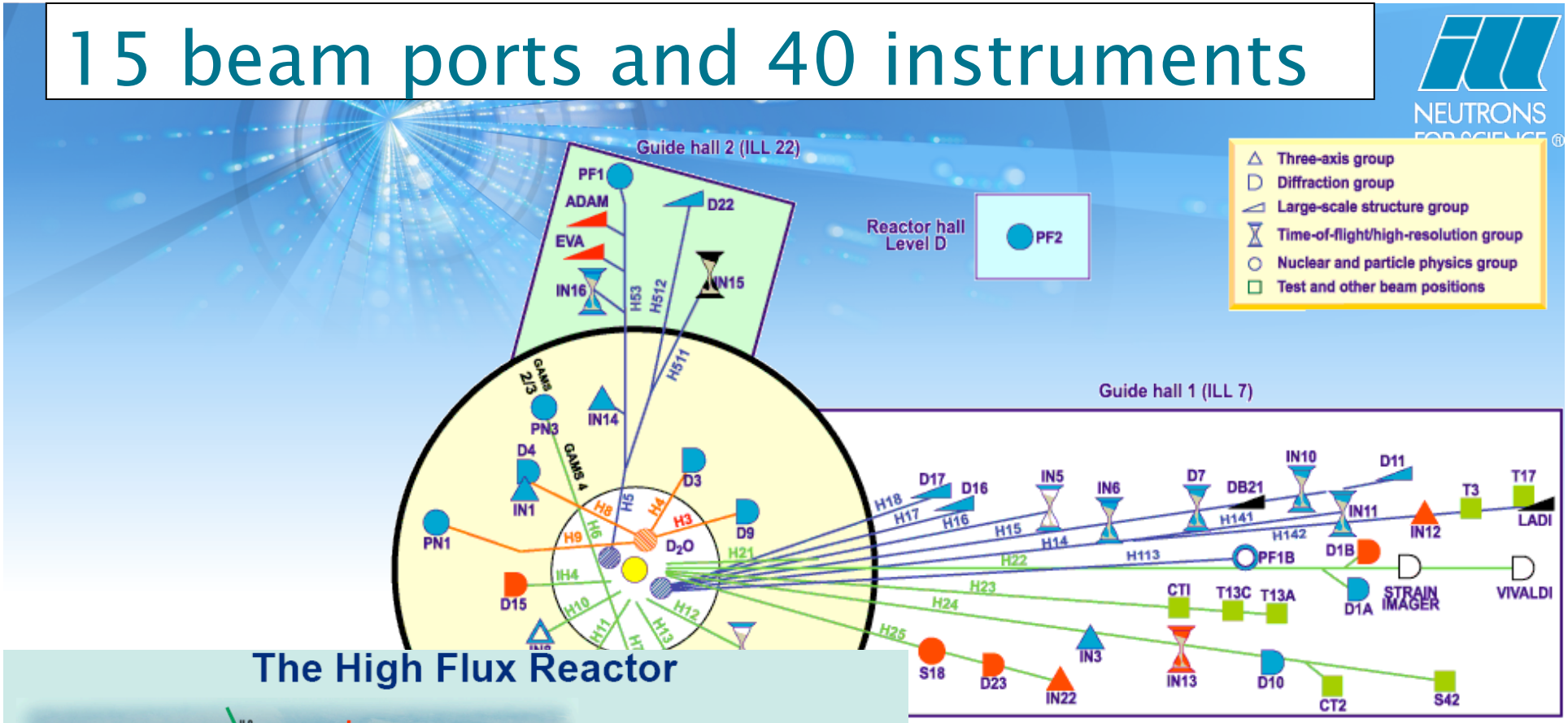
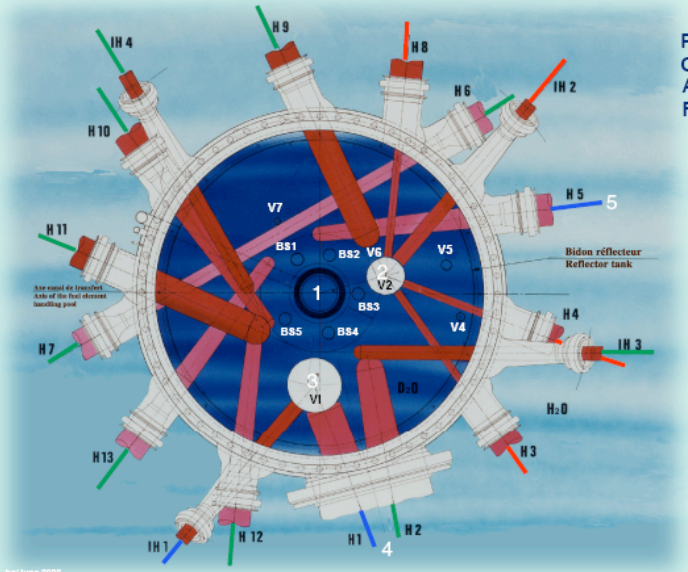
# Refurbisment and Upgrade of ILL reactor and instrument suite

NEUTRONS FOR SCIENCE ®

# 15 beam ports and 40 instruments

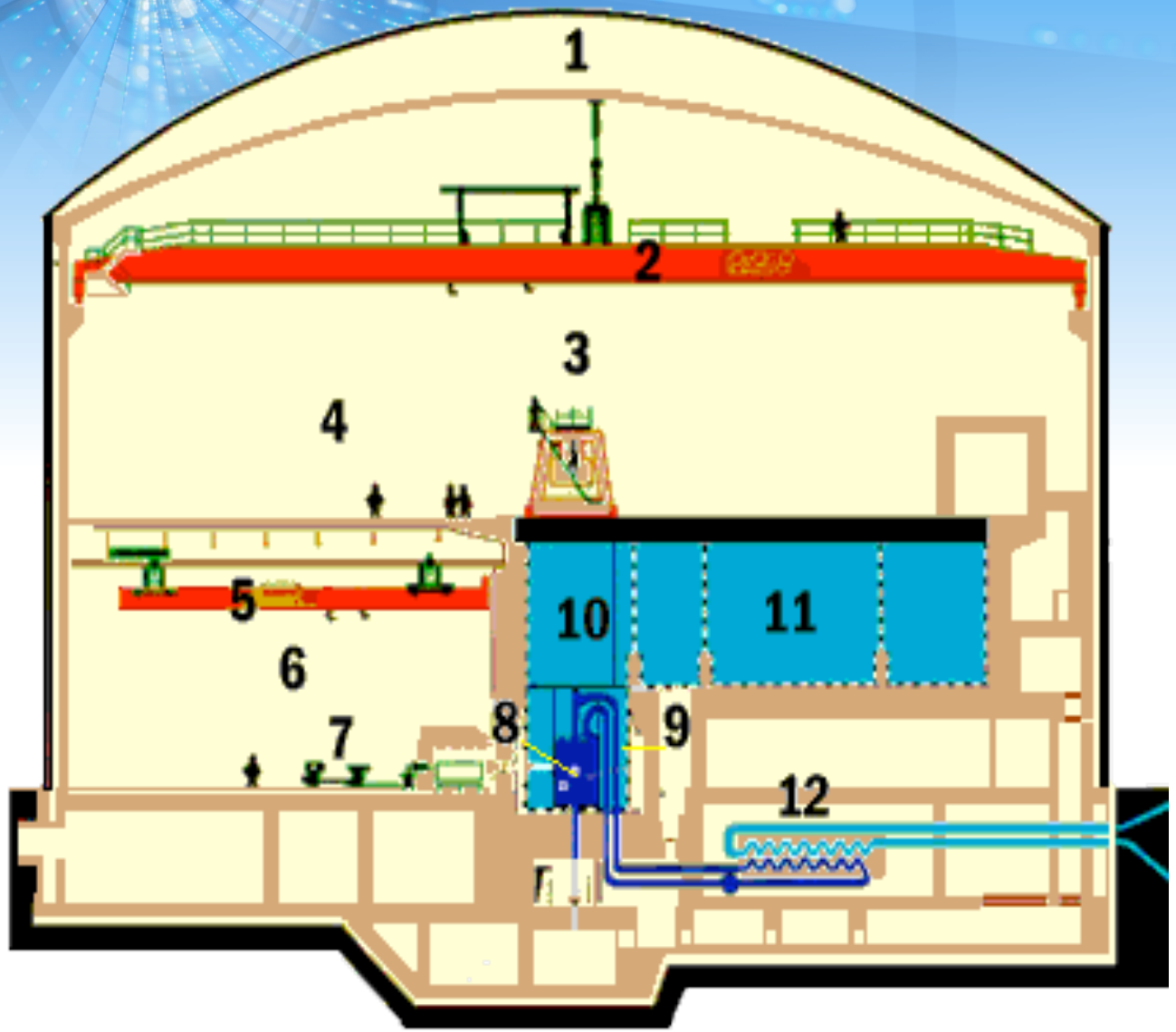



## The High Flux Reactor



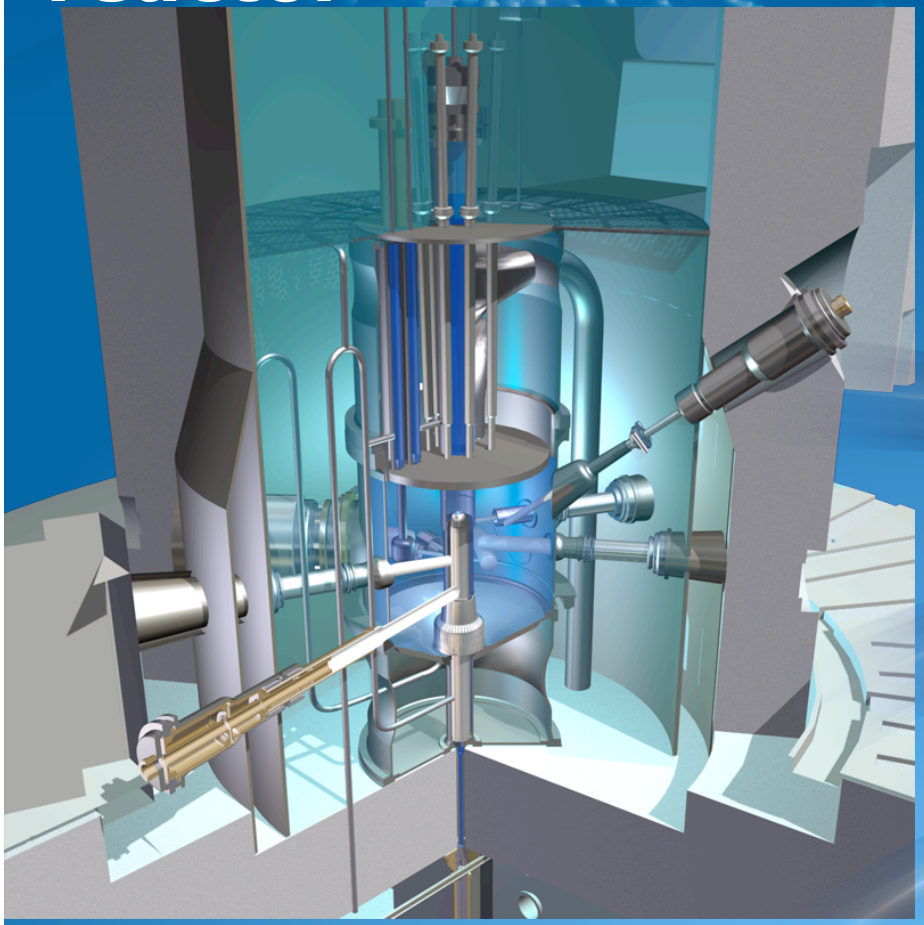

Power : 58.3 Megawatts
Operation : 4.5 cycles of 50 days per year
Availability : 98 - 99%
Fuel element : 9.5 Kg 93% enriched uranium

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


1
2
3
4
5
6
7
8
9
10
11
12

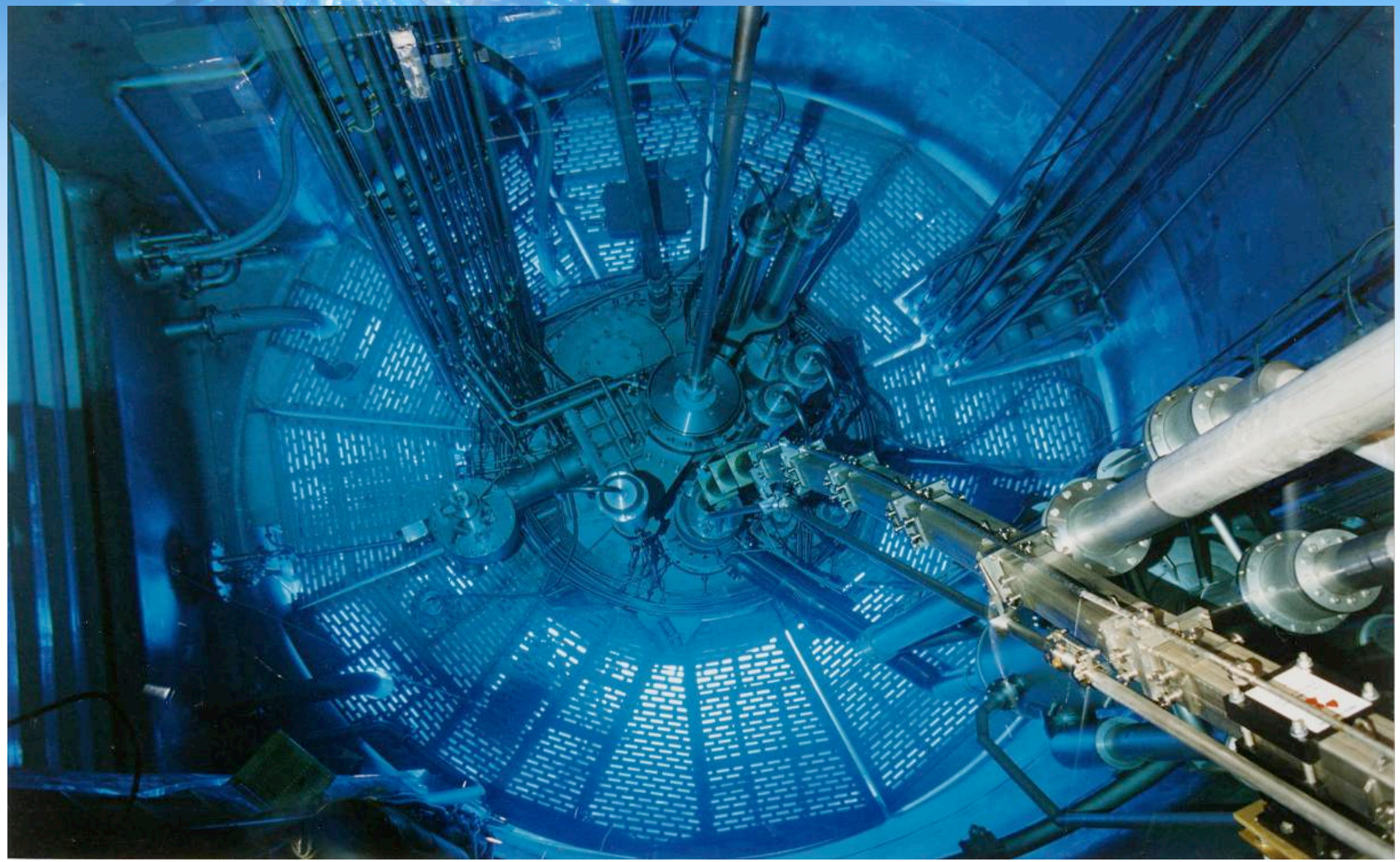
# "RHF": the ILL reactor

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



**200 days of operation per year**
**4 cycles – 58.3 MW**

NEUTRONS
FOR SCIENCE ®



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

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

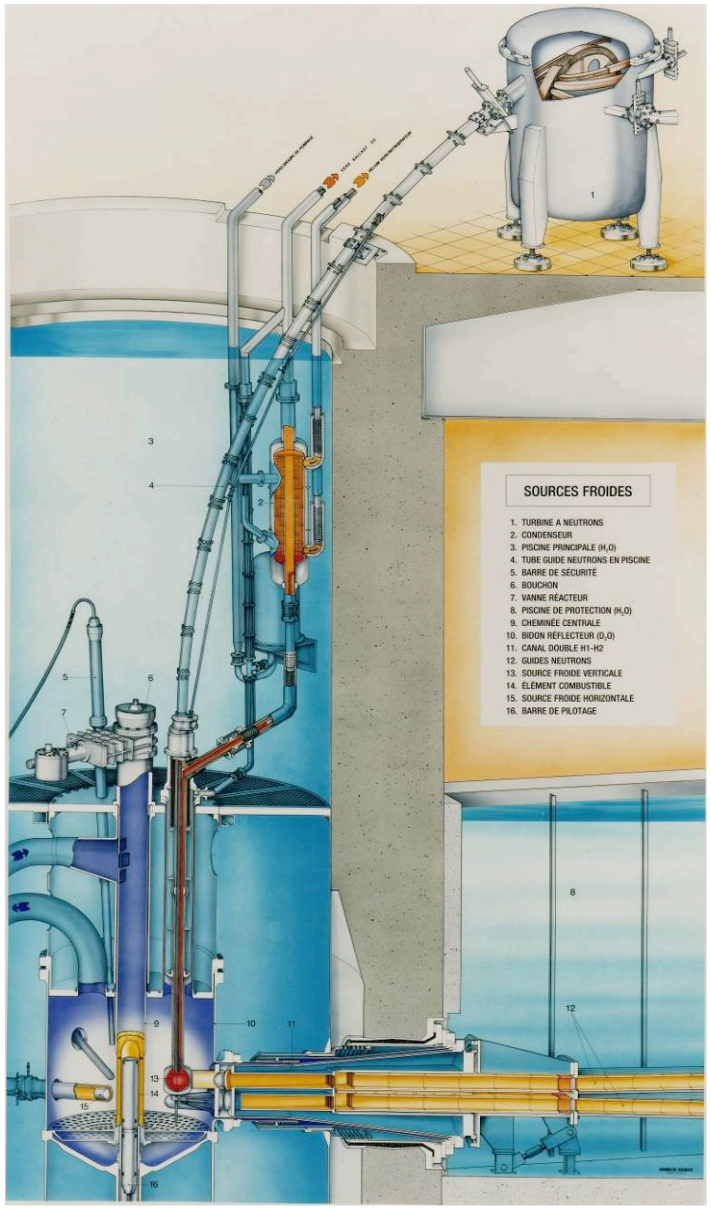
to maintain the ILL's position at the forefront of international science

# 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

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

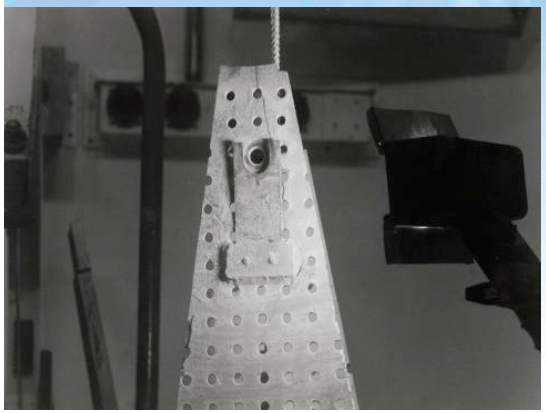


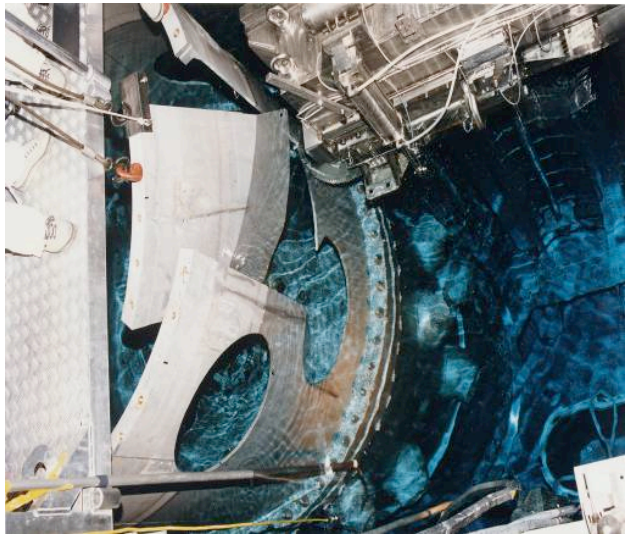

- **1985**: A new vertical cold source equipped with a vertical and curved guide tube connected with a turbine. This device feeds ultra-cold neutrons to the experimental instruments.
- **1987**: a second (horizontal) cold source. It is positioned at the front of a horizontal beam tube. It feeds the second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

# The Reactor

NEUTRONS FOR SCIENCE

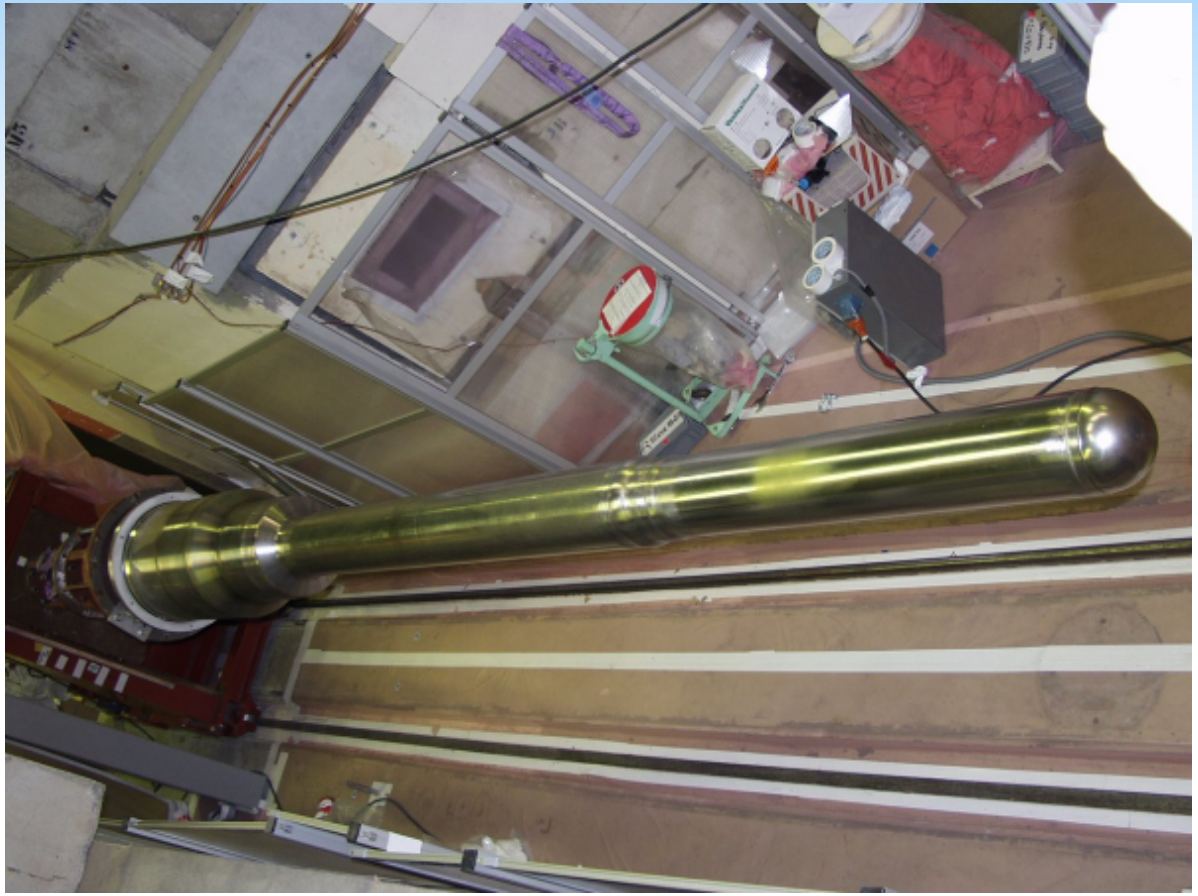
•From 1991 to 1994: replacement of the reactor block; observation of unusual marks on the upper antiturbulence grid.





# The Reactor

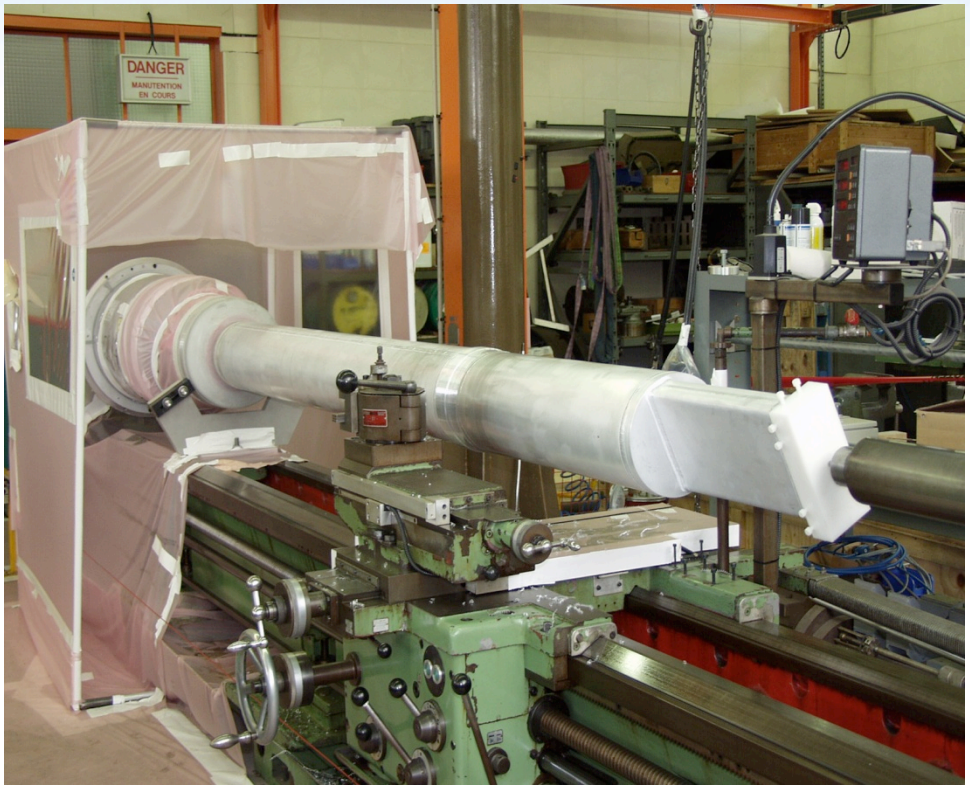
•**2004:** replacement of the aluminium beam tube H9 by a zircaloy tube. This has extended its service life, allowing extended reactor operations and reduced radiation exposure for workers.



# REACTOR OPERATIONS

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

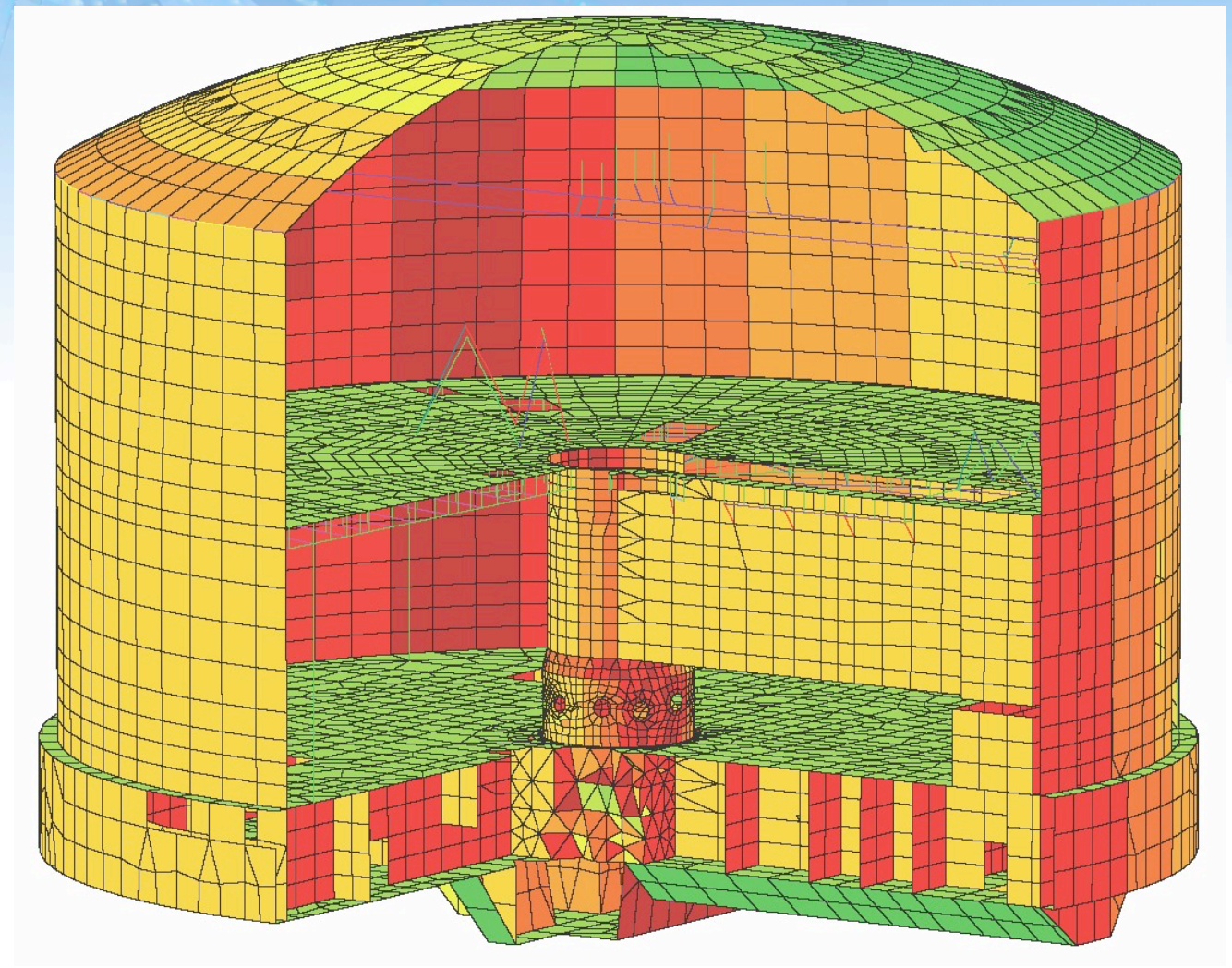
A new contract with the CEA is being signed, in order to examine the properties of irradiated aluminium.
The cost of these studies is being shared.



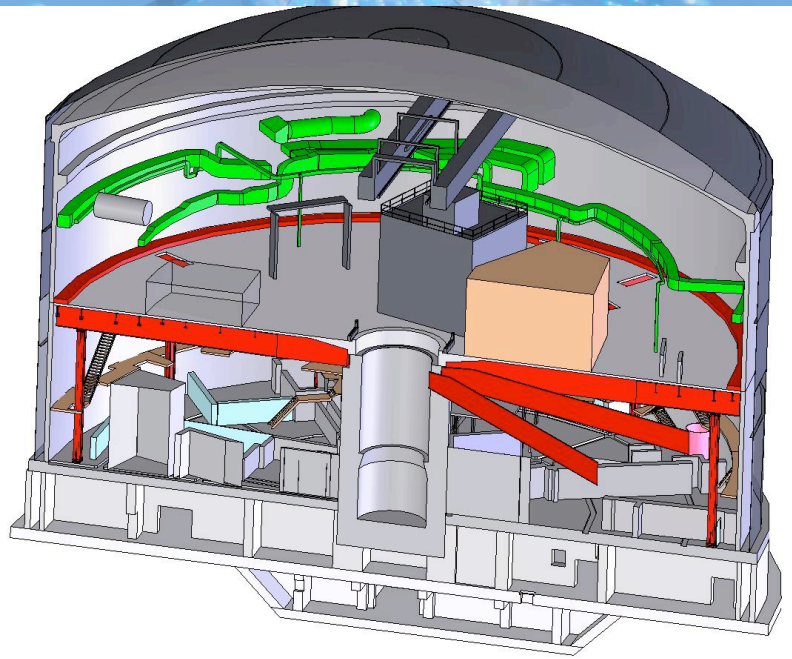
# 2002 - 2007
# REFIT Program

# 2002 safety review led to the "REFIT program"

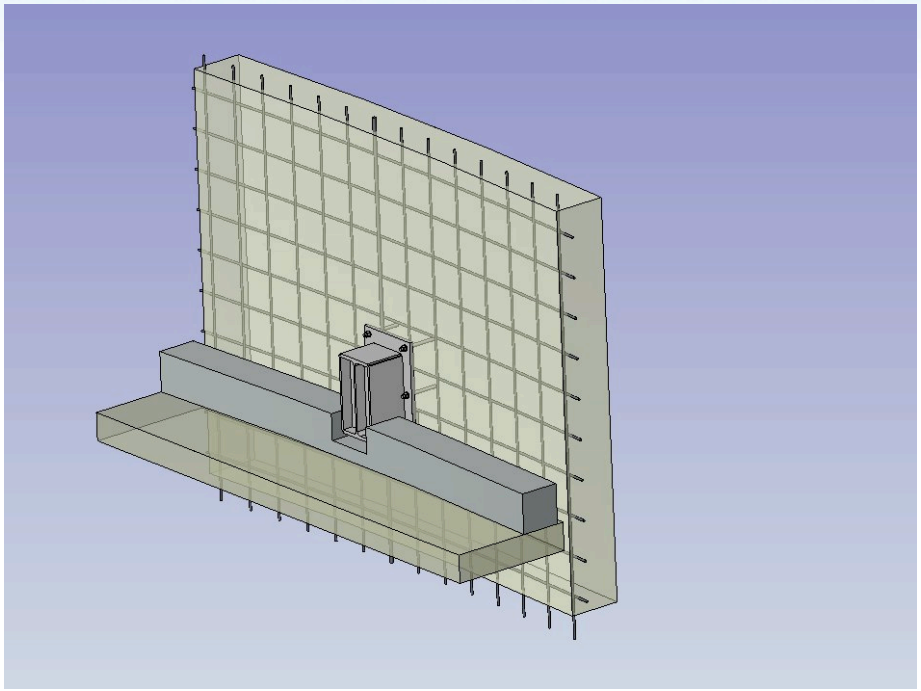
Modeling for seismic studies



# Refit programme



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

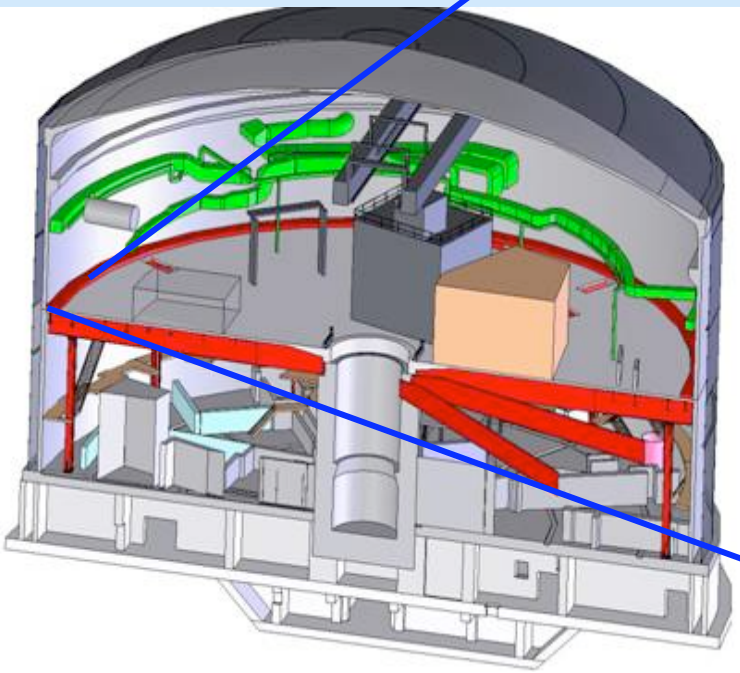


Reinforcement using the so-called "comb" solution

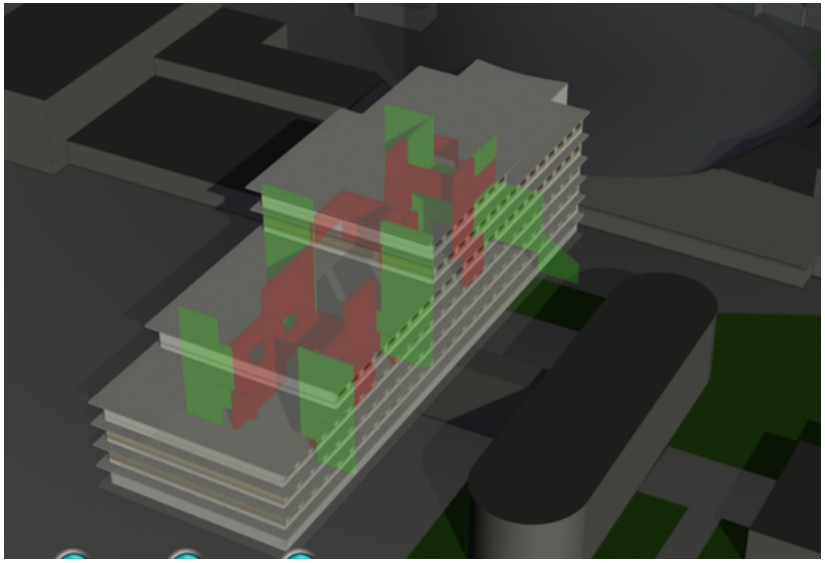
# Seismic reinforcement of ILL5

Reinforced reactor building:

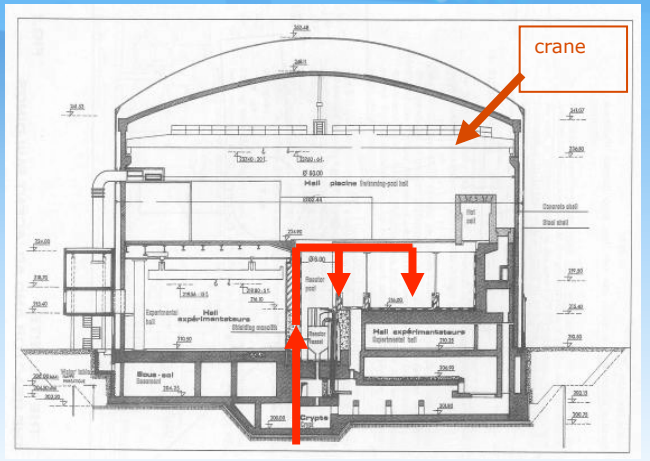
- without its inner buildings on level D floor
- with orthoradial links between level D floor and the inner shell



# Reactor : Refit Program from 2003 to 2007

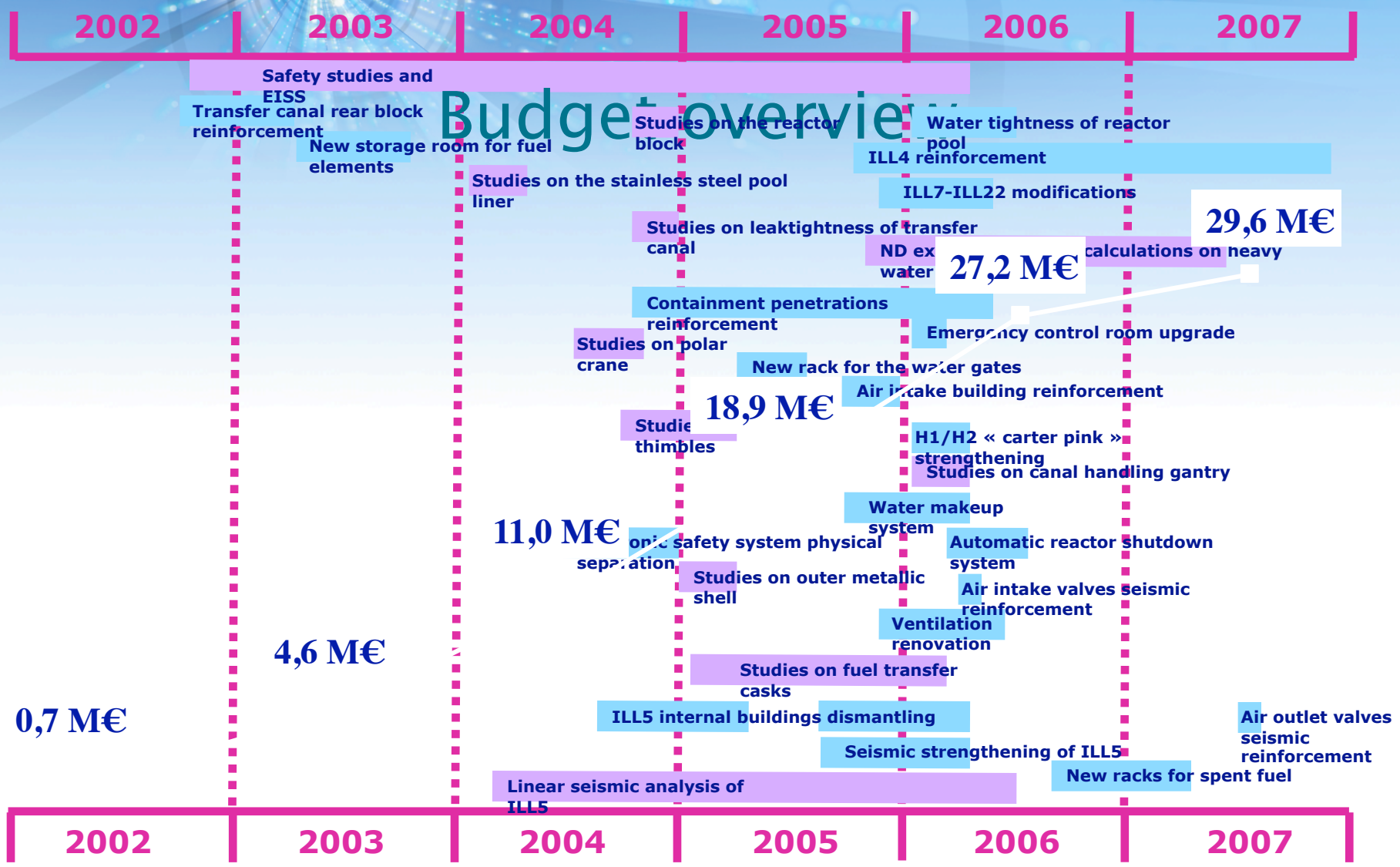


# Reactor : Refit Program from 2003 to 2007




# REFIT Program

## Budget overview

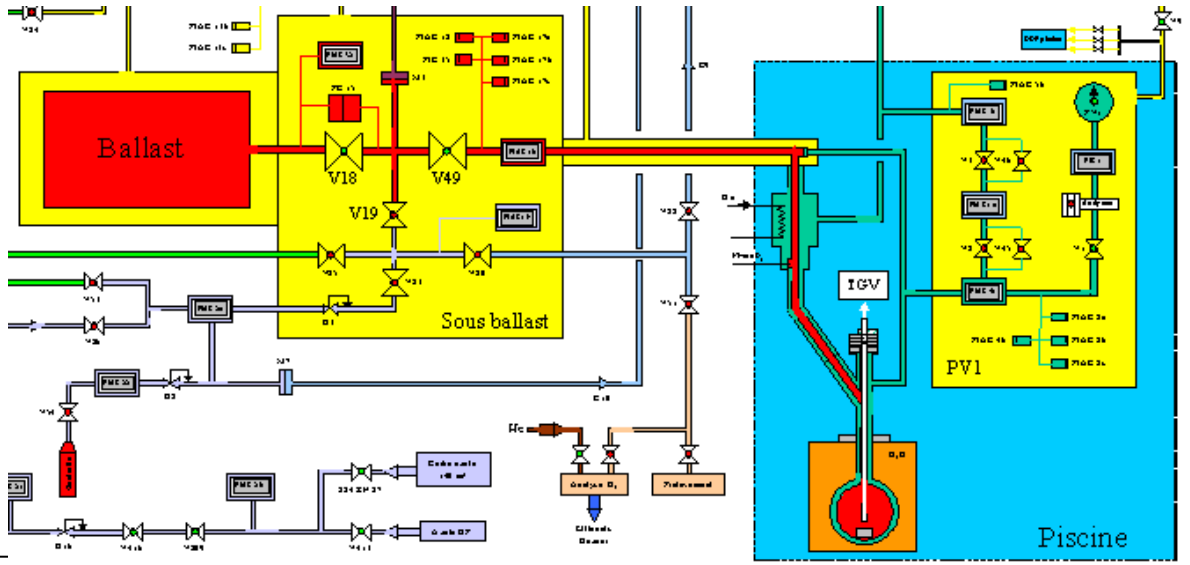


# 2005 - 2017
# Key Reactor Components Program

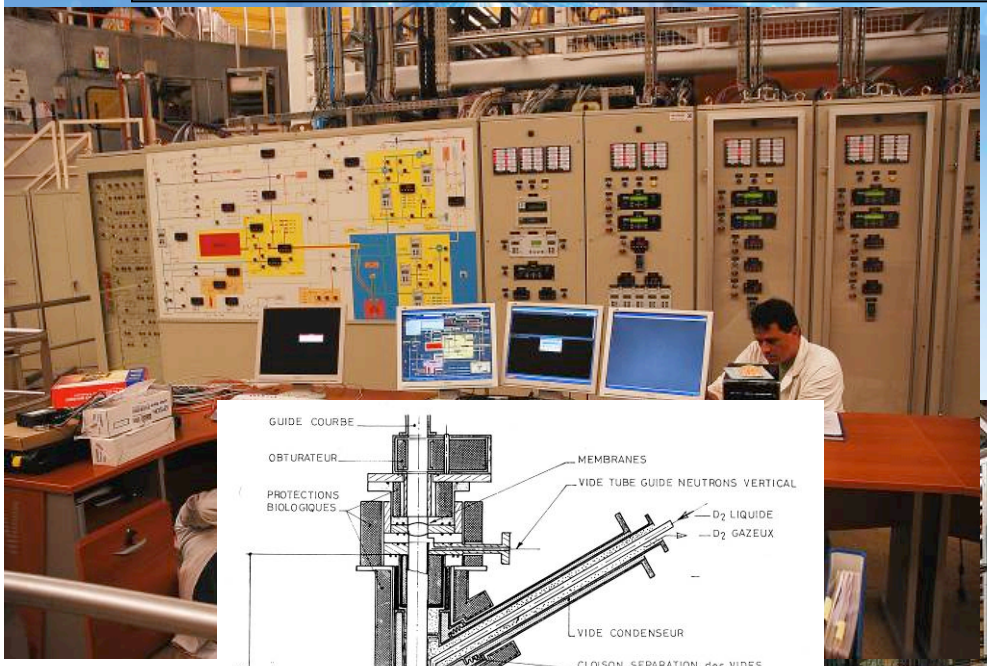
# Key Reactor Components

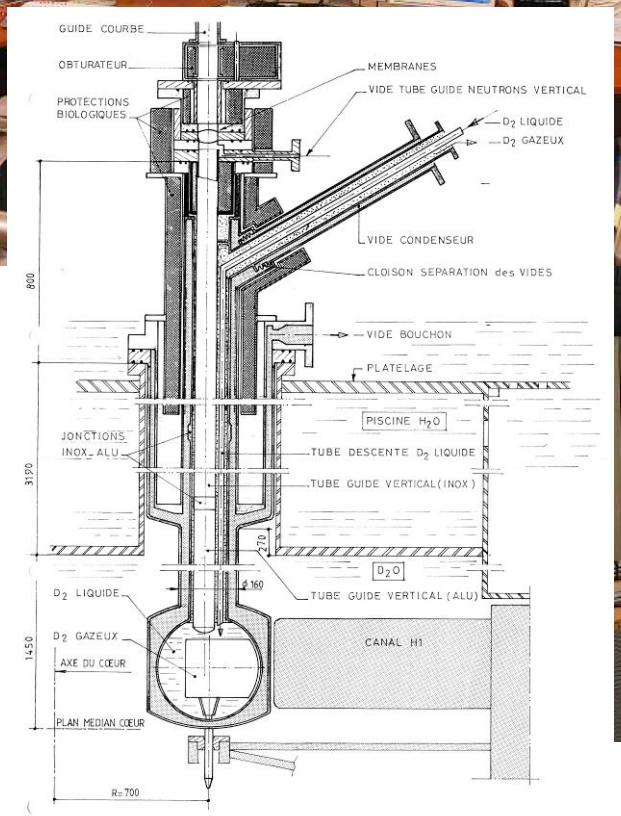
The aim of the **Key Reactor Components programme** is to guarantee reliability until 2024. Indeed several important systems have been operating for 35 years. The main focus of this programme is on:

- 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



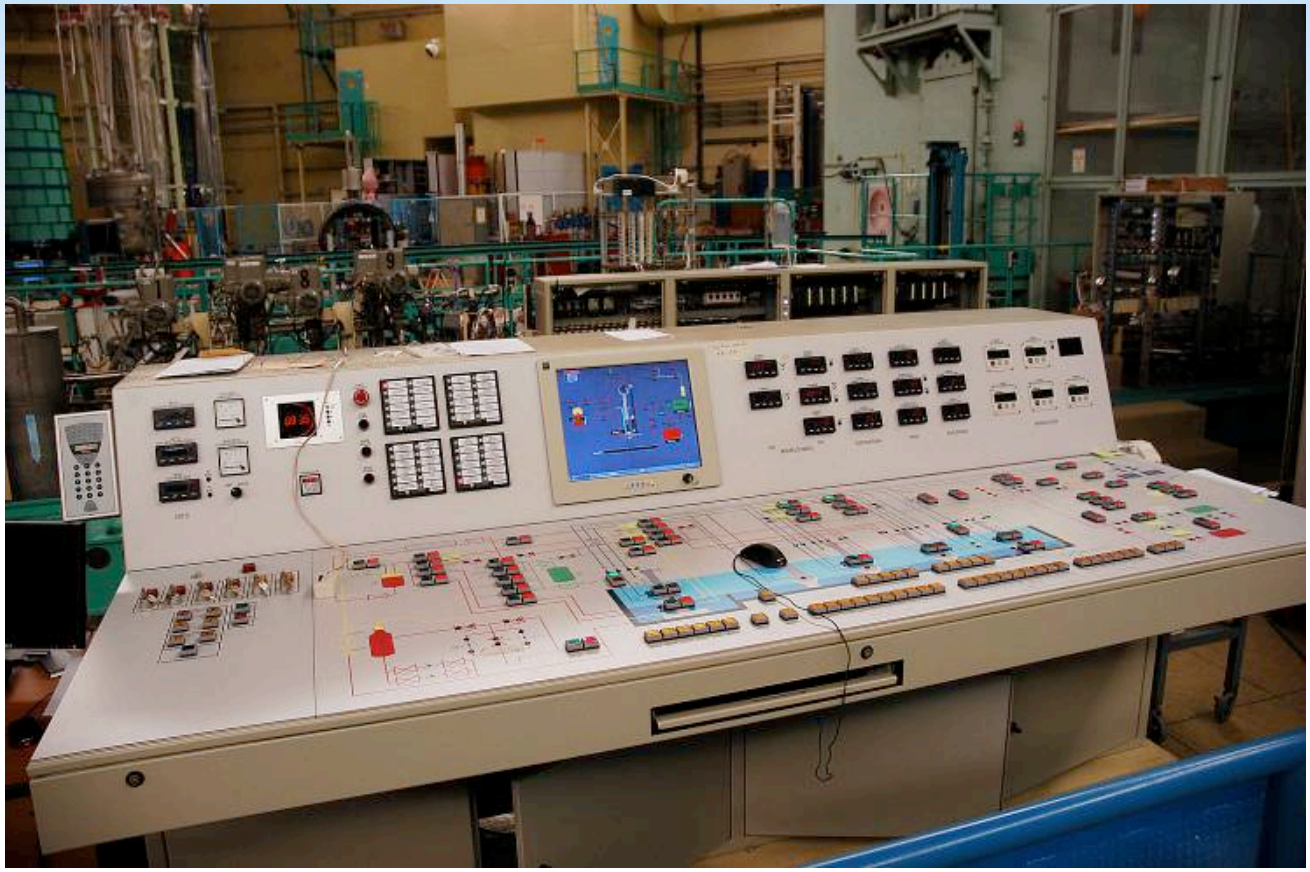



SOURCE FROIDE

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

- High-tension facility: 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

NEUTRONS FOR SCIENCE

### Key reactor components

- Overhead polar crane: part of the seismic reinforcement of the facility (planned for completion in November 2009)

## RHF modernization and refurbishment: KRC

NEUTRONS FOR SCIENCE

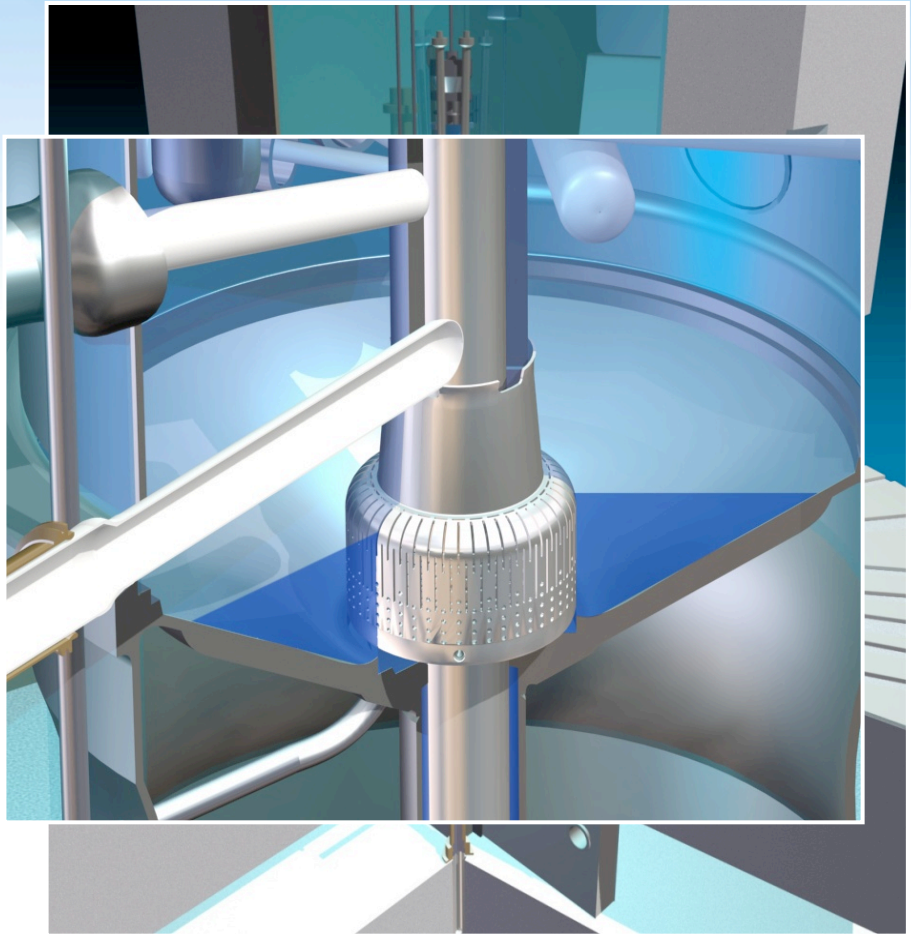
K e y r e a c t o r c o m p o n e n t s

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

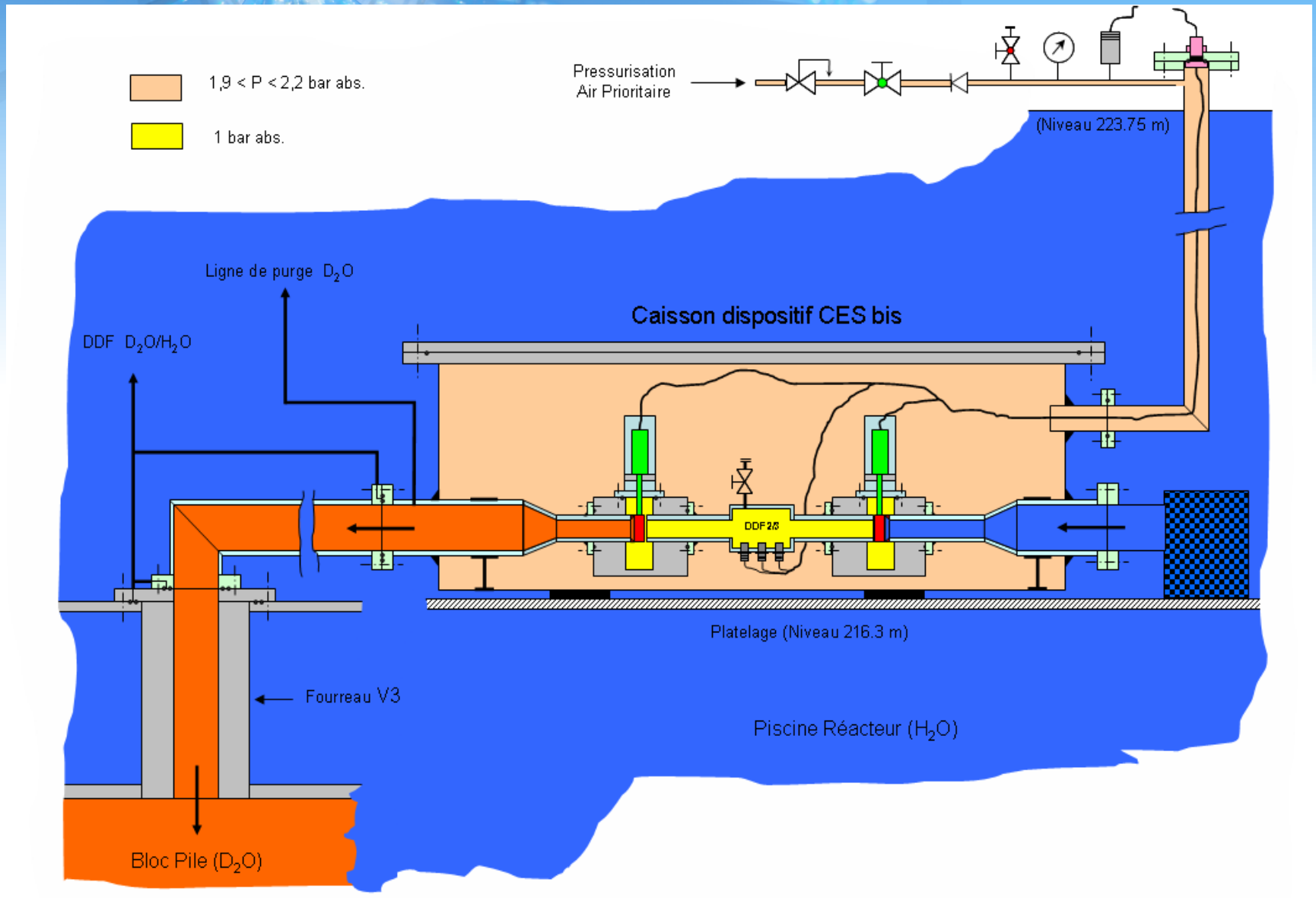
# RHF modernization and refurbishment: KRC

## Key reactor components

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



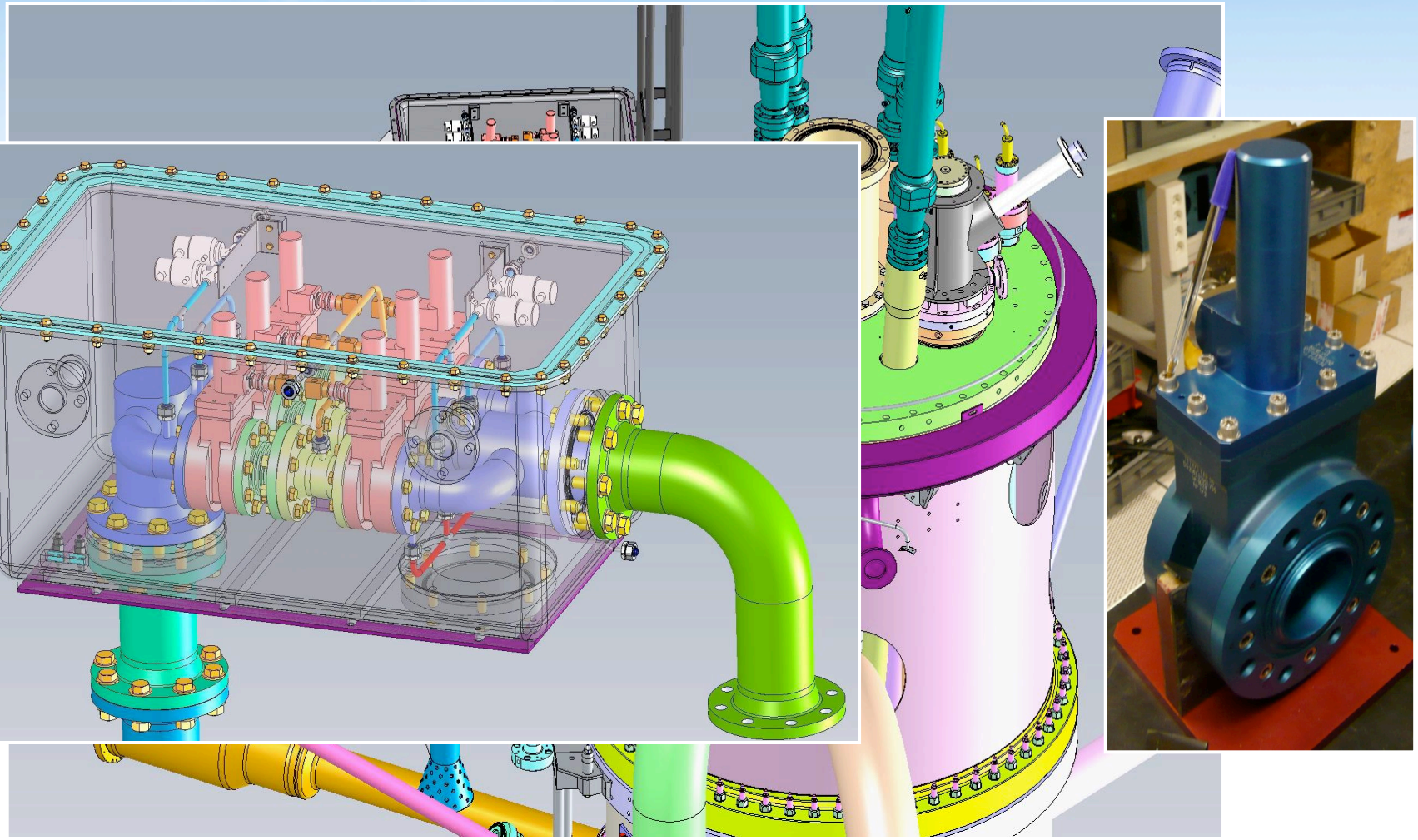
# Emergency reflood circuit



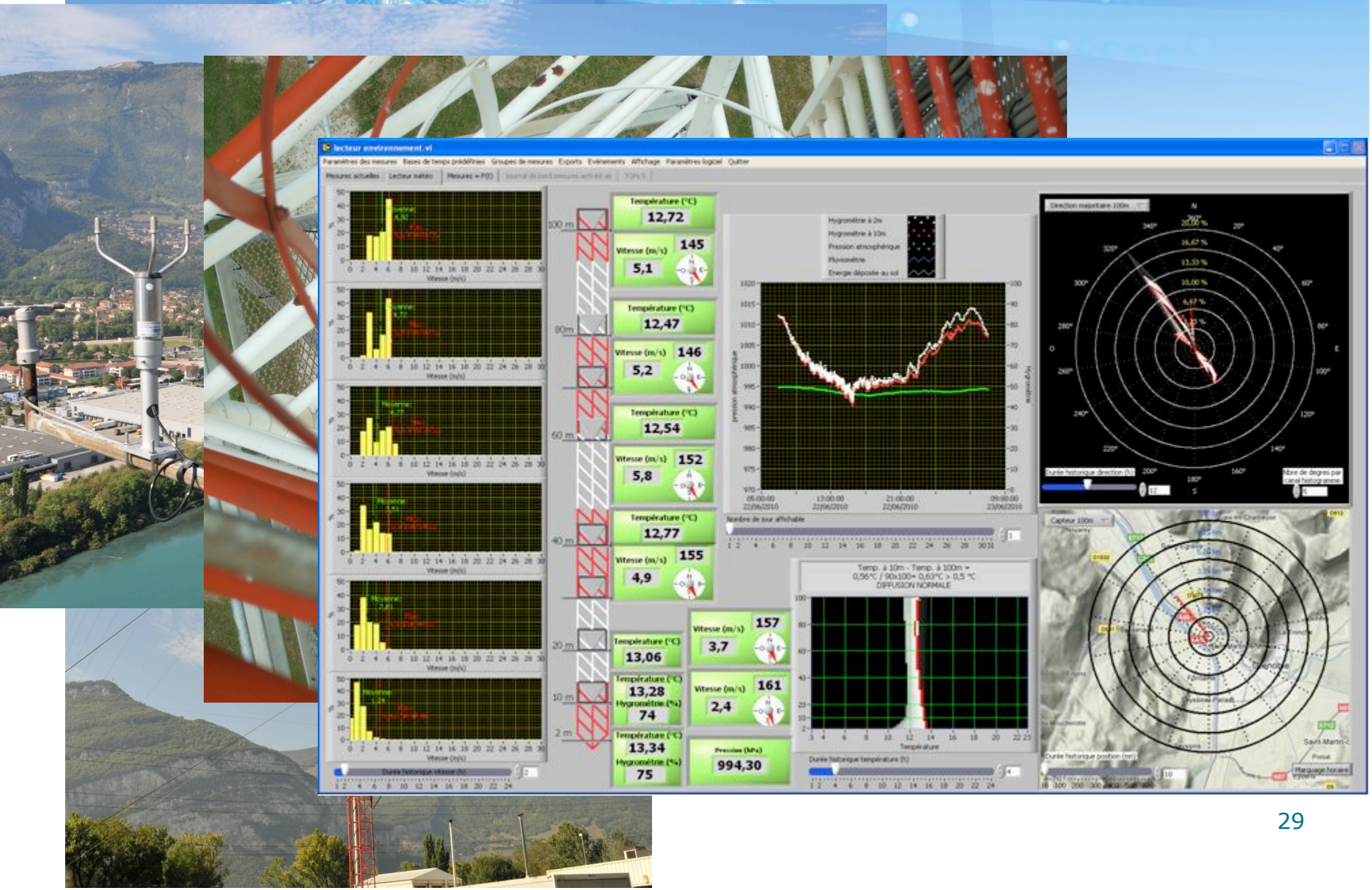
# RHF modernization and refurbishment: KRC

Key reactor components (continued)

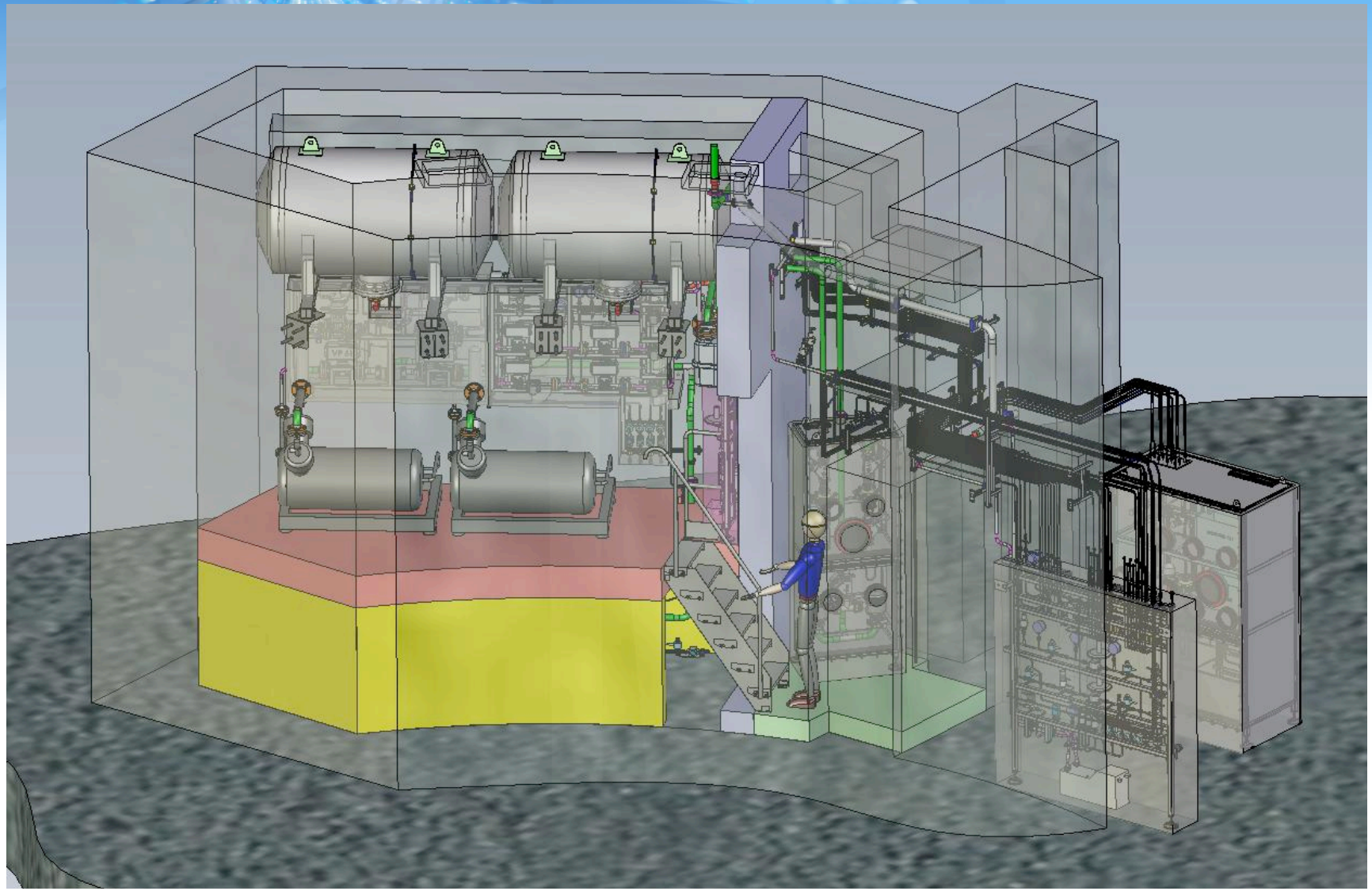
- Primary circuit: the emergency core reflood circuit using pyrotechnic valves (work carried out in 2010)



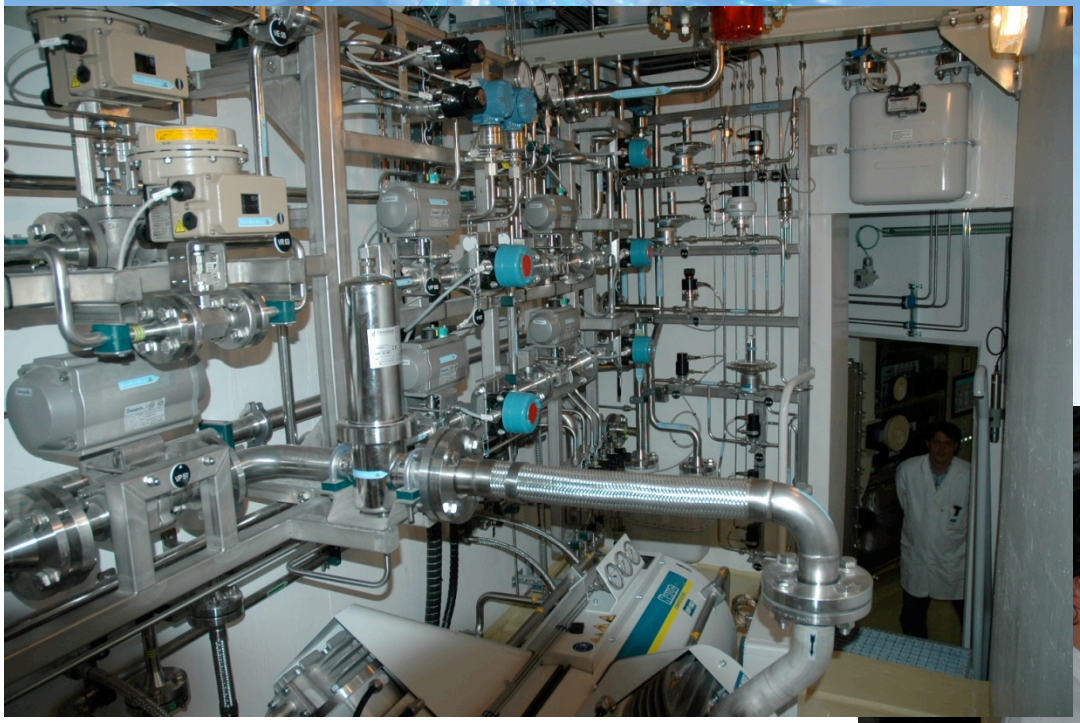
# Winter Shutdown 2009/2010



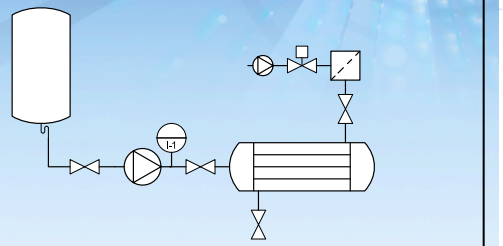
# Gaseous decay tank



# 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

Hier, mercredi 10 mars, nous avons reçu et mis en place le nouveau filtre Beaudrey.

Son installation va continuer pendant quelques jours…

Fond de fosse nue avec bonde de dessablage

# RHF modernization and refurbishment: Heavy water management

NEUTRONS FOR SCIENCE

Key reactor components

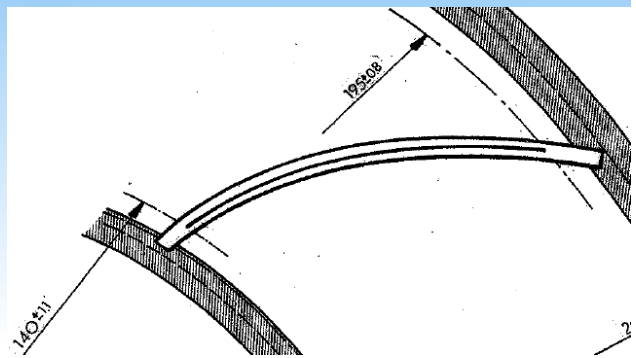
- Heavy water management: The decision not to refurbish the detritiation facility (2008) implies new facilities for sending the reactor's heavy water for processing and re-importing treated heavy water (studies in progress)

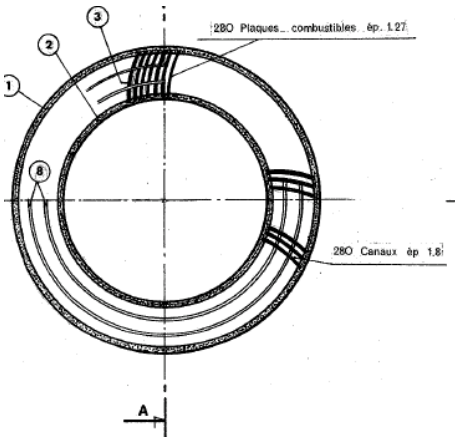
# Fuel conversion from HEU to LEU

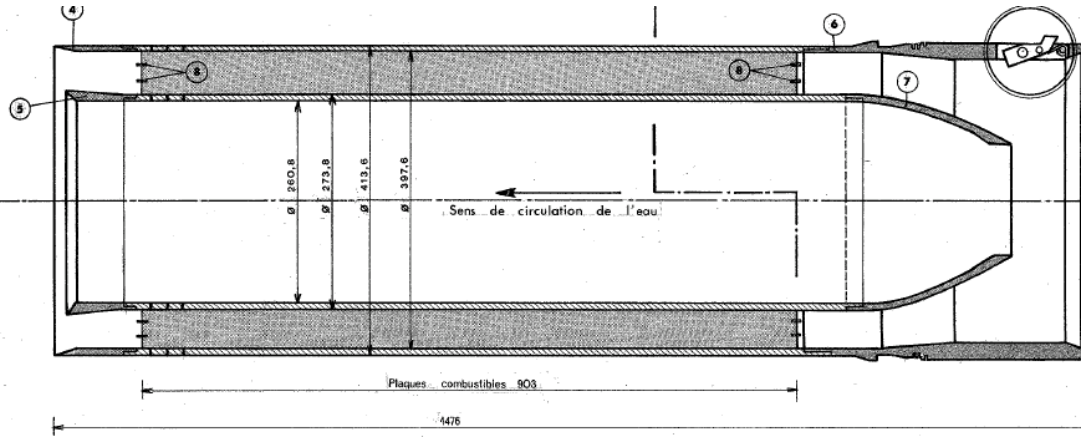
# The ILL neutron source

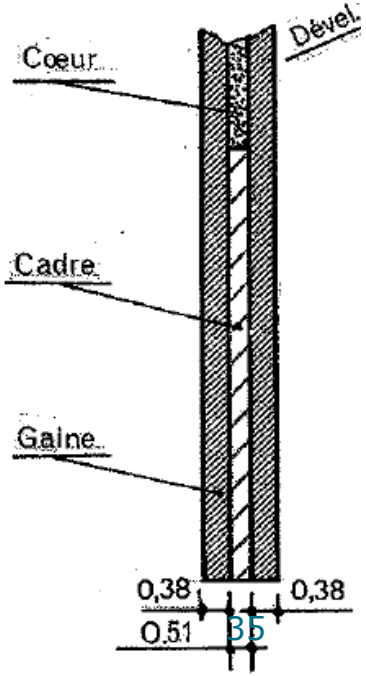
10 kg of uranium 235 inside the single fuel element:

- 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

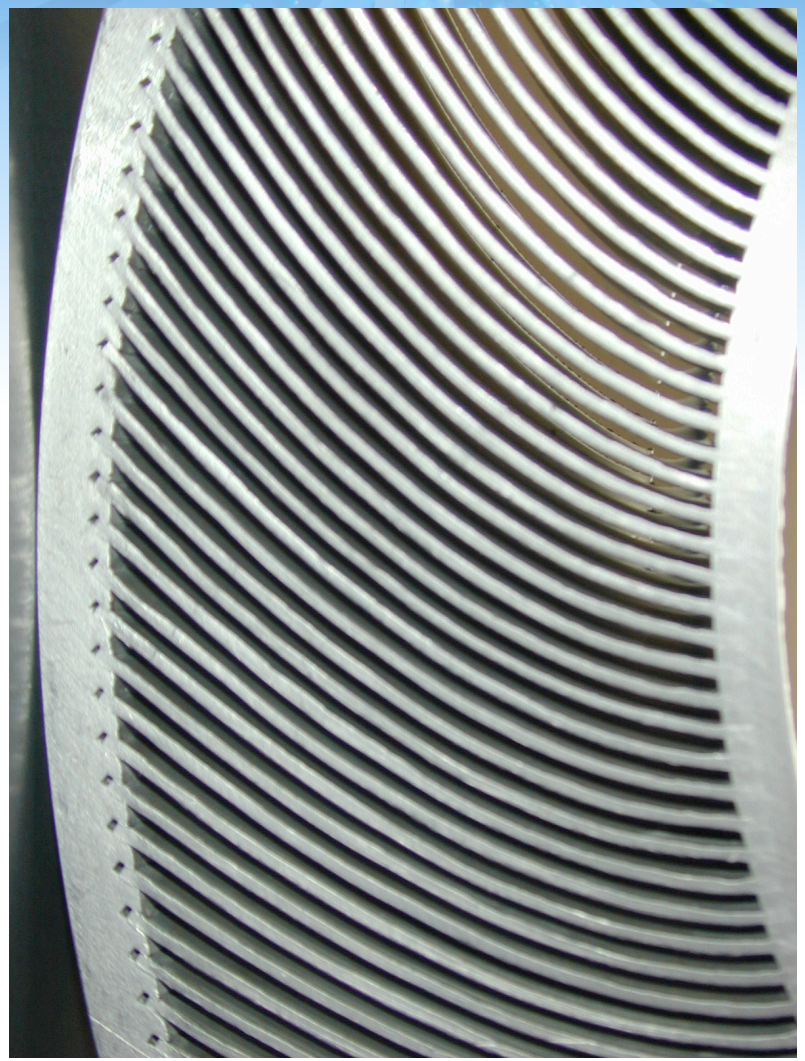


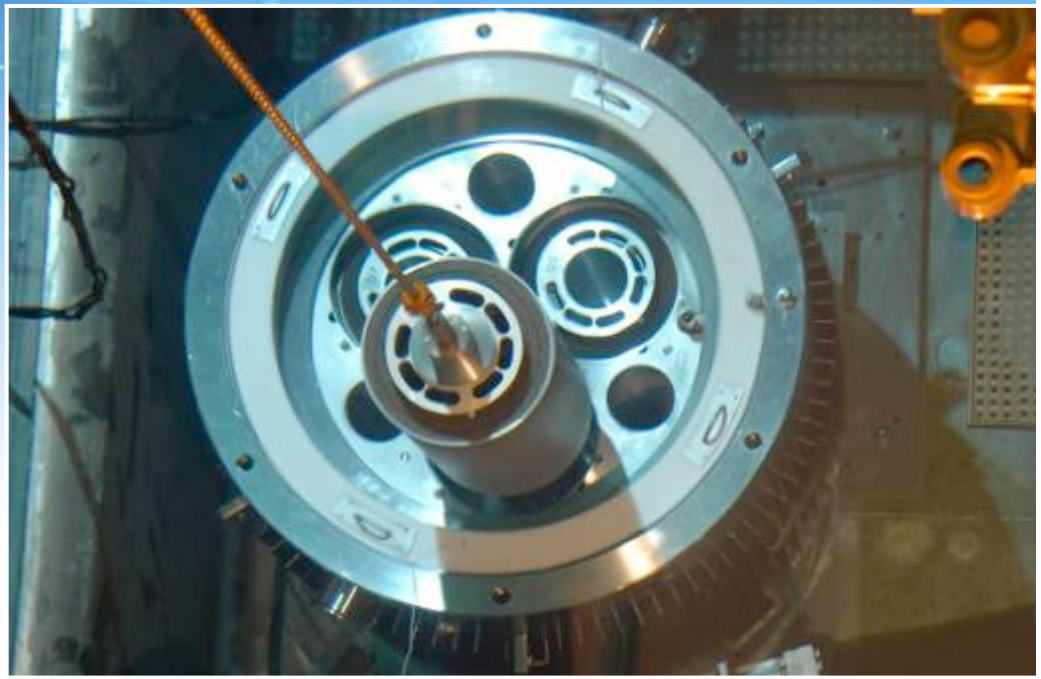



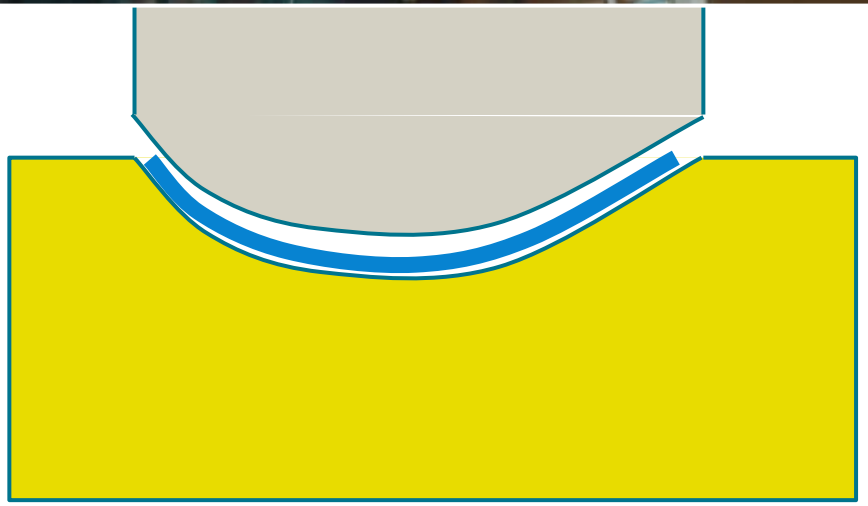



# Consequences on fuel-plate fabrication

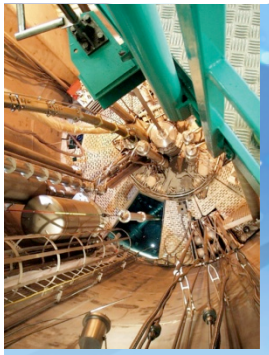






# Safety analysis

- 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

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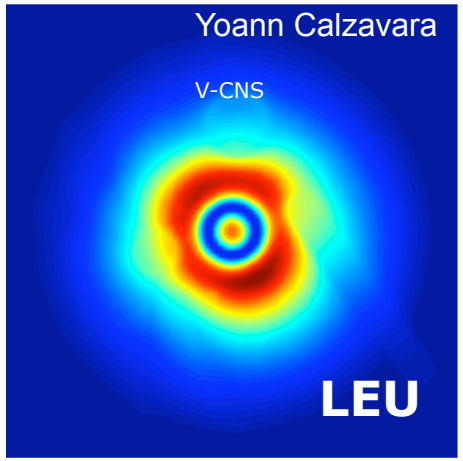
- External detritiation of hea
- Conversion fr
  - *(MoU 8*
  -

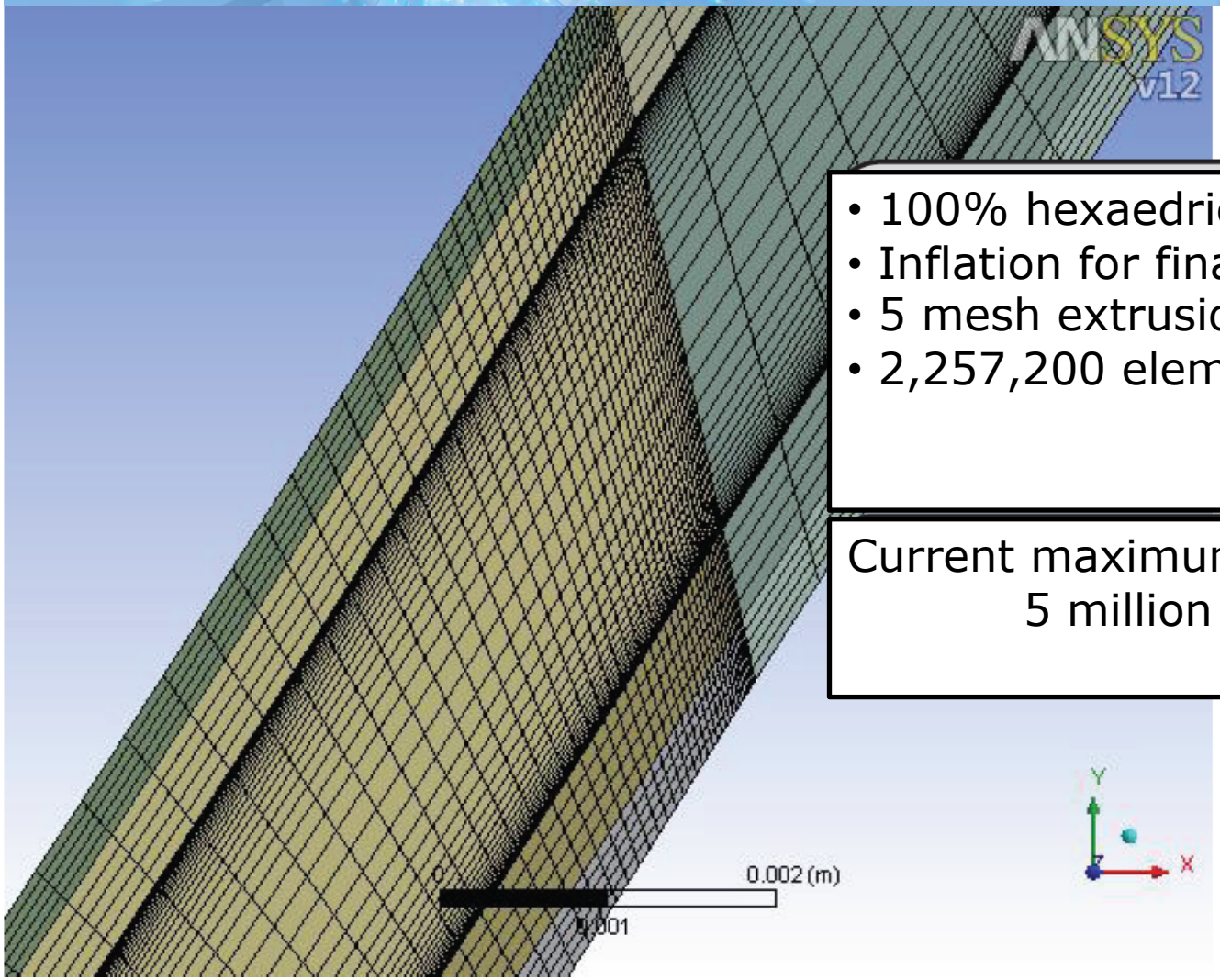
- Supply of HEU fuel

HEU export licence submitted to DOE in 2010
Delivery in 2012

# Fuel management : LEU conversion

# Calculation mesh

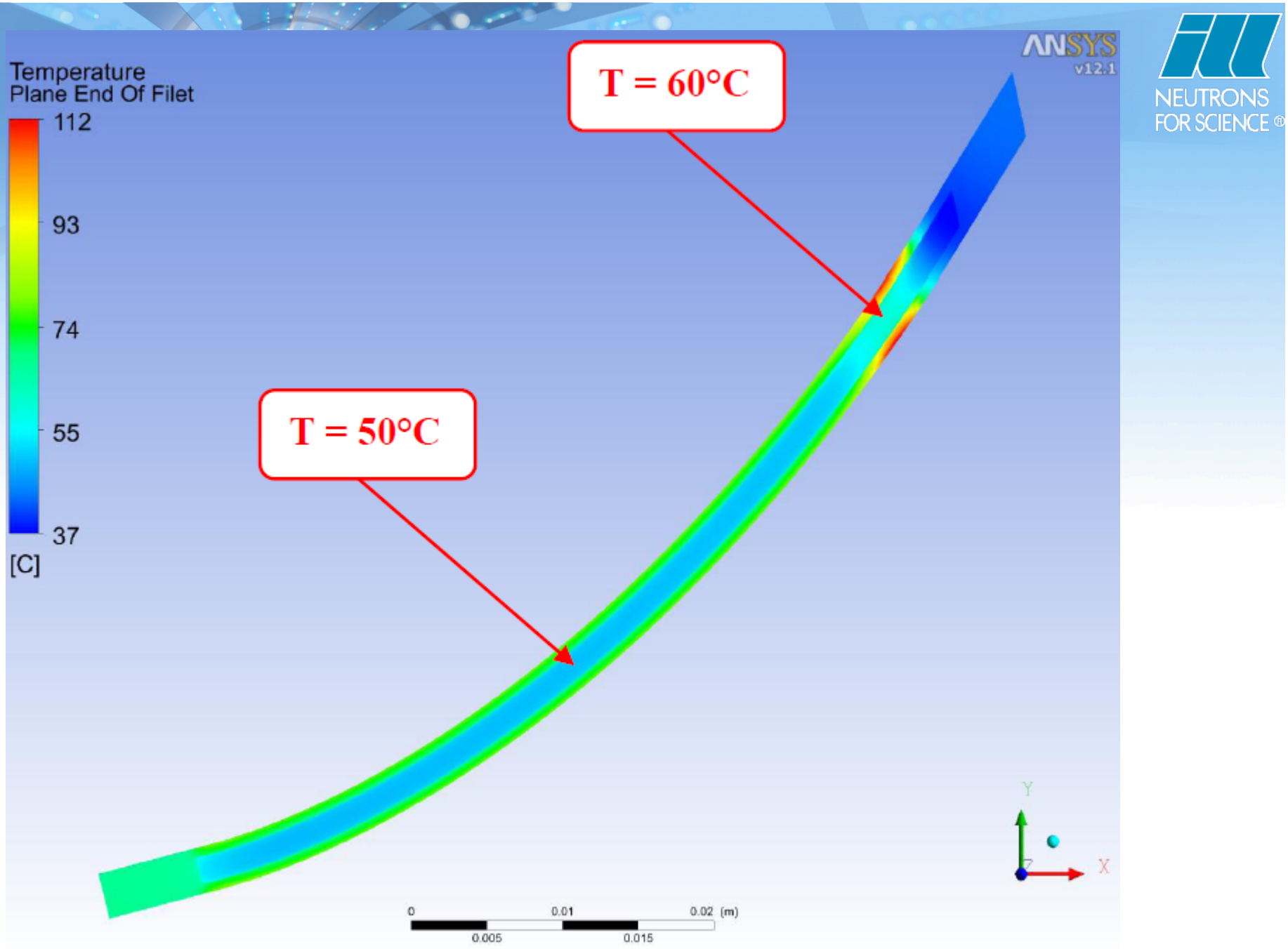


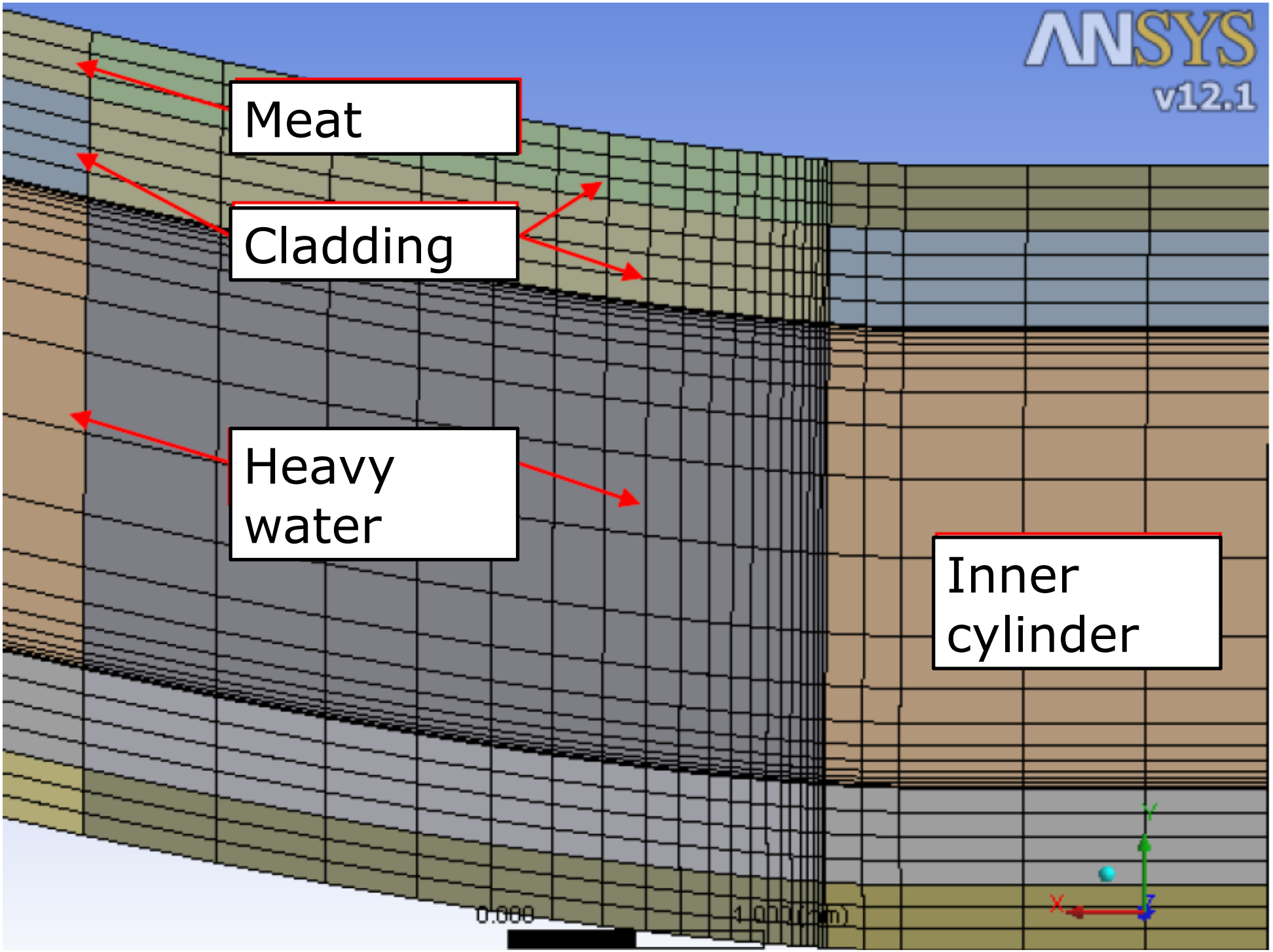

- 100% hexaedric
- Inflation for final levels
- 5 mesh extrusions
- 2,257,200 elements

Current maximum calculation :
5 million elements

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

$$y \approx 10\,\mu m$$

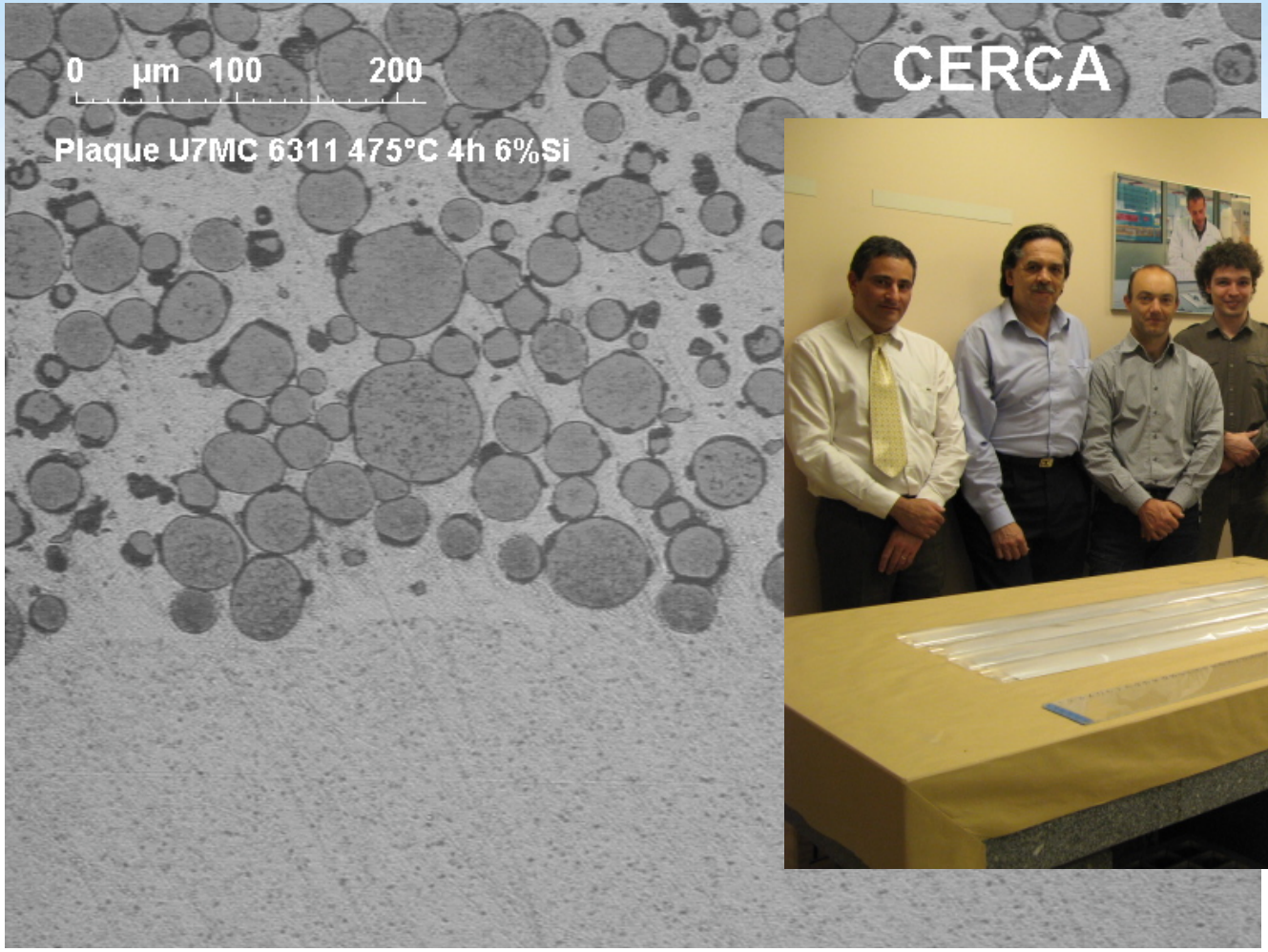

Temperature
Plane End Of Filet
112
93
74
55
37
[C]
T = 60°C
T = 50°C
ANSYS
v12.1
0
0.01
0.02 (m)
0.005
0.015
Y
Z
X


ANSYS
v12.1
Meat
Cladding
Heavy water
Inner cylinder
0.000
1.00 (m)
Y
X
Z

# Fuel management

## Lowly Enriched Fuel Element

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

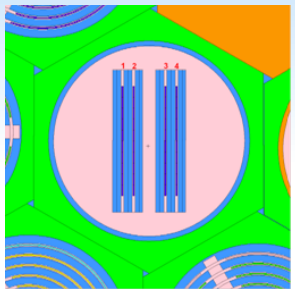



LÉONIDAS
ADVANCED LEU TECHNOLOGY GROUP

# LEONIDAS Experimental Program

NEUTRONS FOR SCIENCE

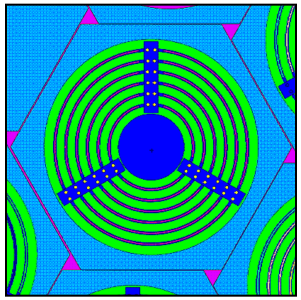
- International results show that the addition of Si to the matrix stabilizes growth of the interaction layer between UMo and Al matrix



- 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 »**



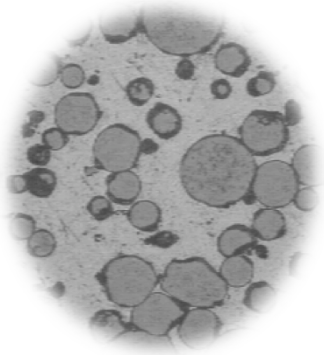
- Therefore, there is an absolute necessity to test the best combination of these parameters under representative conditions of high performance research reactors (470 W/cm², 11 m/s for BR2; 500 W/cm², 17 m/s for RHF)

➔**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

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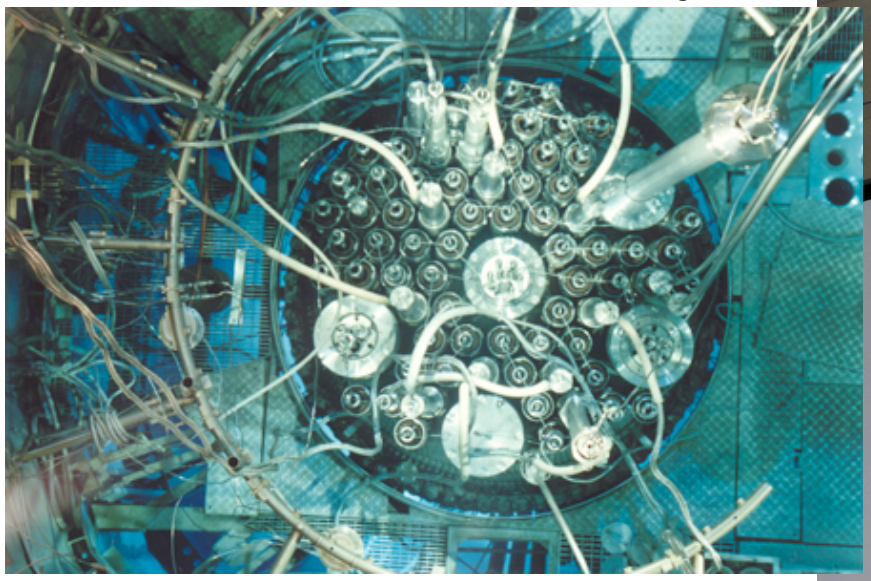
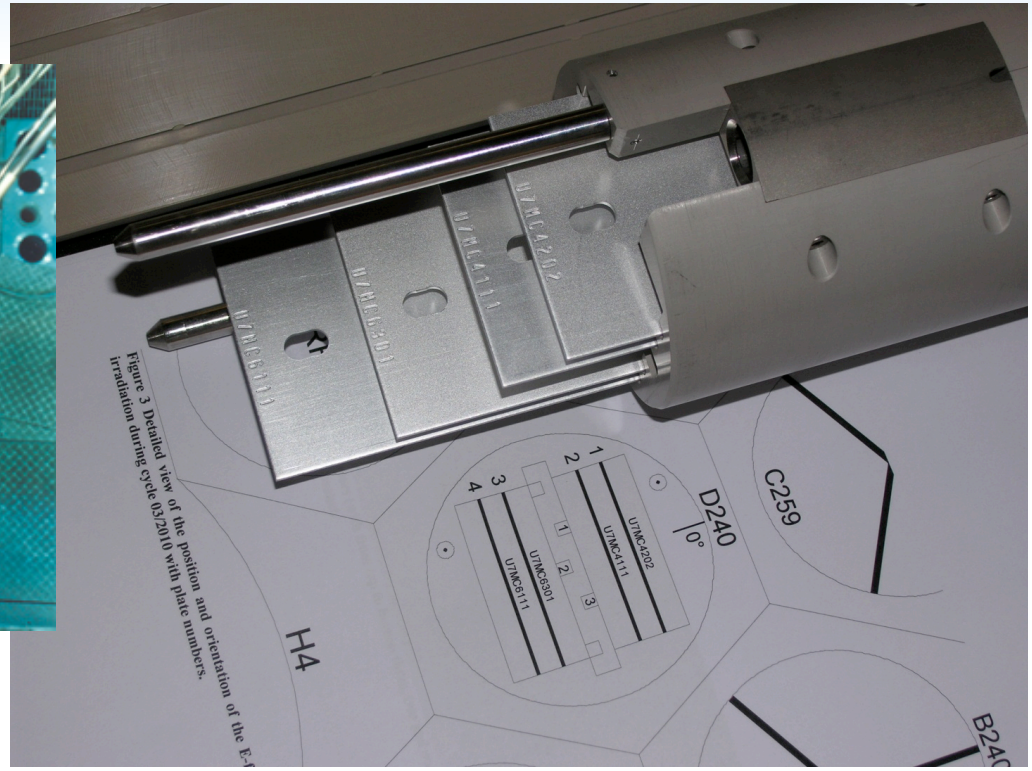
ADVANCED LEU TECHNOLOGY GROUP

NEUTRONS FOR SCIENCE

# 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 %





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ADVANCED LEU TECHNOLOGY GROUP

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# 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/cm$^2$ | 350 W/cm$^2$ | *240 W/cm$^2$* |
| **EOC max heat flux** | 340 W/cm$^2$ | | |

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# The Conversion Roadmap After LEONIDAS A Shared Goal of Participants

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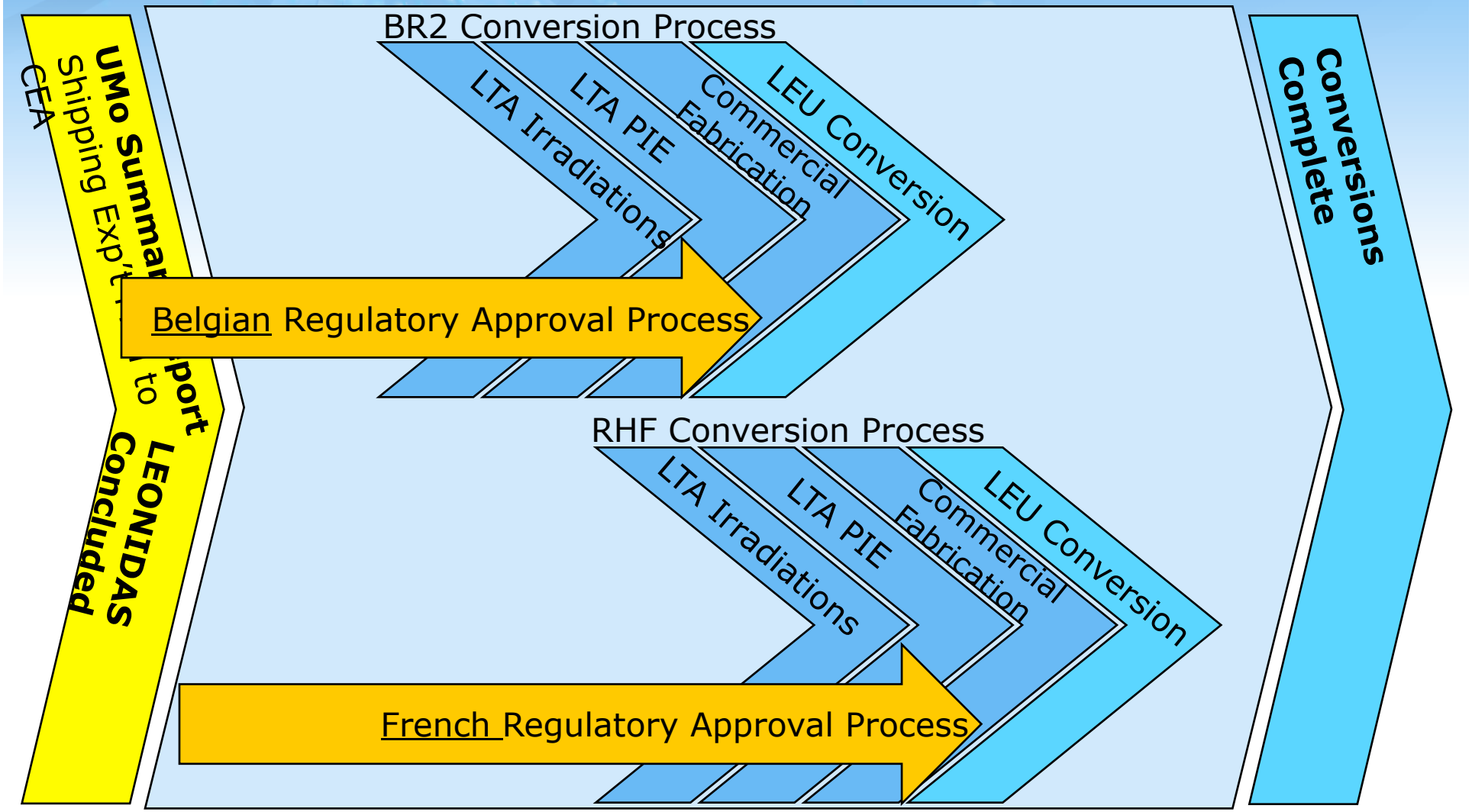

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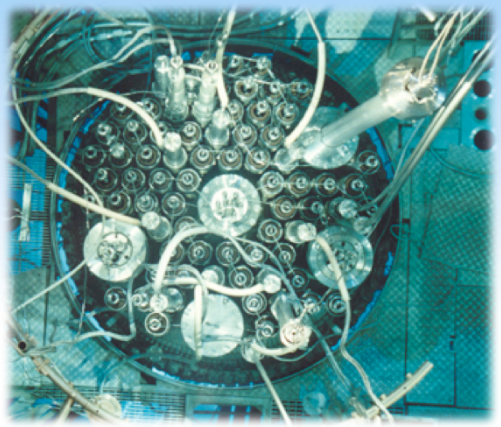
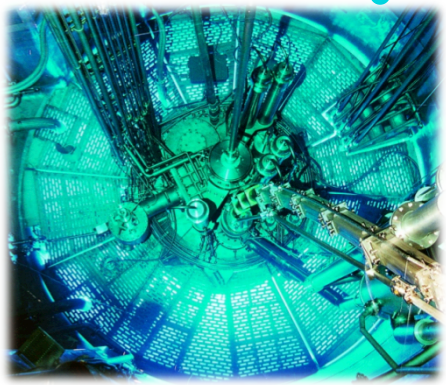
# Roadmap to Actual Conversion
# After the LEONIDAS Program

- **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

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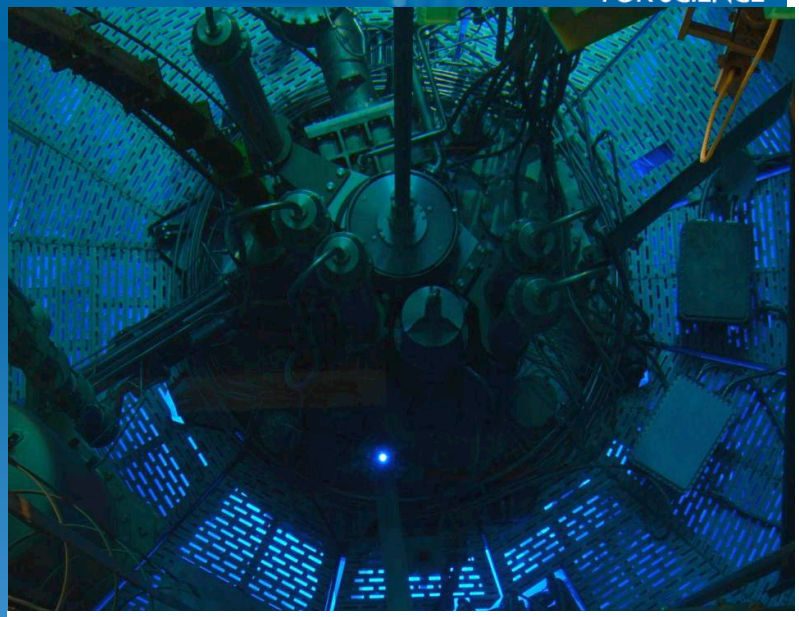
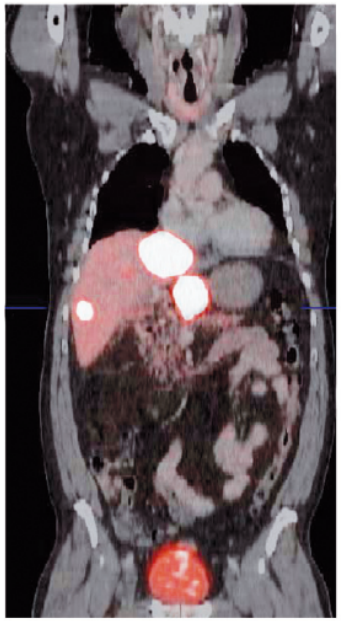
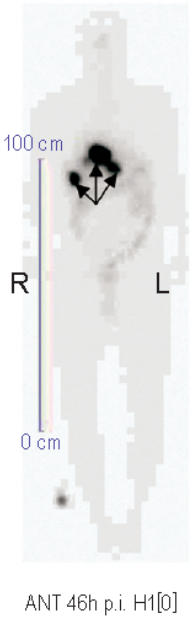


Production of $^{188}W$ with high specific activity (>3 Ci/g) by double-neutron-capture requires a thermal flux >1E15 n/ $cm^2$/s. With its present authorization ILL can provide about 5 TBq $^{188}W$ per year.

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.

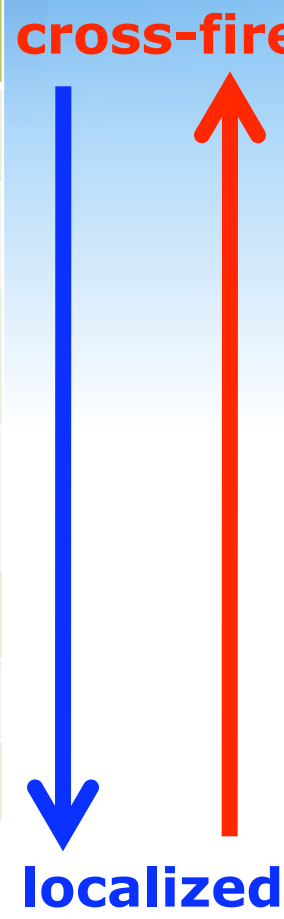





Credit: Zentralklinik Bad Berka

# Radionuclides for RIT and PRRT

| 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<br>5, 17, 40 $e^-$ | 75 | **2 mm**<br>**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** |

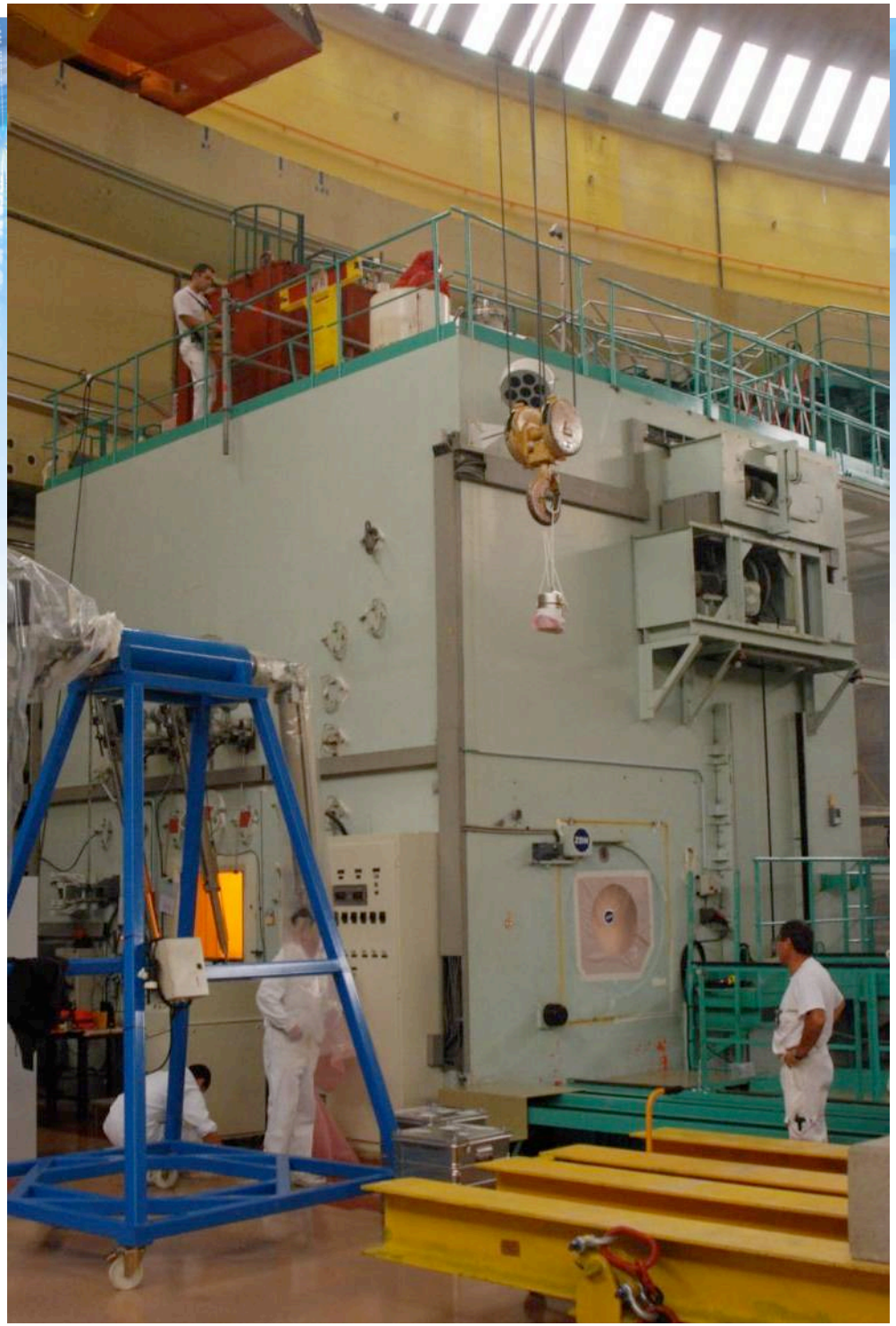



**Estab-lished isotopes**

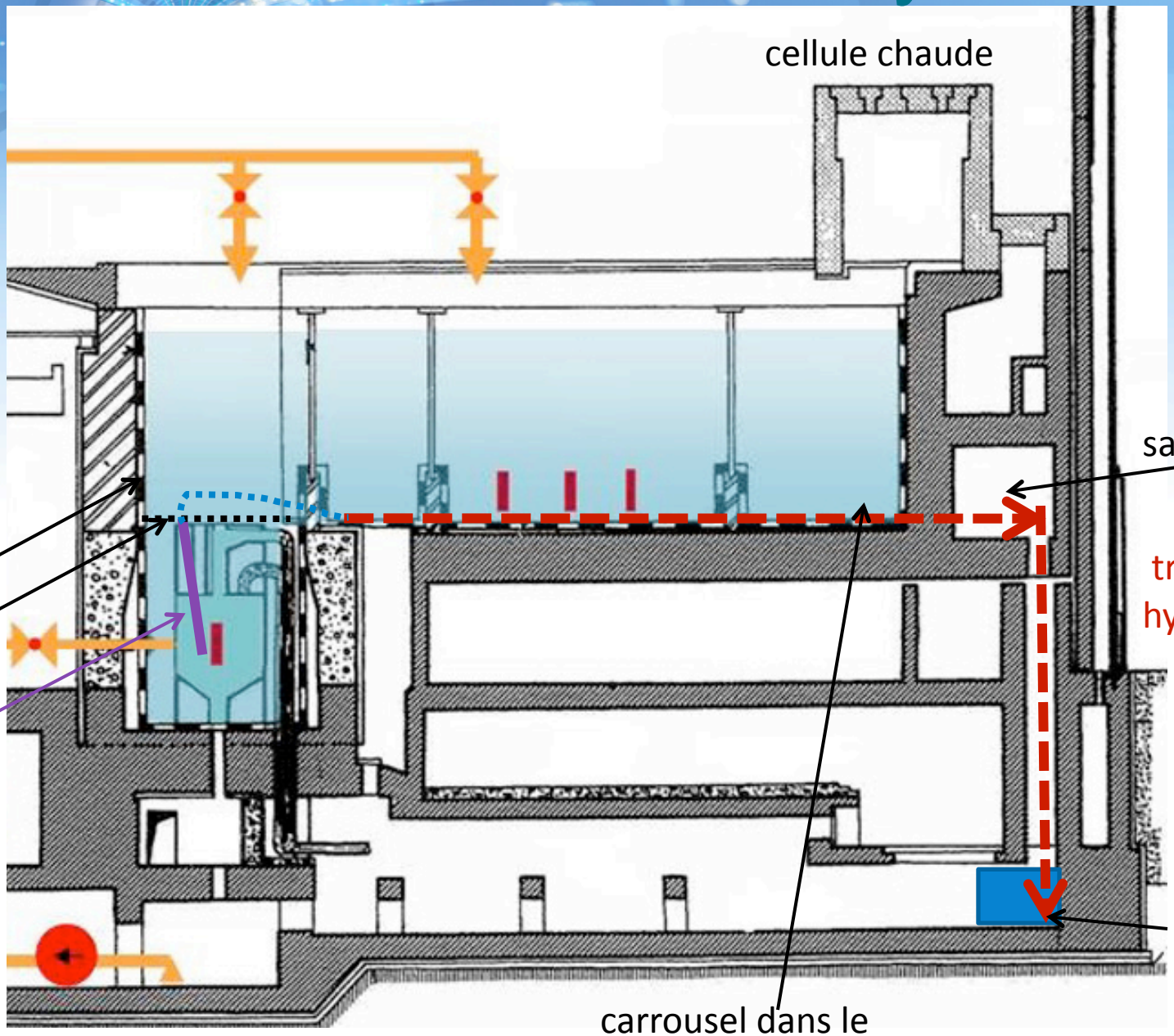
**Emerging isotopes**

**R&D isotopes: supply-limited!**

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



# Layout of new irradiation system



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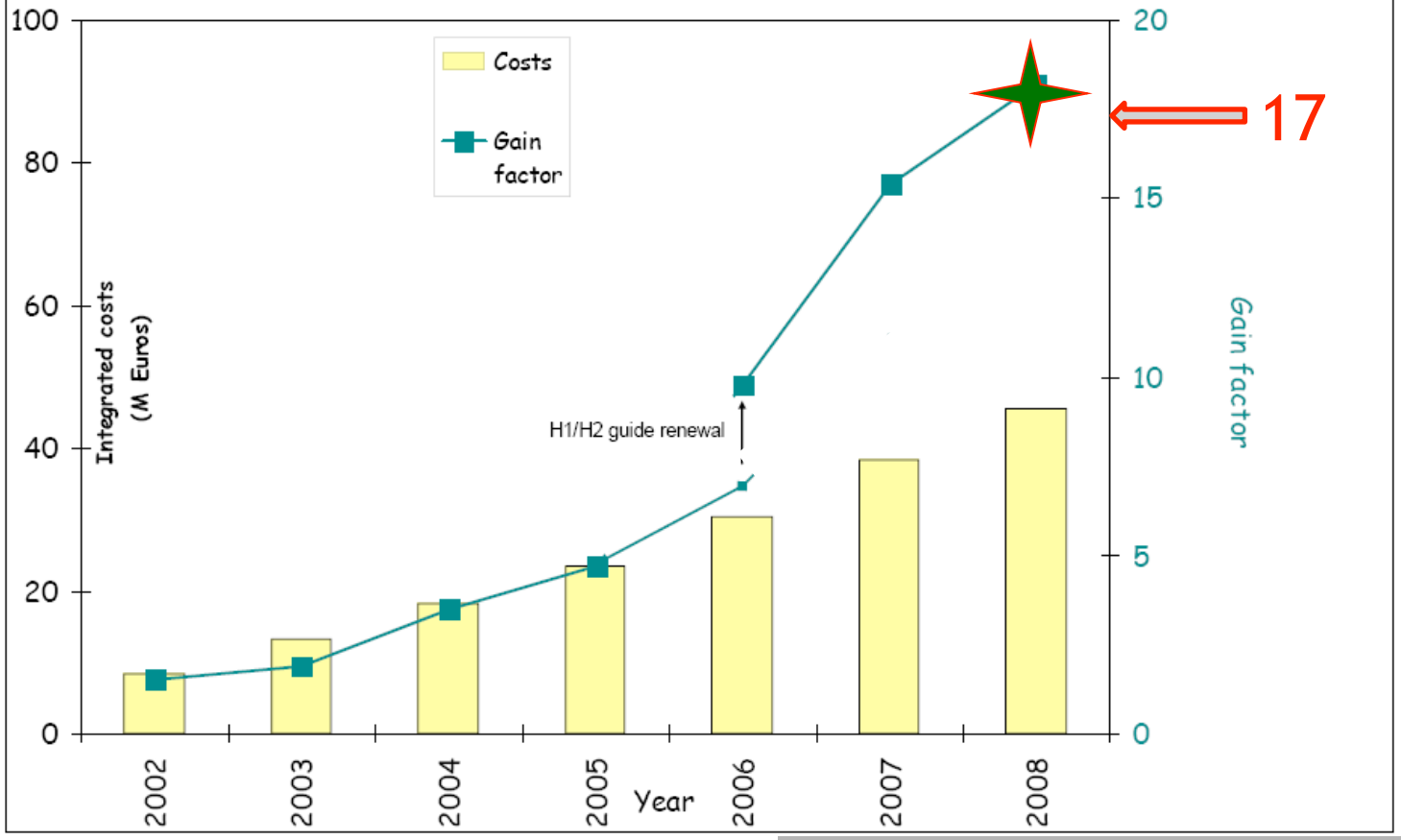
# The MILLENNIUM PROGRAM

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

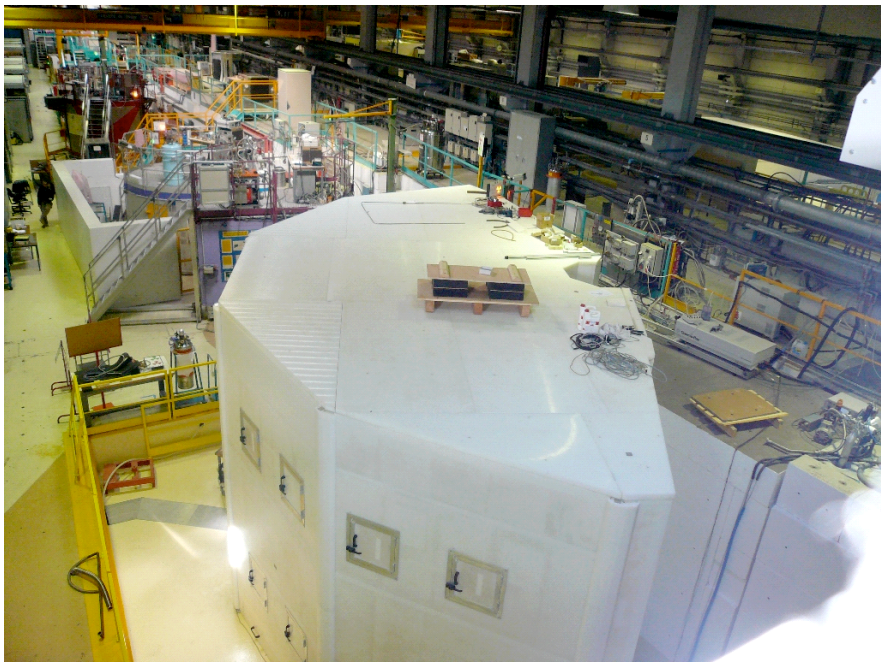
## Gain factors (data collection rate) after completion of Phase M-0

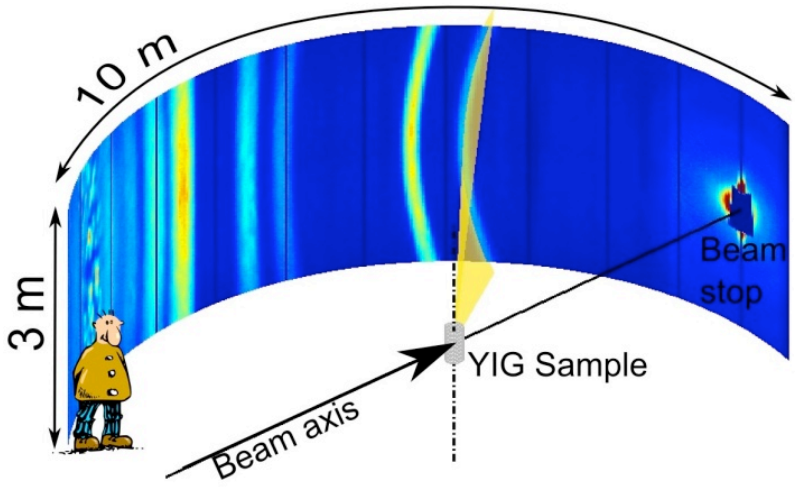


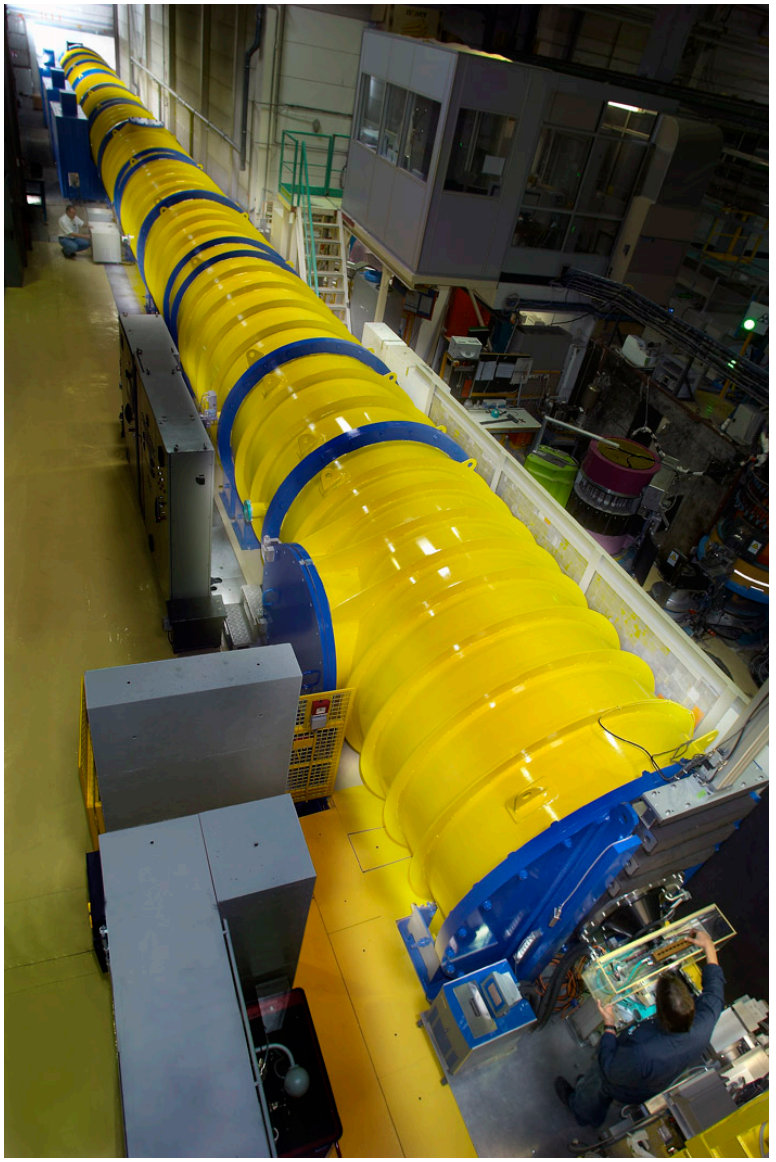

27 public + 10 CRG instruments

# Final Review of IN5 and D11

-Assessment of ILL's efficiency in project management -



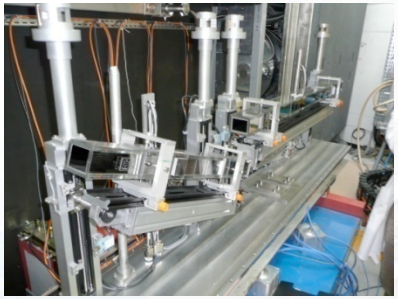


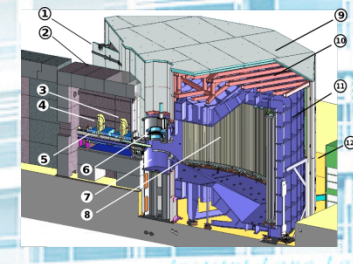



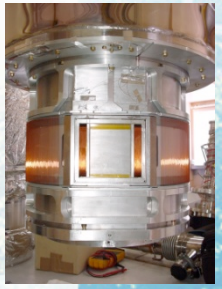
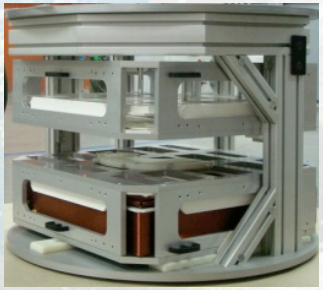
# Millennium Programme - Phase M-0

Completed end of 2008!!

Spent budget: 38.2 M€ (2001-2008)



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More than simply neutrons...

# Planning through the next decade..
# ...Perspectives

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## Millennium Phase M-1

(2007 – 2014)

Total budget: ~41.57 M€

(without staff costs)

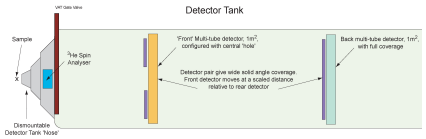
# Addressing the Future:
## Millennium Programme Phase M-1 2007- 2013

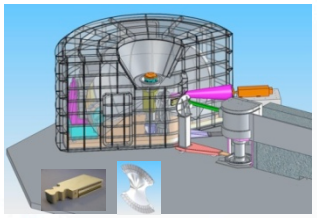
- 5 new instruments

HR-BS IN16B

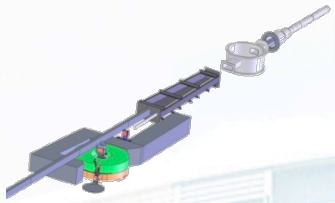
NSE WASP

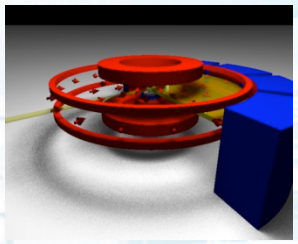
SANS D33



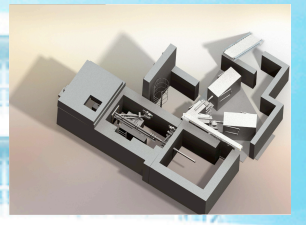



TAS ThALES





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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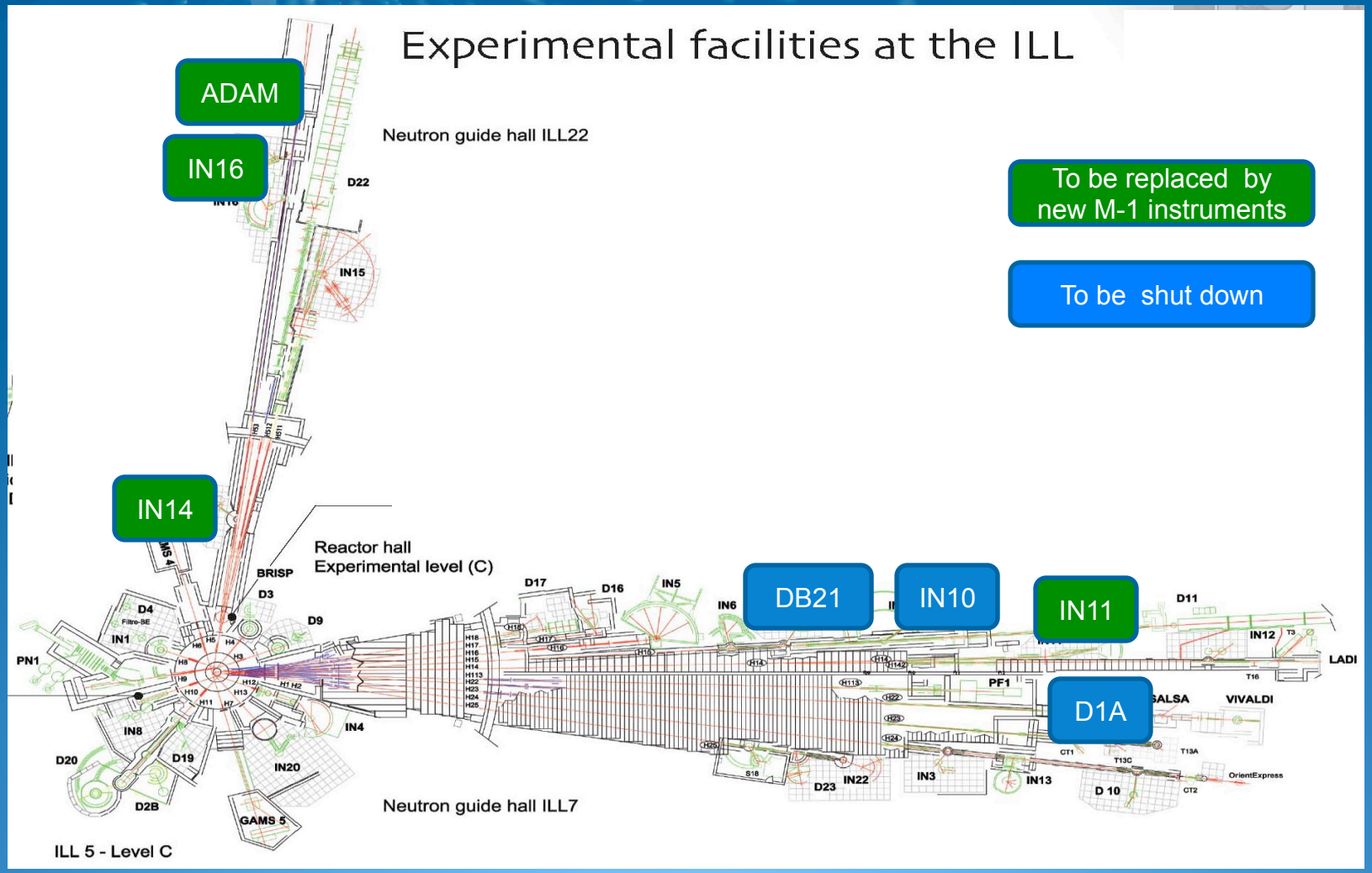
More than simply neutrons...

# Extension of neutron guide hall ILL7 (April 2010)

# …..phasing out 7 instruments (2010 -2013)



# Planning through the next decade..

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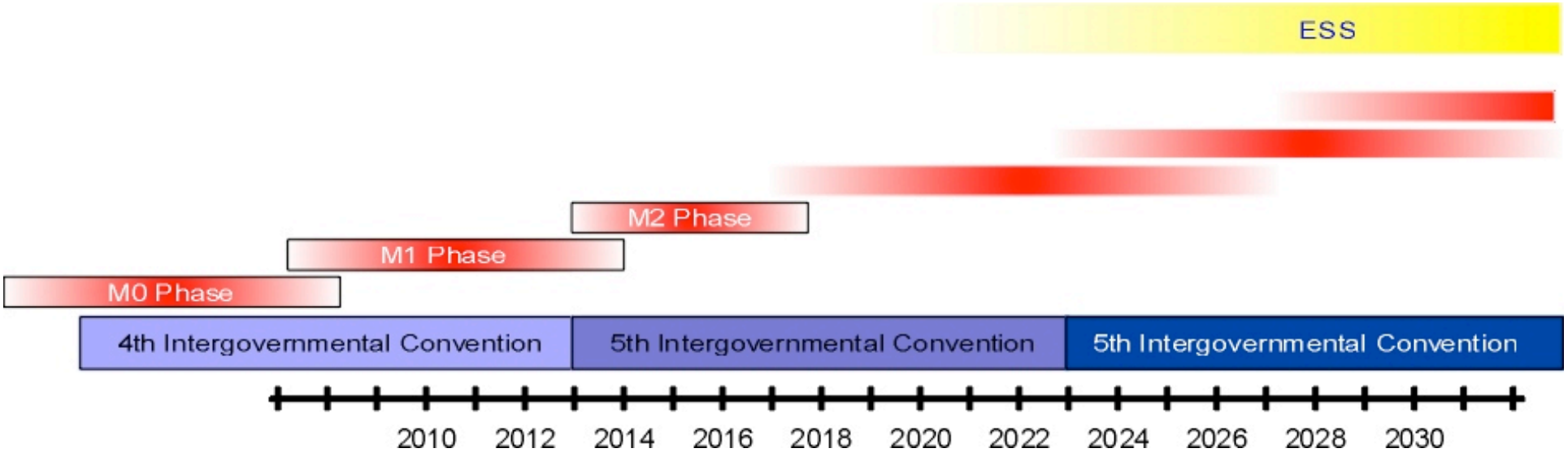
## Millennium Phase M-1

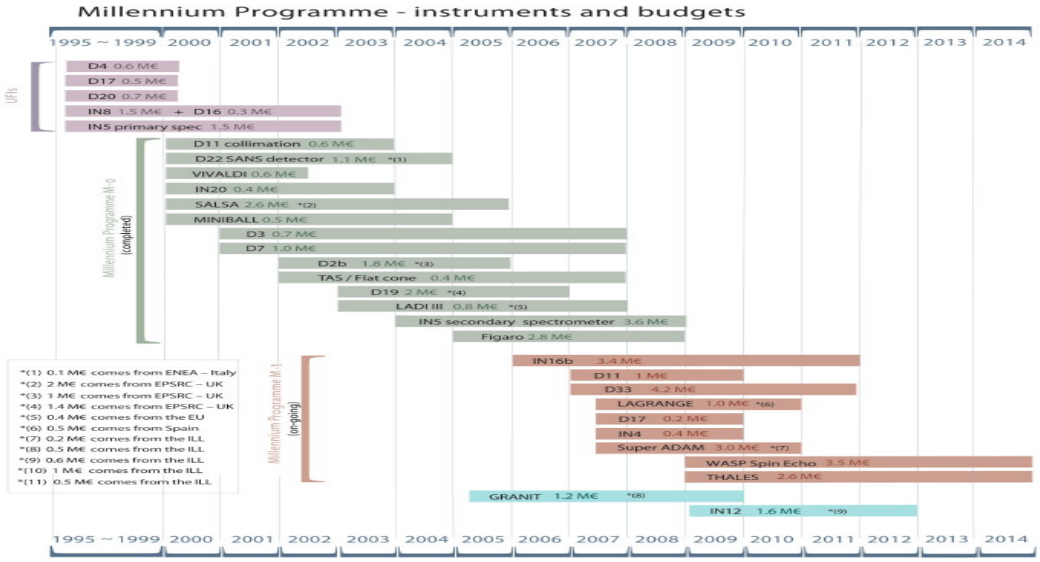
(2007 – 2014)

## Phase M-2

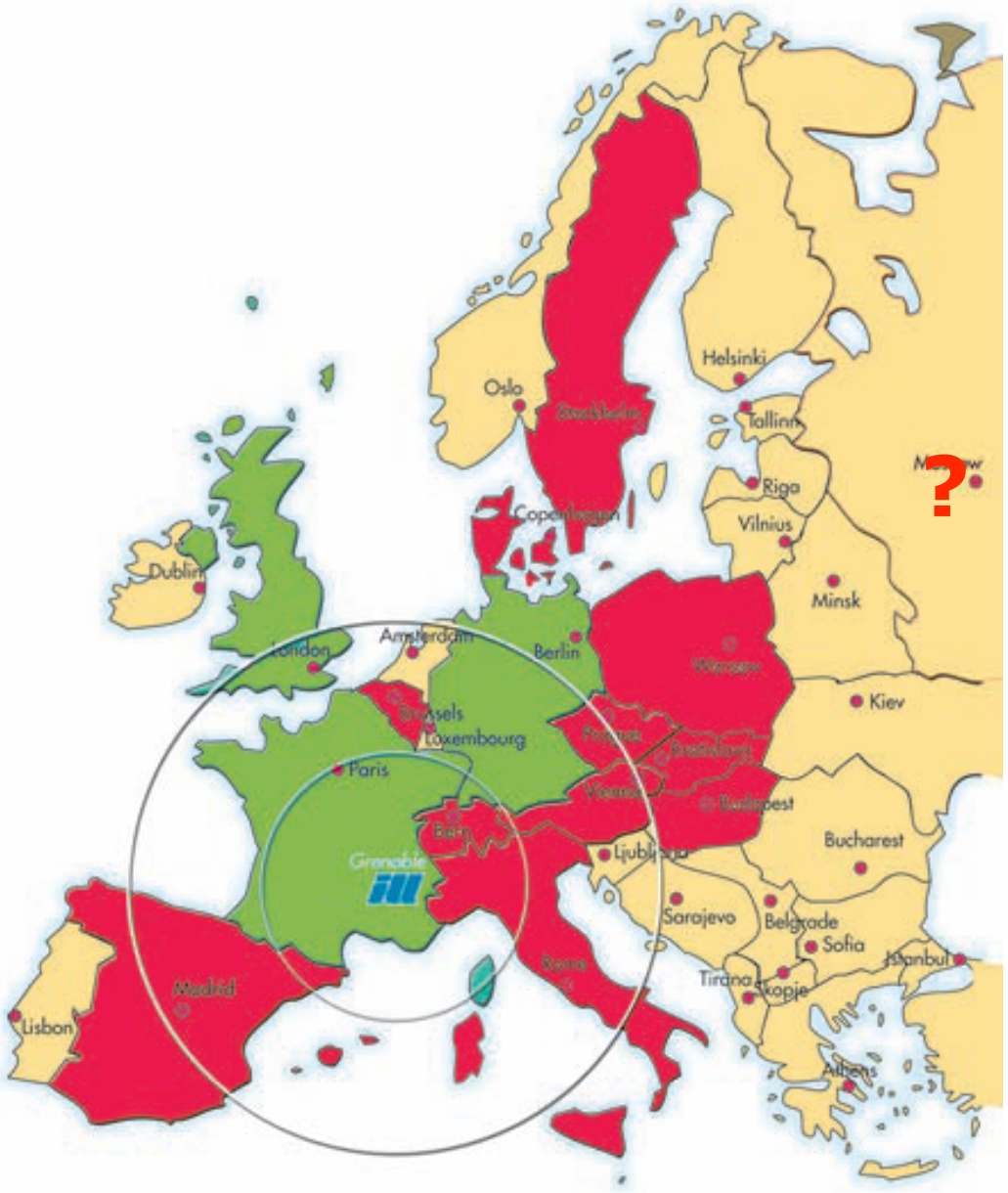
(2013 – 2017)


# 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


**Thank you for your attention**

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

# Welcome to the ILL