4: ^{177}Lu, ^{161}Tb, $^{166}Dy/^{166}Ho$, ^{193}Pt, ^{71}Ge, etc.

Test irradiations started in 2009.



Radionuclides for RIT and PRRT

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Radio-nuclide	Half-life	E mean (keV)	Eγ (keV)	Range
Y-90	64 h	934 β	-	**12 mm**
I-131	8 days	182 β	364	**3 mm**
Lu-177	7 days	134 β	208, 113	**2 mm**
Tb-161	7 days	154 β 5, 17, 40 e^-	75	**2 mm** **1-30 μm**
Tb-149	4.1 h	3967 α	165,..	**25 μm**
Ge-71	11 days	8.0 e^-	-	**1.7 μm**
Er-165	10.3 h	5.3 e^-	-	**0.6 μm**

cross-fire

localized

Estab-lished isotopes

Emerging isotopes

R&D isotopes: supply-limited!

Modern, better targeted bioconjugates require shorter-range radiation ⇒ need for adequate (R&D) radioisotope supply.

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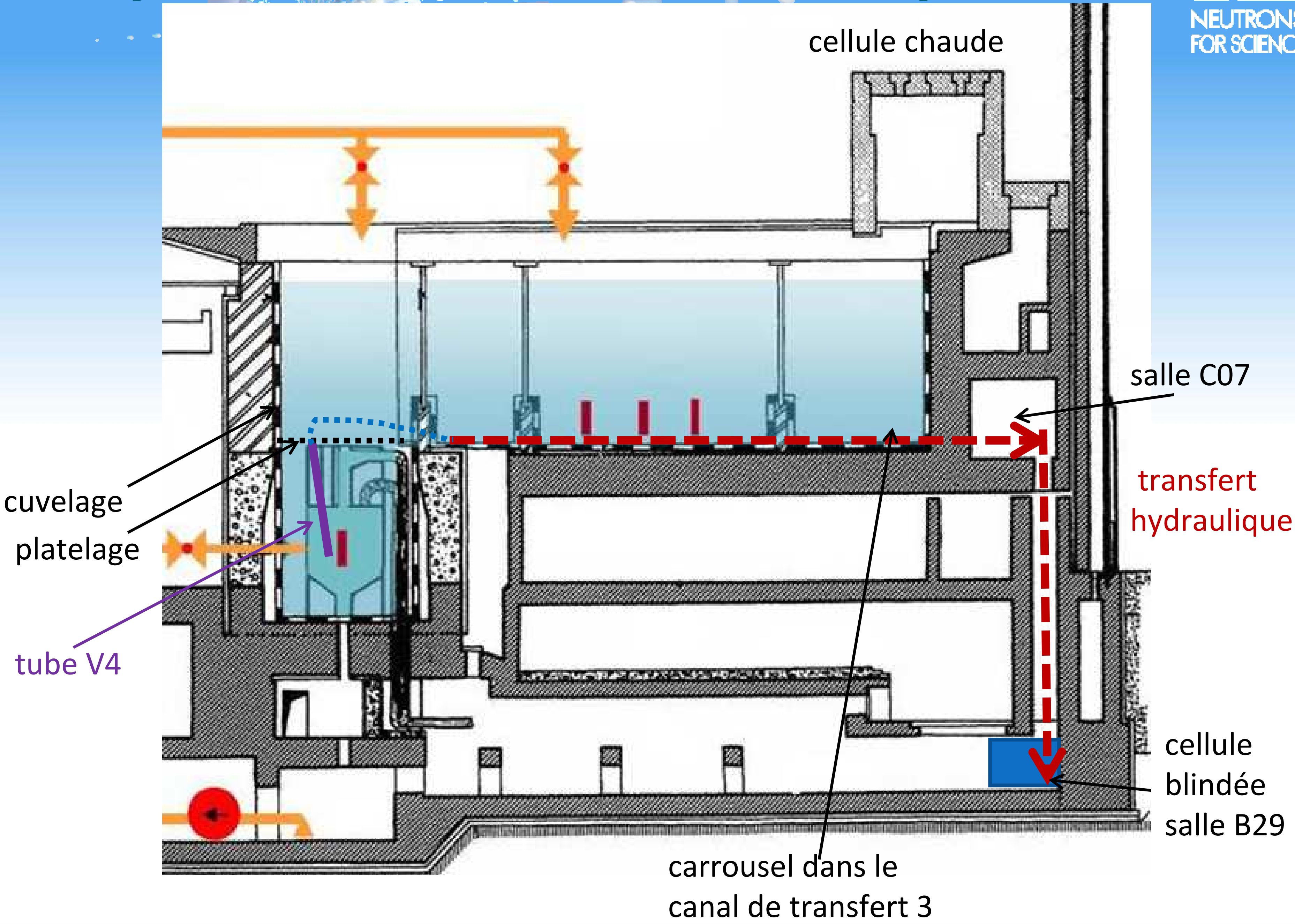
FOR SCIENCE ®

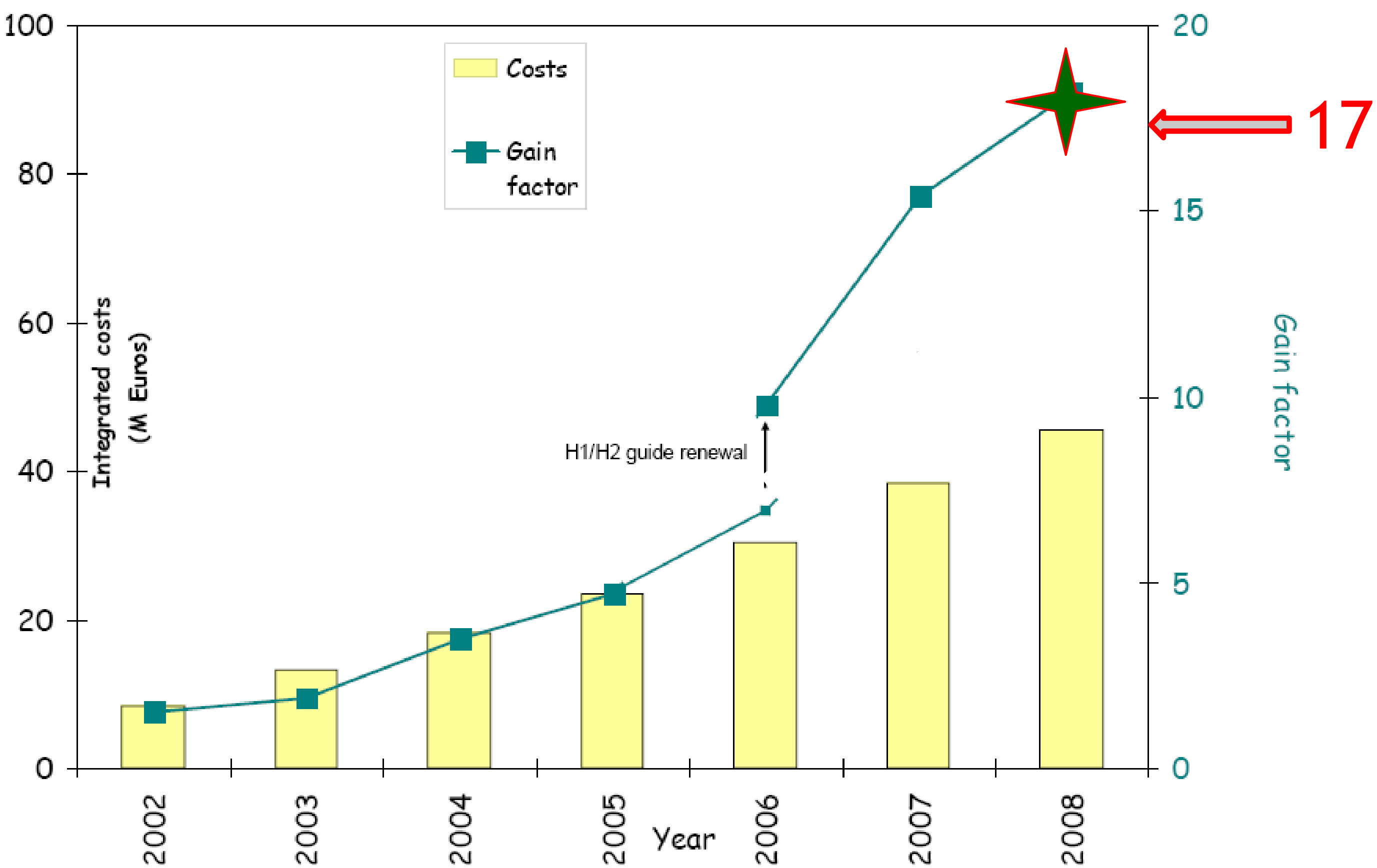
Layout of new irradiation system



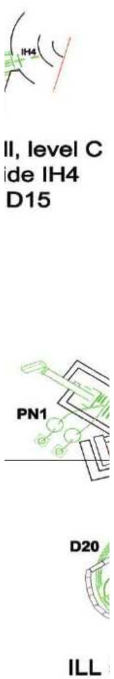
The MILLENNIUM PROGRAM

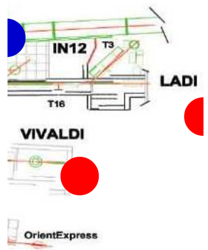
Modernisation of ILL's instrument suite: Phase M-0
(2001 – 2008)

Gain factors (data collection rate) after completion of Phase M-0



ll, level C
ide IH4
D15

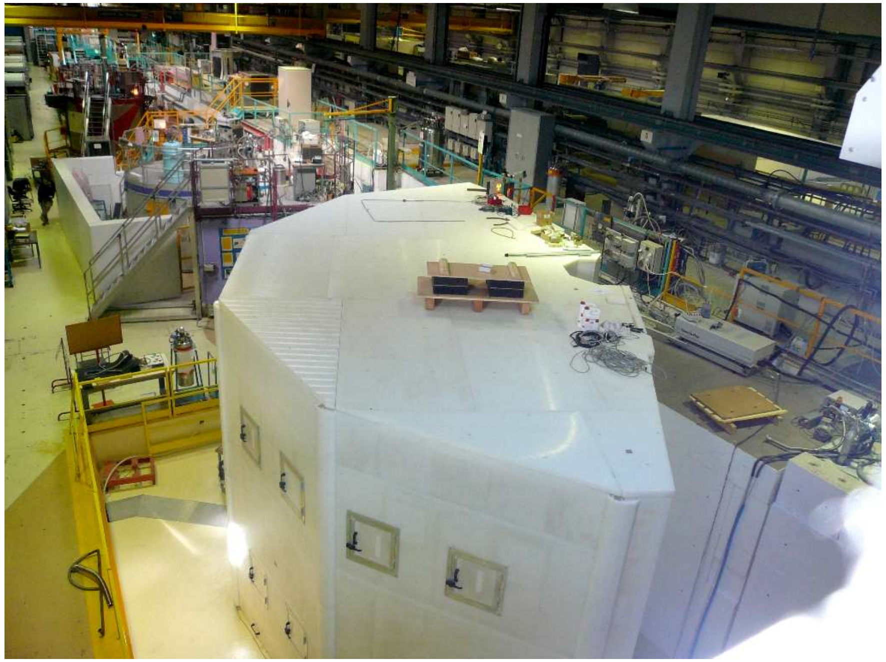


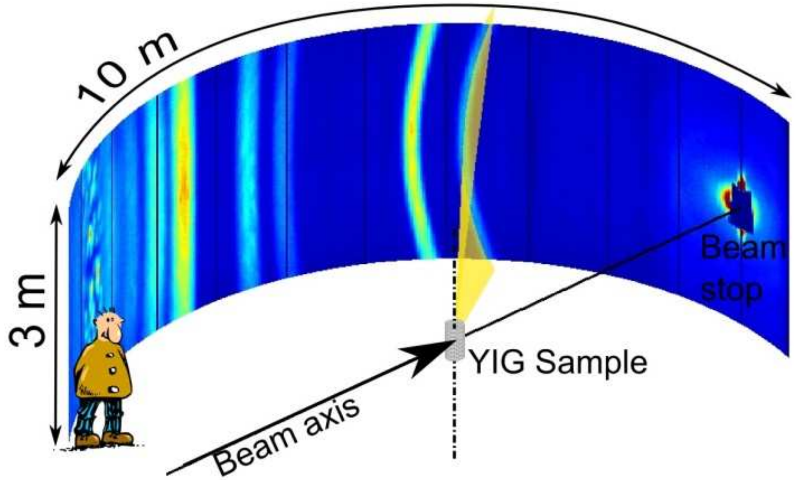


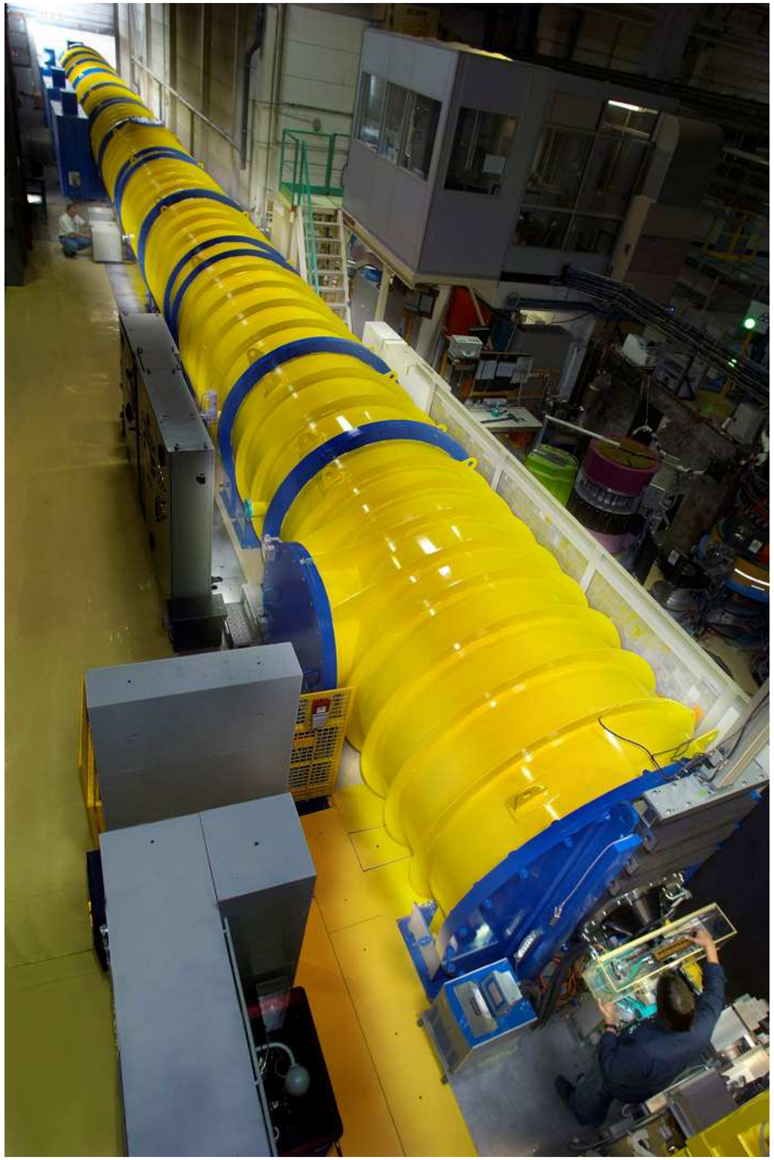
27 public + 10 CRG instruments

Final Review of IN5 and D11

-Assessment of ILL's efficiency in project management -





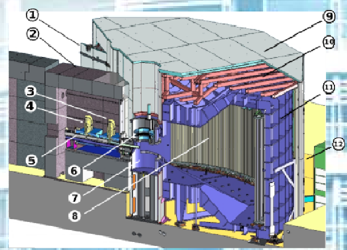


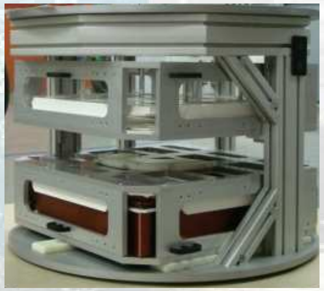
Millennium Programme - Phase M-0

Completed end of 2008!!

Spent budget: 38.2 M€ (2001-2008)



Planning through the next decade..
…Perspectives

Millennium Phase M-1

(2007 – 2014)

Total budget: ~41.57 M€

(without staff costs)

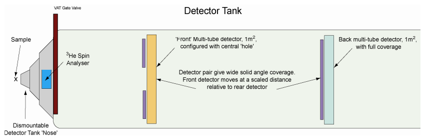
Addressing the Future:
Millennium Programme Phase M-1 2007- 2013

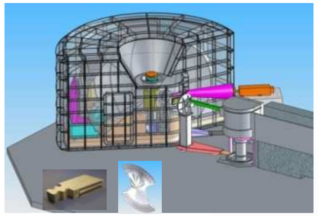
- 5 new instruments

HR-BS IN16B

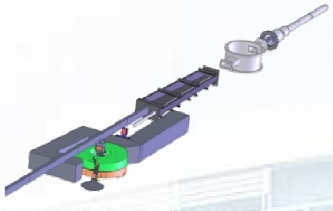
NSE WASP

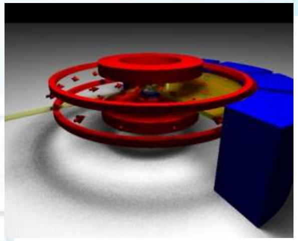
SANS D33



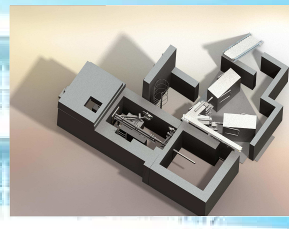


TAS ThALES





SuperADAM



- 4 upgrades of instruments

D17 (reflectom.) ☺ ; IN1 (hot TAS/Lagrange) ; IN4 (ToF) ; IN12 (TAS)

↷ 6 neutron guide projects (~600 m new guides)

- 6 instruments to be phased out
- Advanced sample environment: high B, T, p

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More than simply neutrons...

Extension of neutron guide hall ILL7 (April 2010)

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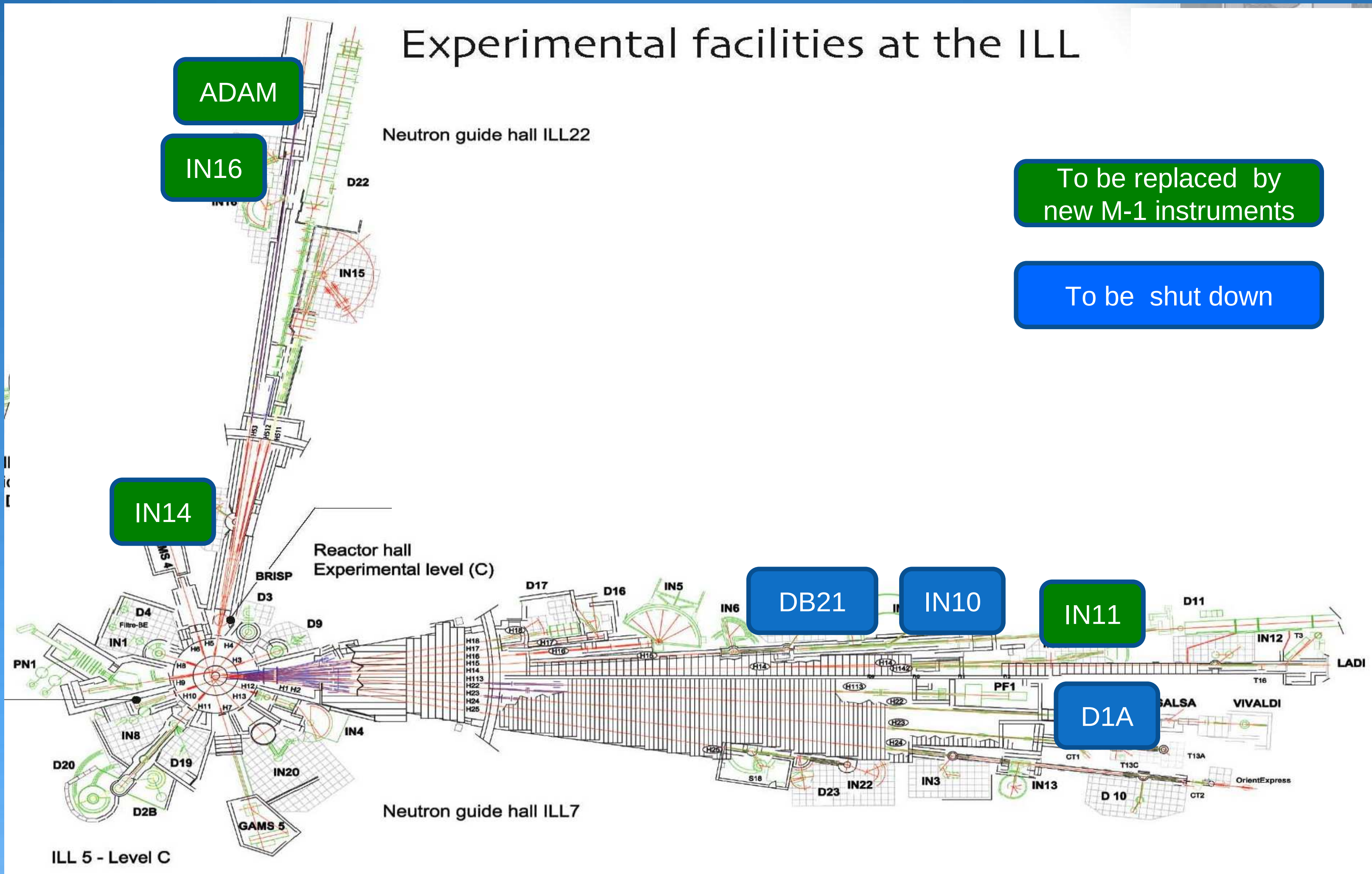
….phasing out 7 instruments (2010 -2013)



Planning through the next decade..

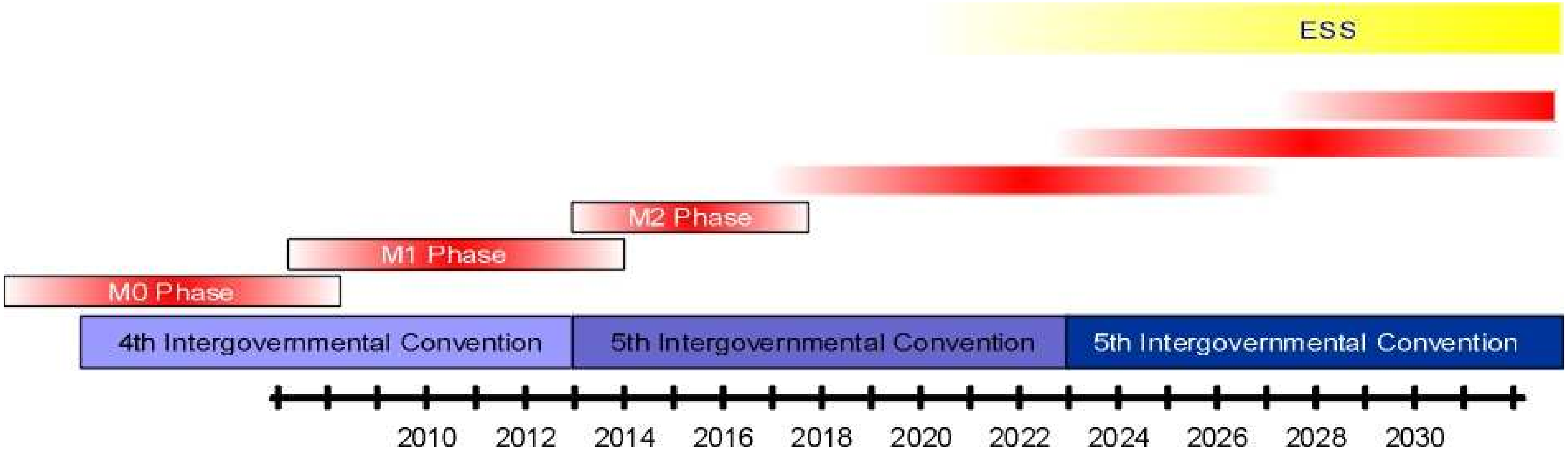
Millennium Phase M-1

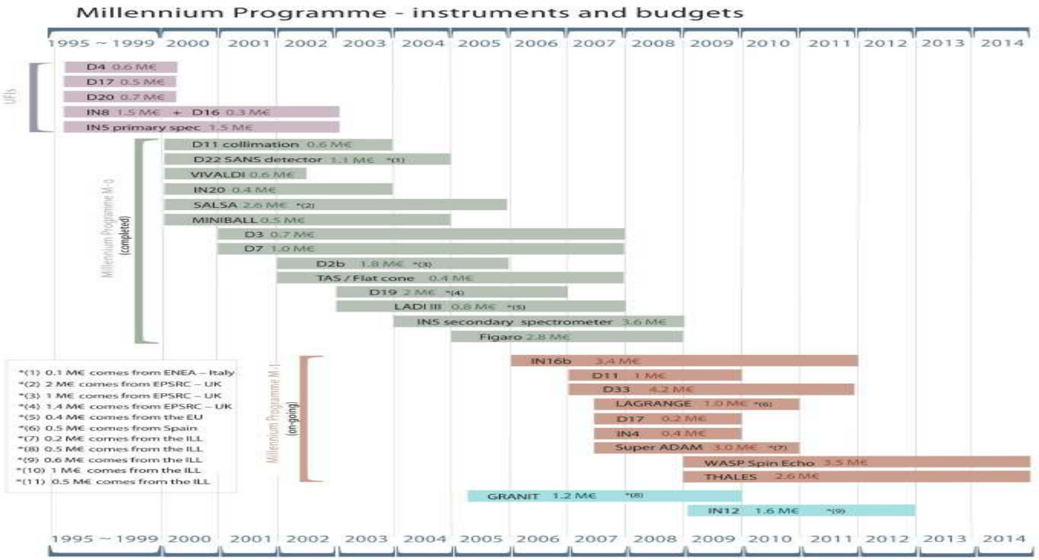
(2007 – 2014)

Phase M-2

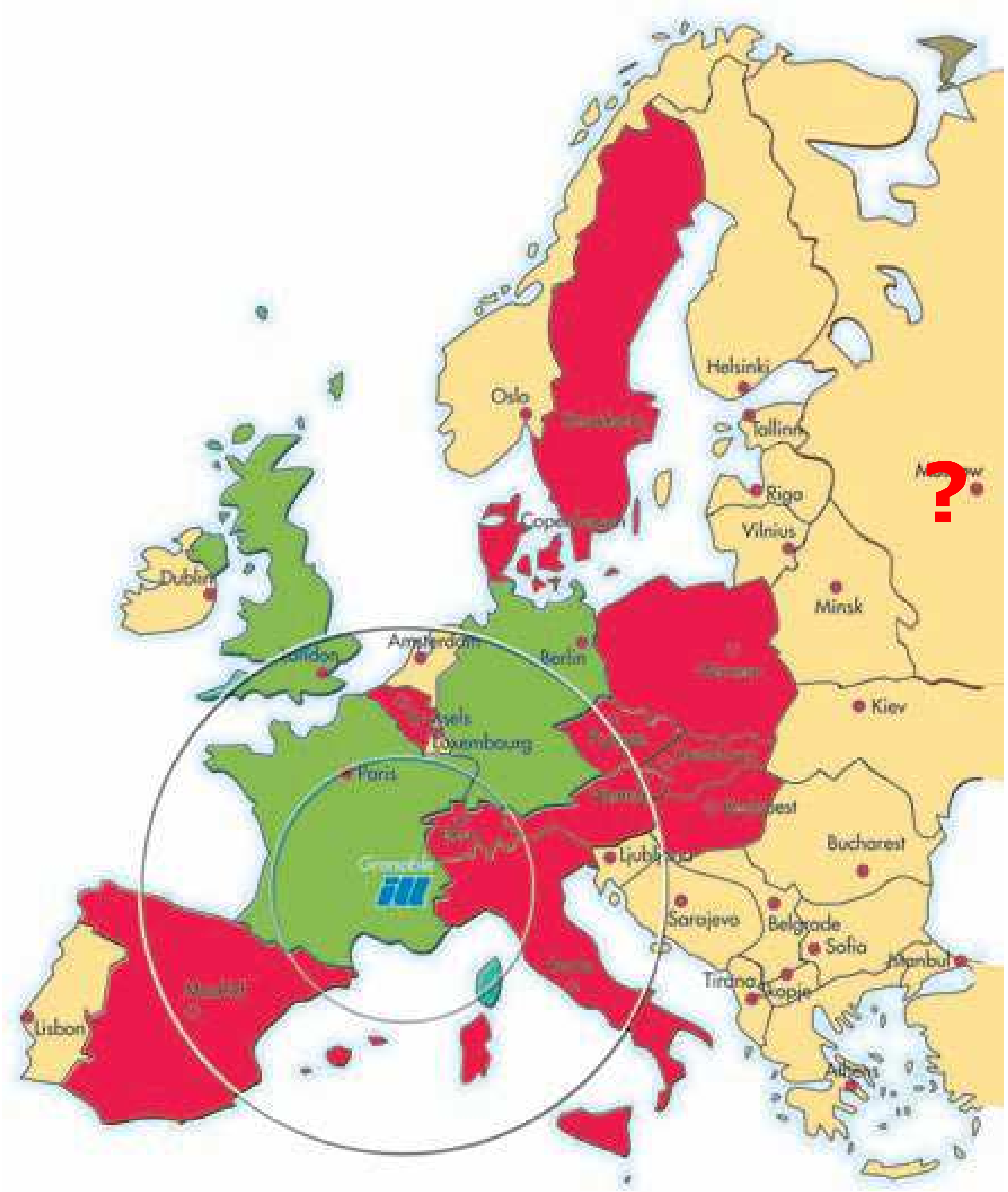
(2013 – 2017)

Preparing for the future





The ILL and its Scientific Partners



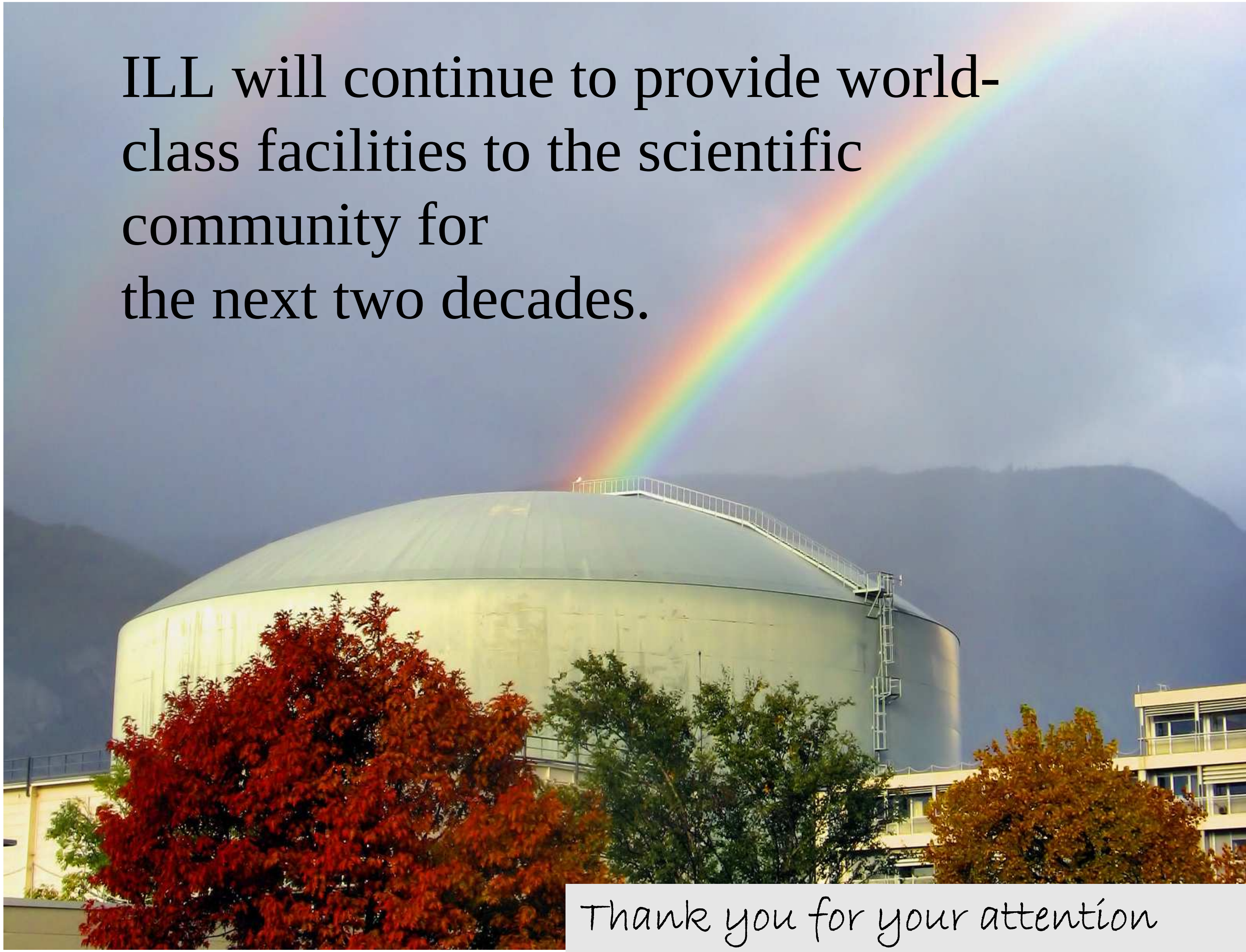
Scientific Partners:

3 Associate countries D, F, UK

12 Scientific Member countries

DK SK in 2009

ILL will continue to provide world-class facilities to the scientific community for the next two decades.



Thank you for your attention

Photo taken by Dr. Martin Mansson, ETH Zuerich-PSI on 4-November 2009

Welcome to the ILL