PAUL SCHERRER INSTITUT

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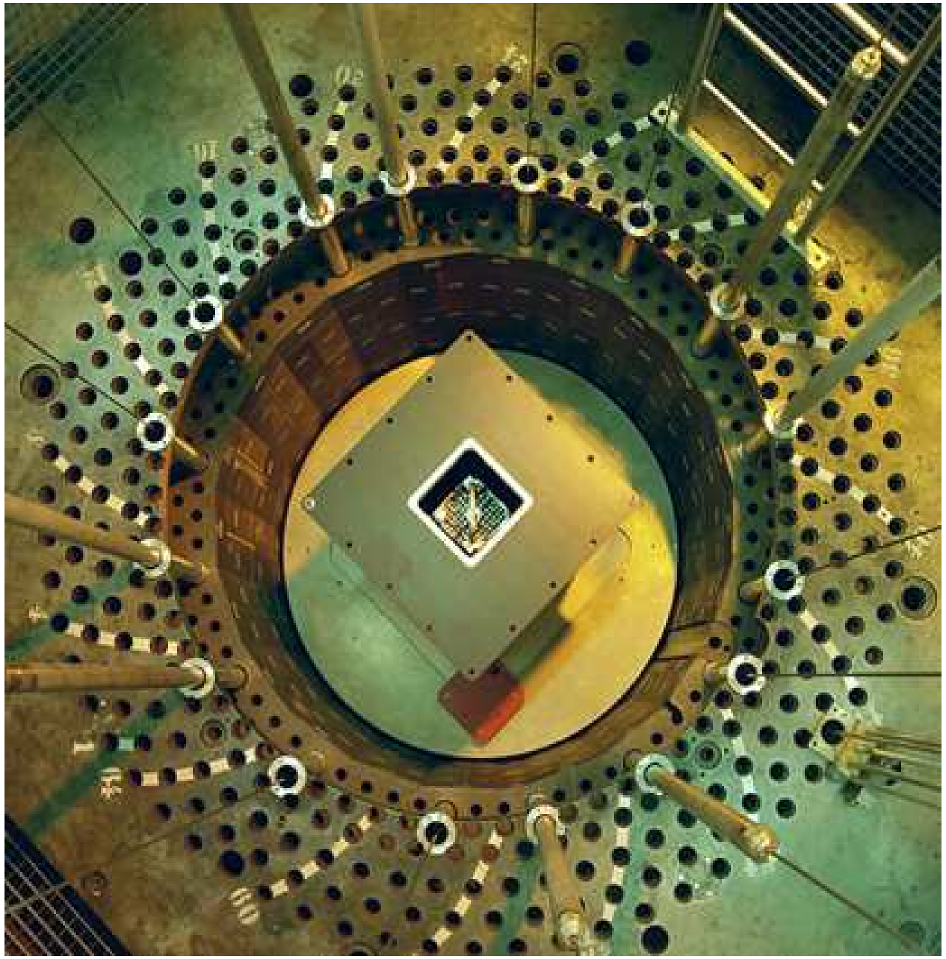
Paul Scherrer Institut – IGORR Conference

G. Perret, K.A. Jordan, O. Köberl et al.

PROTEUS zero-power reactor - Future exp. programmes

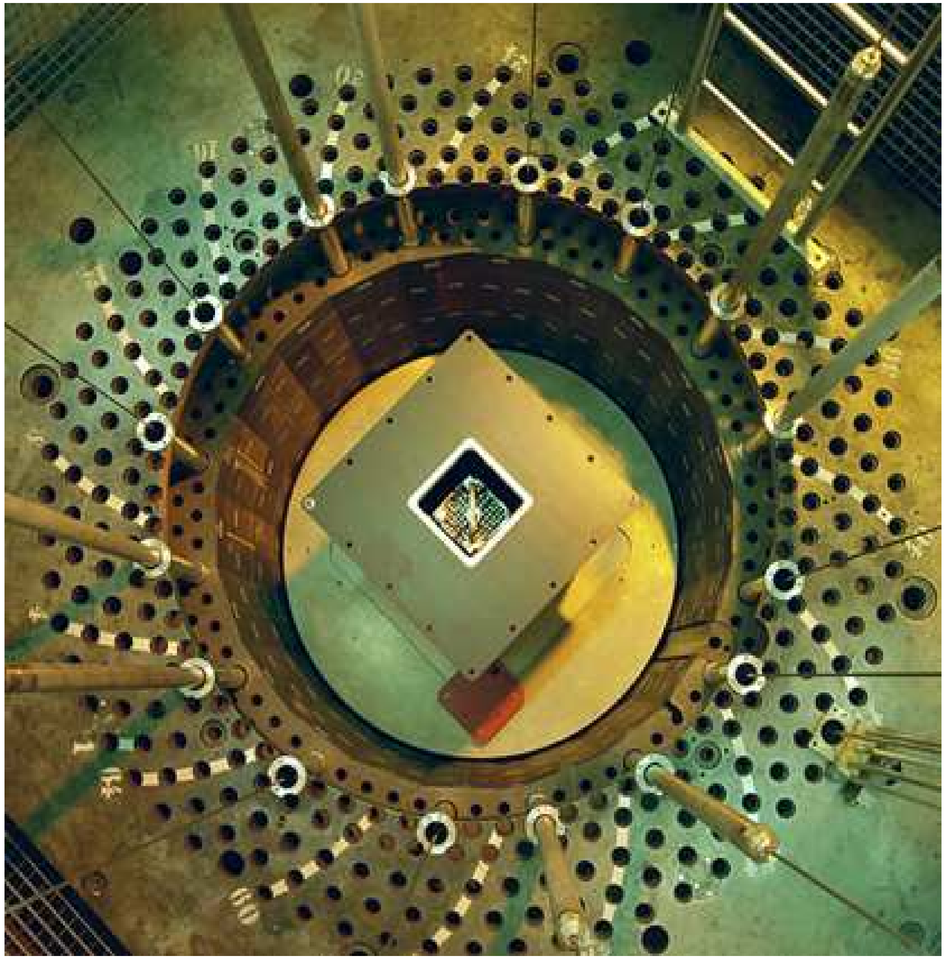
PROTEUS



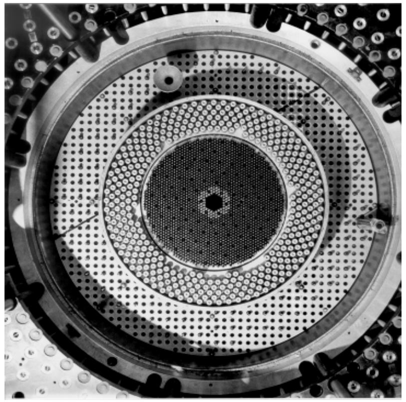
Zero power research fission reactor

- First operation: 1968
- Power < 1kW
- Thermal flux < 5×10^9 n/cm²/s
- Driven system
  (graphite / D_2O / buffer / test zones)

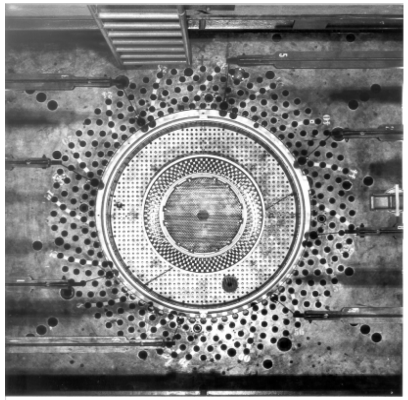
PROTEUS – Past experimental programmes



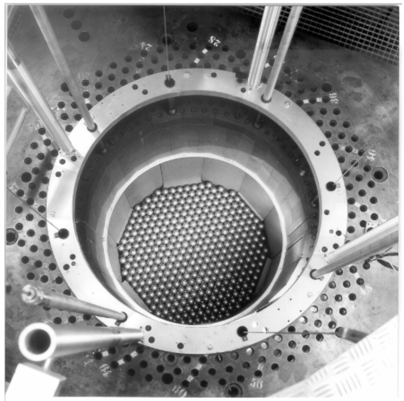
GCFR



HCLWR



HTR

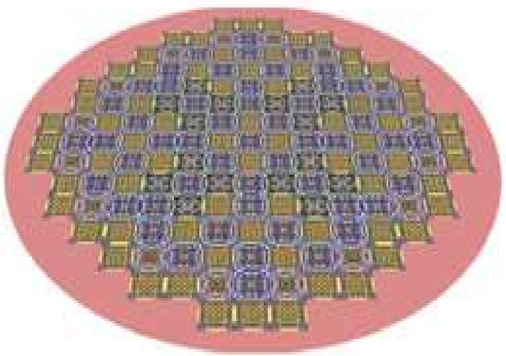


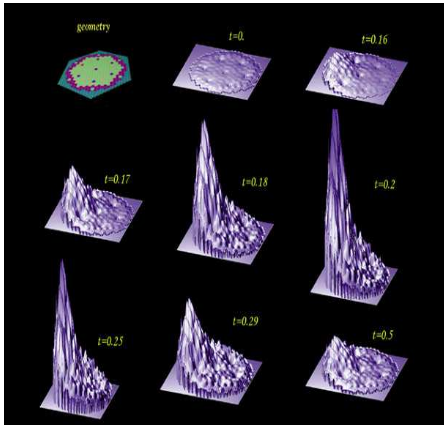
LWR-PROTEUS

Large-scaled Irradiated Fuel Experiments @ PROTEUS

Motivations

Burn-up extension and initial enrichment increase in the context of fixed-cycle length, decreasing batch fraction, zero burnable poison penalty and full low-leakage loading patterns produce highly-heterogeneous core configurations, particularly at beginning of cycle.





High-burnup fuel is less known

Extended experimental database needed (γ- and n-emissions, isotopics, examinations)

Increased Core Heterogeneity

Pin power distributions across fresh/burnt interfaces, instrumentation response

Increased Core Heterogeneity

Reactivity of burnt fuel and reactivity effects (e.g. isothermal reactivity coefficient)

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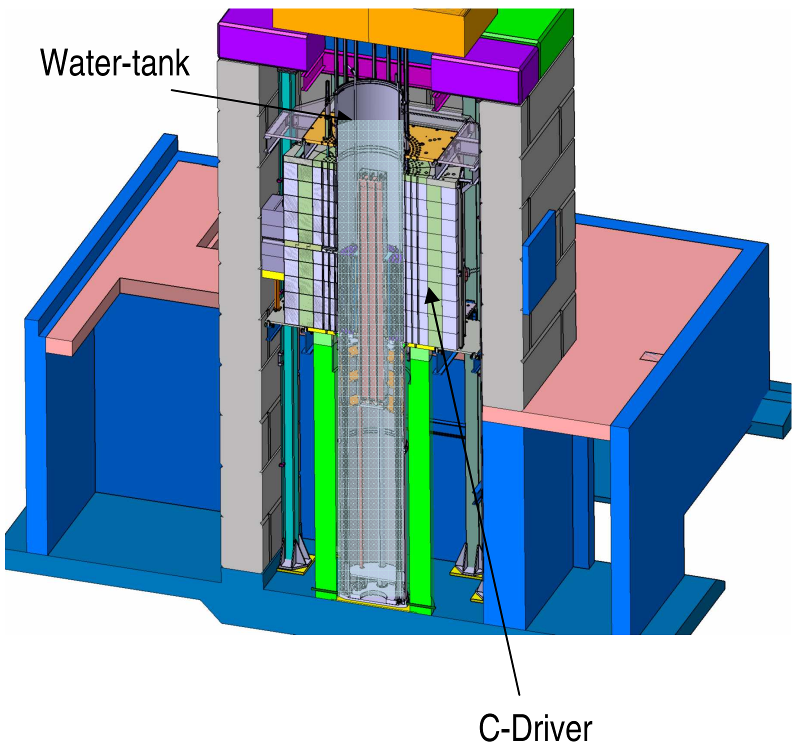
Large-scaled Irradiated Fuel Experiments @ PROTEUS

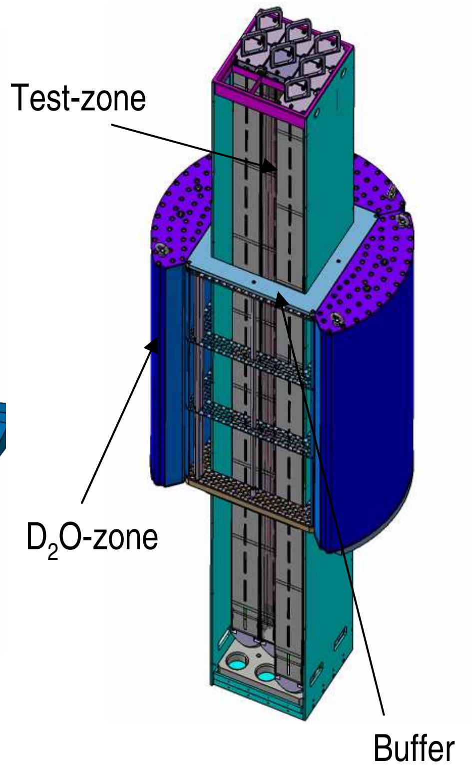
Goals

The LIFE@PROTEUS joint experimental programme aims at studying the interface between highly burnt and fresh fuel assemblies in pressurized and boiling water reactors using the PROTEUS zero power research reactor.

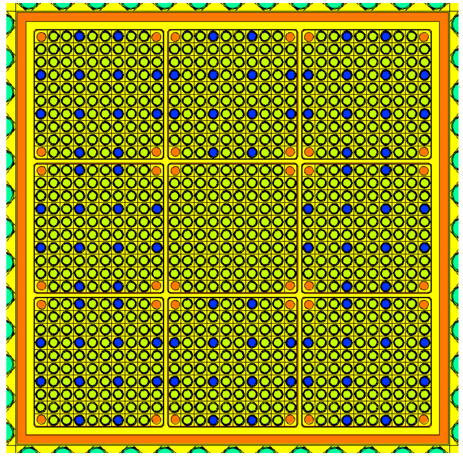
Reactor block



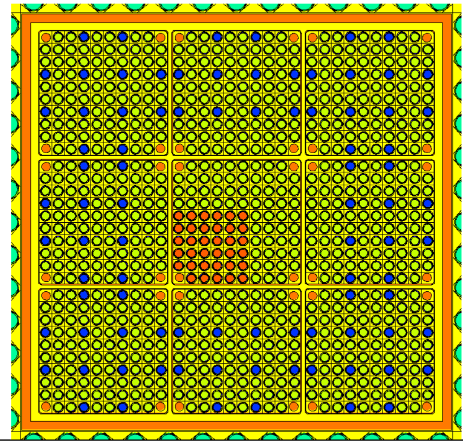
Reactor components



Fresh fuel config.



Burnt fuel configs.(40, 60 GWd/t)



Large-scaled Irradiated Fuel Experiments @ PROTEUS

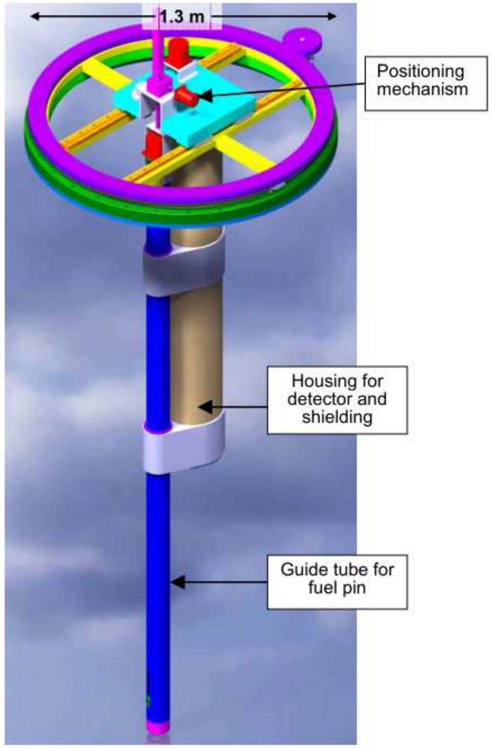
Measurements in **PROTEUS**

- Non destructive assay of burnt fuel pins
  - Passive gamma and neutron counting with possible axial dependence
  - Within-pin burn-up monitor (^{137}Cs, ^{134}Cs, ^{154}Eu) and density radial distributions by emission and transmission tomography

- Fission rate measurement in burnt and fresh fuels by delayed neutrons and high energy gamma-rays measurement after re-irradiation in PROTEUS
  - Delayed neutrons – repeated irradiation per day, ~10 min
    – meas. time ~ 15 min
  - Delayed gamma – 1 to 2 irradiations per day,
    high power (>100W), 15-30 min.
    – meas. time ~1-2 hours

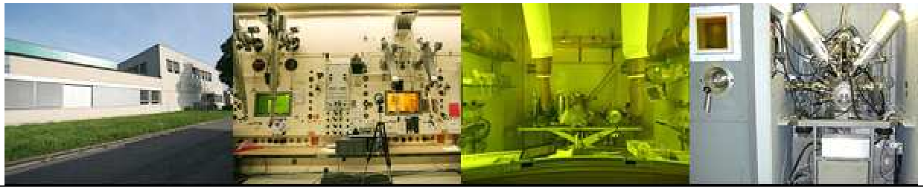
- Reactivity measurements

Measurement station
In PROTEUS



Measurements in the **Hot-Lab**

- Destructive assay of burnt fuel burn-up and isotopic composition
  - Limited number of pins
  - Pins irradiated in PROTEUS or siblings



LIFE@PROTEUS – Current activities

Interface with PROTEUS Upgrade project

– Dose rate and criticality calculation of fuel storage
– Predict safety parameters of the core and define approach to critical strategies

Core configuration pre-calculation

- Core loading representative of a burnt/fresh pin interface
- Core geometries which could be modeled by Monte Carlo and deterministic production codes
- Sensitivity analysis (geometry, power history during irradiation, cross-sections…)

Measurement technique development / adaptation

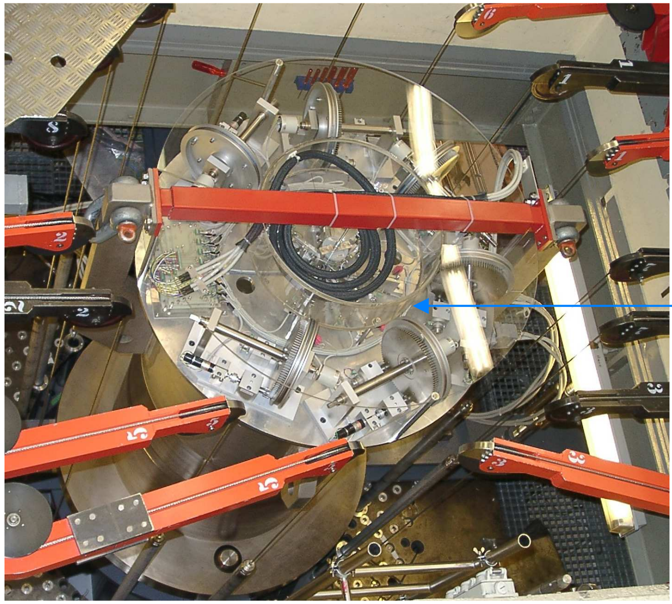
- Fission rate determination in burnt and fresh fuel using emitted delayed neutrons and gamma-rays
- Distribution of density and fission product within the burnt pins

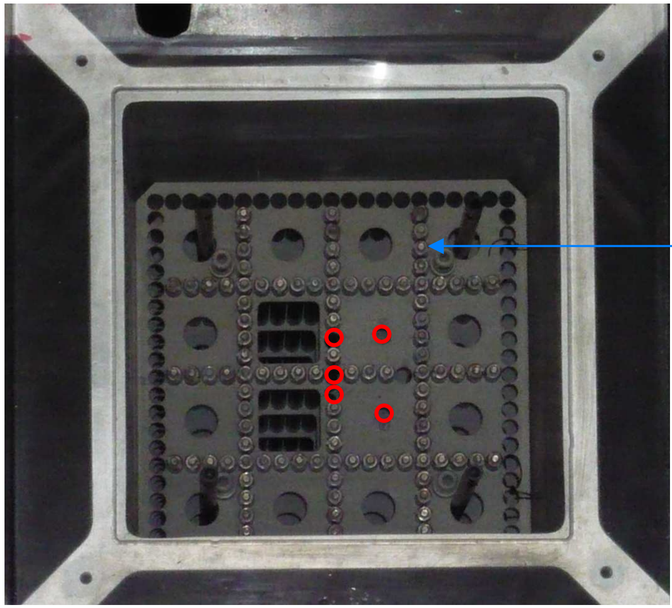
Design of the measurement station

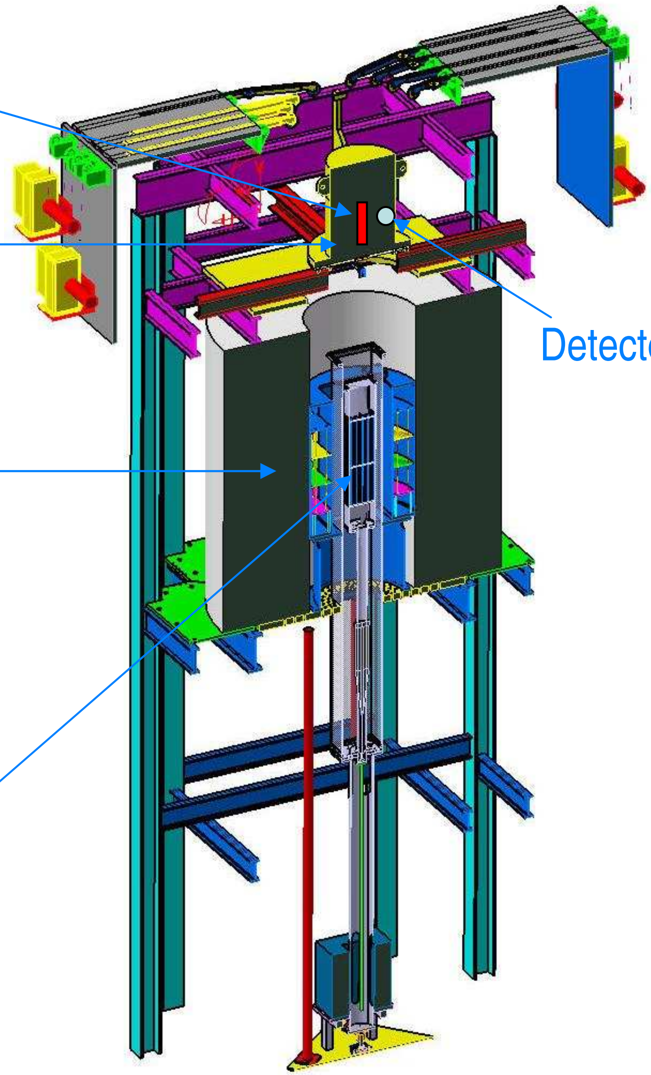
- Modeling using Monte Carlo codes and results gathered during the measurement technique development

Measurement technique development

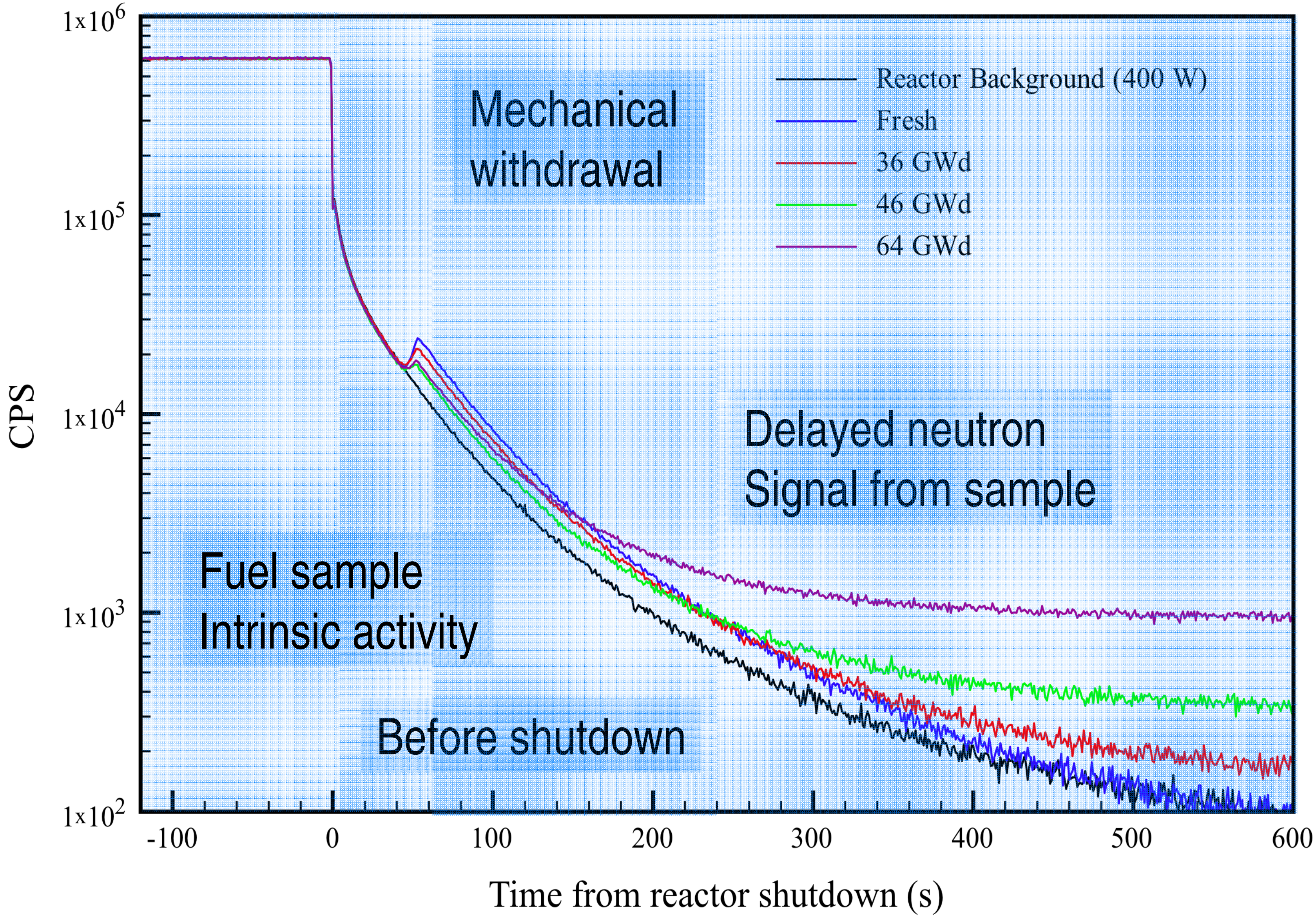
Wechselflasche Optimization for LIFE (WOLF – Phase B)



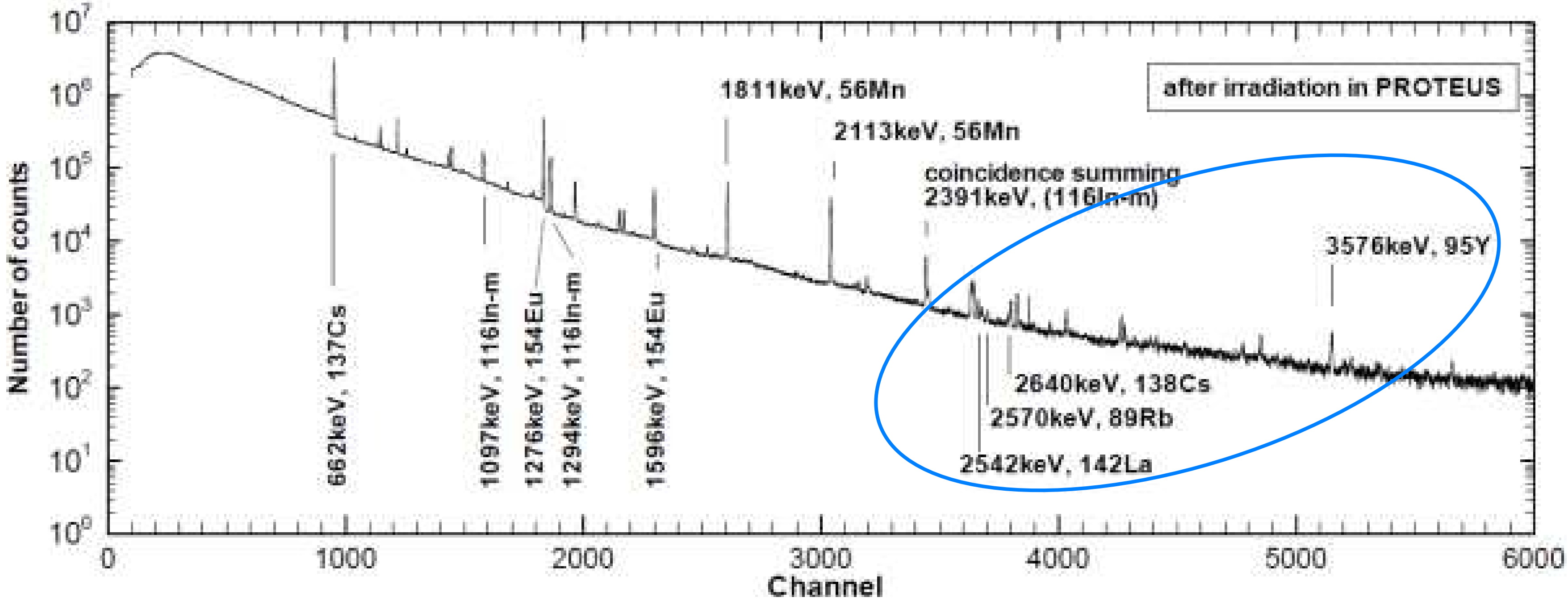




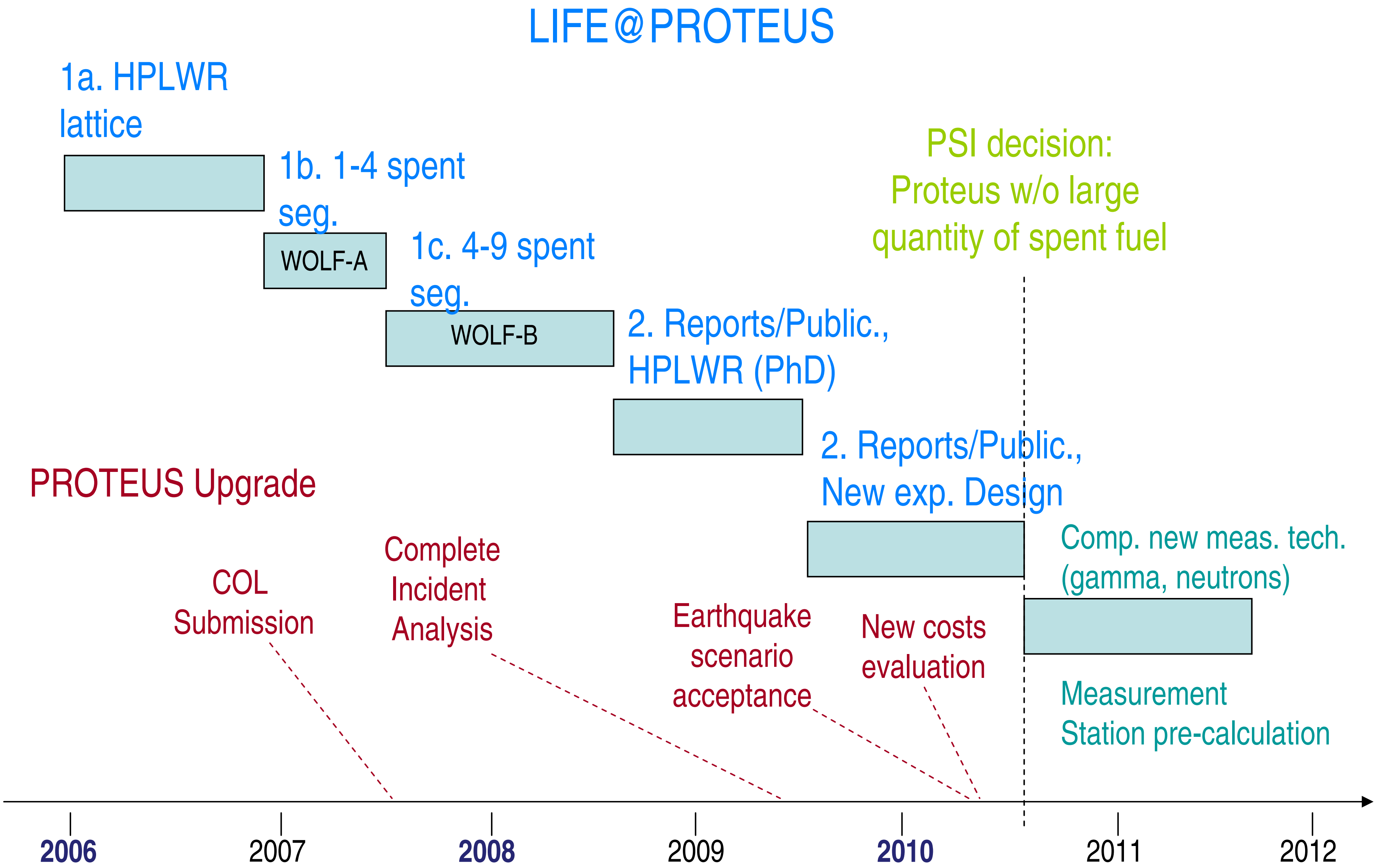
Delayed neutron measurement techniques



Delayed gamma measurement techniques



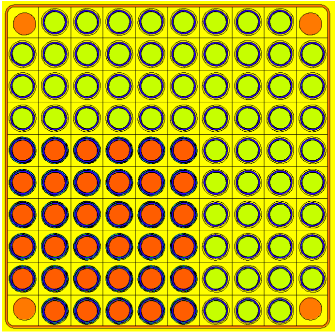
PROTEUS – Time frame



Ideas for future experimental programmes

Irradiated fuel experiments

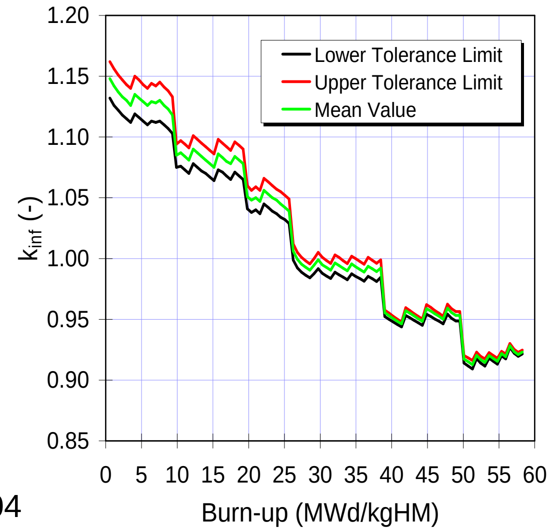
- Create a reduced spent fuel interface using spent fuel samples (overcladed)

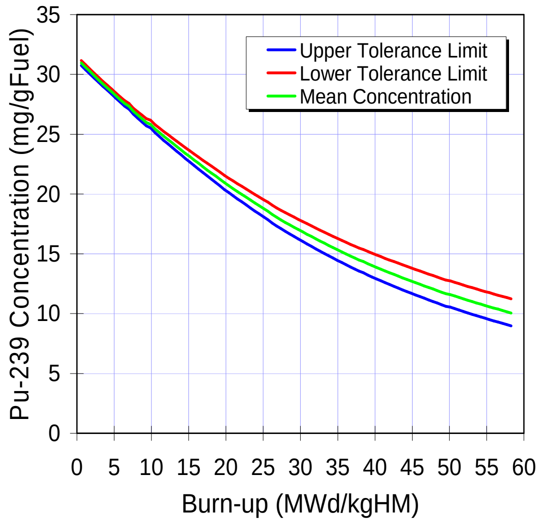


Motivation

- Good agreement between code results and reactor instrumentation measurements benefits from multiple feedbacks (compensating errors) and are therefore not well suited for code validation
- Isotopic composition of fuel samples not well known because of burn-up calculation scheme limitations
- Need to consider all uncertainties (geometrical, composition, covariance between nuclear data)

Macian et.al., 2004





Ideas for future experimental programmes

Irradiated fuel experiments

Addressed problems

- Detail investigation of not well-known geometrical parameters (channel bowing, fuel swelling, irradiation uncertainties) in the uncertainty evaluation with dedicated experimental configurations
- Detailed investigation of uncertainties in burn-up calculations and measurements
- Interpolate predictions of isotopic from MC-ICP-MS measurements using stochastic and deterministic codes
- Perfecting fission rate measurement in spent fuel (lower uncertainties, improved robustness)

Build up an experimental and calculation database with uncertainties considerations for international reactor physics benchmark and code validation

More ideas for future experimental programmes

Better spent fuel characterization - safeguards

- Large set of UOX/MOX spent fuel samples (PWR/BWR) with burn-up varying from 30 to 120 GWd/t
- Perfecting novel delayed neutron and gamma techniques for fission rate determination in spent fuel
- Use flexibility of PROTEUS to achieve different spectra
- Association with other non-destructive assay techniques in PROTEUS
  – emission and transmission tomography, differential die-away techniques, neutron coincidence/multiplicity, passive neutron and gamma counting
- Planned to expand set of burnt samples (higher initial enrichment)
- Synergy with Irradiated fuel experiments to better characterize fuel

Alternate experimental programmes @ PROTEUS

Innovative fuel characterization

- Innovative fuel has been identified as potential fuel of choice to burn plutonium and minor actinides in LWR in open and closed cycles
- Expertise of PSI in Inert Matrix Fuel (IMF)
- Sphere-Pac fuel

Higher fresh fuel enrichment (>5 wt.%) and higher burn-up of the burnt fuel

- Tackle the new limits which are for example currently investigated in Japan
- Challenge because of the enhanced gradient at the burnt/fresh fuel interface

Thorium systems

- Thorium in PWR, and tight lattice BWR or HCLWR (heterogeneities and negative void coefficient)
- Burn plutonium
- Micro and macro heterogeneities of fuel
- THOR initiative

Conclusions

- LIFE@PROTEUS had planned to feature experiments with full length fresh and burnt PWR fuel pins and investigate fission rate distribution measurement at their interface
- LIFE@PROTEUS has been abandoned because of the unforeseen associated difficulties and cost required for the refurbishment of the facility to host this programme
- Novel measurement techniques to measure fission rate in spent fuel has been successfully developed
- Alternate experimental programmes at PROTEUS which benefit from the assets of PROTEUS are currently assessed
  - Reduced LIFE set-up
  - Better fuel characterization and safeguards
  - Innovative fuels
  - Higher enrichment
  - Thorium systems

Many thanks to

- The PROTEUS operating team for their constant availability and support to experiments
- **swiss***nuclear* for their partnership in the LIFE@PROTEUS program

Thank you for your attention.