Criticality Safety Issues related to Disposal of Spent Fuel

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Content

- Aspects and challenges of disposal criticality safety
- Approaches for disposal criticality analysis
- Examples and results from resent work
- Needs, proposals

Criticality analysis for final disposal of spent fuel - Objectives

To demonstrate that

- Criticality is excluded or can occur only at sufficiently low probability
- Possible consequences of criticality would be low compared to the overall safety analysis of the repository

Operational phase: Conventional approach, e. g. sub-criticality by canister design, analysis of transport accidents etc.

Post-closure phase: Time period of analysis, e. g. 10^6 years after closure, performance of the repository in the long term

Aspects of post-closure criticality analysis

- Time frame of analysis: 10^4 a …. infinity (?)
- Performance of spent fuel packages
- Geological evolution scenarios
- Material mixtures which might be formed in the repository
- Consideration of fuel burn-up (inventory, axial burn-up profile)
- Variation of the SF nuclide inventory

Challenges of disposal criticality analysis

- Determination of long term performance of fuel packages and repository site
- Definition of best estimate/conservative scenarios
- Neutron cross section data for relevant material compositions (e. g. salt, clay, crystalline rock)
- Validation of calculation tools and data for that application
- Determination of consequences of a hypothetical criticality

Disposal criticality analysis - different approaches

Deterministic

- Definition of (generally accepted) bounding scenarios
- Determination of conditions for sub-criticality. e. g. required minimum fuel burn-up, number of assemblies per canister etc.

Probabilistic

- Consider all credible scenarios where criticality cannot be excluded by physical arguments
- Determination of probabilities for criticality through analysis of event trees
- Estimation of parameters (+ uncertainties) for characterizing the event chains of investigation

Burn-up credit application for final disposal

Operational phase

- Controlled handling and storage of containers for ≈ 40 years
- No burn-up credit required for actual German cask designs (up to 4.5 % ^{235}U, 5.3 % Pu_{fiss}) due to fuel rod consolidation and fixed neutron absorbers

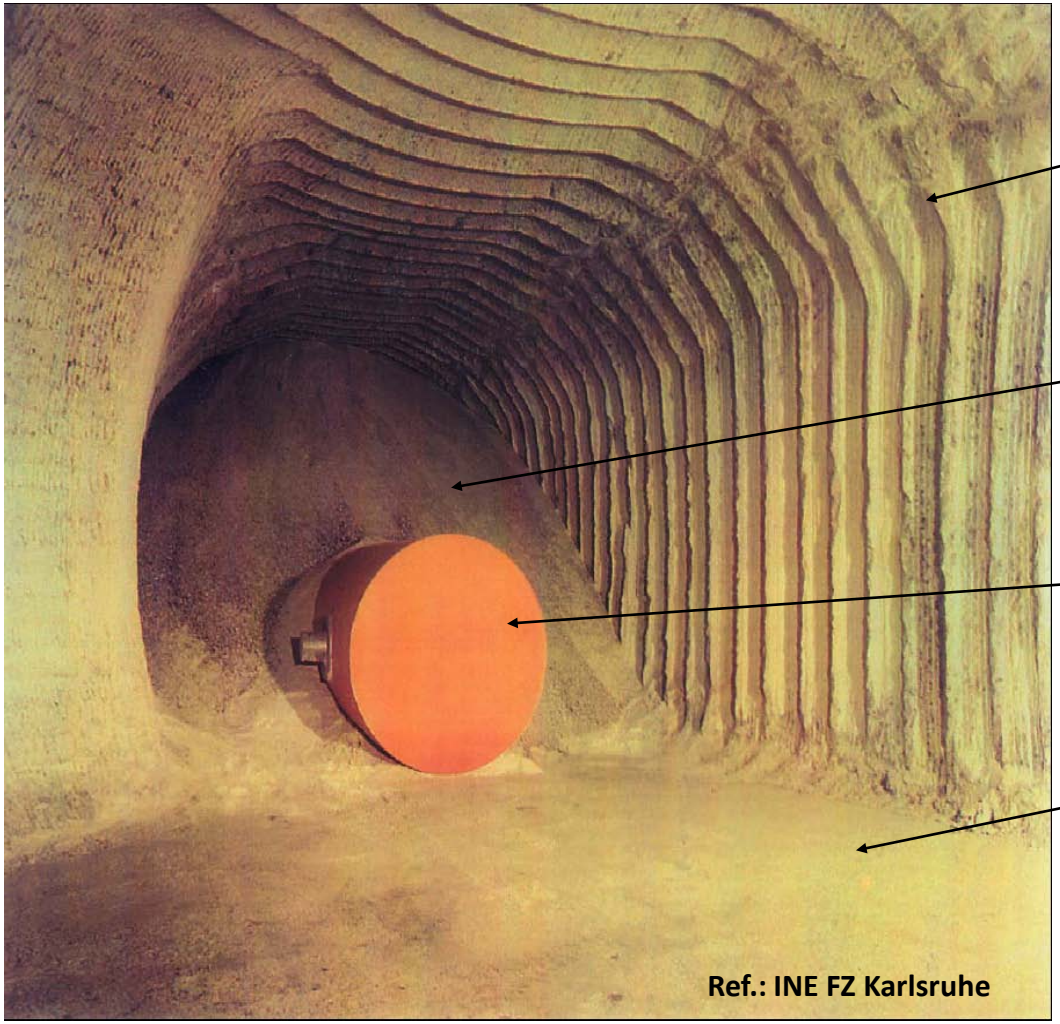
Post-closure phase

- No direct control of fuel containers
- Performance under geological and geochemical processes, to be analyzed e. g. up to 10^6 years
- Actinide-only BUC assumed for generic studies on long term criticality safety of a repository

Final Disposal of SNF and HLW in Germany – Amounts

- Approximately 11 000 t HM of spent fuel from LWR operation, including 1 000 t of MOX fuel
- 4 800 canisters of vitrified HLW from commercial reprocessing
- 8 t HM of HTR fuel, 0.8 t ^{235}U + ^{233}U
- 40-50 kg HM/year from research reactor operation (HEU fuel)

German disposal concept for spent fuel in POLLUX casks – example salt



Host rock (salt)

Backfill (crushed rock salt)

POLLUX cask

Placement gallery floor

Performance of a disposed hot container in salt rock

Ref.: Institut für Nukleare Entsorgung (INE) FZ Karlsruhe

Scenarios under Evaluation

Various changes of in-cask geometry due to degradation of

- Fuel cladding
- Fuel matrix
- Fuel baskets

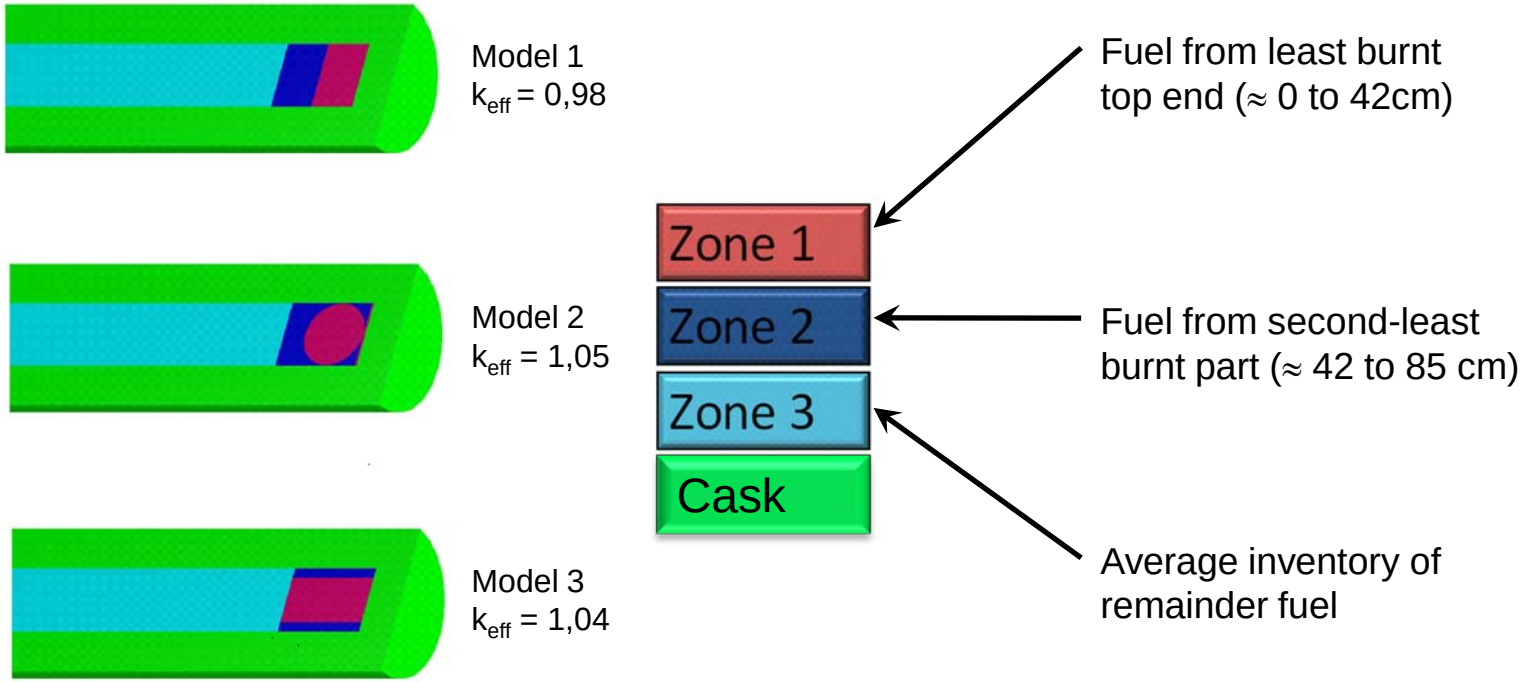
Mobilisation of fissile nuclides

- Inside a cask
- Transportation to the backfill, precipitation
- Separation of Uranium and Plutonium

Formation of porous Uranium mineral phases inside a cask

- Actually appears as main contributor to the risk of re-criticality

Examples of analyzed hypothetical arrays of degraded spent fuel in a disposal cask considering axial burn-up profile



Porous UO_x + yH_2O mineral phases, no chlorine in the moderator being considered; actinide-only PWR fuel, initial enrichment 3,6 wt% ^{235}U, 40 GWd/tHM average burn-up, 10^5 years decay time

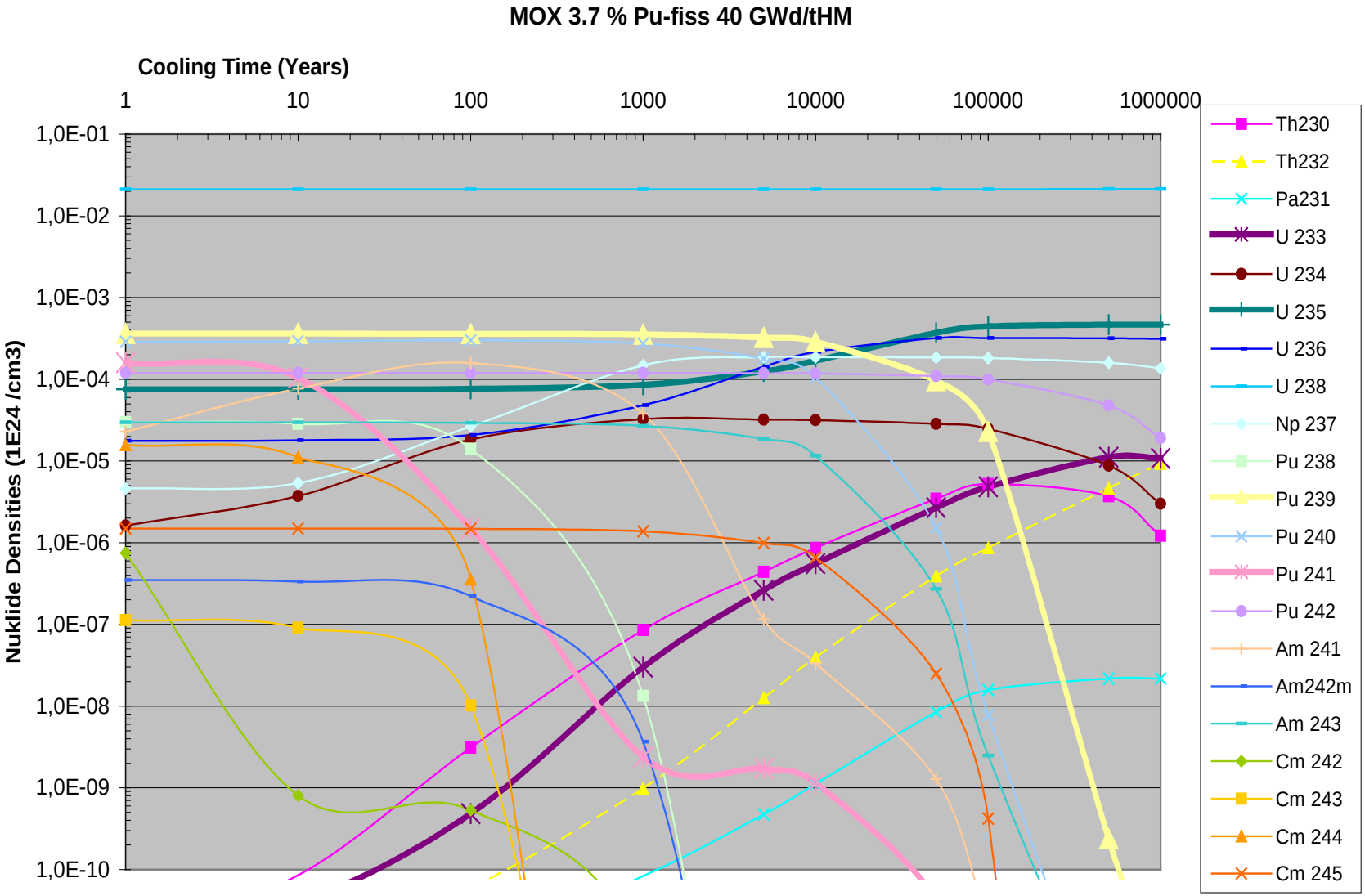
Results of the Deterministic Analysis

For disposal of low enriched LWR fuel criticality

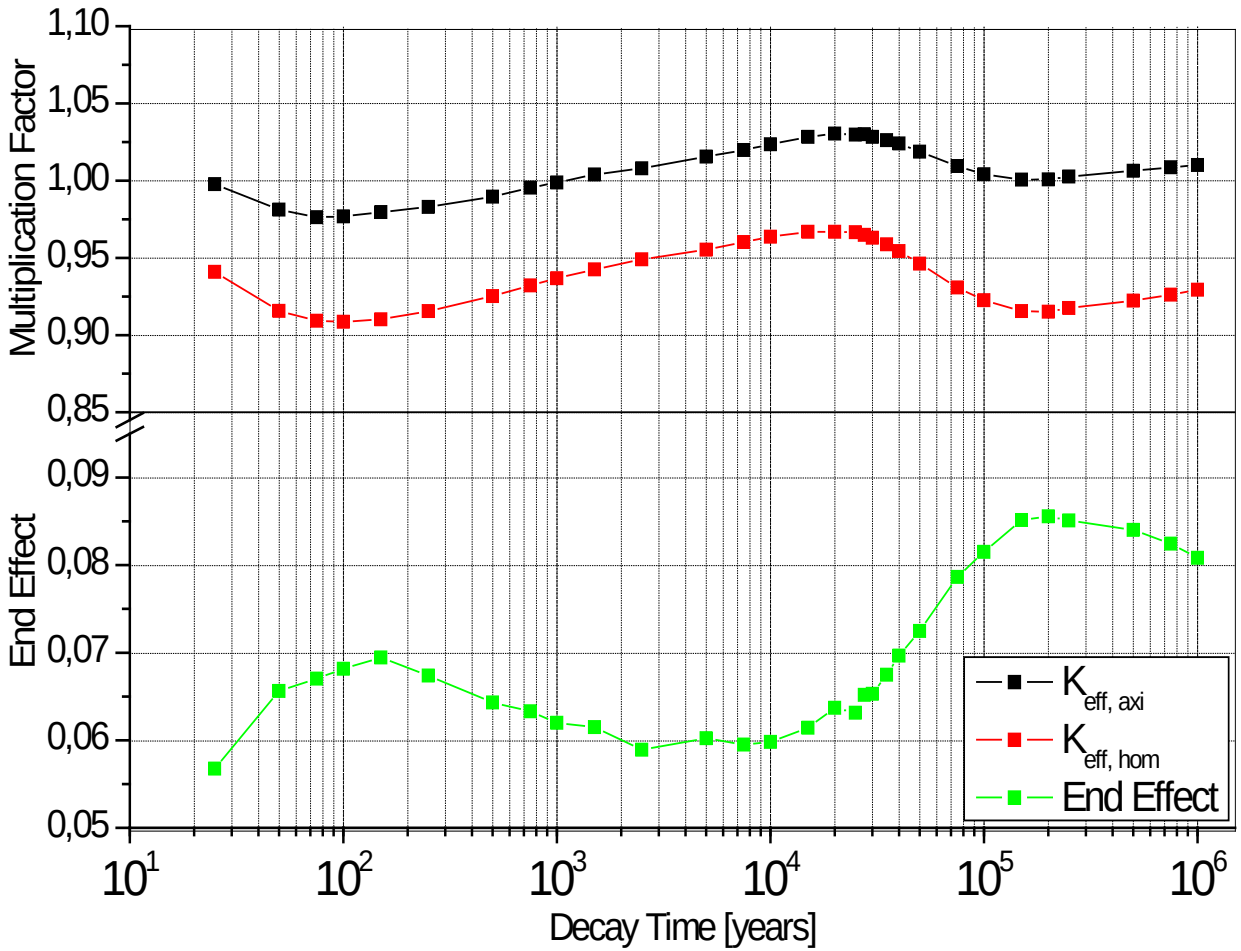
- Is conceivable only for low average fuel burn-up (≤ 20 MWd/kg)
- But: Scenarios of fuel rod degradation considering axial burn-up profiles based on hypothetic assumptions might lead to calculated k_{eff} > 1.0 also for burn-up > 20 MWd/kg
  → determination of minimum required burn-up is necessary

Disposal of medium or highly enriched fuel may be problematic

Variation of nuclide densities with decay time



Multiplication Factors and End Effect (exemplary)



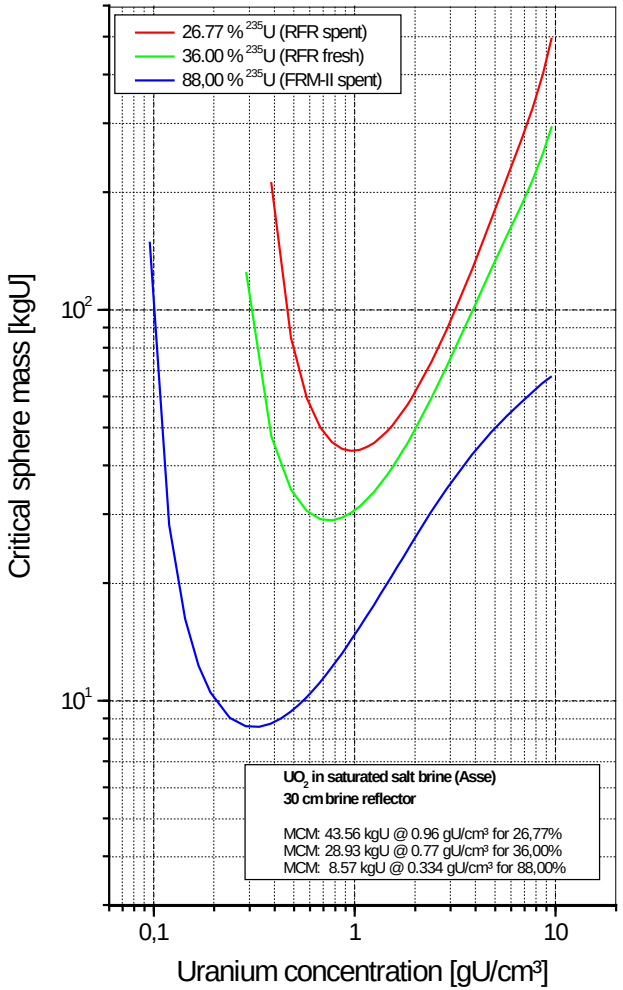
Infinite x-y fuel rod lattice
Water/iron reflected (z)
Water moderated
Uranium Dioxide

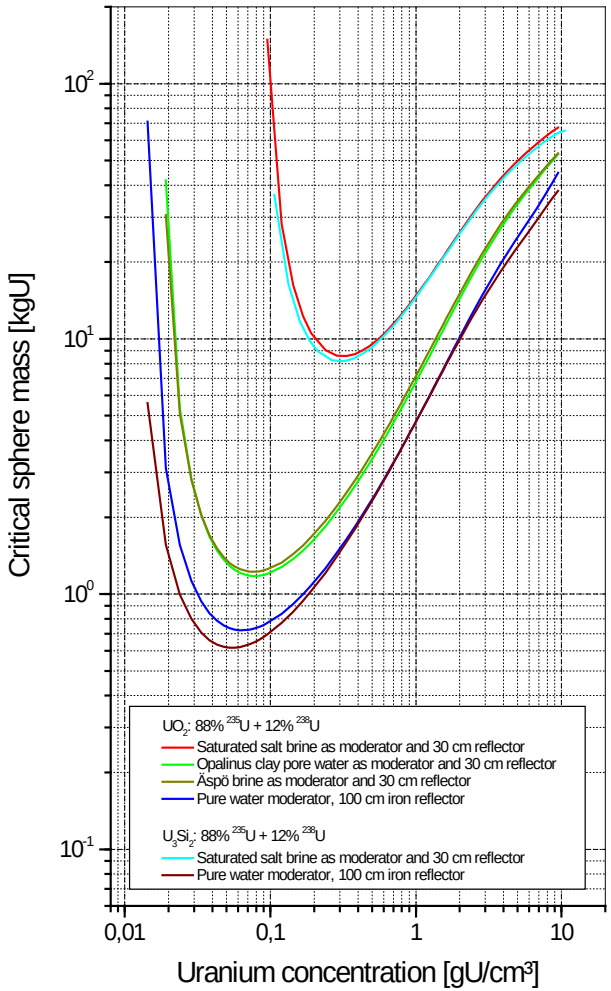
- 3.6 wt% ^{235}U initial
- 40 GWd/tHM av.

With and **without** consideration of a *burn-up profile*

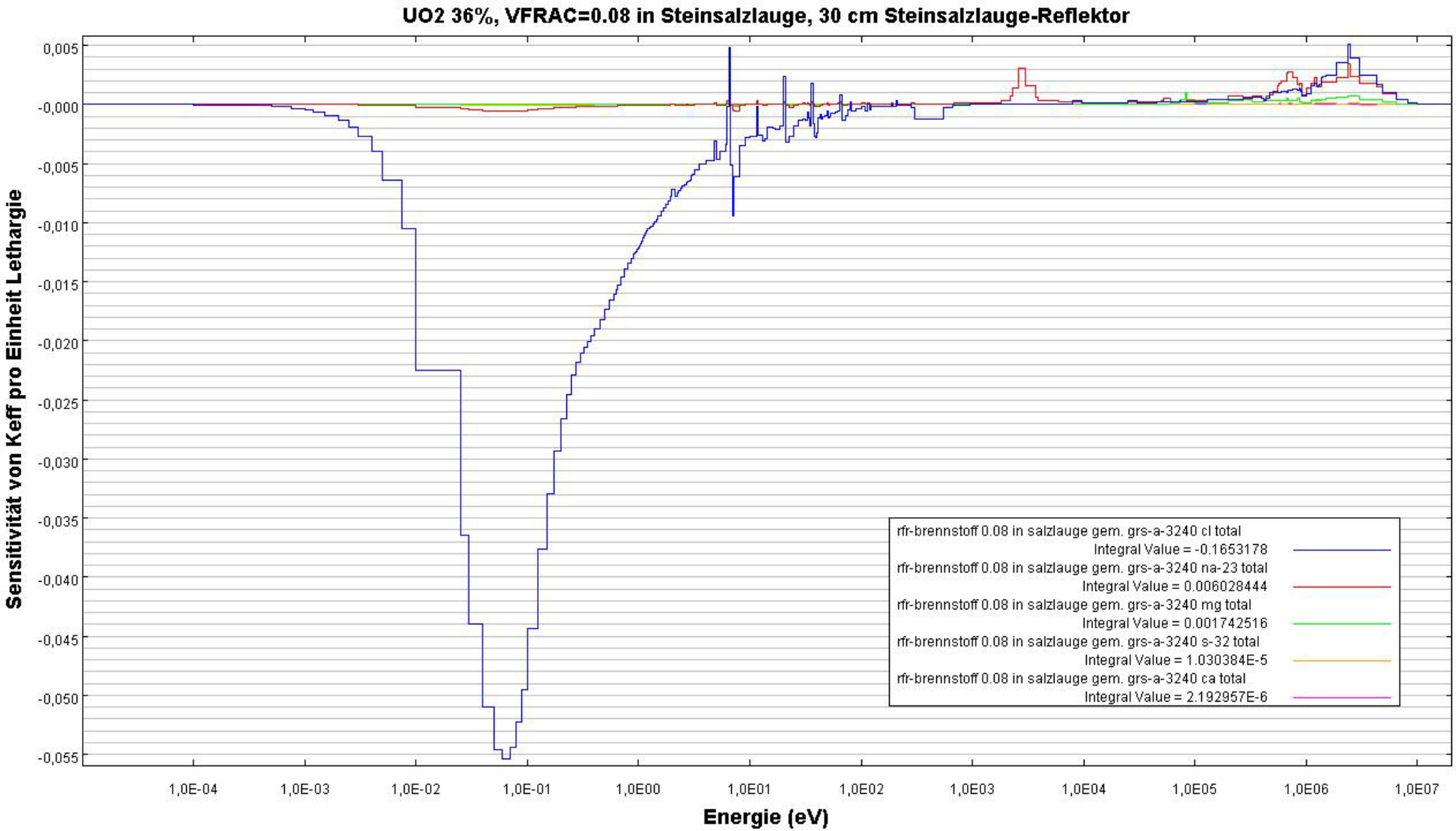
End Effect: variation explainable considering the different half-lives of the Pu isotopes and of ^{241}Am and their axial distributions

Disposal of Research Reactor Fuel – Critical Parameters





Disposal of Research Reactor Fuel – Validation of Calculations



Disposal criticality analysis – Needs, Proposals

Evaluation of cross section data for nuclides of “geological” material mixtures, in particular ^{35}**Cl**, Si, Al, Ti, Ca, Mn, S, P

Benchmarking for code validation and comparison

- Burn-up
- Criticality
- Excursion analysis

Development of an international, free available data base

- Collection of parameters etc. relevant for disposal criticality
- Contribution from countries working on this issue

Thank you for your attention!