



28th Exchange Meeting:
Belgian R&D programme on Spent Fuel

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	Time	Presented by
1. Context	13.40 – 14.50	*Where we stand*
Belgian context for the management of spent fuel		Sophie Pedoux (NIRAS-ONDRAF)
Spent nuclear fuel: Why should we know more … today?		Kevin Govers (NIRAS-ONDRAF)
Knowledge management, the spent fuel platform		Valentin Kerleguer (FANC)
The global work programme of the spent fuel platform explained		Tomas Vandoorne (NIRAS-ONDRAF)
Q&A		
Coffee break	*14.50 – 15.20*	
2. Practical aspects	15.20 – 16.00	*From reactor to research*
Rod extraction at Doel-3		Jonas Stichelbout (Engie)
Loading of the container, transport to SCK CEN		Xavier Bairiot (SCK CEN)
Q&A		
3. R&D programme details	16.00 – 16.50	*Gaining insights*
The experimental spent fuel R&D program		Marc Verwerft (SCK CEN)
Characterizing of spent nuclear fuel through modeling & calculations		Augusto Hernandez Solis (NIRAS-ONDRAF) Gert Van den Eynde (SCK CEN)
Q&A		
Way forward	16.50 – 17.00	Didier Leonard (SCK CEN)
Drink	*17.00 – 18.00*	



28th Exchange Meeting:
Belgian R&D programme
on Spent Fuel

Belgian programme
on radioactive waste management

R&D programme details

24-11-2026

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Belgian programme
on radioactive waste management

The Experimental Spent Nuclear Fuel R&D Program
-
Losing Knowledge is Not an Option

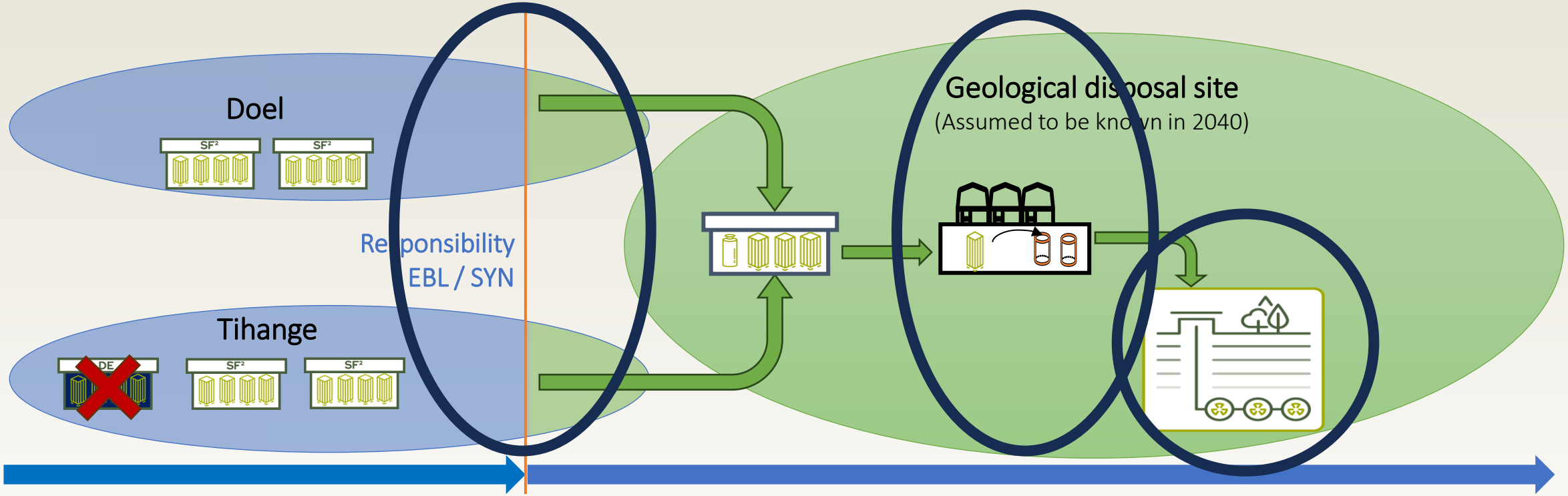
Marc Verwerft

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Reference scenario of NIRAS-ONDRAF for spent fuel management



Temporary storage
→ Until end of dismantling
or 2050

(I) Transfer

ransport
isposal
Tempo
2050 - 2130

(II) Conditioning

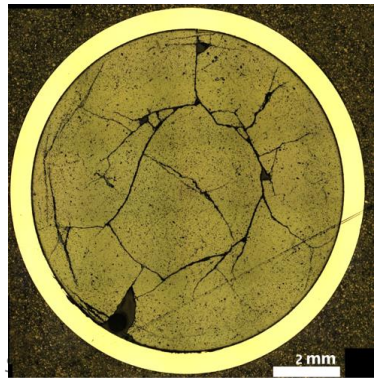
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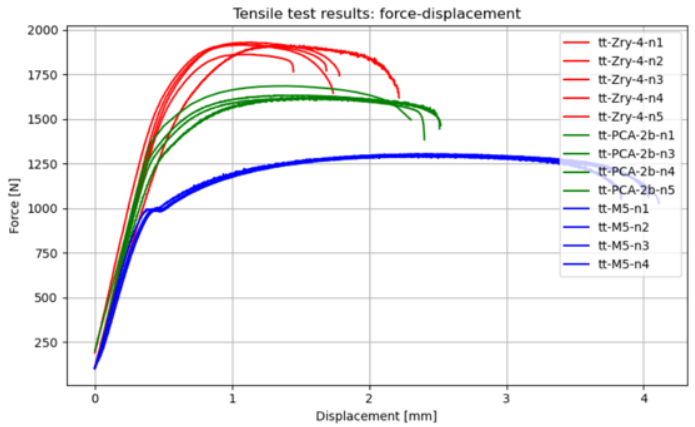
(III) Disposal

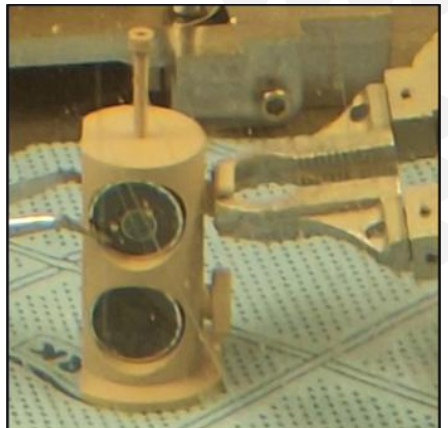
The Experimental Spent Nuclear Fuel R&D Program

Enabling the three stages: Transfer, Conditioning, Disposal

- Transfer – "*From operational records to disposal-ready knowledge*"
- Conditioning – "*From stored fuel to disposal-ready packages*"
- Disposal – "*From engineered barriers to geological safety*"



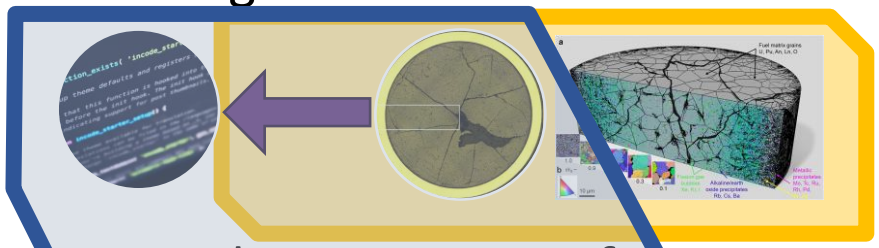




High-level objectives



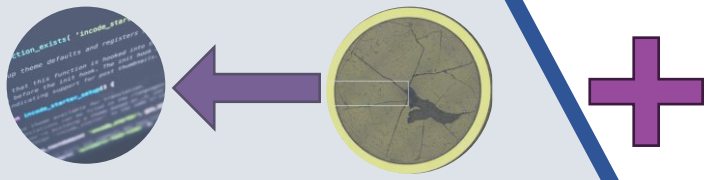
1. Determine radiological and chemical **content** of SNF inventory

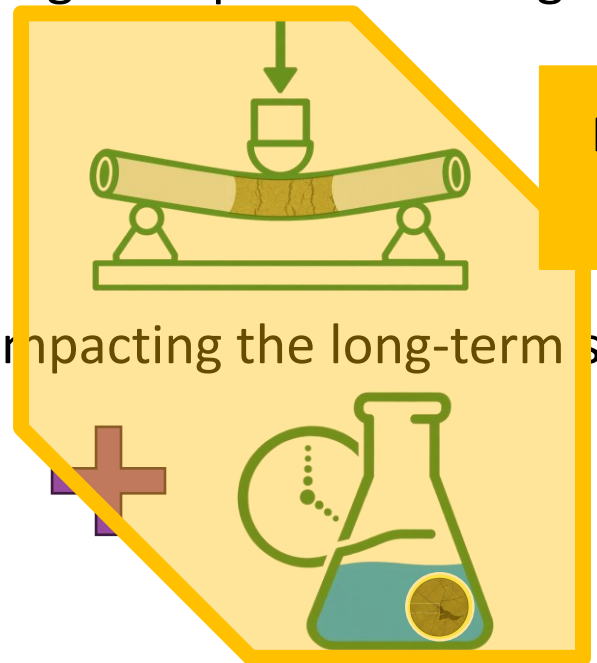


Nuclide inventory validation



2. Determine the properties **of SNF** impacting the operational stages,





Fuel and cladding assessment



Linking representative observations to the full inventory

ne the properties of SNF impacting the long-term safety

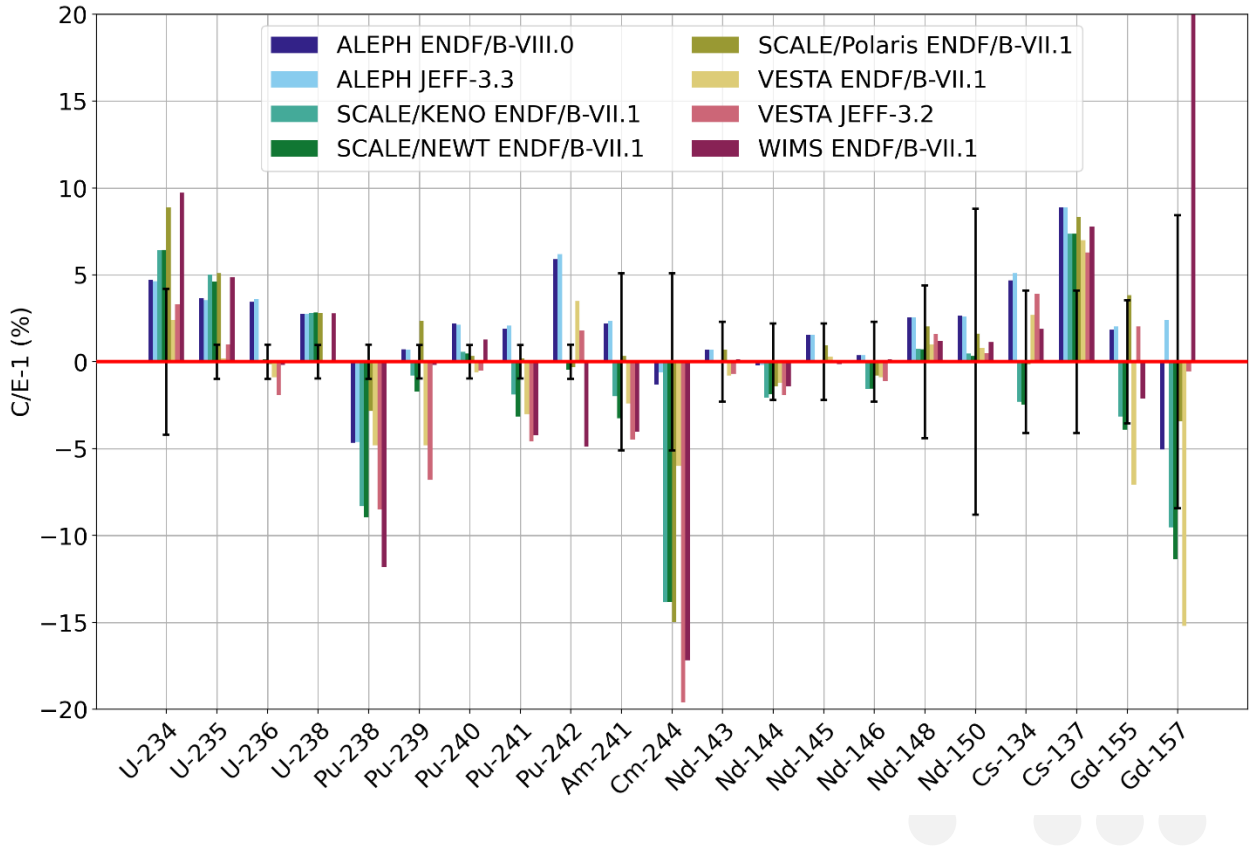


Transfer stage – *"From operational records to disposal-ready knowledge"*

Nuclide inventory validation

- Experimental analysis of:
  - Burnup monitors
  - Actinide content
  - Residual fissile content
  - Long-lived fission and activation products
  - …

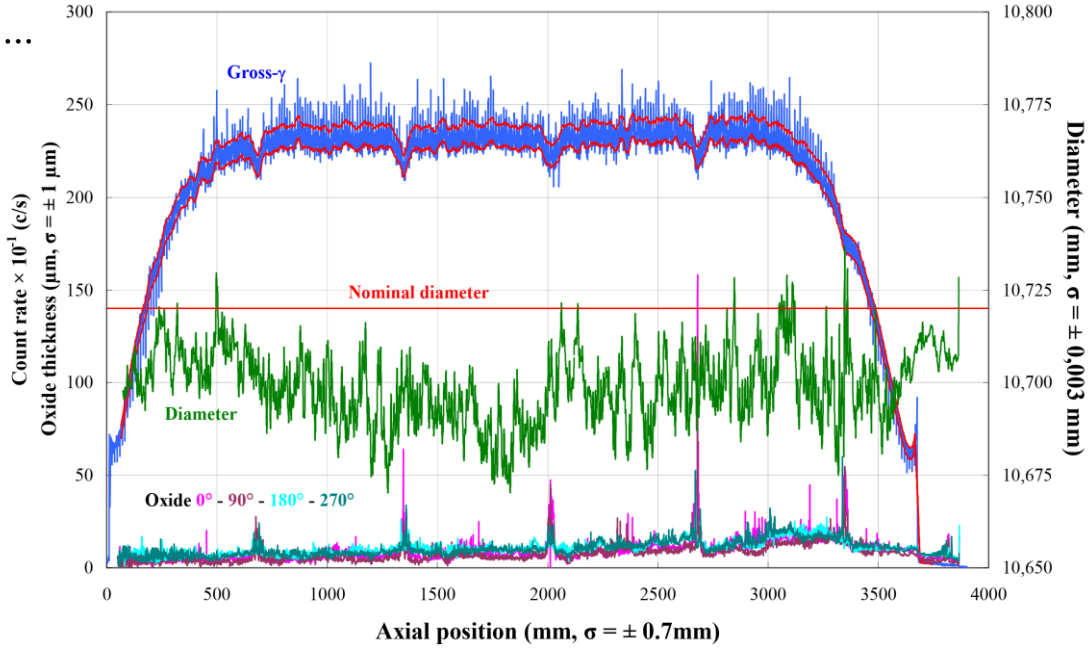




Transfer stage – *"From operational records to disposal-ready knowledge"*

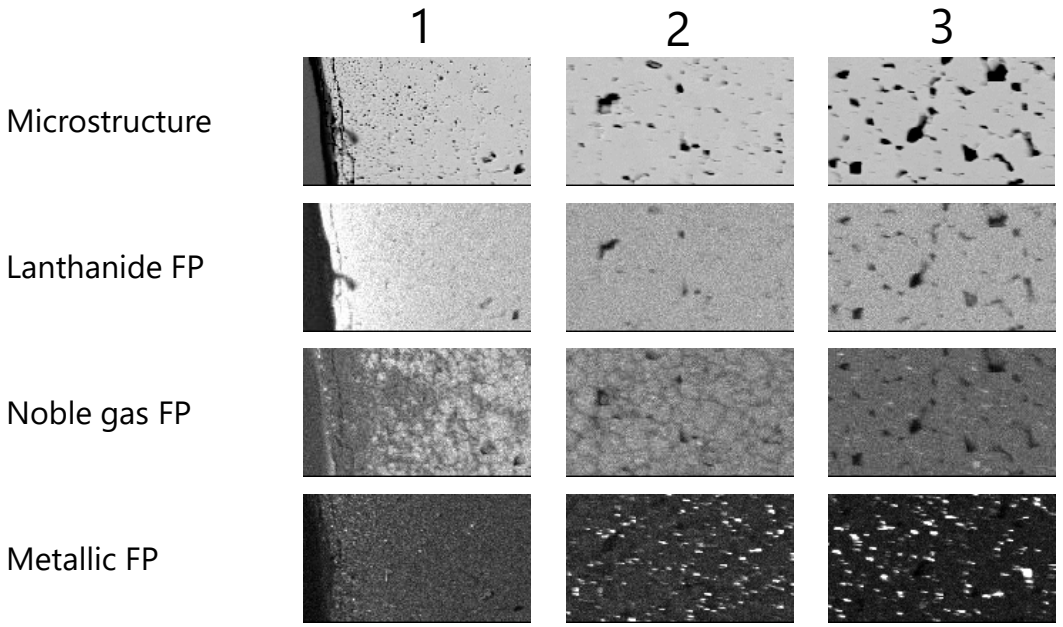
Fuel and cladding state: NDE & DE

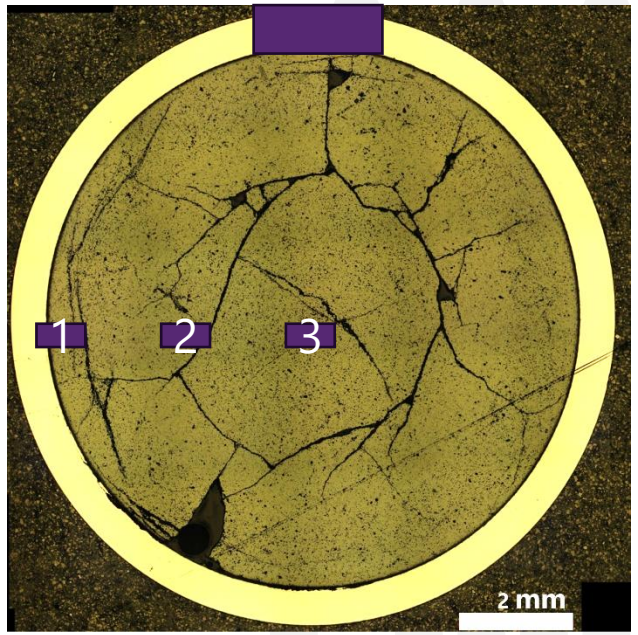
- Non-destructive examinations:
  - Fuel rod gamma profile
  - Dimensional changes (diameter & length)
  - Corrosion
  - Fission gas release
  - …

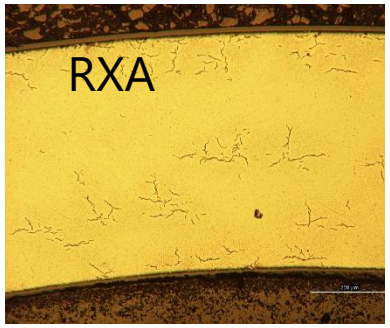


Transfer stage – *"From operational records to disposal-ready knowledge"*

Fuel and cladding state: NDE & DE





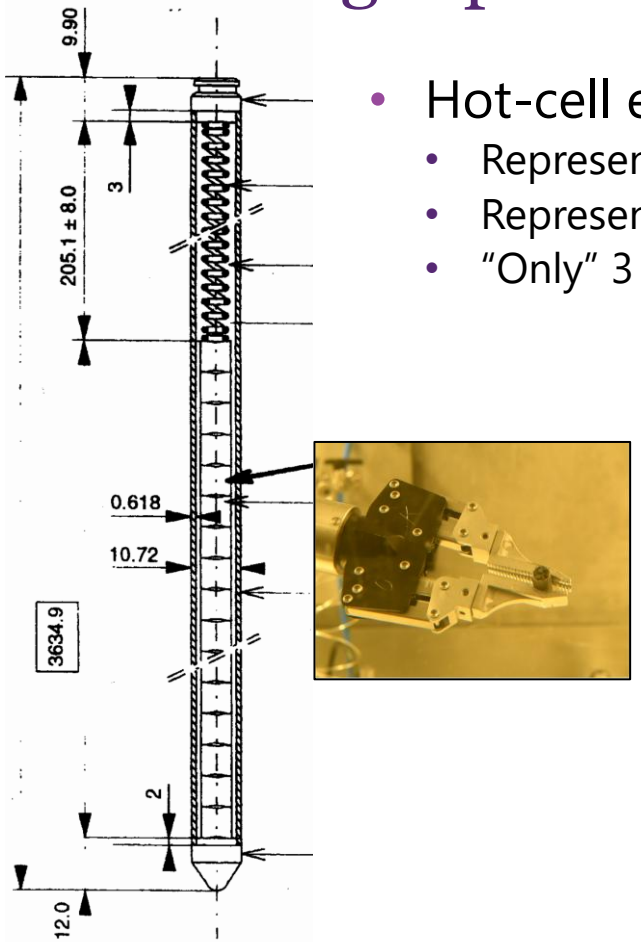




- Destructive examinations:
  - Fuel condition
  - Fuel-clad interaction
  - Hydriding
  - Fission product distribution
  - …

Transfer stage – *"From operational records to disposal-ready knowledge"*

Linking representative observations to the full inventory



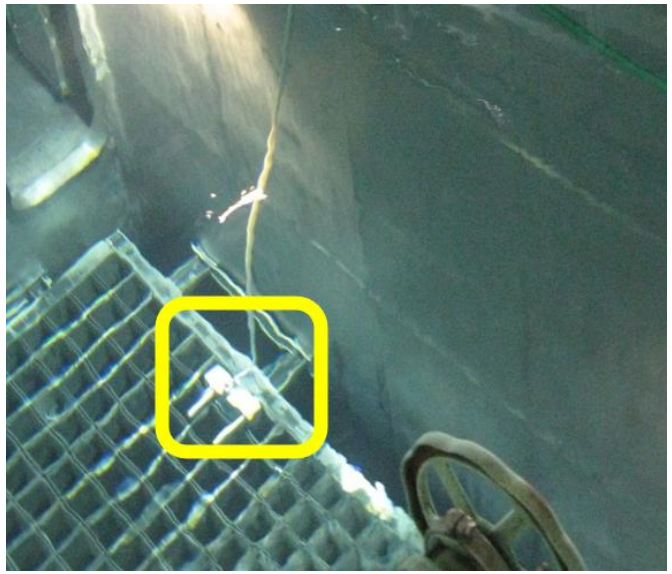
- Hot-cell examinations
  - Representative fuels: UO_2, $(U,Gd)O_2$, MOX
  - Representative clads: Zry-4, PCA2b ™, M5™
  - "Only" 3 assemblies, 10 fuel rods





Transfer stage – *"From operational records to disposal-ready knowledge"*

Linking representative observations to the full inventory

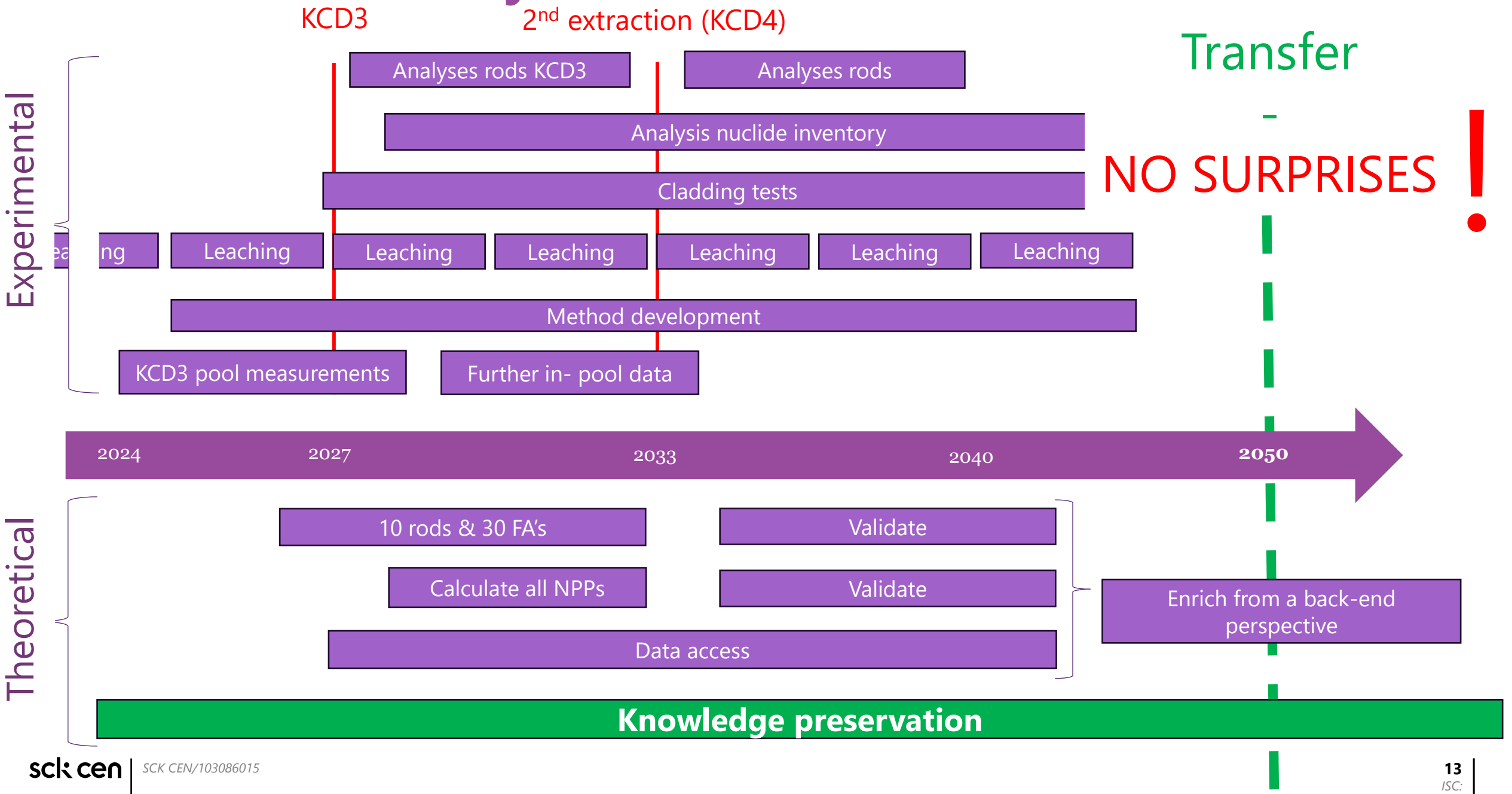






- Poolside observations:
  - Larger set of fuel assemblies selected for dedicated n- & γ- emission
  - Link with existing datasets (~30% of inventory)
  - Prepare the 100% control (at "conditioning" stage)

PHOENIX for the years to come: no time to lose



The Experimental Spent Nuclear Fuel R&D Program

Enabling the three stages: Transfer, Conditioning, Disposal

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Forthcoming Exchange Meetings



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Characterizing of spent nuclear fuel through modeling & calculations

Augusto Hernandez Solis, Gert Van den Eynde

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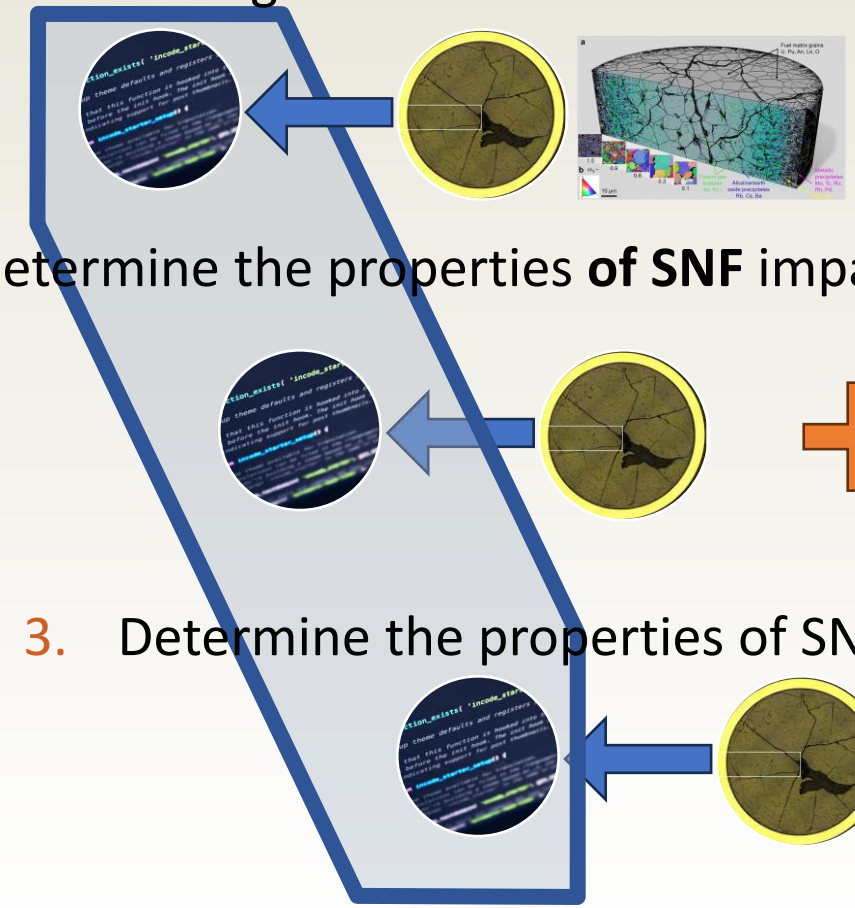
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High-level objectives

All objectives require computational characterisation



1. Determine radiological and chemical **content** of SNF inventory

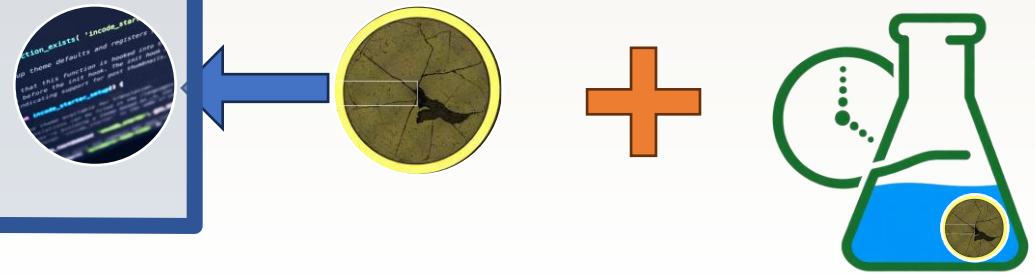




2. Determine the properties **of SNF** impacting the operational stages,



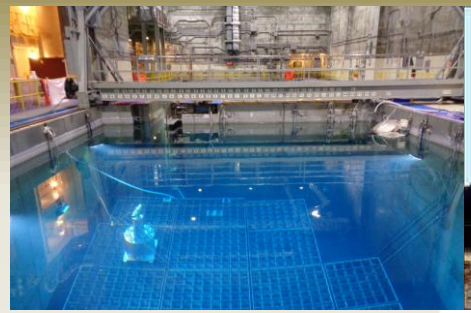
3. Determine the properties of SNF impacting the long-term safety

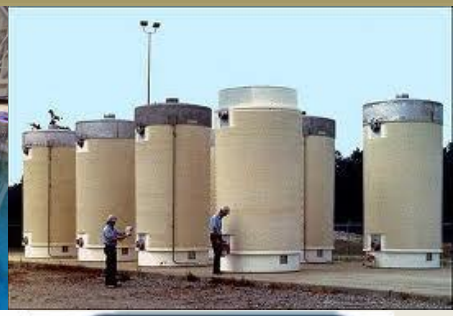


What is available for characterization?

- Modeling & simulation

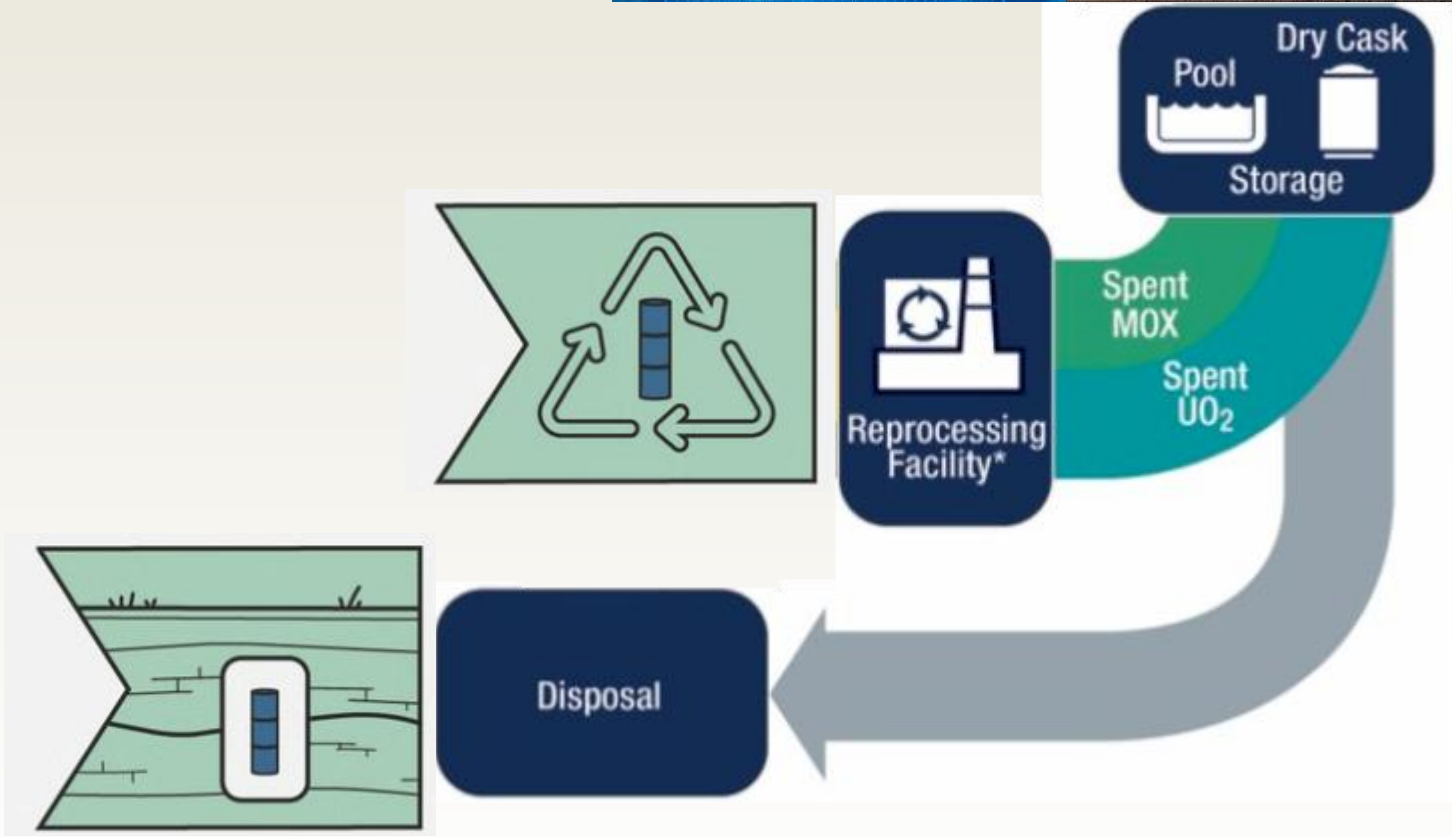
In order to know what to do in the future





- Destructive analysis

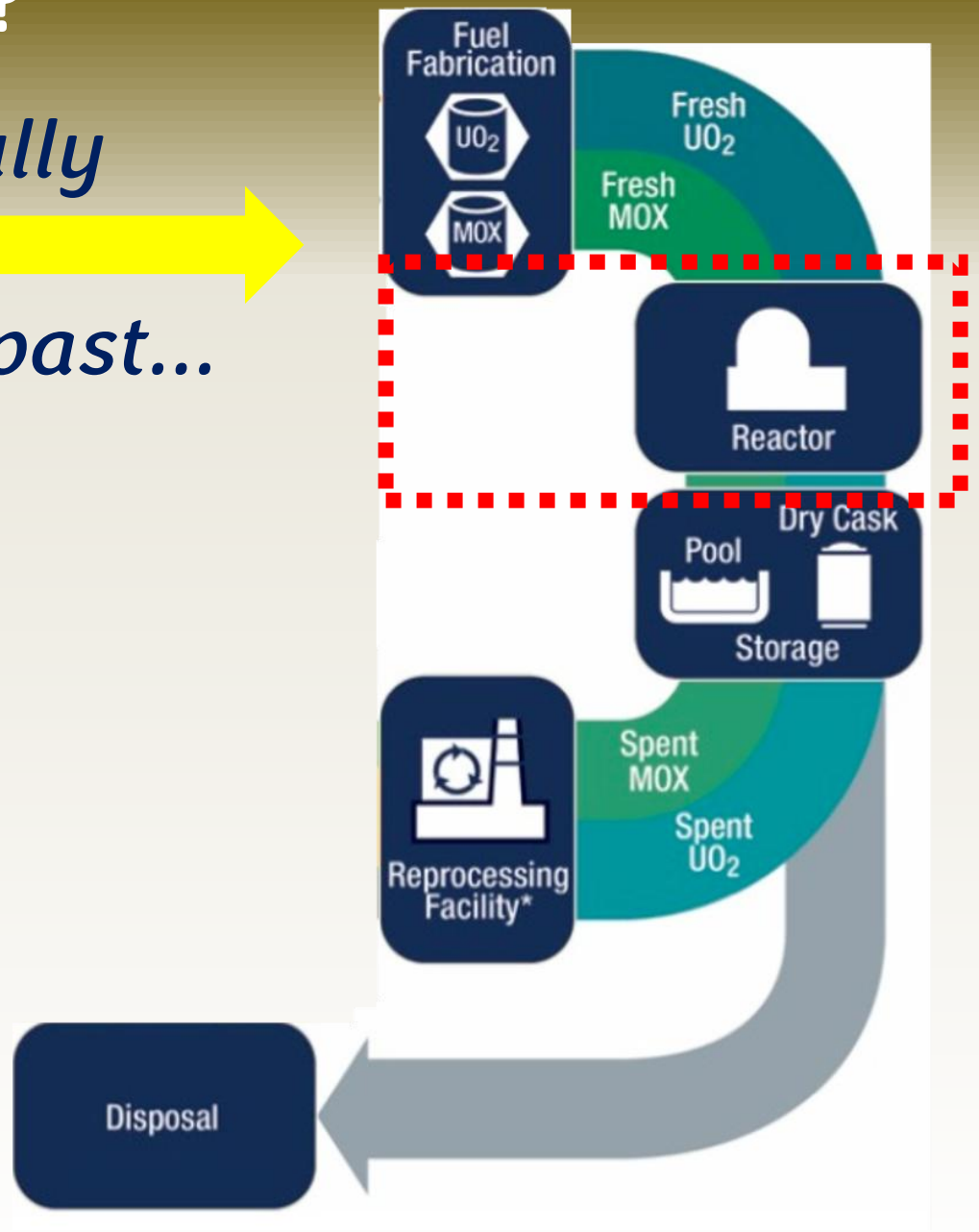
- Non-destructive analysis



What is available for characterization?

- Modeling & simulation

We need to fully understand the past…



The past reactor cycles of the Belgian reactor fleet will be computationally modeled and simulated

Full operational lifetime of all reactors

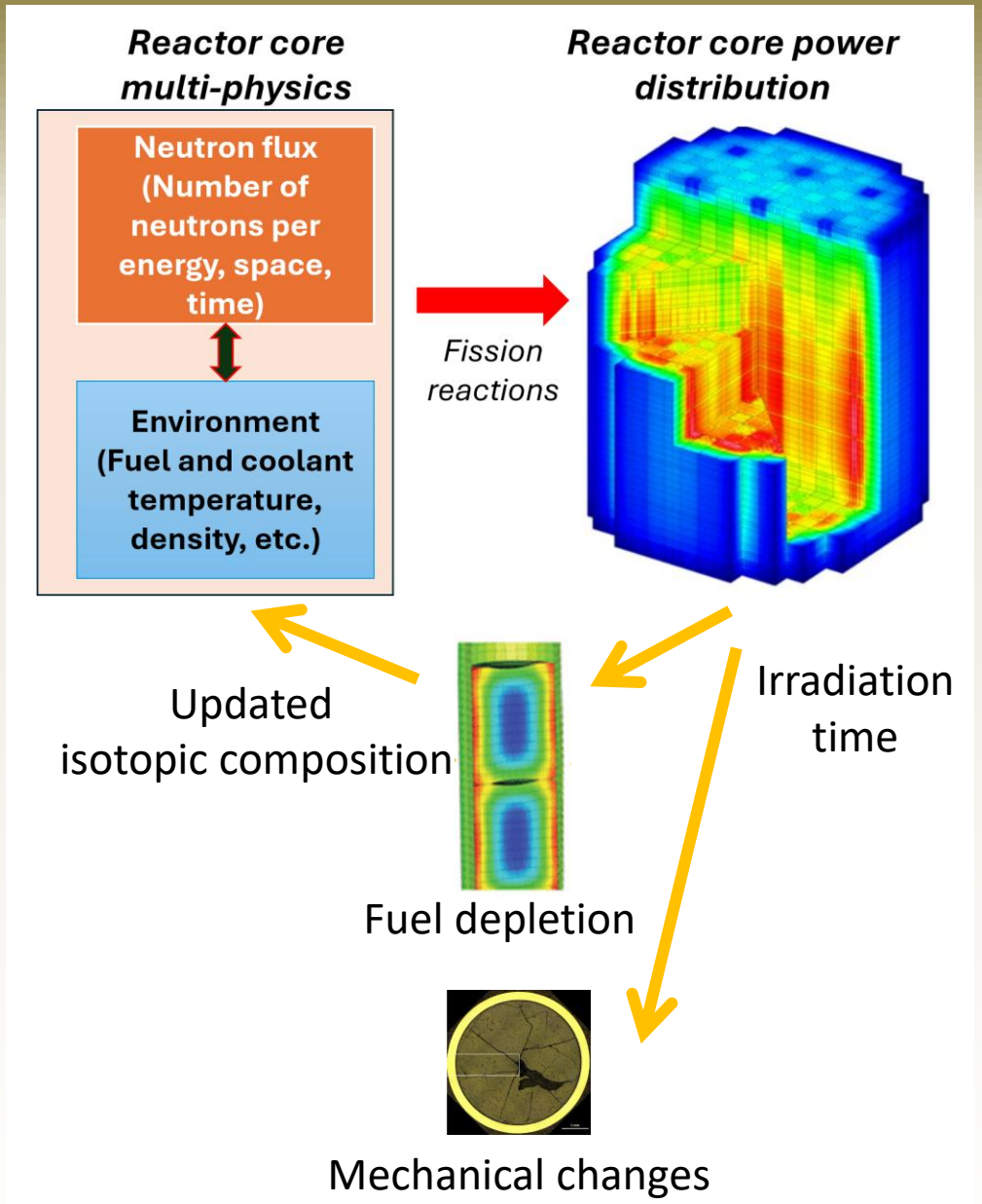
TV3

Cycle modeling & simulations – Overview

- In-core fuel management of the Belgian fleet focused on safety of operation and cost efficiency
  - ❖ Past simulations not necessarily focused on back-end strategies
    - ✓ Spent fuel detailed nuclide inventory, and local power histories may not have been computed

Therefore…

The fuel cycle back-end needs a holistic modeling of the reactor cycle operation



TV1

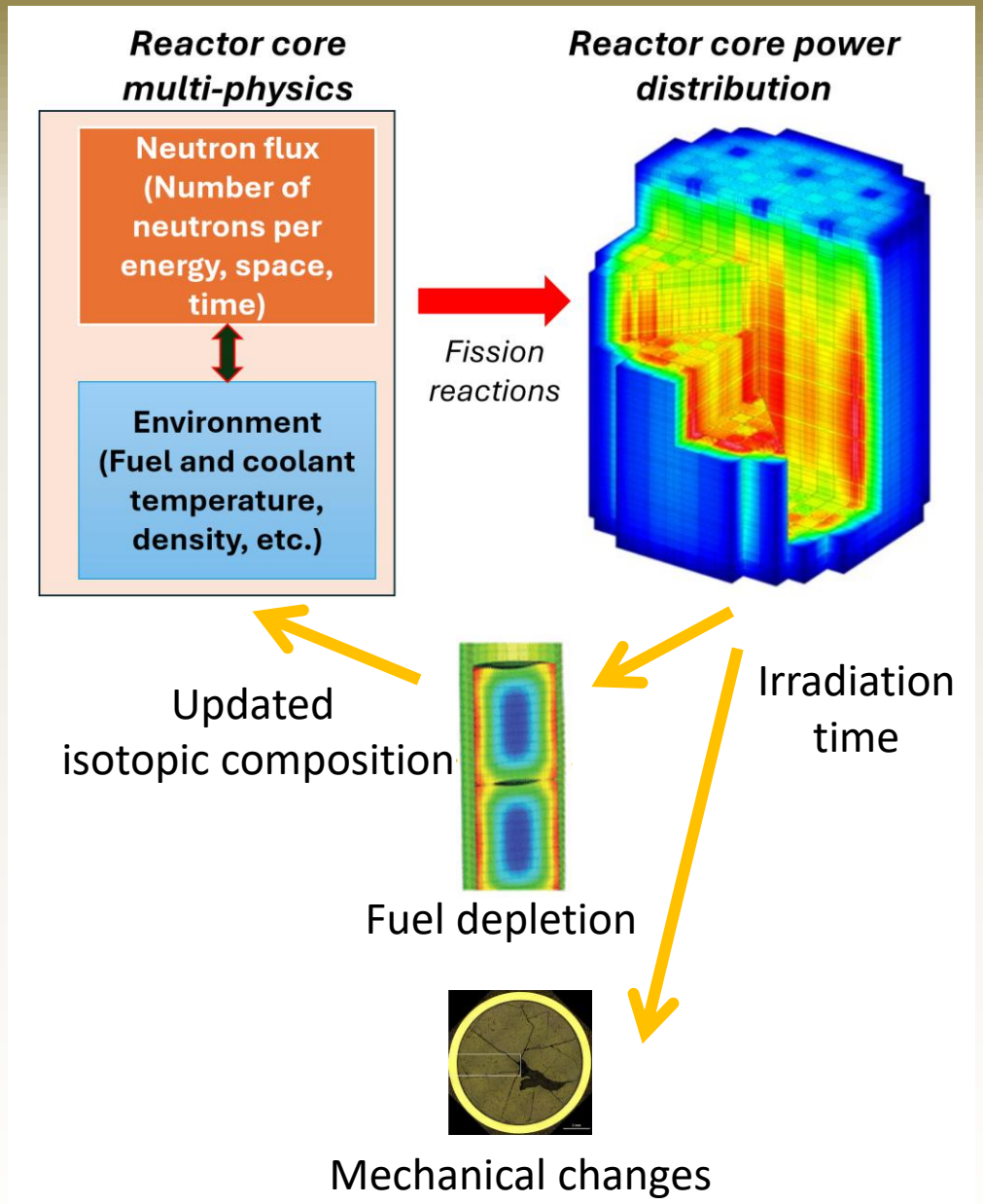
Cycle modeling & simulations – Overview

- Such a reproduction of the reactor fleet operational lifetime should aim at:

1. Obtaining a realistic power distribution in the reactor core.
This detailed power history is an essential input
to calculate the mechanical state of the fuel rods

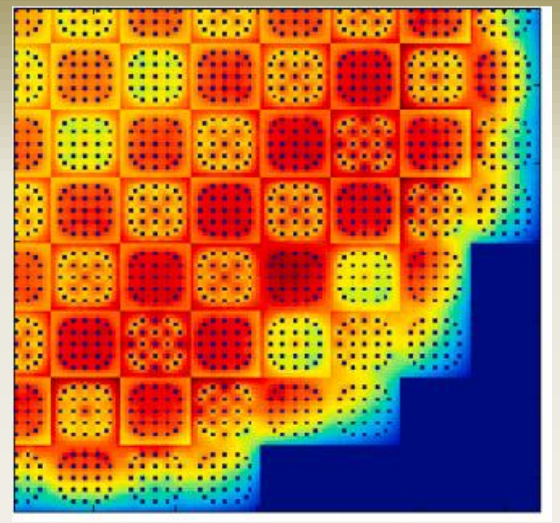
2. Best estimate computation of the nuclide inventory
+ determination of uncertainties

3. Preserving the knowledge by the Belgian state in computing observables of interest for SNF management

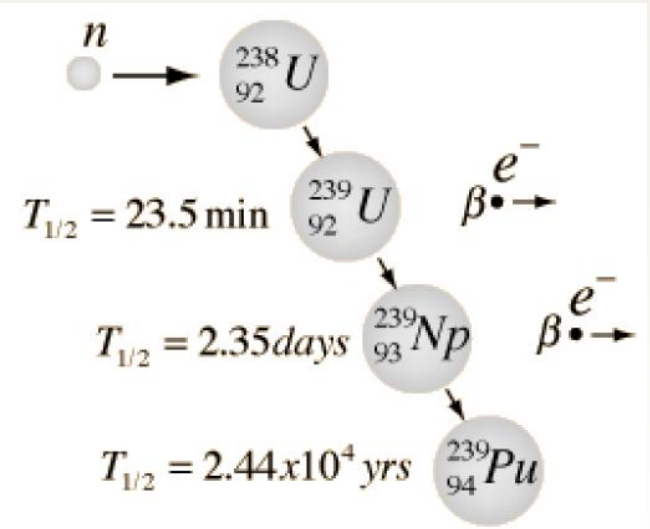


Cycle modeling & simulations – Objectives

- **To obtain the spatial distribution of the power in the reactor core at different scales**
  - ❖ Assembly and rod level – both average and axial distributions
    - ✓ Pin-power reconstruction is expected along the cycle
  - ❖ Of significant importance for best estimate FGR studies



- **To compute the nuclide inventory for each assembly**
  - ❖ Decay heat for disposal package & repository design/loading
  - ❖ Neutron & gamma emission for shielding
  - ❖ Chemically mobile radionuclides for long-term safety
  - ❖ Criticality safety studies
  - ❖ Radio- and chemical toxicity of SF



Cycle modeling & simulations – Knowledge sharing from ENGIE

ENGIE/TRACTEBEL ⟷ **NIRAS-ONDRAF**

Phoenix law foresees knowledge sharing from ENGIE to NIRAS-ONDRAF for future SF management:

- **Access to data & documents from ENGIE**
  + Acquire complementary data from fuel vendors
- **Integration of experts within ENGIE's teams**
  - ➢ **Knowledge and competence sharing**
  - ➢ **Correct understanding and use of ENGIE data**

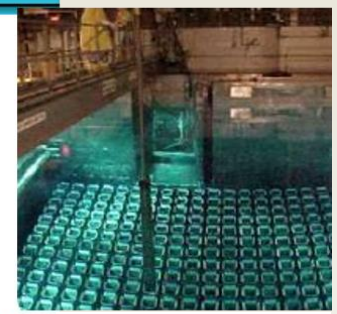
Assembly data

- Assembly ID
- Assembly type
- Initial enrichment
- Discharge burnup
- Cycle start and end dates
- HM mass (U/Pu)
- Geometric configuration
- Materials of construction
- Design dimensions
- Control components

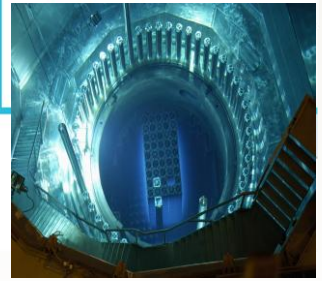


Reactor data

- Cycle specific burnup
- Soluble boron
- Rod insertion history
- Batch loadings
- Axial burnup profiles



- Cycle power



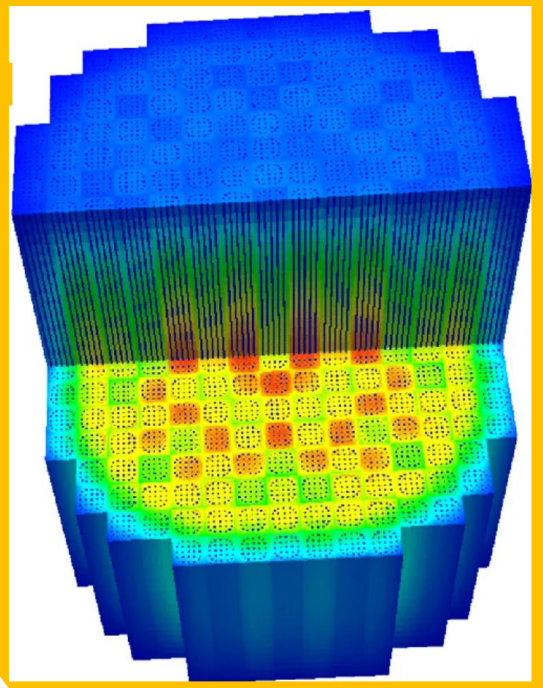
To reproduce the Belgian cycle from the beginning, data may come in all forms

- Well structured databases
- Digital
- Analog (e.g. paper, booklets)

Cycle modeling & simulations – Collaboration

Data integration

Computation of the spatial distribution of the power and inventory along each cycle, at the same time



NIRAS-ONDRAF

Deterministic based methodology (same as ENGIE)

SCK CEN

Stochastic based methodology (R&D oriented)

Why SNF characterization through modeling Summary

The need

- **SF management strategies depend on an accurate knowledge of:**
  - ❖ **Nuclide inventory**
  - ❖ **Conditions of operation (e.g. power) leading to it**
- **Important for decay heat, radioprotection, safety studies and Fission Gas Release**

The goal

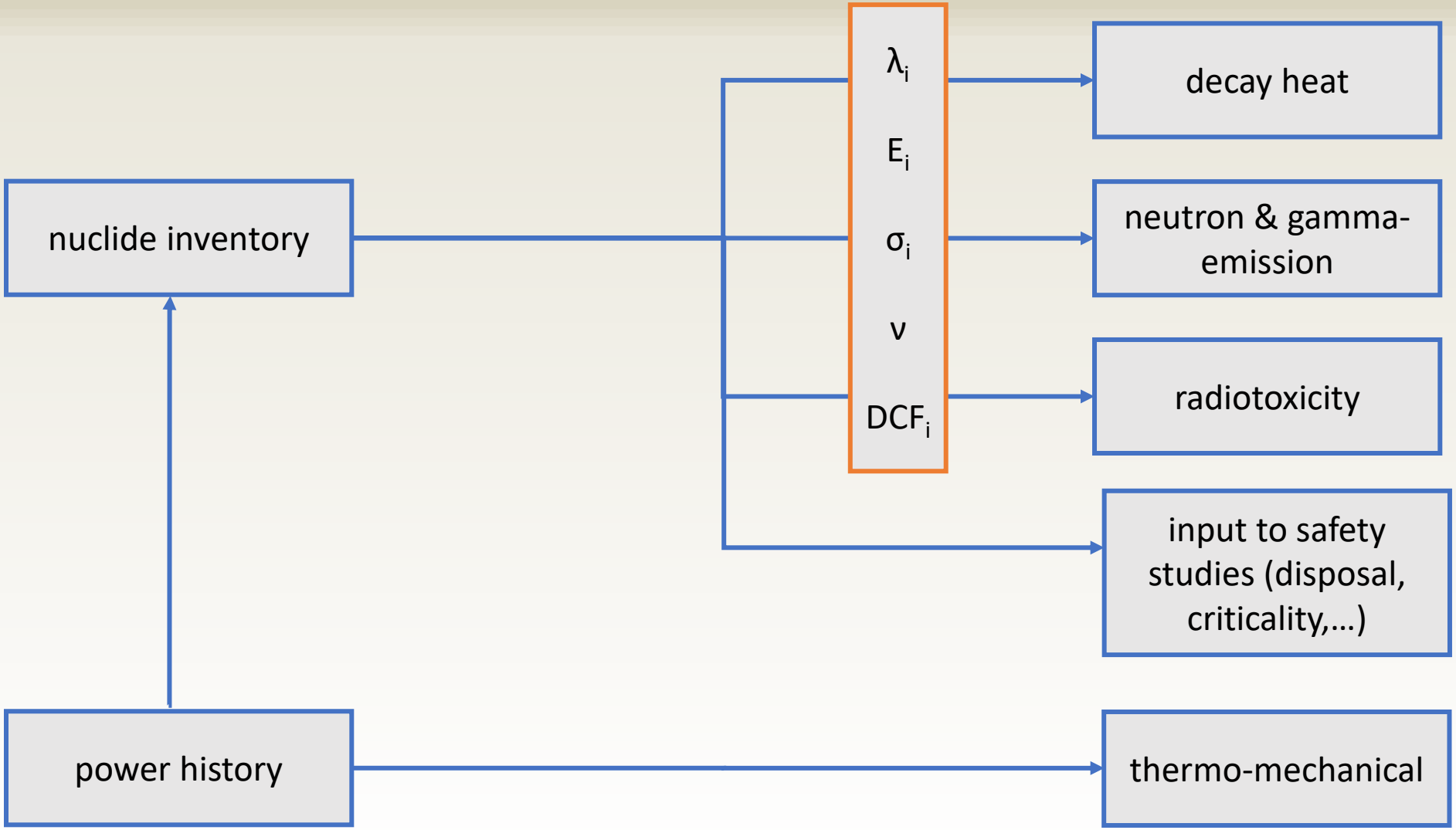
- **Perform state-of-the-art modeling and computer simulations of the Belgian fleet cycle operation**
  - ❖ **Best estimate multi-physics computation of observables of interest at the same time**

The strategy

- **The simulation objectives can be achieved by a neat data integration procedure with ENGIE**
- **Collaboration between NIRAS-ONDRAF & SCK CEN is foreseen to bring modern modeling methodologies to achieve the project objectives**

TV1

Computational SNF characterization by “microscopic approach”



Calculating the neutron flux/power history

$$\hat{\Omega}\cdot\nabla\varphi\left(\boldsymbol{r},E,\hat{\Omega},t\right)+\Sigma_{\mathrm{t}}(\boldsymbol{r},E)\,\varphi\left(\boldsymbol{r},E,\hat{\Omega},t\right)$$
$$-\int_{4\pi}\mathrm{d}\hat{\Omega}\int_{0}^{\infty}\mathrm{d}E'\,\Sigma_{\mathrm{s}}\left(\boldsymbol{r},E'\to E,\hat{\Omega}'\to\hat{\Omega}\right)\varphi\left(\boldsymbol{r},E',\hat{\Omega}',t\right)$$
$$-\frac{\chi(E)}{4\pi}\int_{4\pi}\mathrm{d}\hat{\Omega}'\int_{0}^{\infty}\mathrm{d}E'\nu(E')\,\Sigma_{\mathrm{f}}(\boldsymbol{r},E',t)\,\varphi\left(\boldsymbol{r},E',\hat{\Omega}',t\right)$$
$$=0$$

- Solving the “Neutron transport equation”
- Requires reactor core geometry and materials
  - Fuel geometry & composition
  - Temperatures (fuel and moderator) → need for thermo-hydraulic coupling
  - Other impacting factors: boric acid concentration, control rod position, …
  - “One cycle follows the next…”

“Deterministic methods”

- Discretization of variables
- Fast
- Limited energy/spatial resolution

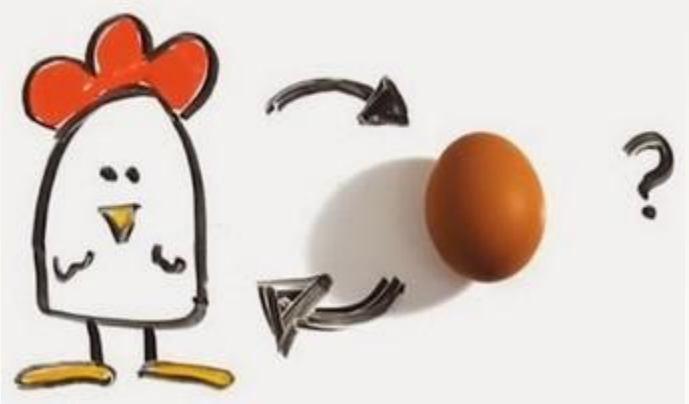
“Monte Carlo methods”

- Repetitive “simulation” of physical system
- Slow(er)
- “No limits” on energy/spatial resolution

The Bateman equations

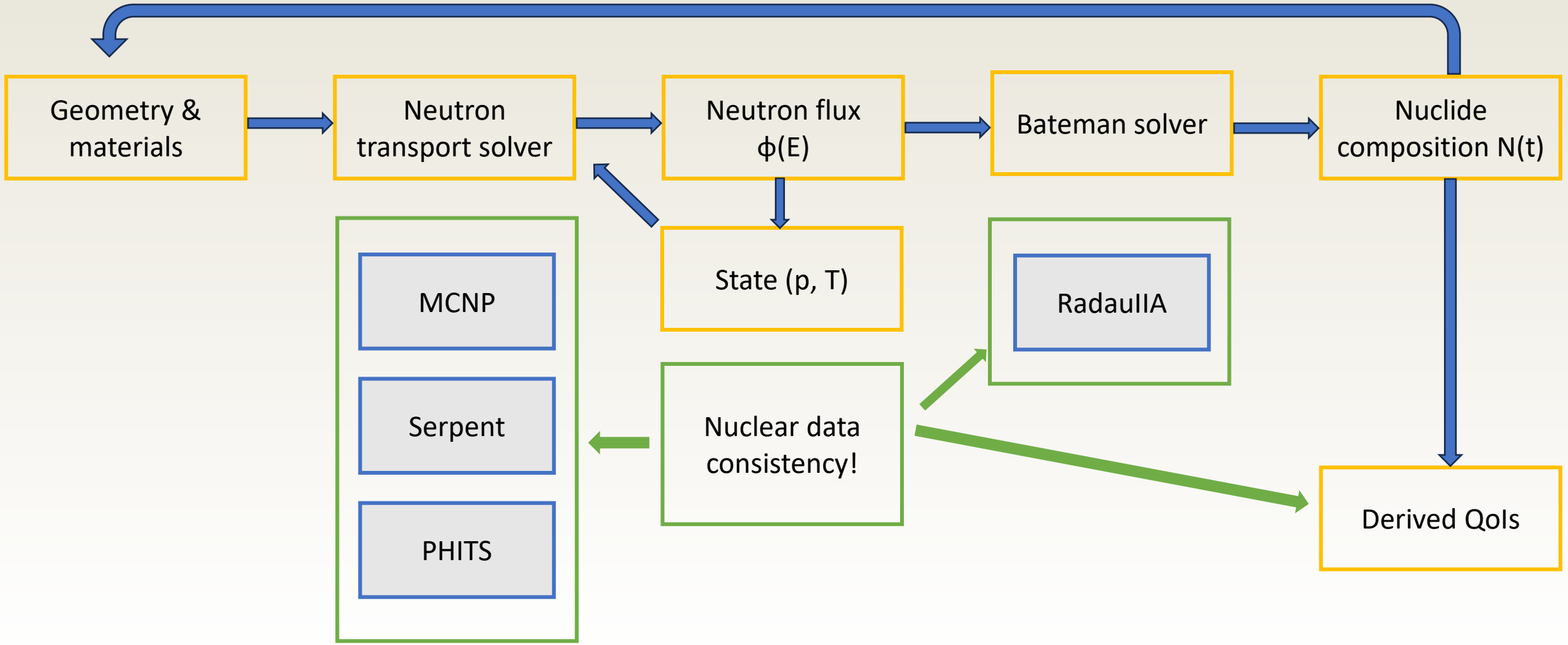
$$\frac{\mathrm{d}}{\mathrm{d}t}N_i(t) = \sum_{j\neq i}\left[\lambda_{j\to i} + \int_0^\infty \sigma_{j\to i}(E)\phi(E)\,\mathrm{d}E + \int_0^\infty \gamma_{j\to i}(E)\sigma_{\mathrm{f},j}(E)\phi(E)\,\mathrm{d}E\right]N_j(t)$$
$$-\left[\lambda_i + \int_0^\infty \sigma_{\mathrm{a},i}(E)\phi(E)\,\mathrm{d}E\right]N_i(t)$$

- Neutron flux ϕ(E) depends on N(t)!
- Spatial granularity
- Operator measures power P(t), not ϕ(E)
- “Burn-up” [MWd/kg]
  - Energy deposition models!



TV2

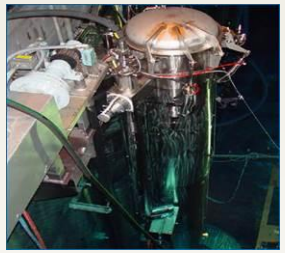
ALEPH v3 : SCK-developed tool for the Monte Carlo method

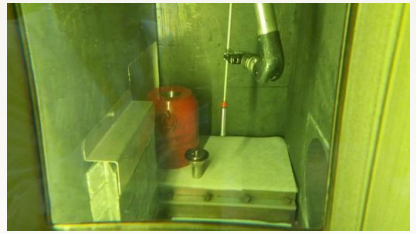


Validated approach?

Comparison to experiments

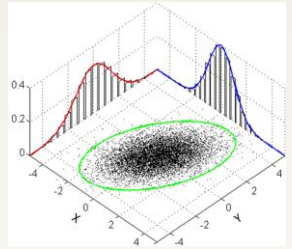
- ARIANE, MALIBU, REGAL
  - Nuclide inventory
- CLAB
  - Decay heat
- SCK/JRC
  - Neutron emission
  - Ion fork MOX
- Engie
  - Ion fork, in-core measurements, ...





Uncertainty quantification

- Sensitivity analysis
- Uncertainty propagation
- Target accuracy



Thermo-mechanical properties

- Important for fuel pin integrity
  - State of cladding
  - Fission Gas Release (FGR)
- Reference code = TRANSURANUS (EU-JRC developed)
- Needs
  - Fuel fabrication databook
  - Linear power production in pin as a function of time = output of reactor cycle calculations

Next steps

- Test-drive the computational approach on reference benchmarks
  - BEAVRS
  - Tihange1

- Apply the computational approach on the fuel assemblies selected for rod extraction
  - Interaction with Engie (Electrabel, Tractebel, Synatom) to get as much fuel data and reactor core operational data as possible
  - Identify data gaps
  - Compare results, identify sensitivities, …
  - Identify data storage and computational needs

TV1

Summary

SCK CEN and NIRAS/ONDRAF are working together on developing a

“Validated computational spent nuclear fuel characterization method”

that will allow to efficiently analyze the full Belgian SNF inventory and provide us, FANC/Bel-V and the general public confidence in the results



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Way forward

Didier Léonard

24-11-2026

Exchange Meeting

NIRAS ONDRAF

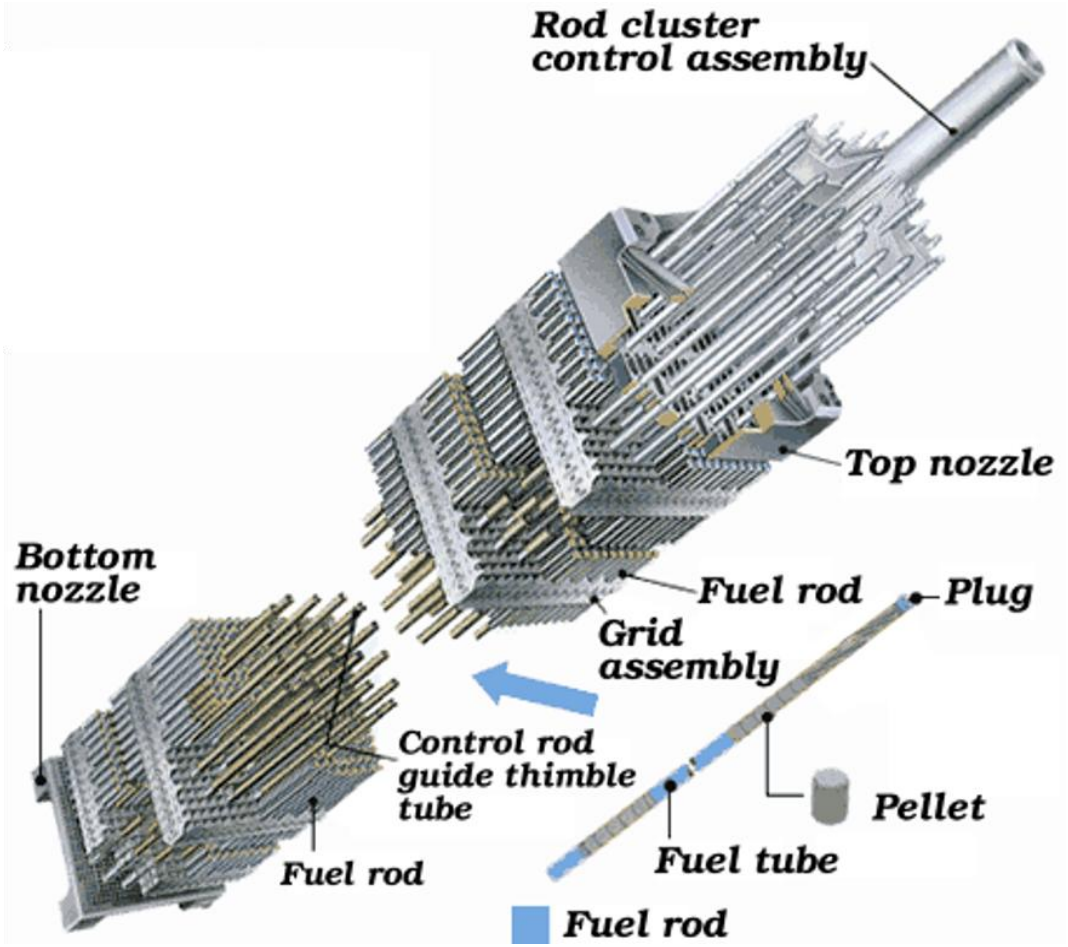
EURIDICE

sck cen
Exploring
a better tomorrow

FANC AFCN
FEDERAAL AGENTSCHAP VOOR NUCLEAIRE CONTROLE
AGENCE FÉDÉRALE DE CONTRÔLE NUCLÉAIRE

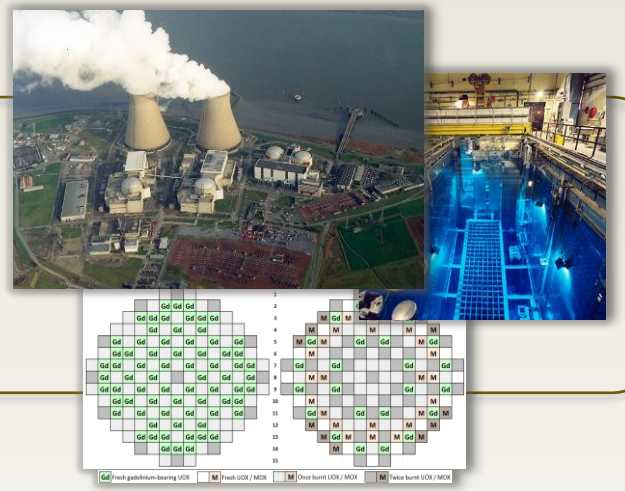
Securing spent fuel expertise in Belgium

Losing knowledge is not an option.



Knowledge preservation

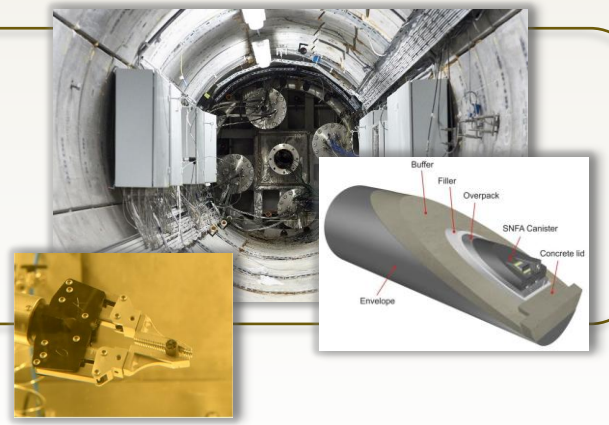
ELECTRABEL
TRACTEBEL
SYNATOM



FANC & BEL-V

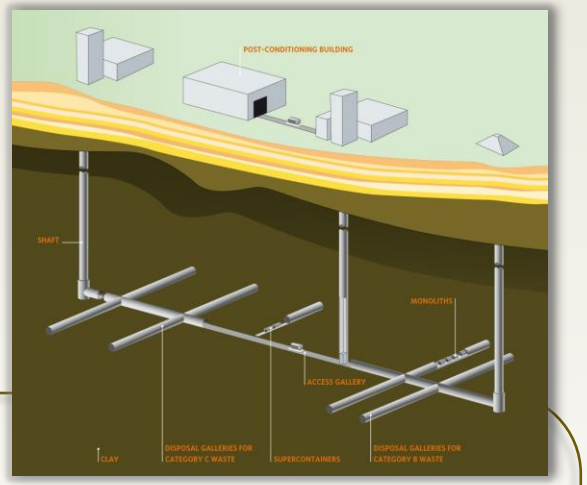
NIRAS-ONDRAF

SCK CEN



BeGov

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Knowledge merging:

- Data sharing
- Knowledge buildup through calculations & experiments
  - Spent fuel rod extraction
  - Tests and examinations on spent fuel
  - Spent fuel poolside measurements

High-level objectives

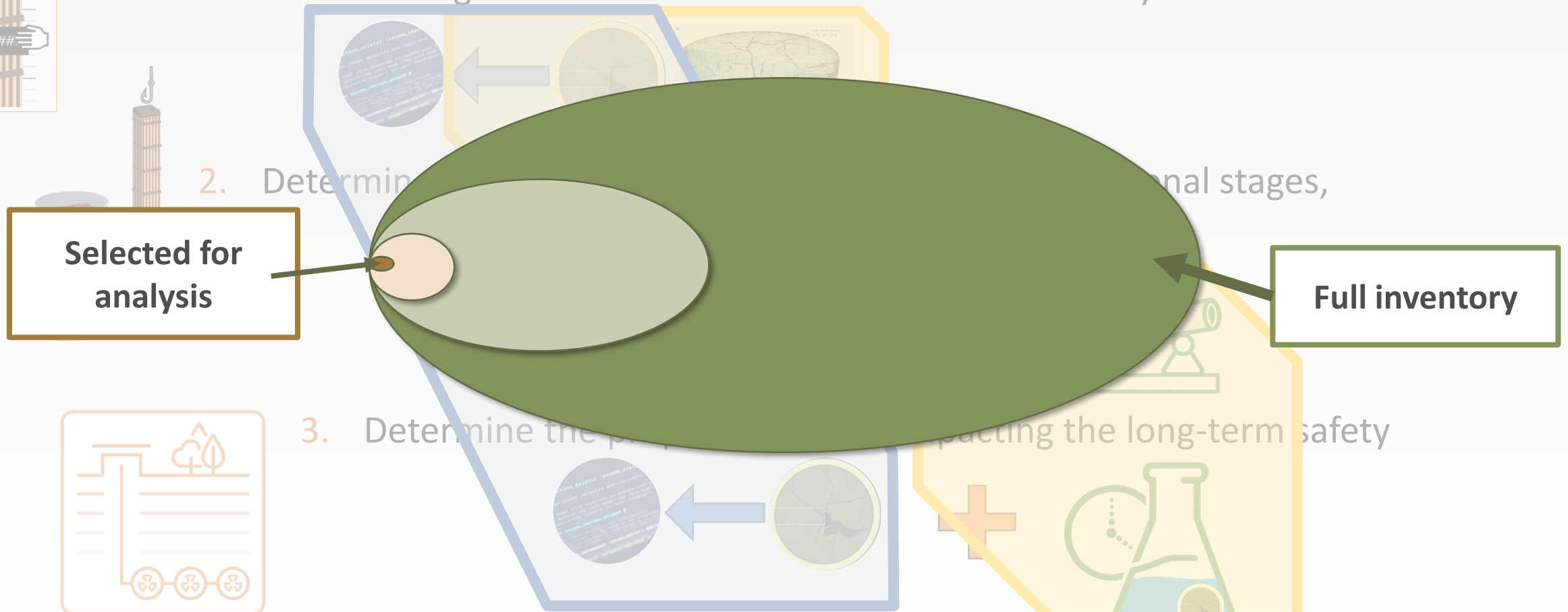
➔ the challenge



1. Determine radiological and chemical **content** of SNF inventory

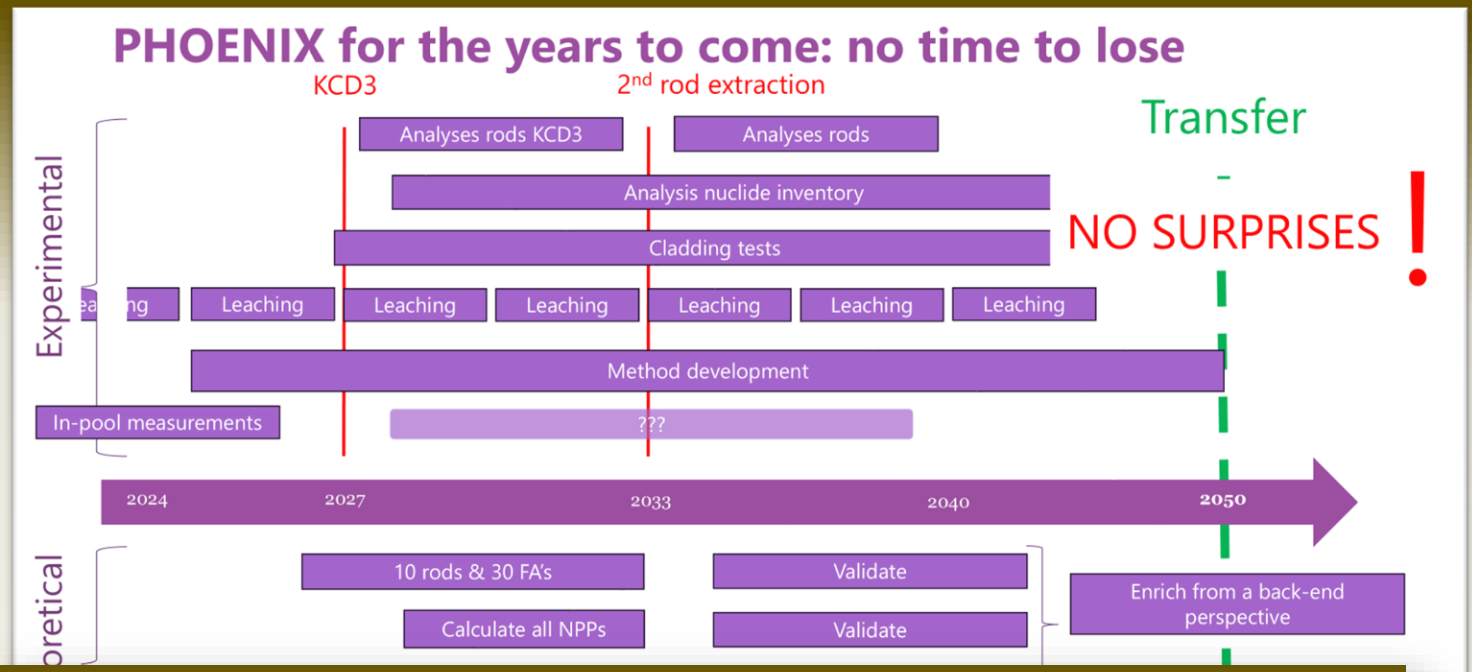
2. Determin nal stages,

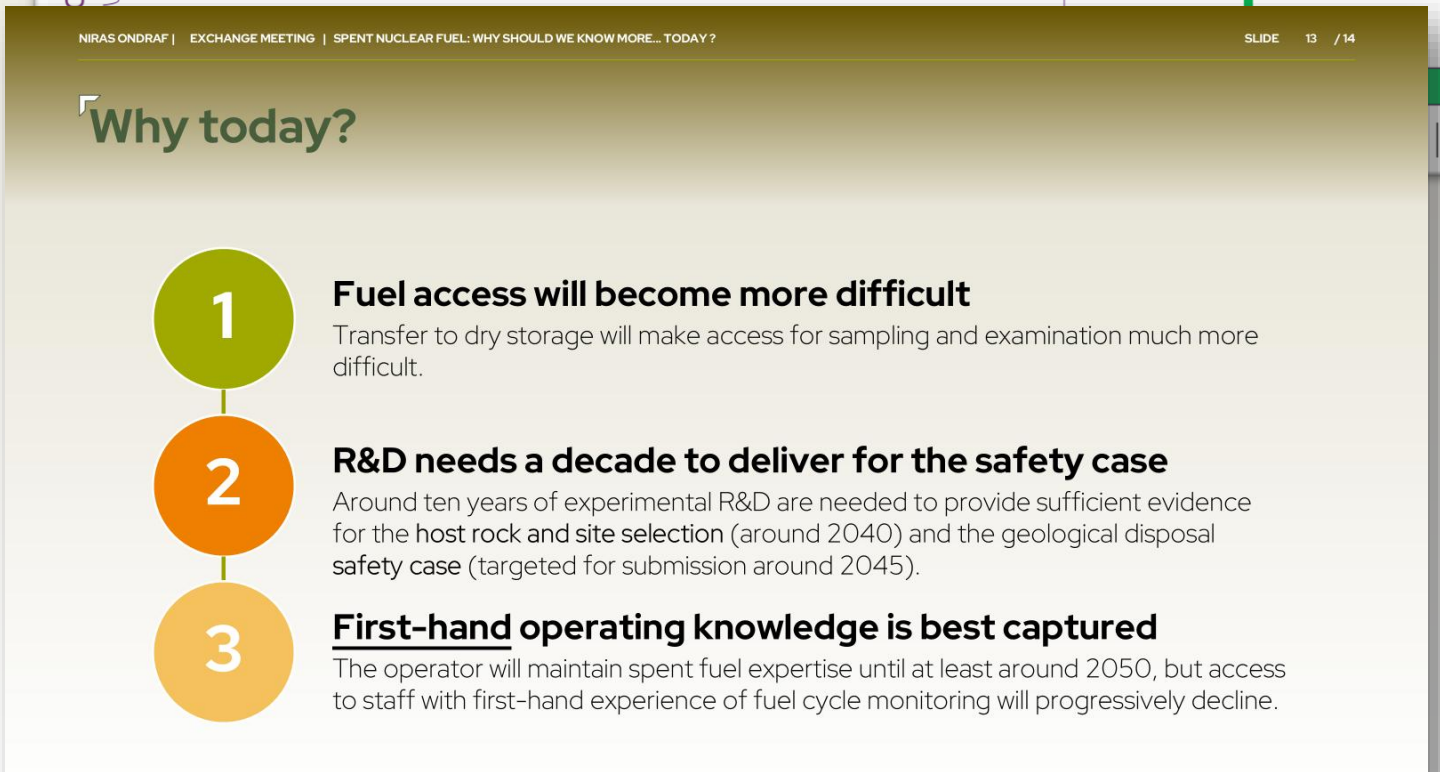
3. Determine the p pacting the long-term safety



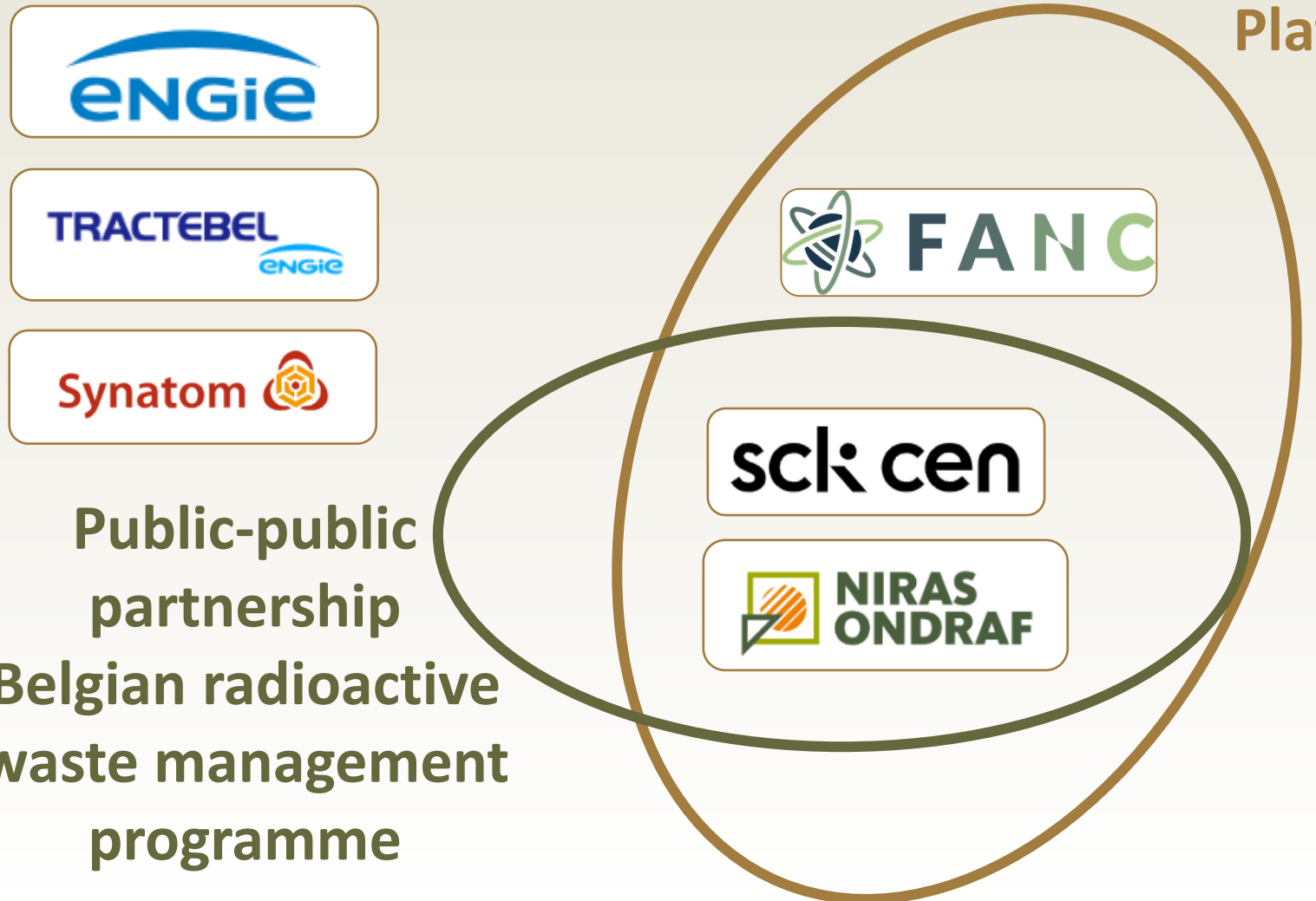
R&D programme for the years to come

Still no time to lose





Collaboration is the key



Public-public partnership Belgian radioactive waste management programme

Platform Spent Fuel

BEL V
Belgian TSO

HEDERA