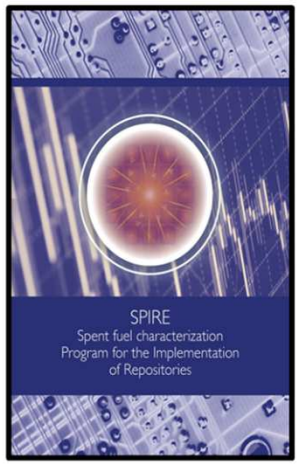
SPent fuel characterisation **P**rogram for the **I**mplementation of **Re**positories

WP2 & WP4

Development of measurement methods and techniques to characterise spent nuclear fuel



Henrik Widestrand and Peter Schillebeeckx

25 – 26 October 2016, Cordoba, Spain

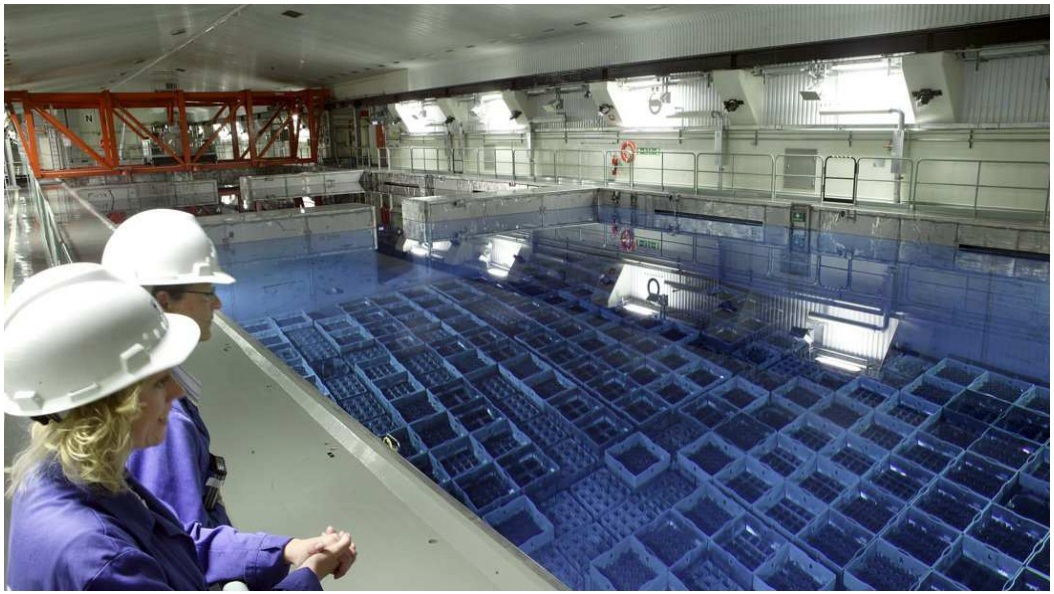
IGD-TP 7th Exchange forum

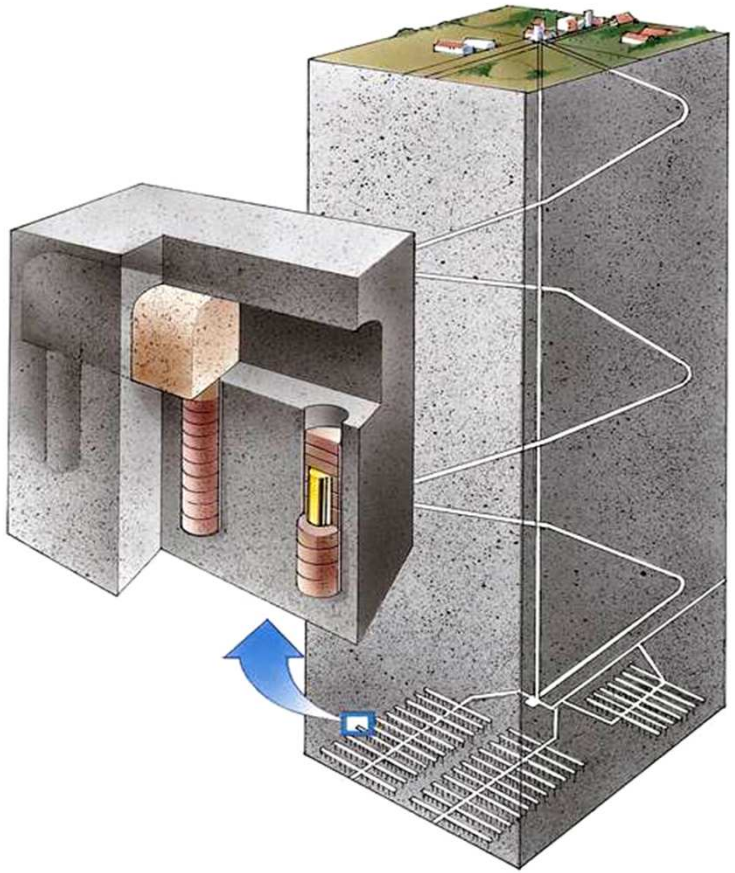
Interim storage or final disposal of spent nuclear fuel

Characterisation of **S**pent **N**uclear **F**uel (SNF) is required for a safe, secure and economic storage and disposal.

Main observables of interest:

- Decay heat
- Neutron and gamma-ray emission
- Reactivity



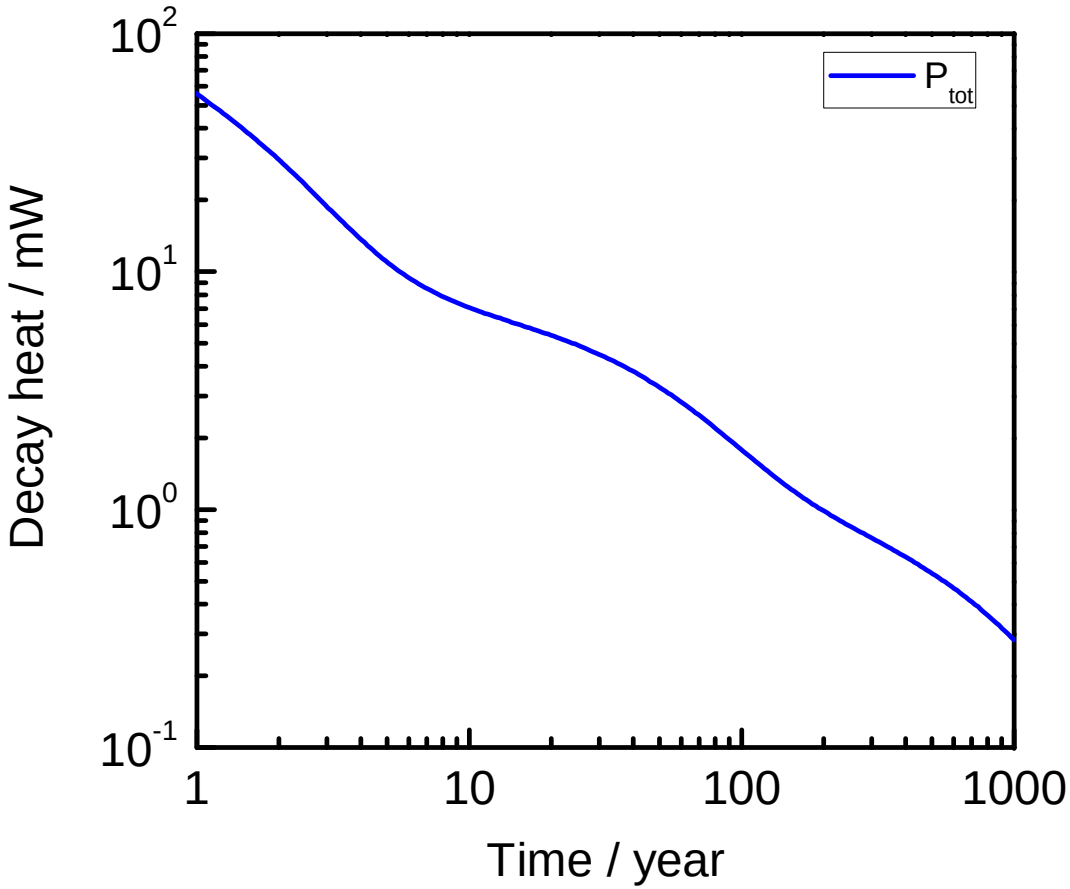


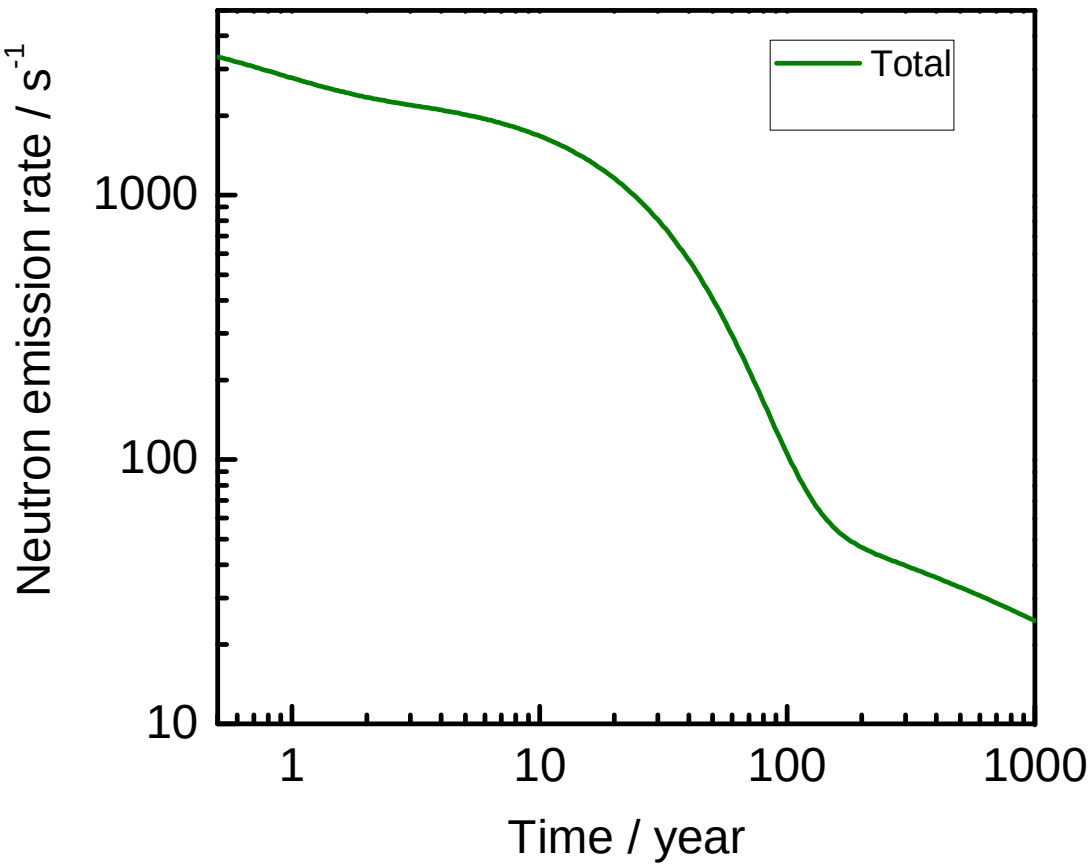
Optimum design of storage conditions: theoretical predictions

Quality of **predicted observables** depends on:

- Quality of the **calculation methods** (codes + nuclear data)
- Quality of the **irradiation history** + **engineering details** of the SNF

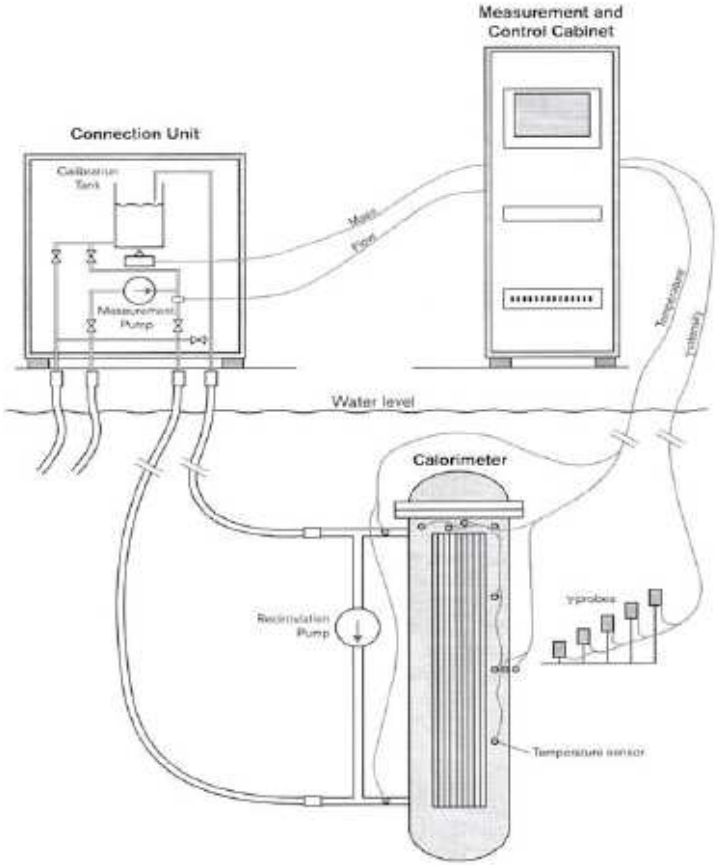
PWR UO_2 pellet
$^{235}U/U$ = 4.8 %
m(U) = 4.4 g
Burnup = 44 GWd/tU





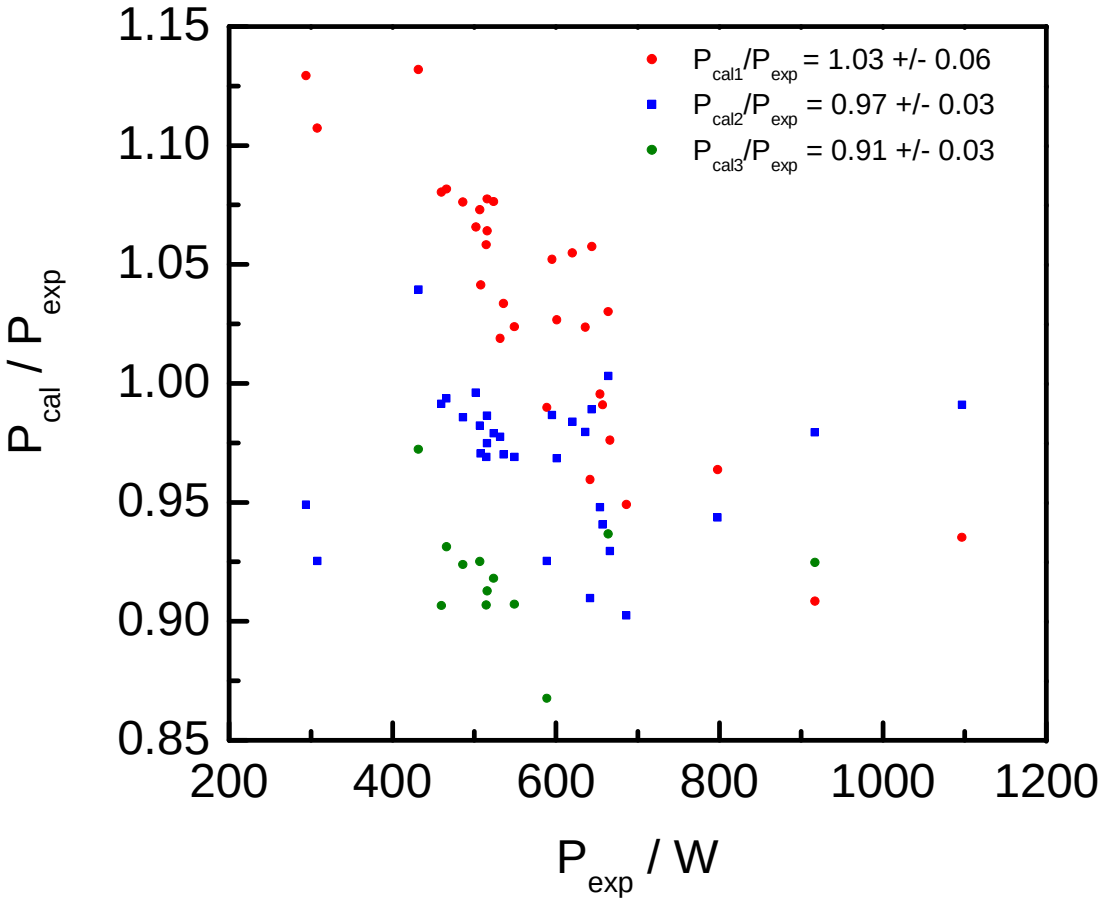
Present status : e.g. decay heat

Calorimeter at CLAB



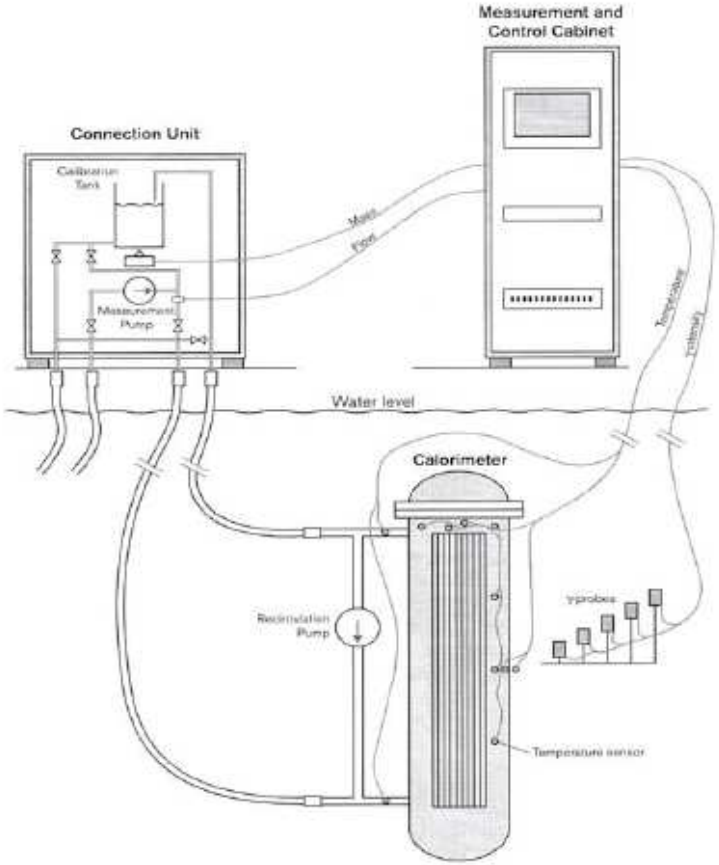
Experiments on PWR at CLAB (1998)

Different codes (cal3 = SIEMENS)



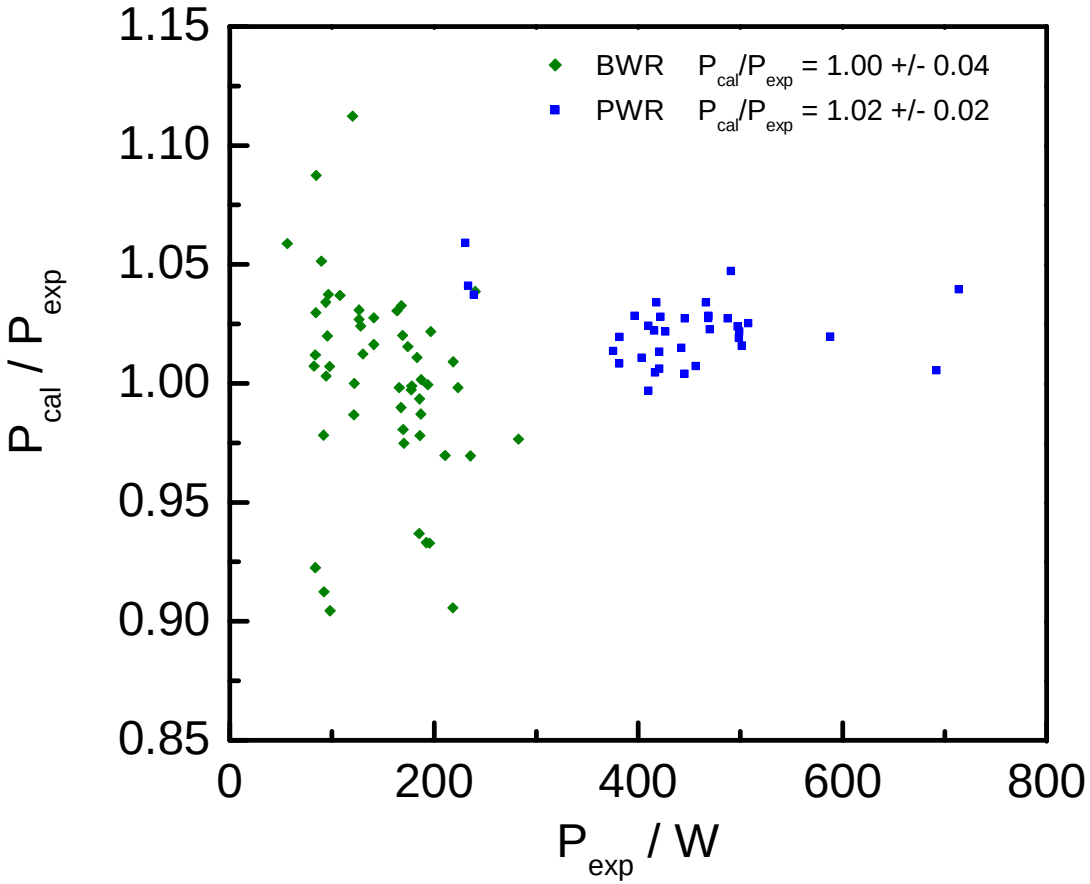
Present status : e.g. decay heat

Calorimeter at CLAB



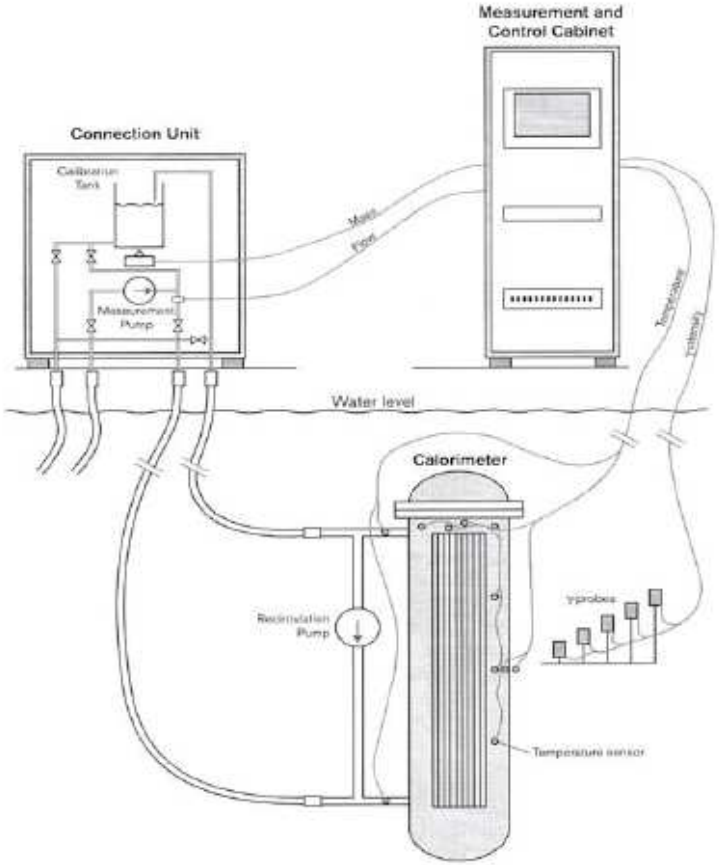
Experiments at CLAB (2003 - 2004)

Calculations: ORIGEN-S



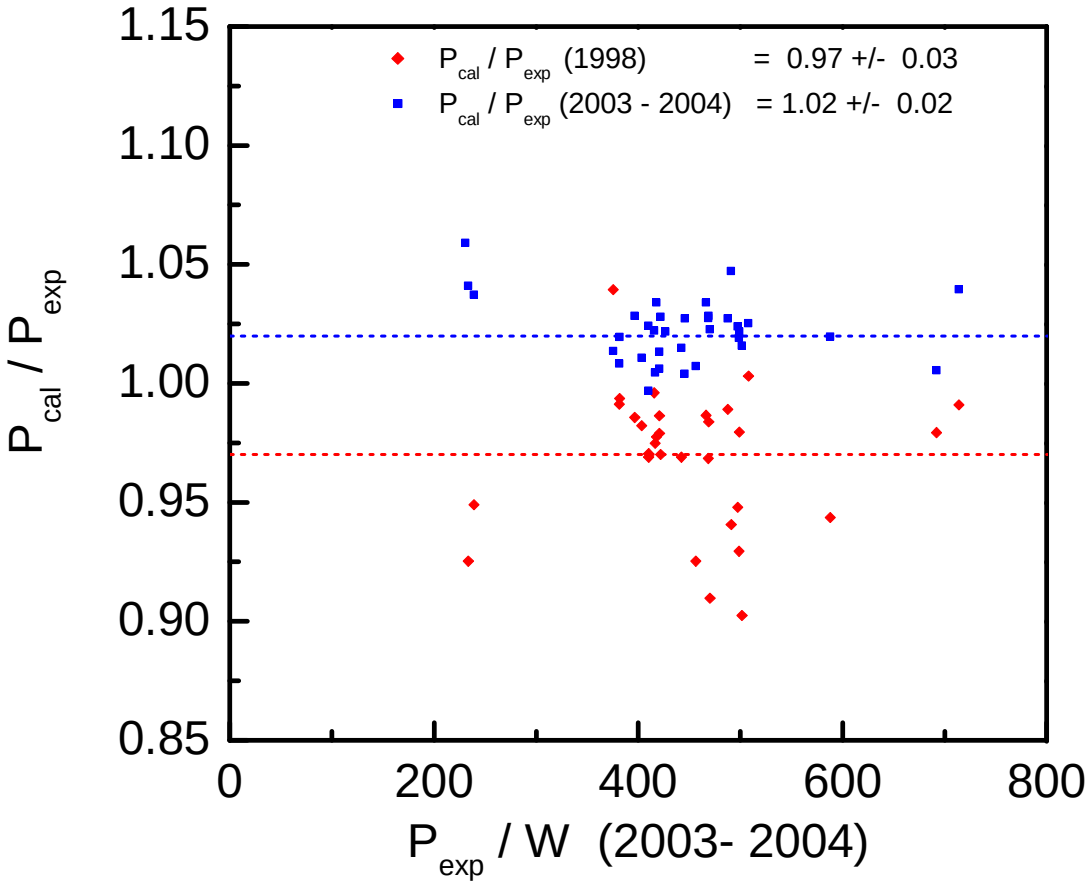
Present status : e.g. decay heat

Calorimeter at CLAB



Experiments at CLAB (1998 and 2003 - 2004)

Calculations: ORIGEN-S



WP2 & WP4

Objective :

Develop **innovative N**on **D**estructive **A**nalysis (NDA) techniques and **improve existing** ones for the characterization of **S**pent **N**uclear **F**uel (SNF), to:

- Reduce bias effects and uncertainties of experimental data
- Validate & improve theoretical models (including nuclear data)
- Verify irradiation histories and improve incorrect data
- Define correlation procedures between observables
  e.g. gamma-ray $\Leftrightarrow$ heat

Separation between WP2 & WP4 : logistic reasons

WP2 : radionuclide sealed sources and reference materials

WP4 : highly radioactive irradiated nuclear material

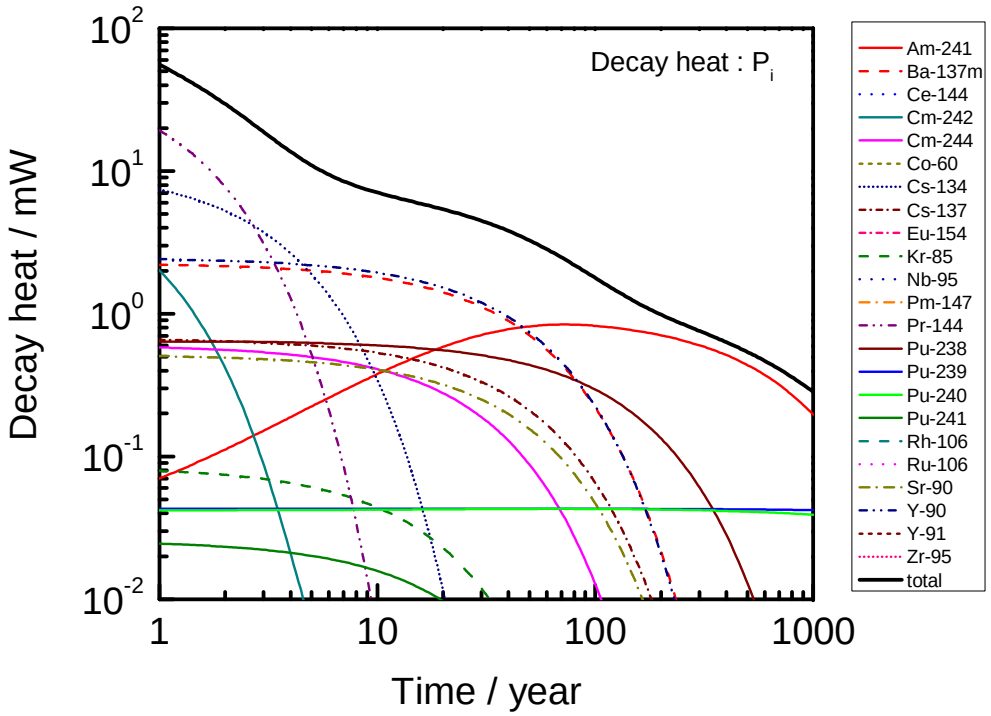
WP2 & WP4

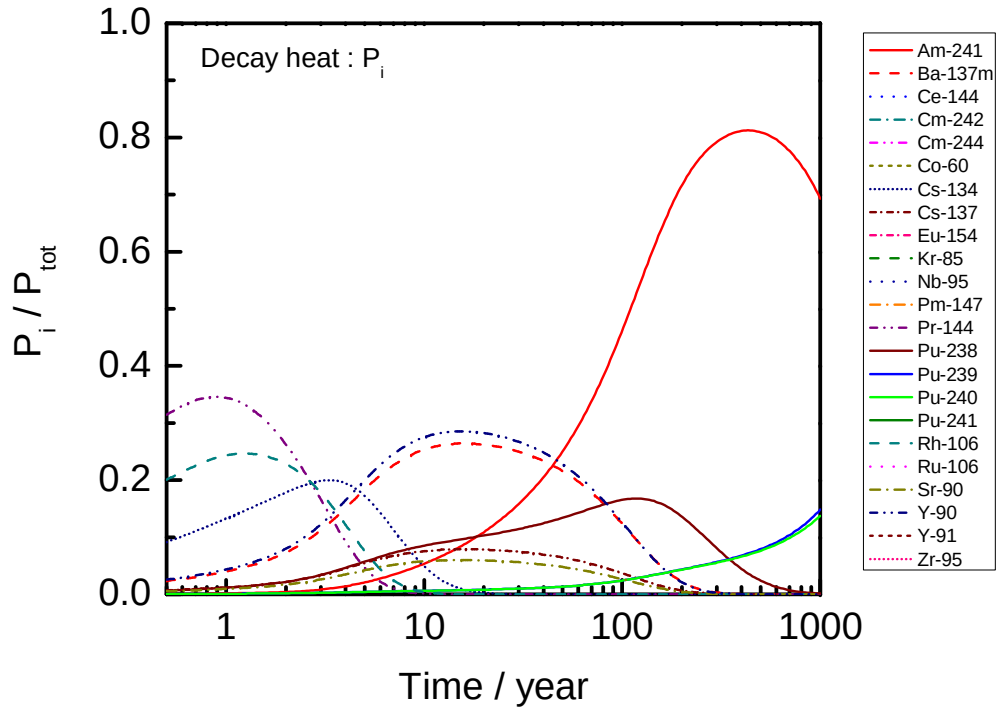
- Develop, improve and validate **NDA** techniques to **directly** measure
  - decay heat
  - neutron emission
  - gamma-ray emission
  - reactivity
  - nuclide vector

  avoiding complex and time consuming **chemical analysis**
- Make use of other efforts:
  - Next Generation Safeguards Initiative (NGSI) of DOE/NNSA
  - EURATOM/DOE/SKB agreement (Action Sheet -50)
  - JAEA/JRC collaboration agreement (characterisation of melted fuel by NDA)
  - FP7 project: First Nuclides
  - International projects: ARIANE, MALIBU, REGAL

Example: decay heat

Improve fundamental understanding of measurement process
Identify the main metrological parameters, e.g. source terms



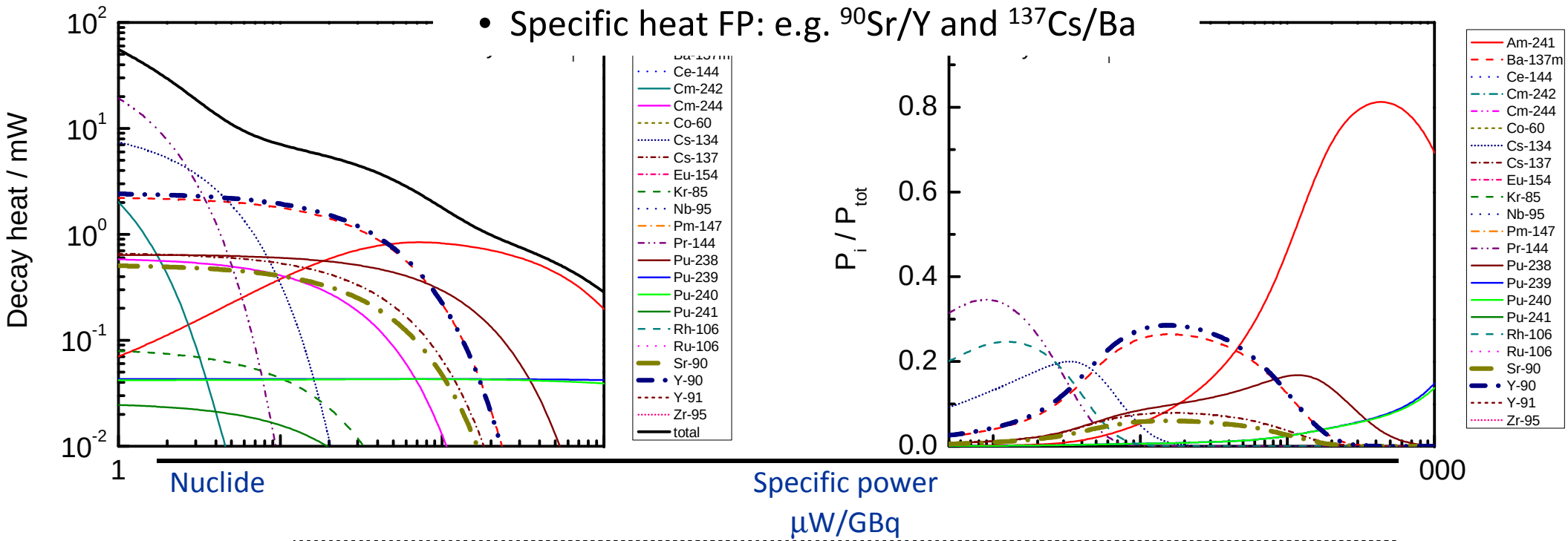


PWR UO_2 pellet
$^{235}U/U$ = 4.8 %
m(U) = 4.4 g
Burnup = 44 GWd/tU

Example: decay heat

Cooling time : 5 y < t < 50 y (β^- decay of FP)

- Fission yields
- Specific heat FP: e.g. ^{90}Sr/Y and ^{137}Cs/Ba

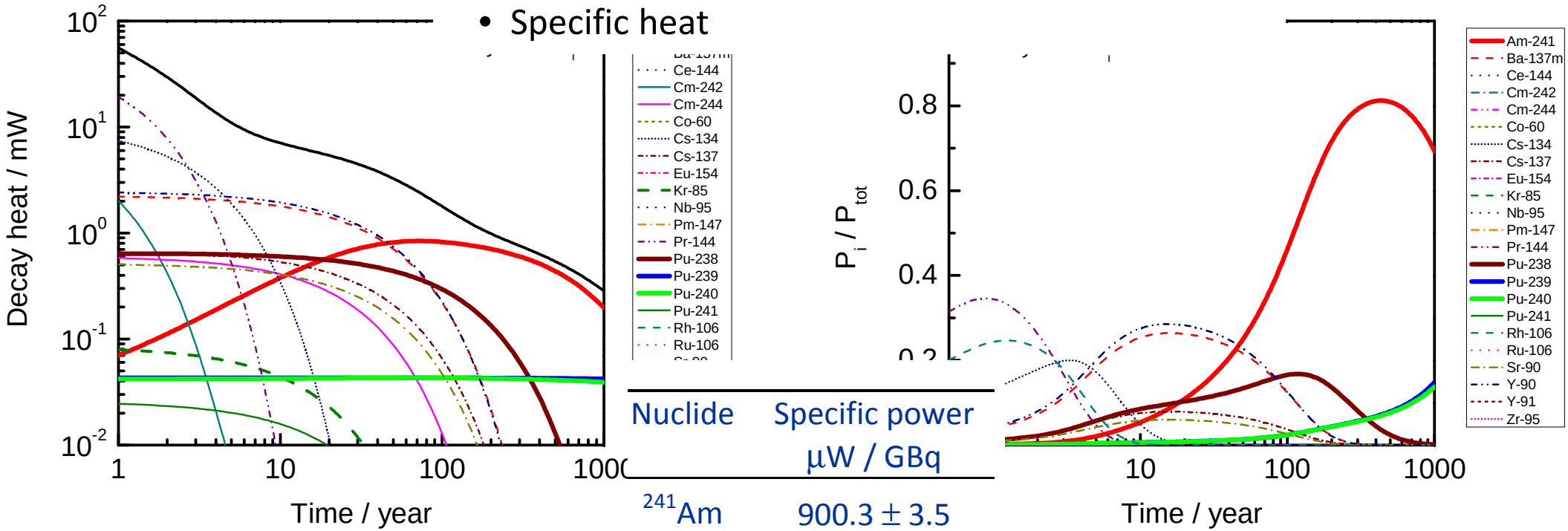


	Ramthun (1973) (experimental)	Collé (2007) (theoretical)	Libraries		
			JEF-2.2	JEFF-3.1.1	ENDF/B-VII.1
^{90}Sr		31.4	27.2	27.9	31.4
^{90}Y		150.0	148.0	149.5	149.6
^{90}Sr/^{90}Y	183.0 ± 2.7	181.4	175.2	177.4	181.0

Example: decay heat

Cooling time : 10 y < t (^{241}Am and ^{238,239,240}Pu)

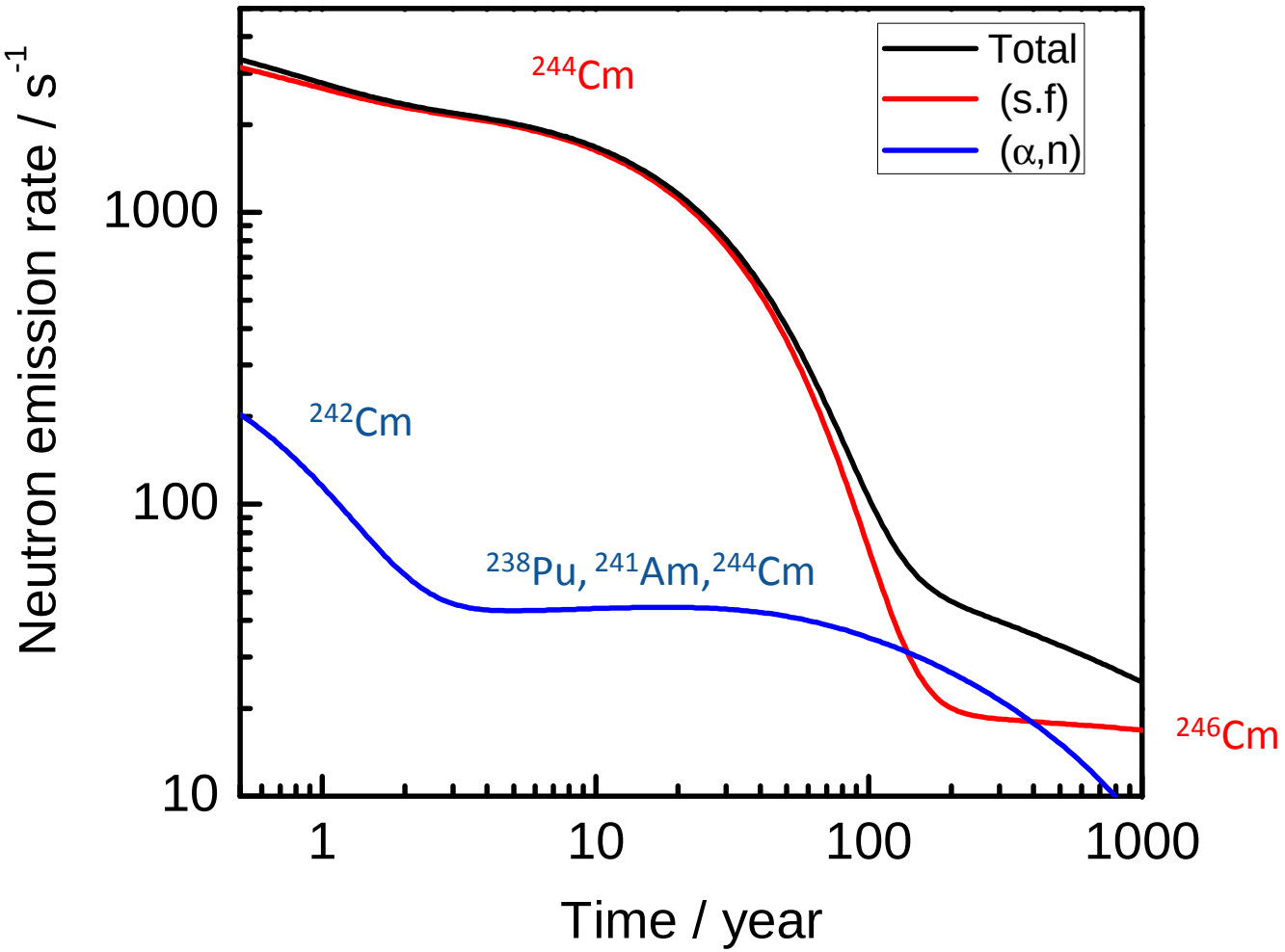
- Production: **σ(n,γ)** and σ(n,f)
- Specific heat



Nuclide	Specific power µW / GBq
^{241}Am	900.3 ± 3.5
^{238}Pu	896.2 ± 0.5
^{239}Pu	840.4 ± 1.1
^{240}Pu	843.1 ± 1.1

Example: neutron emission

Identify metrological parameters of the measurement process

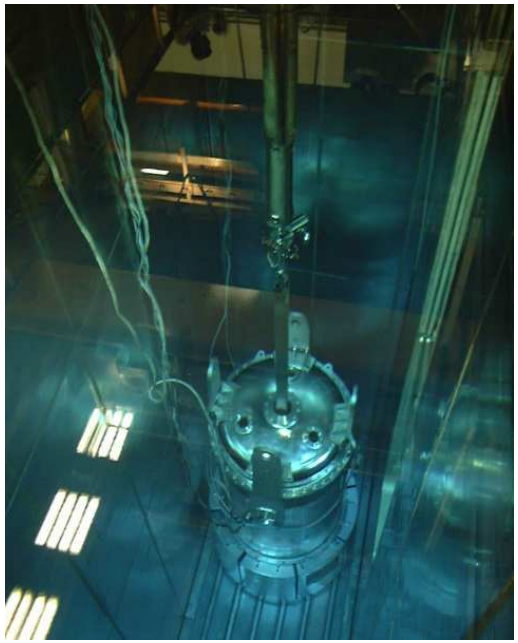


PWR UO_2 pellet
$^{235}U/U$ = 4.8 %
m(U) = 4.4 g
Burnup = 44 GWd/tU

NDA methods: improve & refine existing NDA technique

Fuel assemblies

- Decay heat
  - Calorimetry
  - Gamma-ray spectrum

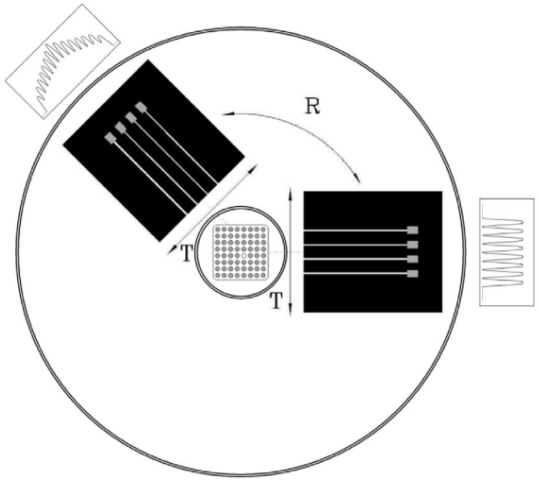


- Gamma-ray emission
  - Tomography
  - Gamma-ray spectrometry
- Reactivity (collaboration with LANL, Action Sheet-50)
  - Differential Die-Away (DDA) ,
  - Differential Die-Away Self-Interrogation (DDSI)

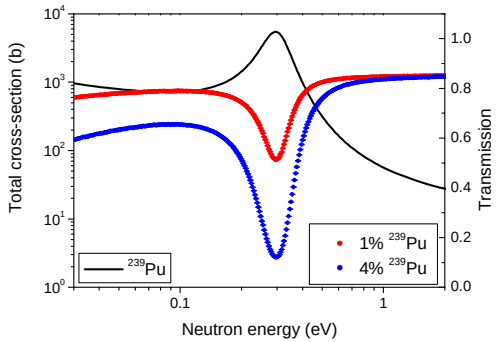
NDA methods: innovative NDA techniques

Fuel assemblies

- Radiation hard neutron detector (Diamond technology)
  - Miniature detector (control channels)
  - Stand-alone
  - Integrated in e.g. DDA, DDSI, SINRD

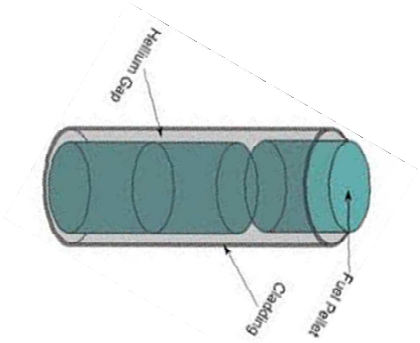


- Gamma-ray detectors: LaBr, CeBr, CZT
  - Spectrometry
  - Tomography
- Reactivity
  - Self-Interrogation Neutron Resonance Densitometry (SINRD) (SCK•CEN)



NDA methods: innovative NDA techniques

Small samples

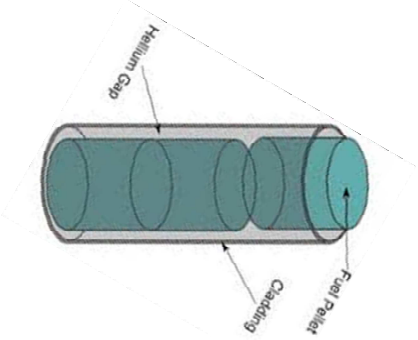


- Direct NDA measurement of observables (outside hot cell)
  - Heat , neutron, gamma-ray, nuclide vector
  - Transport sample from hot cell to device
  - ⇒ Avoid chemical analysis

- Use of well-characterised samples with documented history
  - FP7 : First Nuclides
  - REGAL project organised by SCK•CEN

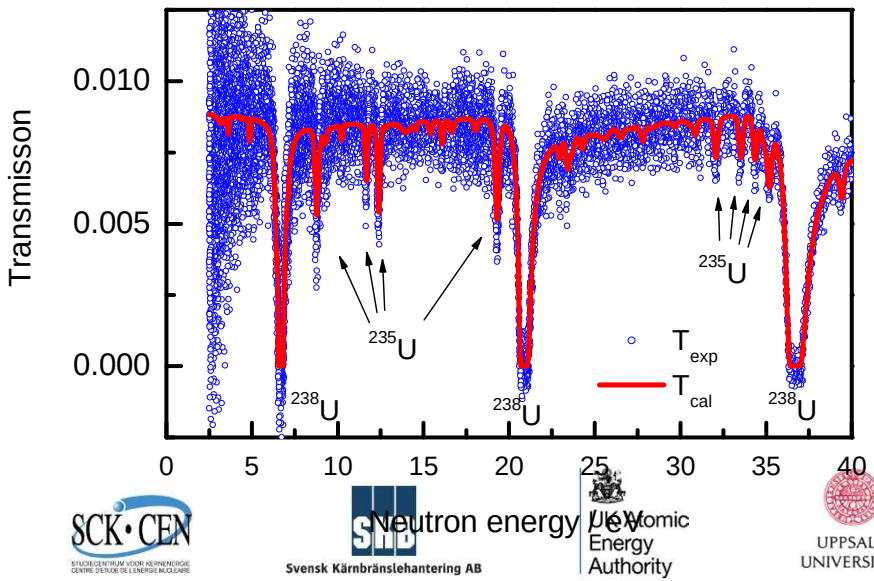
NDA methods: innovative NDA techniques

Small samples



- Proof- of-principle: neutron output
  - Direct related to Cm-quantity

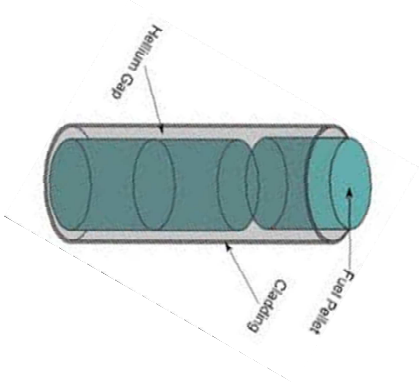
- Final objective
  - Neutron and gamma-ray emission
  - Heat by calorimetry (including existing solutions)
  - Nuclide vector by Neutron Resonance Transmission Analysis (NRTA)



Facilities

Small samples

SCK•CEN



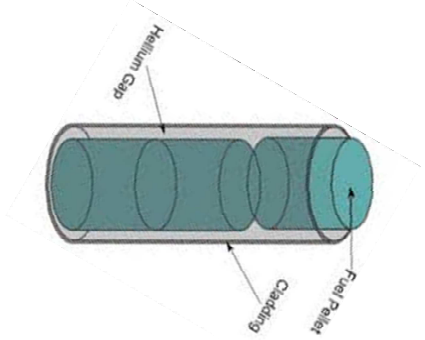
Fuel assemblies

- NPP Preussen Elektra
- CLAB –Sweden

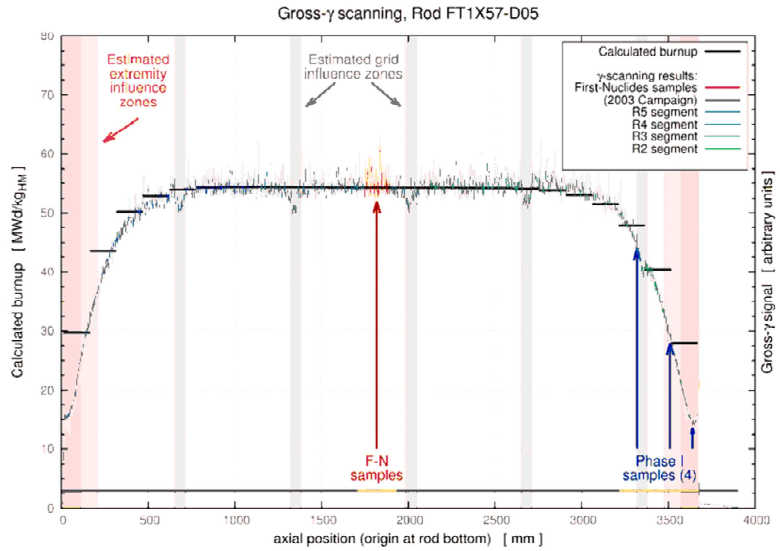
European Commission | LGi sustainable innovation | Preussen Elektra | Paul Scherrer Institut PSI | SCK•CEN | SKB Svensk Kärnbränslehantering AB | UK Atomic Energy Authority | Uppsala Universitet

Facilities: SCK•CEN (Mol, Belgium)

Small samples



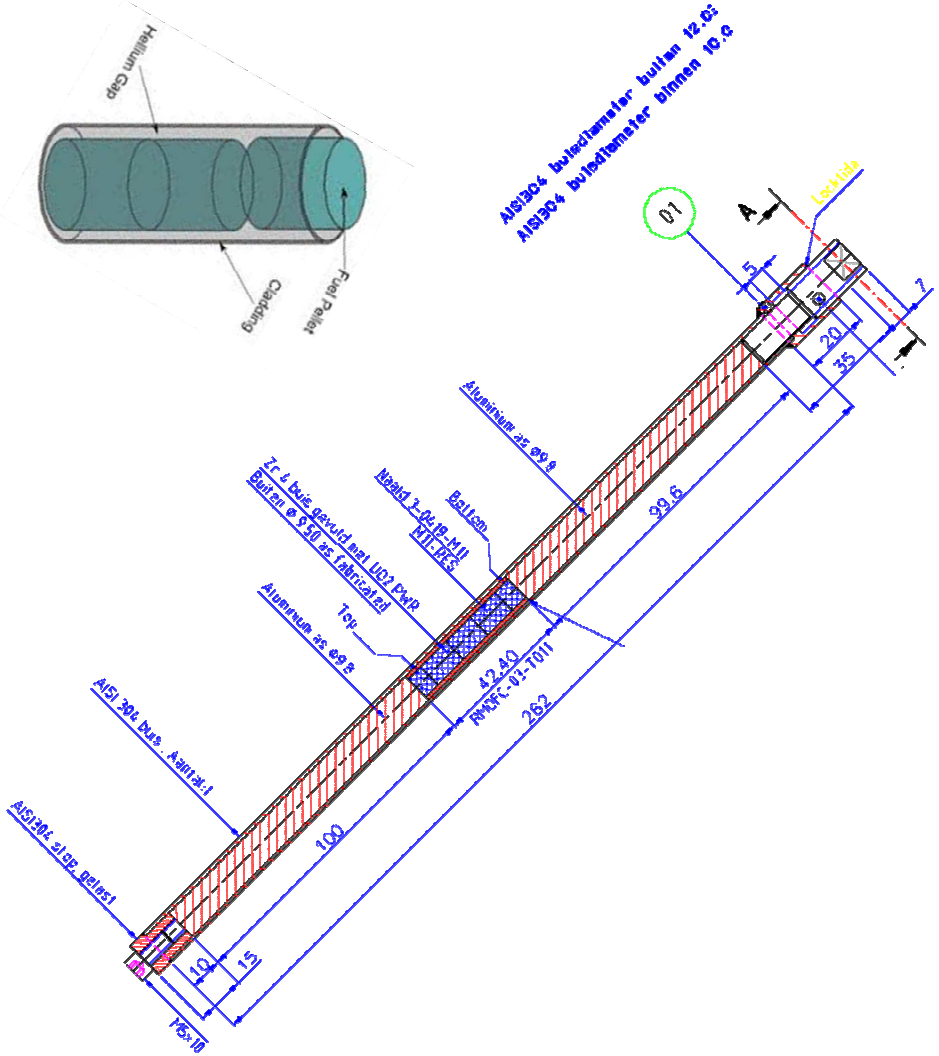
- Small sample objective
  - Test calculation models on well-defined samples
  - Measurement of nuclear data (specific heat)
- Samples from previous & ongoing projects
  - Profit from the FP7 “First Nuclides” project
  - Well-known radiation history
  - Radio-chemically analysed
  - Sliced pellet sample available
  - Solute samples available

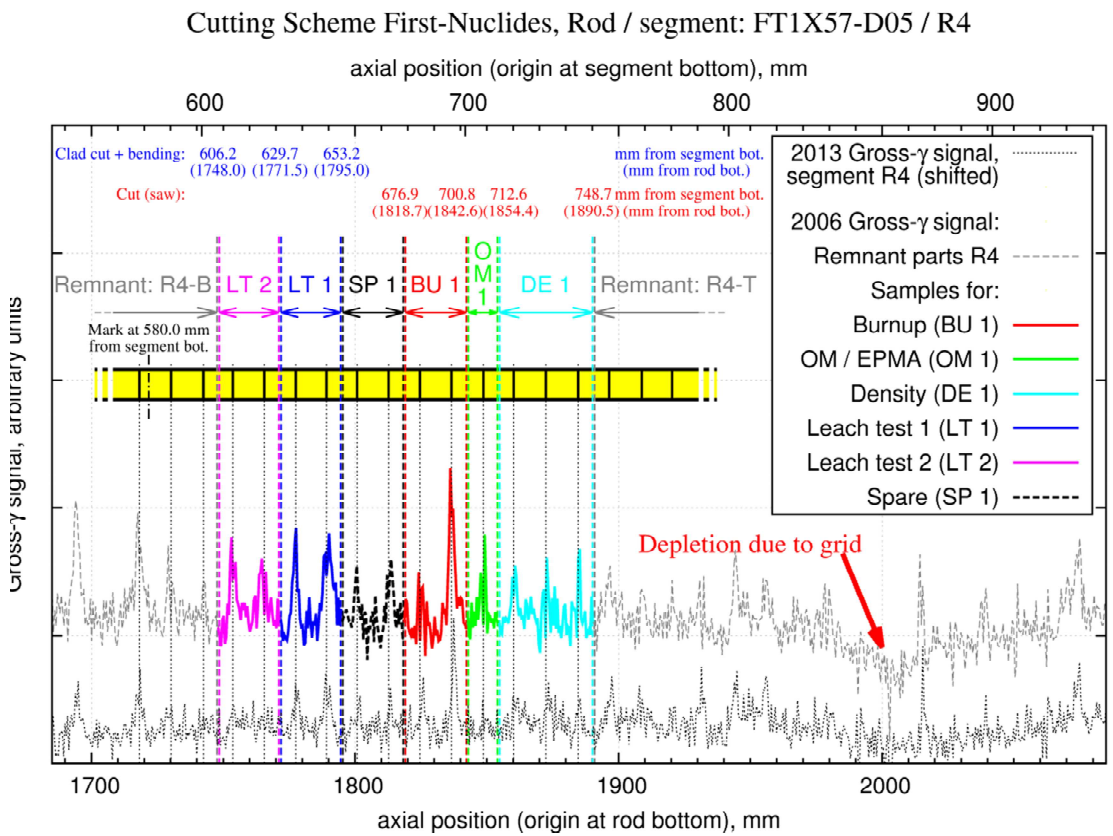


Facilities: SCK•CEN (Mol, Belgium)

Small samples

- Analysis of encapsulated spent fuel samples (e.g. 3 pellets)





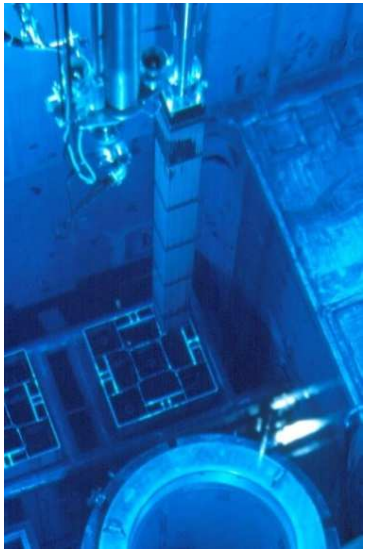
European Commission | LGi sustainable innovation | Preussen Elektra | Paul Scherrer Institut PSI | SCK•CEN | SKB Svensk Kärnbränslehantering AB | UK Atomic Energy Authority | Uppsala Universitet

NDA methods: improve & refine existing NDA technique

Fuel assemblies

Measurements on a wide variety of SFA (BU, IE, CT)

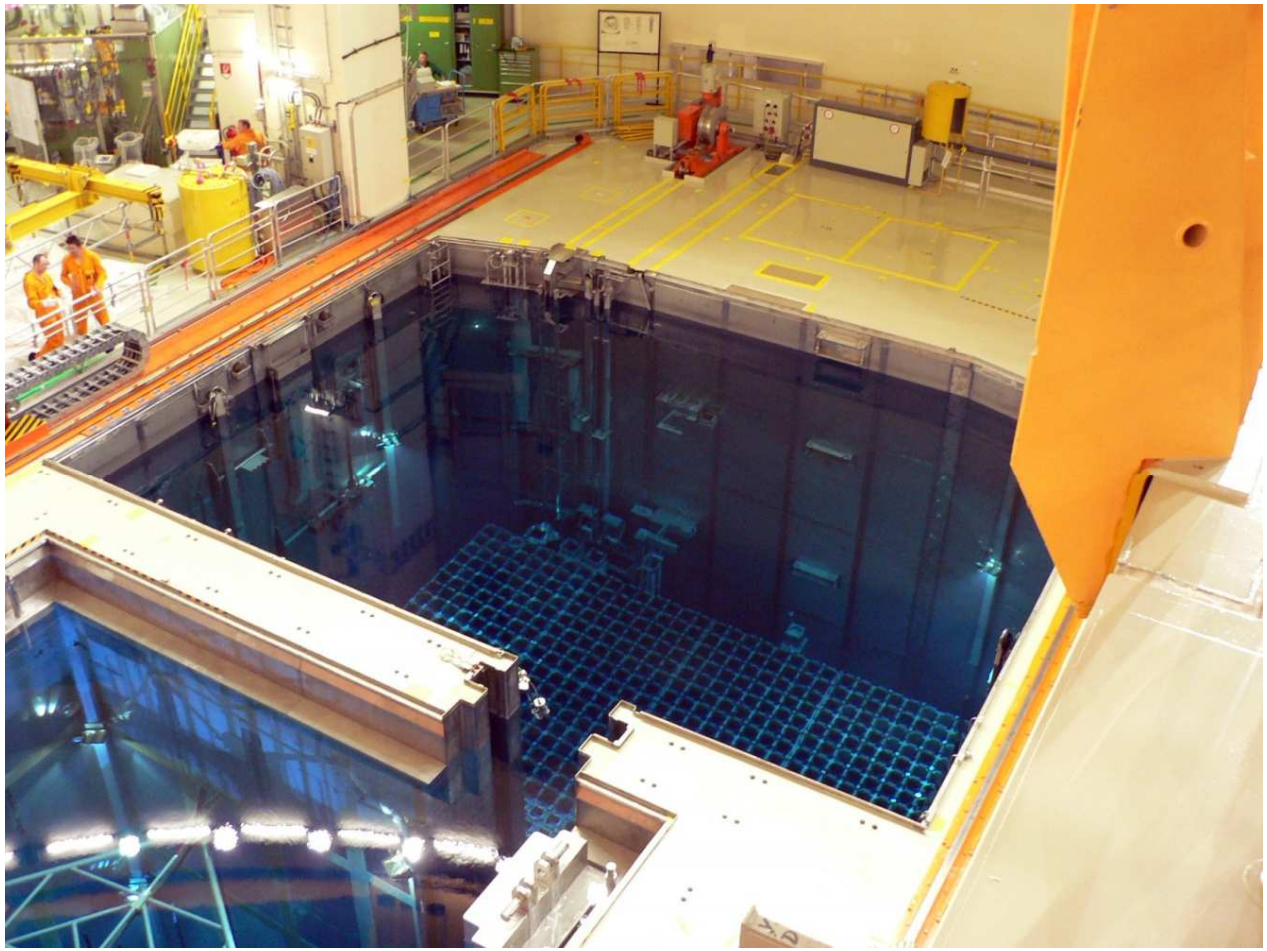
- Define realistic performance values (uncertainties)
- Define correlation schemes between different observables
- Use NDA results to improve irradiation histories



Facilities: Preussen Elektra (NPP-site, Germany)

Fuel assemblies

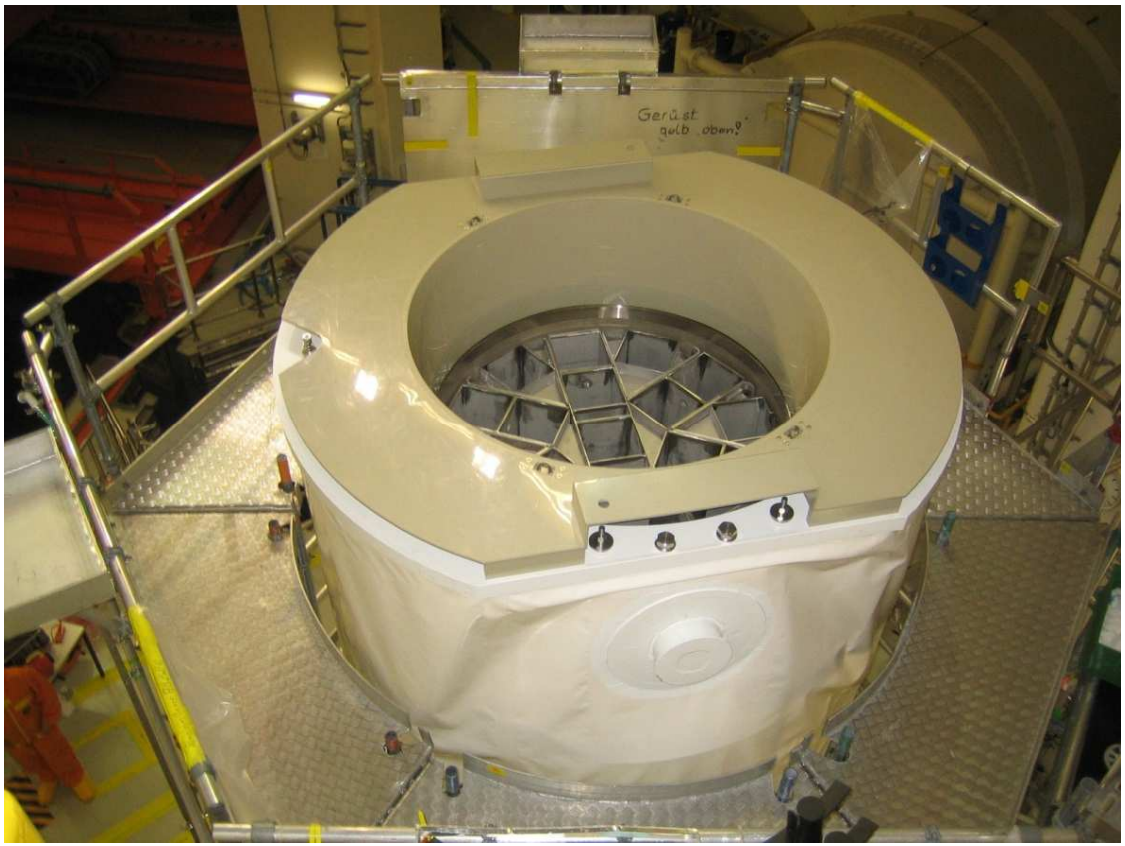
- Fuel pool inside reactor building holds ~ 700 fuel assemblies in each plant



Facilities: Preussen Elektra (NPP-site, Germany)

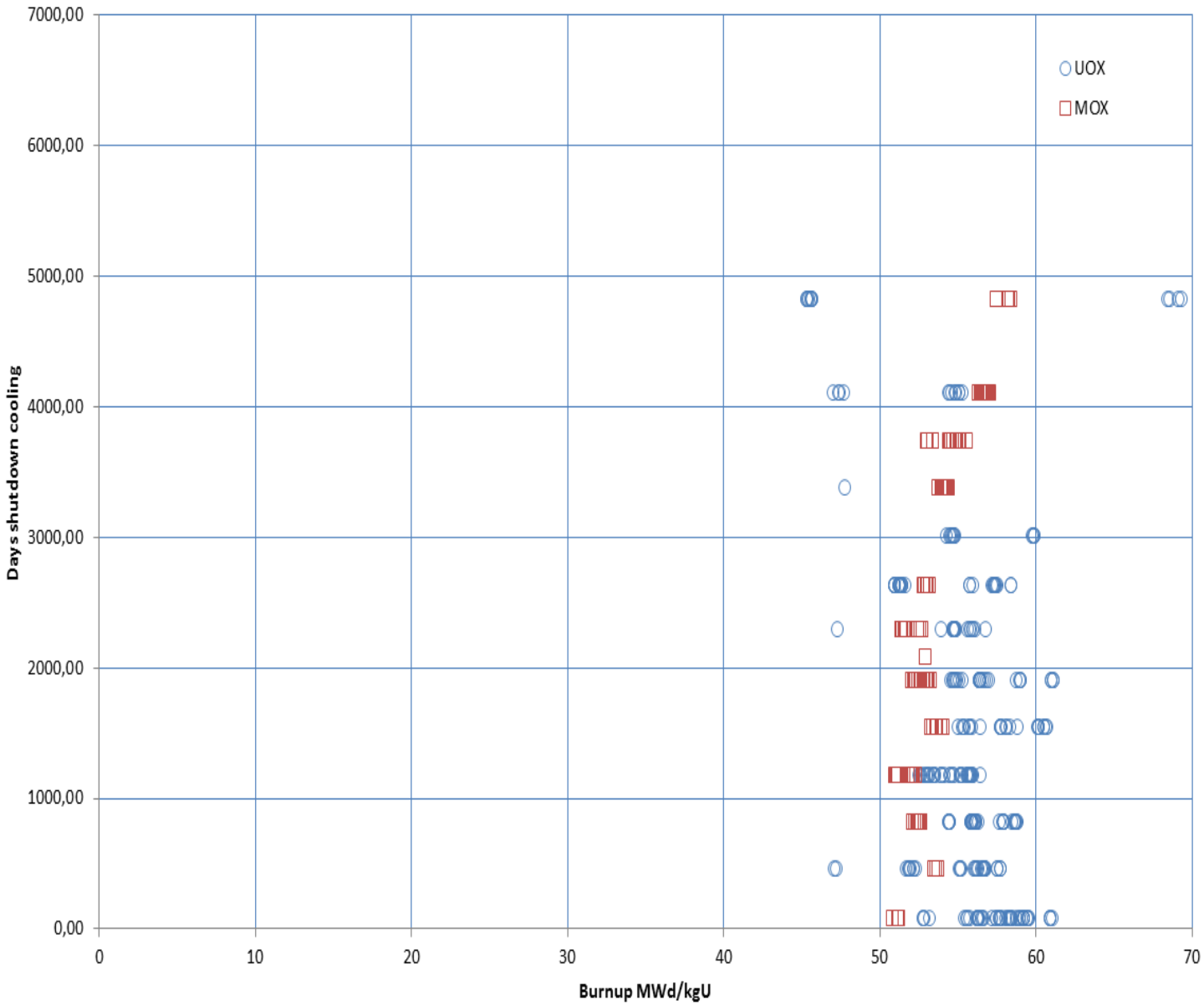
Fuel assemblies

- Fuel is loaded into dry storage casks after about 5 - 10 years of shutdown cooling for interim storage



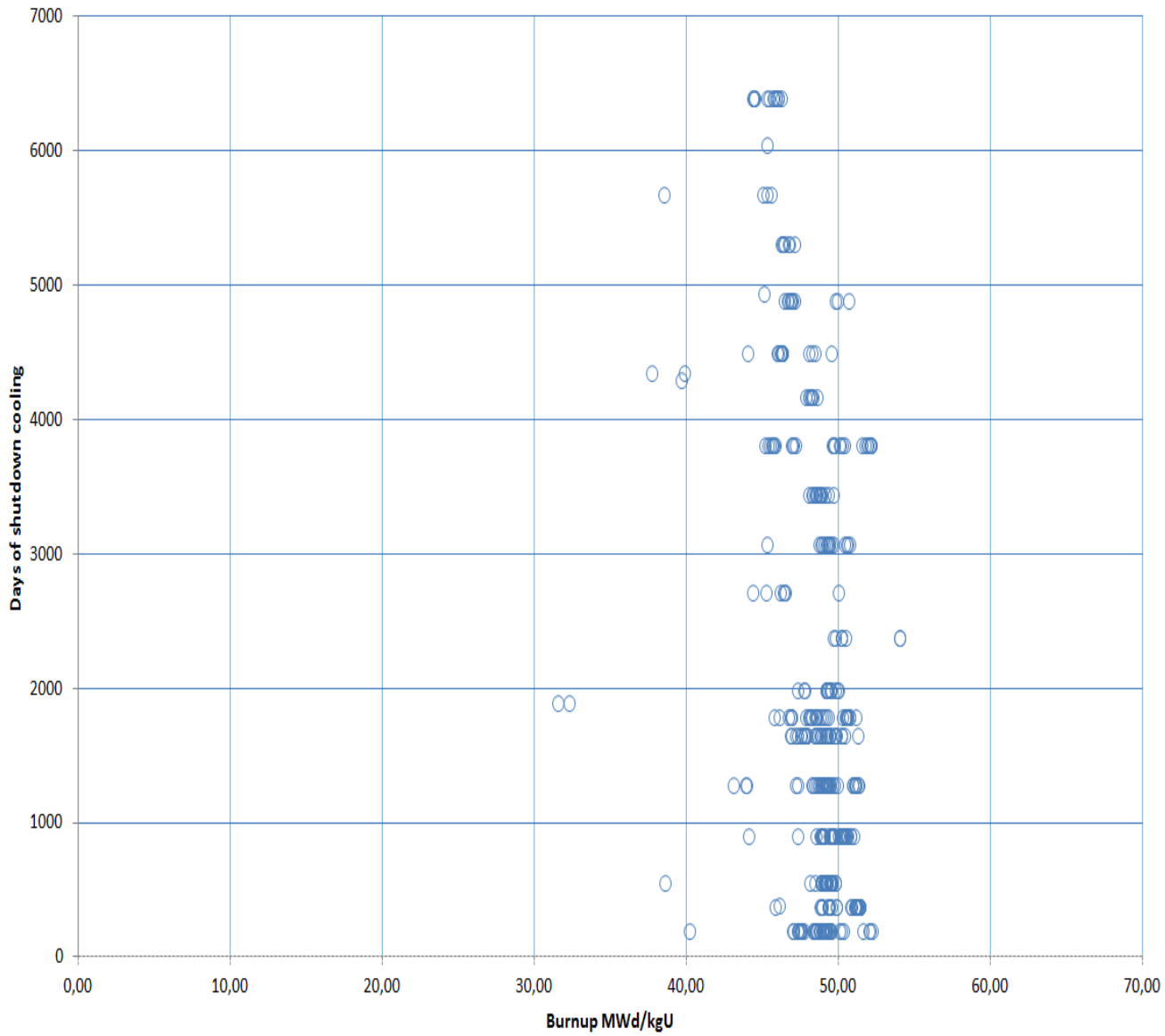
Facilities: Preussen Elektra (NPP-site, Germany)

- Example plant 1 (18x18) spent fuel inventory in pool
- MOX and UOX
- BU: 50-60 MWd/kgU
- CT ~ 1 -15 y



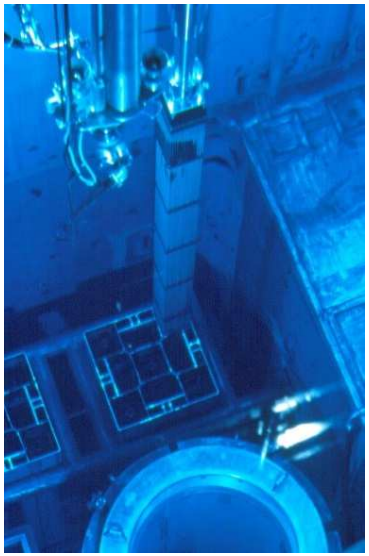
Facilities: Preussen Elektra (NPP-site, Germany)

- Example plant 2 (16x16) spent fuel inventory in pool
- UOX
- BU: 45-53 MWd/kgU
- CT ~ 1 -15 y



Facilities: CLAB (Oskarshamn, Sweden)

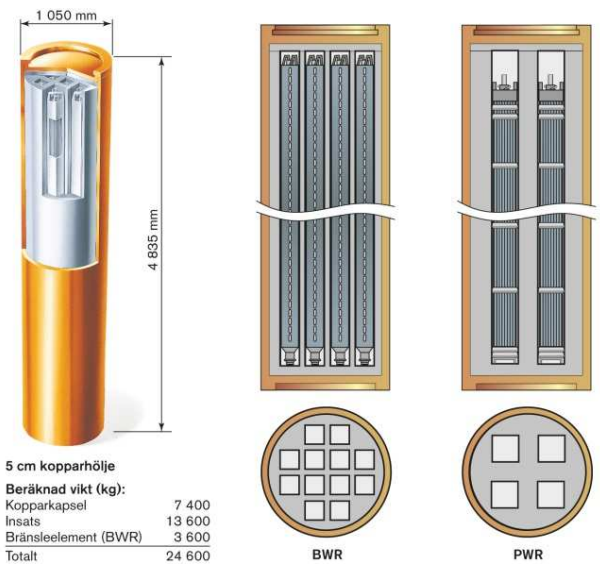
Fuel assemblies



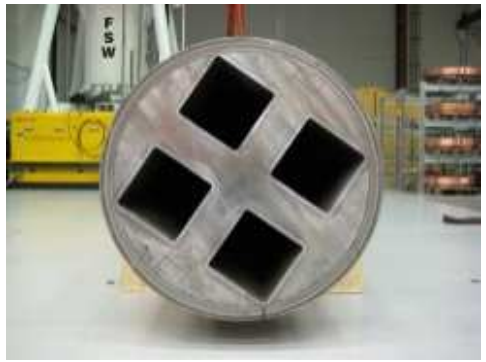
- Central Interim Storage Facility for Spent Nuclear Fuel
- LWR fuel assemblies (~ 6300 t BWR and PWR fuel stored)
- Service pool with fuel handling machine
- Calorimeter (BWR and PWR fuel)
- γ-spectrometry scan equipment with collimator
- Experiences from earlier projects
- Approximate fuel properties:
  - 7 fuel types BWR
  - 7 fuel types PWR
  - BU range 10 - 55 GWd/tU
  - CT range (2) 5 - 30 y
  - IE range 2-5%

SKB: business case example

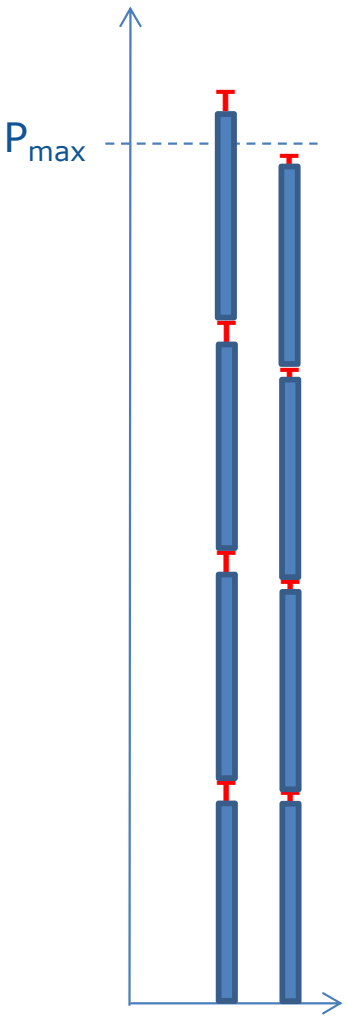
Encapsulation plant



- Optimisation of canister packing
  - Maximum decay heat criteria (~ 1 700 W)
  - Max. mean decay heat per assembly if equally distributed:
    - PWR ~ 425 W,
    - BWR ~ 142 W
  - ~ 6 000 canisters
- Cast iron inserts for
  - 4 PWR or
  - 12 BWR assemblies



SKB: business case example



- Cost per canister
  - ~ 1 M€
- SKB 50 decay heat
  - BWR: mean CT= 17 y mean decay heat = 165 W
  - PWR: mean CT= 18 y mean decay heat = 590 W
- Example
  - 1% increase in number of canisters: 50 M€ in increased costs

→ Reduction in bias and uncertainty of decay heat will improve packing efficiency and reduce empty positions

Thanks for your attention