Uncertainty Propagation in Neutronic Simulations for Irradiation Ageing Studies of Reactor Vessels

IRSN — INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

École Doctorale PHENIICS Doctoral School

MEMBRE DE ETSON

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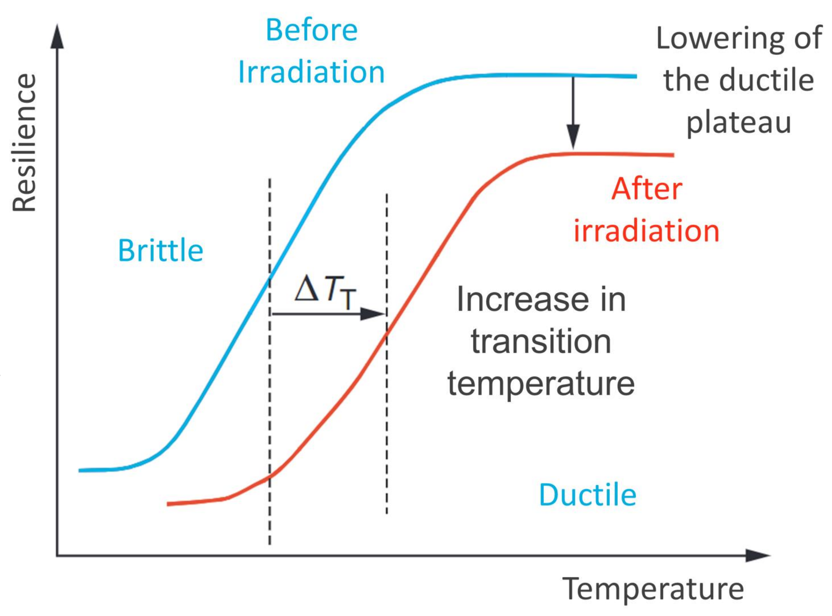
Context

Nuclear Power Plant Life Extension

❑ **Reactor Pressure Vessel (RPV)** ageing is critical due to 3 key factors:

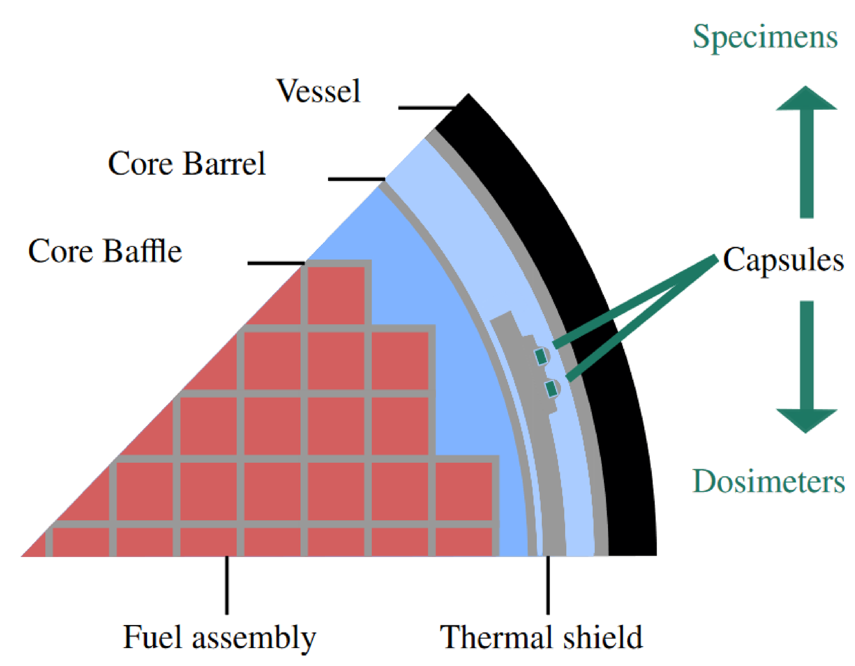
- Essential role in preventing radioactive leakage
- Irreplaceability
- Intense radiation exposure

❑ **Ageing =** how irradiation affects microstructure, changing mechanical properties and mainly affecting **the *ductile-to-brittle transition temperature*** (ΔT_T)



❑ **Previous research** thesis on the subject:

- Uncertainty quantification of the fast flux for a PWR vessel – L. Clouvel (CEA)
- Estimation of the neutron fluence seen by RPV – R. Vuiart (IRSN)



❑ **Surveillance programs** (PSI) use *dosimeters* and *specimens* to gather experimental data for RPV behavior predictions

❑ **Only fast fluence** ($E > 1MeV$) is currently being considered as irradiation indicator

PhD Objectives

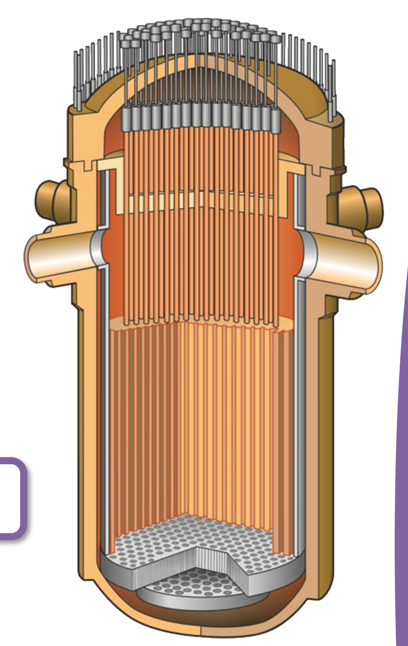
Evaluate fluence uncertainty for PWR vessel

$\Delta\phi_{RPV}$

- ➢ Calculation over whole RPV
- ➢ Considering all energies
- ➢ Develop new methodology

2 options:

- Purely Simulation
- Simulation+Experiments



Key Points

2 — Uncertainty Quantification

❑ Predominantly arising from nuclear data uncertainties

❑ Significant impact when propagated through simulations

1 — Nuclear Data

Essential properties and reaction data for all nuclear calculations

3 — Evaluation of Results

Identifies key uncertainty contributors, guiding strategies to minimize them

Methodology

STEP 1: Sensitivity Analysis

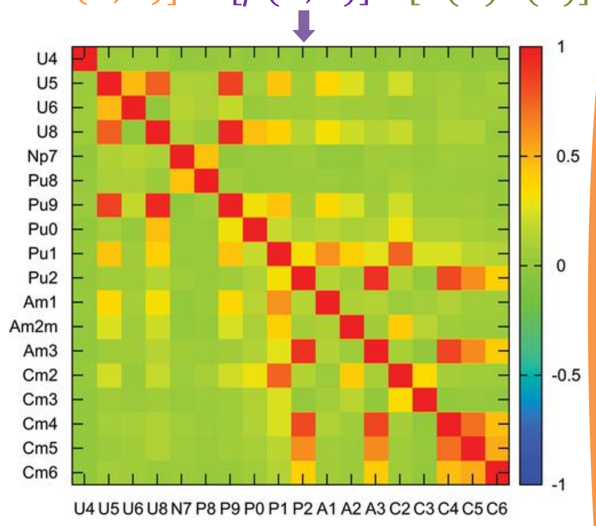
❑ Identifies which parameters significantly impact the response

❑ Evaluate experiments transposability

❑ Sensitivity coefficients are used with covariance matrices for uncertainty propagation

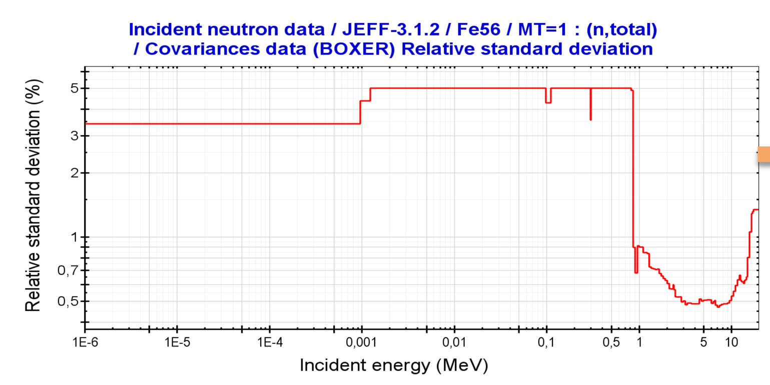
Covariance matrix — Correlation matrix — Standard deviations

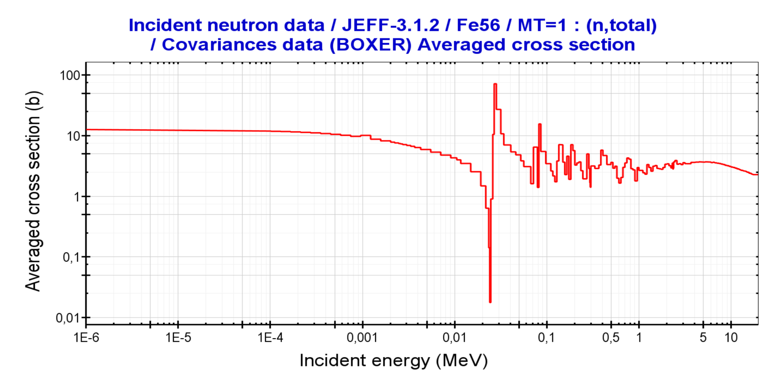
$[COV(X,Y)] = [\rho(X,Y)] * [\sigma(X)\sigma(Y)]$



STEP 2: Uncertainty Propagation

Explores the impact of initial uncertainties on final results, using covariance matrices and approaches like the sandwich formula and sampling method



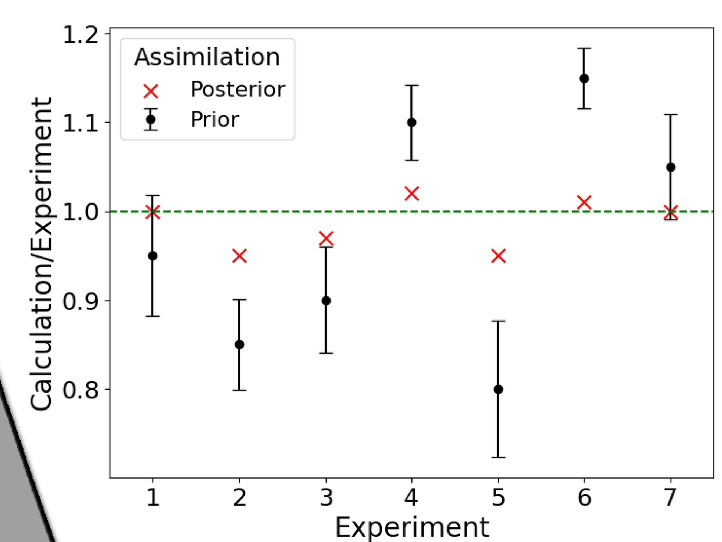


Nuclear data uncertainty → Propagates to → Uncertainty in response ($\Delta\phi_{RPV}$)

❑ **Sandwich Formula:** A first-order approach that combines sensitivity coefficients and covariance matrices

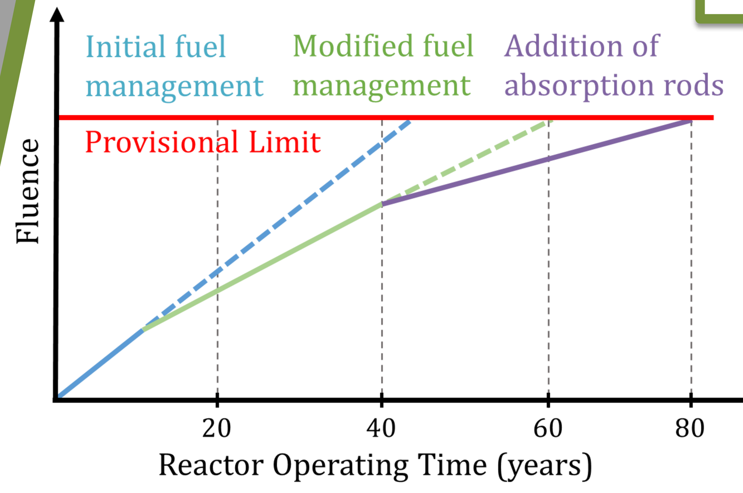
❑ **Sampling Method:** Applies varied inputs within their uncertainty ranges to simulate a spectrum of possible responses

STEP 3: Data Assimilation



A process for improving simulation results by incorporating actual experiment data, ensuring closer alignment with reality

Q&A



❑ **Why is fluence critical for nuclear reactor life extension?** Fluence determines operational limits; managing flux can mitigate fluence accumulation, delaying the limit and extending RPV life.

❑ **Isn't the fluence already known?** Fluence is calculated, not measured. Safety assessments do not consider fluence uncertainty, and calculated uncertainties lack validation from experimental data

❑ **Where can we obtain experimental data for validation?** Given that the PSI data is not shared by EDF, benchmark experiments like **ASPIS** serve as alternative sources for validating our results through data assimilation.