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# Non-Destructive Examination Benches and Analysis Laboratories in support to the Experimental Irradiation Process in the Future Jules Horowitz MTR

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- Why fuel and material irradiations in MTR?
- Non-destructive examinations: a key offer in support to the experiment quality
- Non destructive examination benches and analysis laboratories of the JHR
- Status of underwater gamma - X-ray bench studies
- Conclusions

## Development of a New Nuclear Fuel or Material

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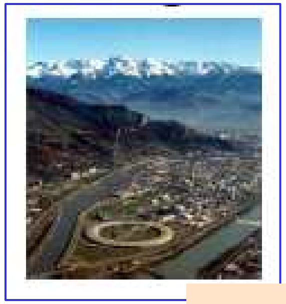
- An irradiation phase is mandatory before development at an industrial scale
  - ✓ Selection of a few suitable microstructures
  - ✓ Basis data characterization and behavior laws
  - ✓ Behavior in off-normal conditions



ESRF

GANIL Cyclotron

- Main irradiation infrastructures used
  - ✓ Gamma or X-ray sources, synchrotrons
  - ✓ Electron or ion accelerators
  - ✓ Fundamental research reactors (neutron beams)
  - ✓ Material test reactors
  - ✓ Power reactors

ILL RR

OSIRIS MTR

**Large and instrumented samples**

**Respect all the nominal environment parameters**

Paluel NPP

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# Why MTRs are Still Necessary ?

## Power reactors cannot be used when

- Necessity of a specific sample design or structure to fulfill the objectives (irradiation speed-up…)
- Operation at reactor limits (high dpa or burn-up, transients…)
- Protocol deals with off-normal or non acceptable operating conditions (power ramp, post-failure behavior…)
- Program is related to safety criteria study (margins, change..)
- Sample properties measured through PIE are not representative
- Full scale power reactor doesn't exist

**Using of MTRs + Dedicated reactors (e.g. for safety tests)**

# Non-Destructive Examinations in MTR: General Objectives

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- **Initial checks of the sample** before irradiation
  - ✓ Handling possible effects (transportation, insertion in the device)
  - ✓ Precise positioning of instrumentation, sensors…

- **Adjustment of the experimental protocol** after a short irradiation run
  - ✓ Power time history fine tuning…
  - ✓ Early unexpected sample behavior

- **Gain of data not accessible through classical PIE in hot cell**
  - ✓ Stress or environment maintain
  - ✓ Fission product short half-lives…

- **On the spot sample status after a test**
  - ✓ Limited handlings to preserve the "as tested" sample geometry
  - ✓ Geometrical changes after an off-normal transient

- **Final NDE tests** after irradiation sequence
  - ✓ On unloaded sample ⇔ reference status before transportation

# Non Destructive Examination Benches in JHR

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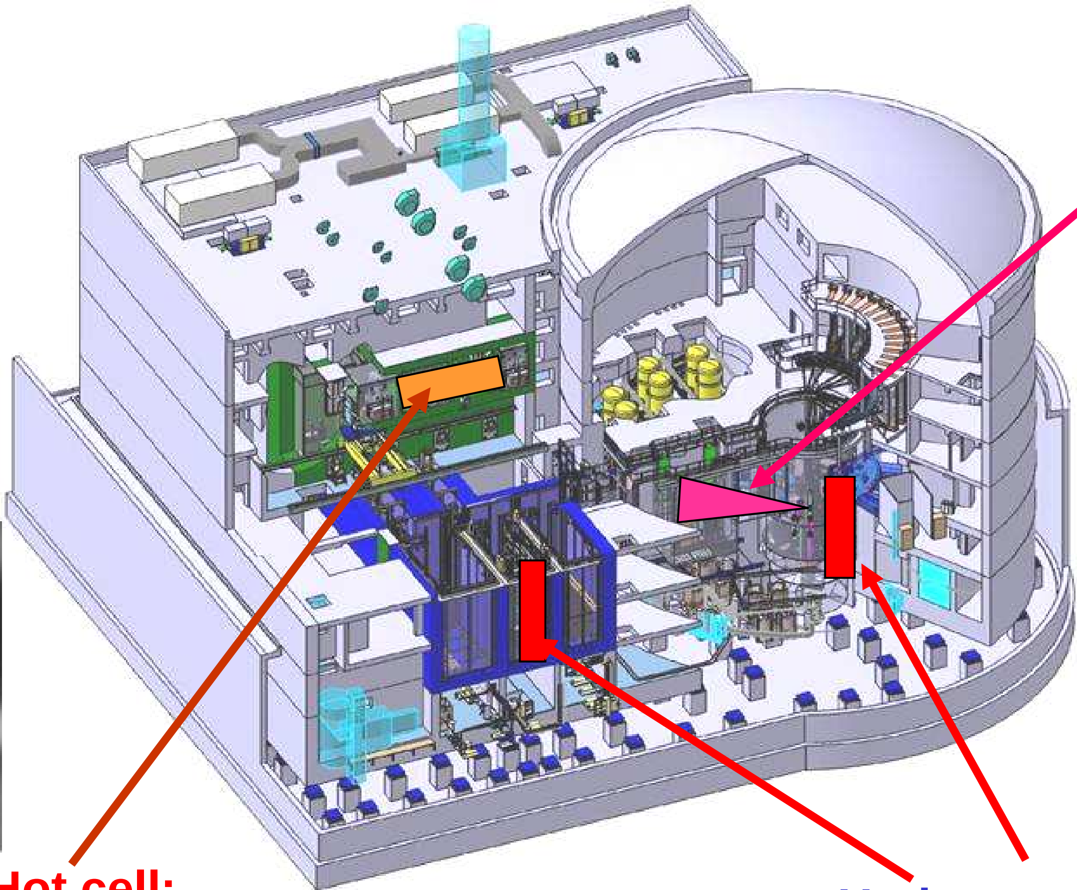
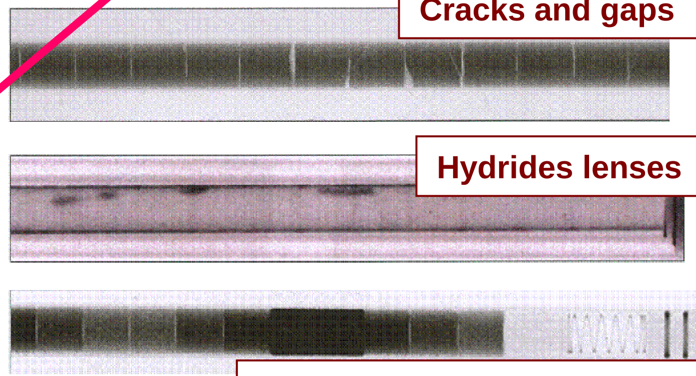



**Underwater Neutron Imaging System**



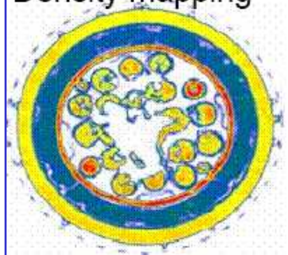

**Fuel Hot cell: Gamma and XR scanning system & multipurpose test benches**

**Underwater photonic imaging systems (X-ray & $\gamma$) in reactor and storage pool**

**Feasiblity study in progress with VTT collaboration**

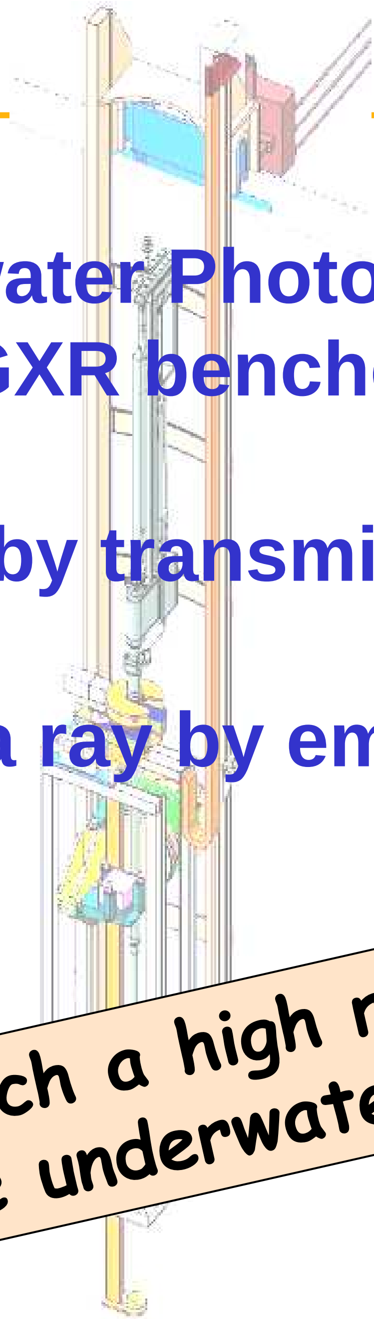
Phebus PF

Density mapping



XR tomography (transmission)

# Focus on JHR Underwater Photonic Imaging Systems
# UGXR benches



## X-ray by transmission

## Gamma ray by emission

**How to reach a high resolution on a large underwater bench?**

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# Main Requirements for the JHR UGXR Benches

- Capable to welcome a fully loaded irradiation device
  - ✓ Up to 750 kg and about 6 m in height
  - ✓ To check samples inside

- Z, Y translations and θ rotation with requested accuracy + reproducibility

- Large vertical and transversal stroke
  - ✓ Due to various samples and instrumentation
  - ✓ Total of 1900 mm in height and 200 mm horizontally

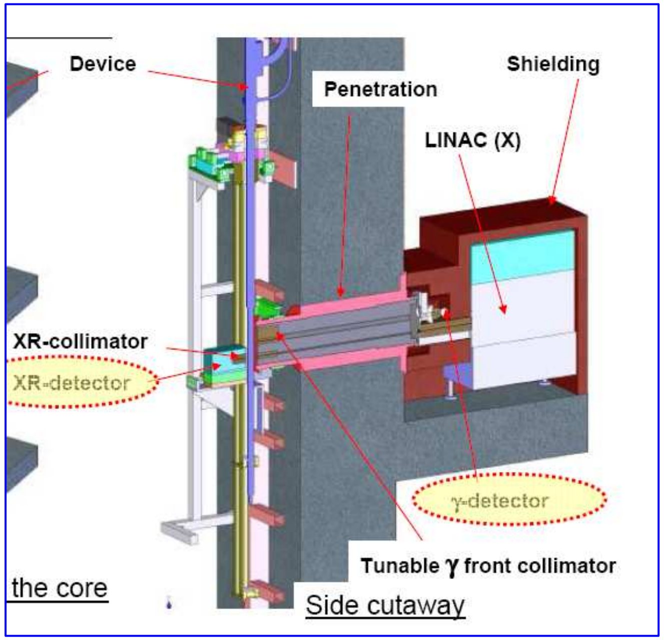
- Smallest details to be detected by tomography
  - ✓ X-ray tomography: Detected : 0,10 mm Quantified: 0,50 mm
  - ✓ Gamma tomography: 0,25 mm 1,0 mm

- To favor examinations during the reactor intercycle on a routine basis
  - ✓ Handling means availability
  - ✓ Limited acquisition times: e.g. 8 h for X-ray tomography on a 100*100*250 mm zone

# Main Challenges for the UGXR System and Technological Solutions

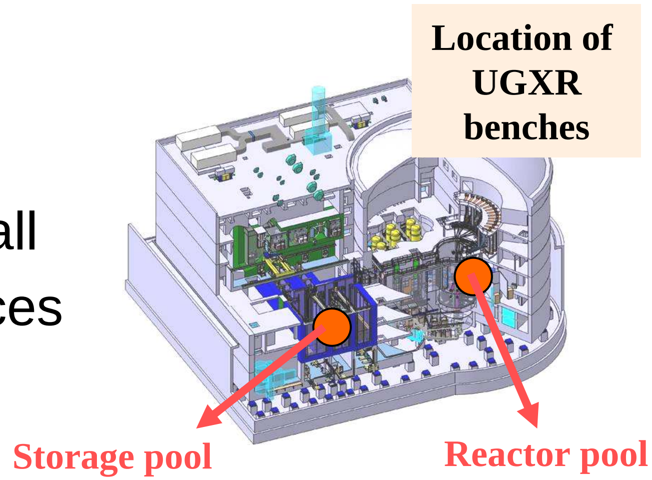
## Challenges:

- ✓ To go through a considerable thickness of metal (several cm)
- ✓ To limit examination time
- ✓ To use UGRX as a standard service offer



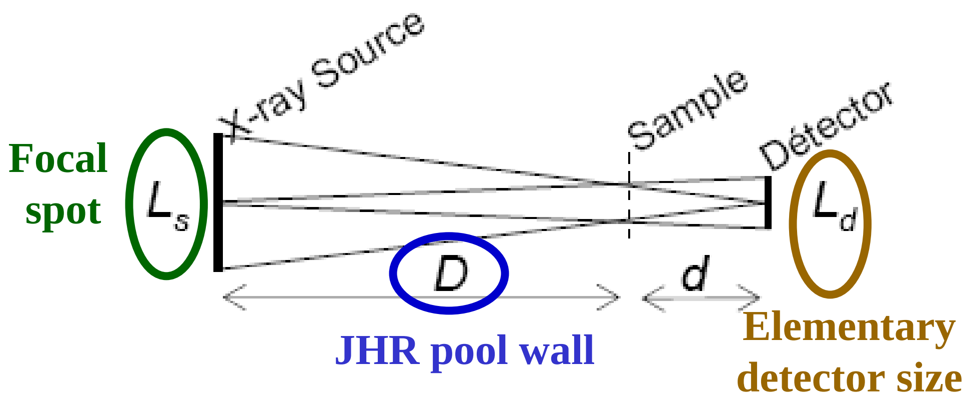

## Strategy:

- ✓ Use of a linear accelerator LINAC in the 6-9 MeV range for producing X-rays
- ✓ To install a shared X-γ feed-through in the pool wall
- ✓ To equip the JHR with 2 identical high performances benches



# How to Reach the Requested Spatial Resolution for X-Tomography? (1/3)

## Step 1 : To define a spatial resolution fulfilling the scientific needs, ambitious but reachable




$$LF = \sqrt{L_s^2 \times \left(\frac{d}{d+D}\right)^2 + L_d^2 \times \left(\frac{D}{d+D}\right)^2}$$

R&D approach through the « geometrical blur » LF

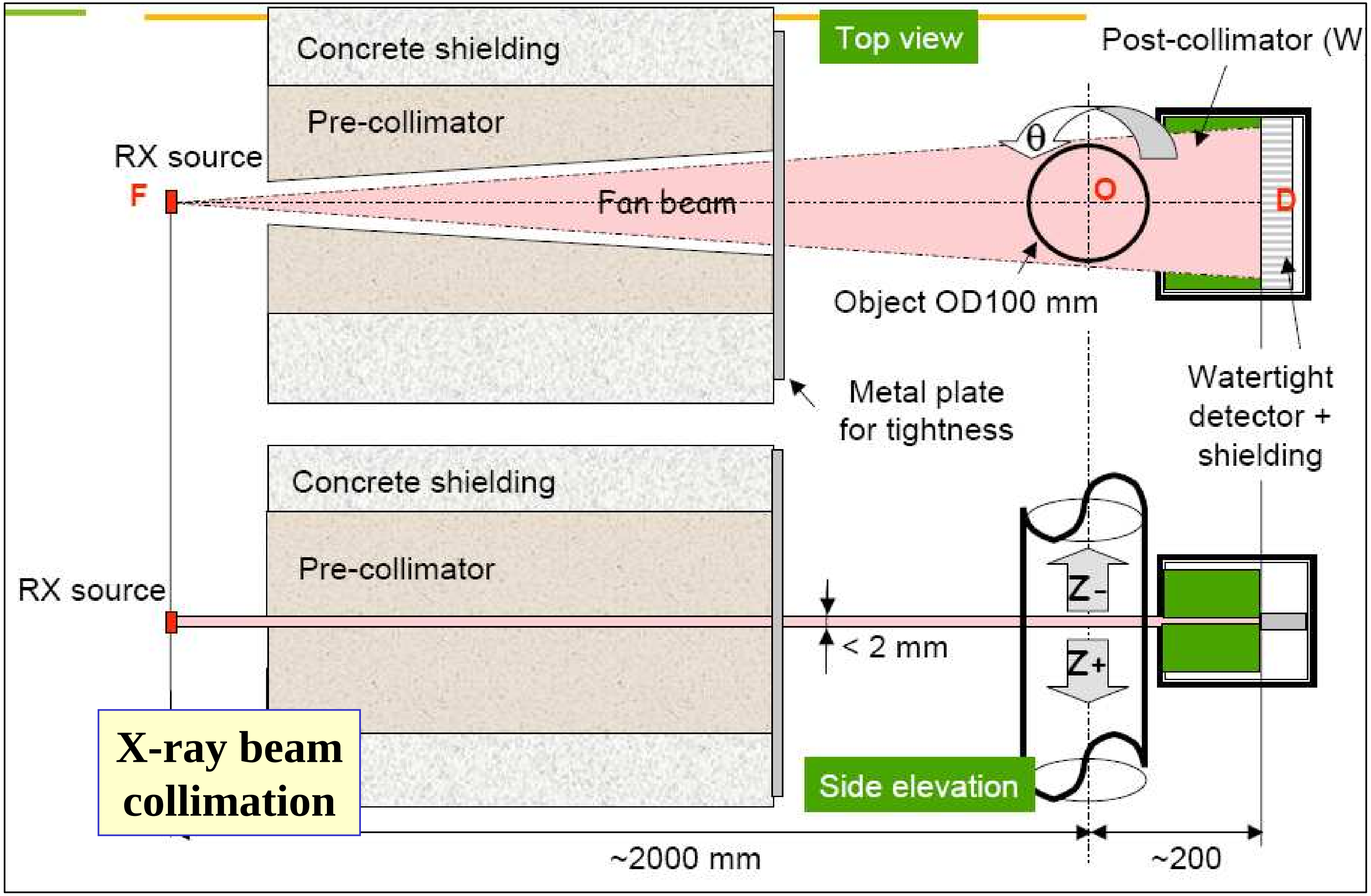
☹ D and d are fixed by the JHR facility design     Ls and Ld are manageable ☺

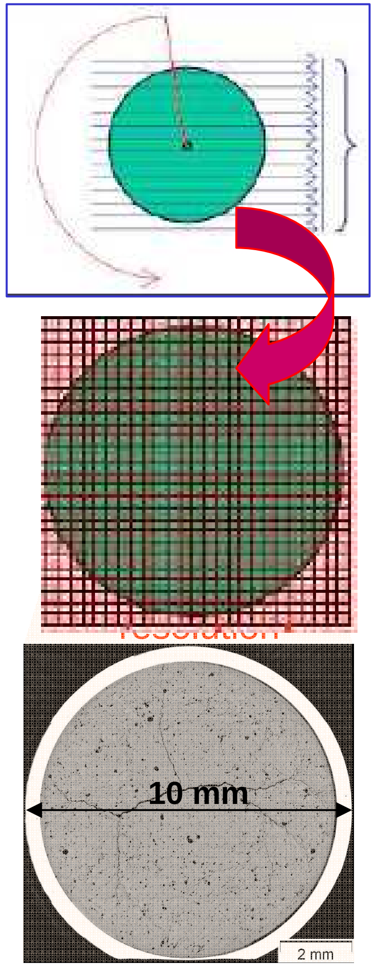
Important R&D work carried out by Oxford Analytical Instruments Oy (FI) and VTT (FI) to reach the best values accessible with the current state of art

**A final target about 100 µm is considered as reachable**

# How to Reach the Requested Spatial Resolution for X-Tomography? (2/3)

## Step 2: To define the best shape for the X-ray beam by collimation

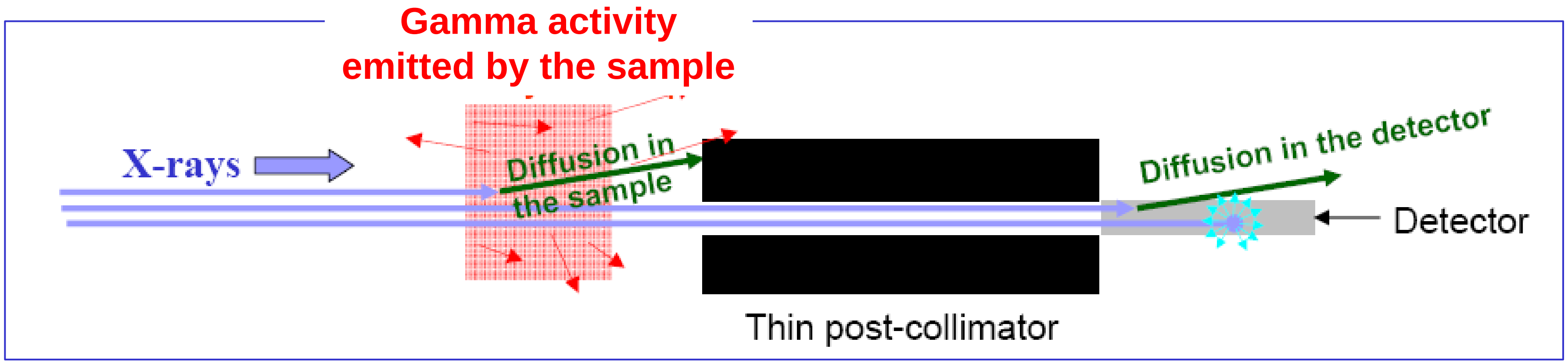


# How to Reach the Requested Spatial Resolution for X-Tomography? (3/3)

## Step 3 : To list parameters influencing the high resolution

- ↳ **Mechanics and Electronics**
- ✓ **Signal sampling and numerating**
- ✓ **Photonic noise reduction and Photon-material interaction etc.**

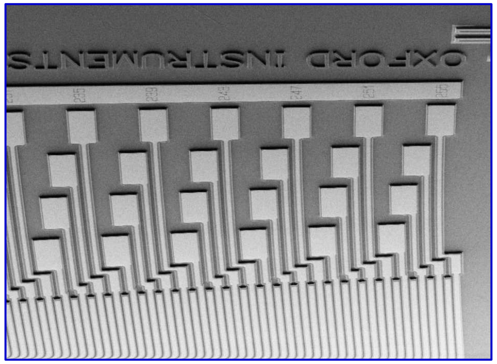



## Other studies carried out by OIA and CEA

- ↳ **Modeling the detector size**
- ↳ **Issues linked to the non-parallel shape of the X-ray beam**
- ↳ **Image reconstruction with a lot of adjacent X-ray detectors pixels**

# Current Technological Choices for X-Tomography

- Focal spot of the X-ray source about 300 µm
- Thin post-collimator (50 µm) ⇔ 1D acquisition
- Pixel width/depth : about 50 µm/50mm
- Elementary detector: Semi-conductor material based on AsGa technology



OIA

**Innovative technology with a far X-ray source**

Know-how available
(CEA-IPSN - Phebus program
1D type acquisition (500 µm)

# Study Work on Gamma Spectrometry

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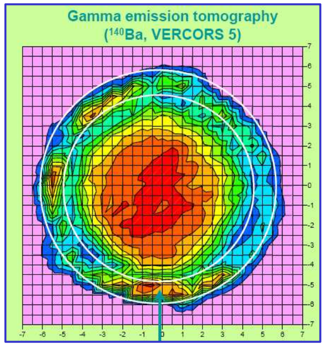
## Design of pre- and post-collimator set

- ✓ Various sample geometries: rods, plates, disks…
- ✓ Type of scientific information required (scanning, tomography...)



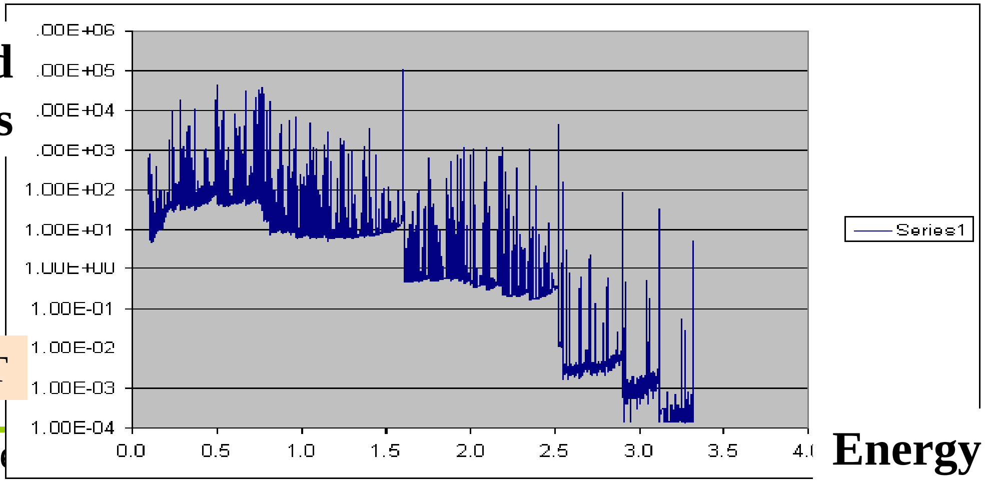

CEA

## Choice for the detector type

- ✓ Volume, material
- ✓ Large range of radionuclide inventories in the sample

Reconstruction of gamma spectra with MCNP code at VTT

Cumulated counts



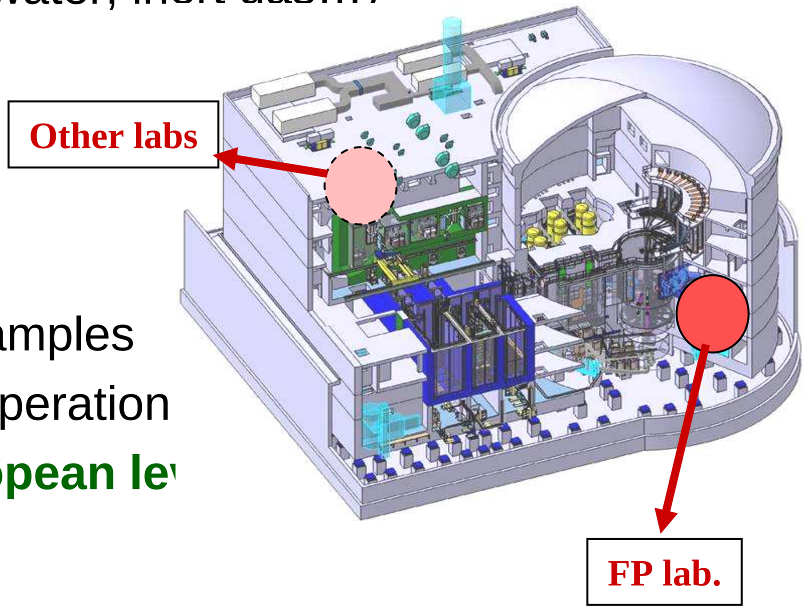

VTT

Energy (MeV)

Example of gamma spectrum reconstruction with MCNP for a LWR rod case

# Analysis Laboratories in JHR

- **Fission product laboratory (FP lab.)**
  - ✓ On-line and delayed measurement of radioactive and stable isotopes
  - ✓ Support to experiment operation (connection with cubicles)
  - ✓ Shielded cells designed for a specific routing fluid (water, inert gas…)
  - ✓ **Equipment will be progressively installed**




- **Chemistry laboratory**
  - ✓ Characteristics of the various coolant chemistries
  - ✓ Physical and chemical analyses on experimental samples
  - ✓ Experiment waste analyses + Support to the JHR operation
  - ✓ **Equipment: Recommendations released at European le (MTR+ I3 program 2006-2009)**

- **Dosimetry laboratory**
  - ✓ Analysis of dose integrators previously recovered in hot cell
  - ✓ Pneumatic transfer channel planned (equipment being studied)

# Conclusions

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- **Work carried out on NDE benches and analysis laboratories is driven by anticipation of users' needs**

- **Design and development work of these means are dependent from:**
  - ✓ Service offer in the MTR experimental process
  - ✓ Maturity of the program requiring the infrastructures
  - ✓ Required performances versus component complexity and integration constraints in JHR
  - ✓ Development  and manufacturing cost

- **Importance to develop analysis infrastructures with existing users community (JHR Consortium, JHIP, European programs)**

- **Target to operate  a first set of infrastructures at the JHR commercial operation  - The whole fleet will be progressively completed**