CRITICALITY SAFETY ANALYSIS USING BURNUP CREDIT FOR A GENERIC TRANSPORT CASK ON BASIS OF THE GERMAN STANDARD DIN 25712

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Outline

- Introduction
- German Standard DIN 25712
- Application case: generic transport cask
- Code validation
- Criticality safety analysis
- Loading curves
- Conclusion

Introduction

- Performing criticality analysis of generic transport cask to:
  - → Follow up international activities, methods, …
  - → Estimate impact of uncertainties and conservative assumptions on neutron multiplication factor
  - → Identify needs for further studies or (tool) developments

  - Generic analysis to demonstrate application of the German Standard DIN 25712: "Criticality safety taking into account the burnup of fuel for transport and storage of irradiated light water reactor fuel assemblies in casks"
    - → Identify needs to meet all requirements
  - – E.g. DIN 25712 allows bounding values or 95%/95% tolerance limits
    - → Advantages, disadvantages of 95%/95% tolerance limits?

- But: approximations and simplifications were used to perform the analysis in a reasonable time

German Standard DIN 25712

- Guideline to perform criticality safety analyses for dry transport and storage casks for light water reactor fuel assemblies taking into account burnup credit
- Acceptable neutron multiplication factor k_{eff} for transport and storage casks is defined by

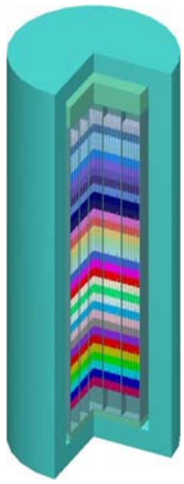
$$k_{eff} \leq 1 - \Delta k_s - \Delta k_u$$

with

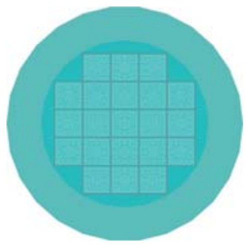
  - Administrative safety margin of $\Delta k_s = 0.05$
  - Overall uncertainty Δk_u of k_{eff}
- Uncertainties of all physical parameters and the validation (i.e. the isotopic correction factors and the code bias) have to be considered in determination of k_{eff}:
  - ⇒ Sufficient large contribution to Δk_u (95%/95% tolerance limit) or bounding value in criticality calculation

Application case

- Generic transport cask model (OECD/NEA WPNCS phase II-C burnup credit criticality benchmark), 21 PWR fuel assemblies

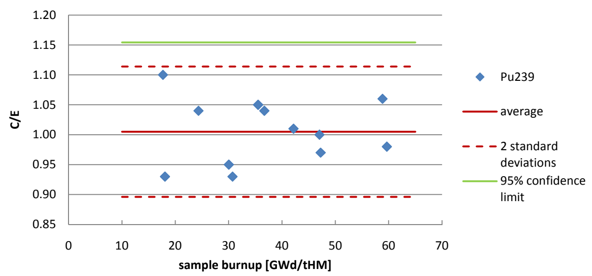


- **Actinides**: U-234, U-235, U-236, U-238, Np-237, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Am-241, Am-243
- **Fission products**: Ag-109, Cs-133, Eu-151, Eu-153, Gd-155, Mo-95, Nd-143, Nd-145, Rh-103, Ru-101, Sm-147, Sm-149, Sm-150, Sm-151, Sm-152, Tc-99



Code validation

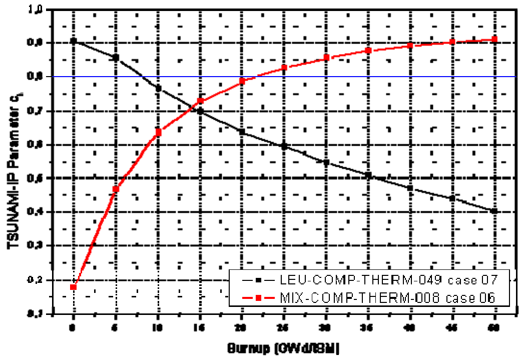
- Depletion calculation:
  - 1D depletion code OREST Version 2006 developed at GRS was used
  - Typical isotopic correction factors were estimated using 12 post irradiation examination (PIE) samples (Takahama-3 and ARIANE)



  - 95% confidence limits were calculated and used as isotopic correction factors
  - Assumption: Ratios of calculated and experimental isotopic number densities are normal distributed and not depending on burnup parameters

Code validation

- Criticality calculation:
  - CSAS5 (KENO V.a) of SCALE package was used
  - Typical code bias was estimated using 92 critical experimental configurations (ICSBEP): 69 UO_2 and 23 MOX
  - Similarity between experiment and application was determined by TSUNAMI-IP parameter c_k



Code validation

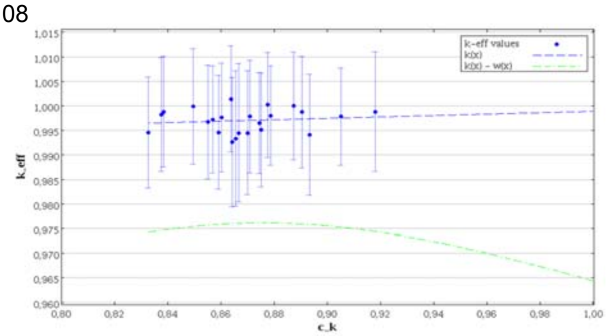
- Criticality calculation:
  - Code bias considering spent fuel (40GWd/tHM):

    Trending analysis on c_k: β = -0.0011, 95% confidence band: w(c_k = 1) = 0.0345

    TSURFER: β = –0.0014 ± 0.0018 (+ burnup variation, input data uncertainties)
  - Estimated 95% confidence limit:

    Trending analysis on c_k: $\beta_{95\%}$ = - 0.0356

    TSURFER: $\beta_{95\%}$ = - 0.0108



Criticality safety analysis

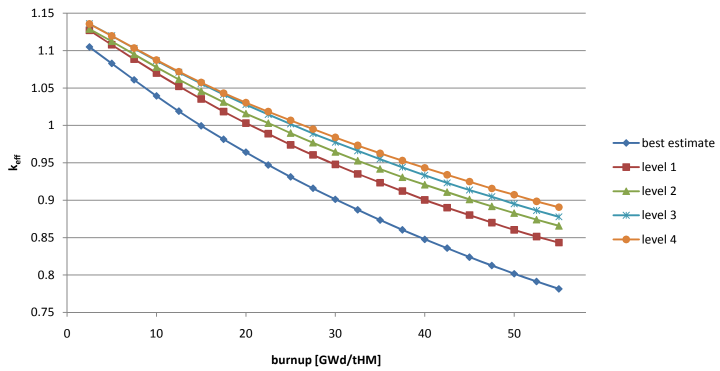
- enrichment of ^{235}U: 2.8 % - 4.4 %, average burnup up to 60 GWd/tHM
- "Best estimate" calculation
- Bounding conditions (successively included):
  - Isotopic correction factors ("level 1")
  - Nuclides ^{109}Ag, ^{95}Mo, ^{143}Nd, ^{145}Nd, ^{101}Ru and ^{99}Tc were neglected due to the lack of available critical experiments ("level 2")
  - Uncertainties and conservative values of the physical parameters ("level 3")

Bounding values considered in depletion calculation	
fuel temperature	900 °C
Pellet swelling	2 % increase in diameter
Moderator temperature	315 °C
Average boron concentration	600 ppm
Uncertainties considered in depletion and criticality calculations, respectively	
Cladding diameter	± 0.005 cm
Fuel density	± 1 %
enrichment	± 0.05 %
Boron concentration (in absorber plates)	± 0.5 %

  - Conservative burnup profiles ("level 4")

Criticality safety analysis

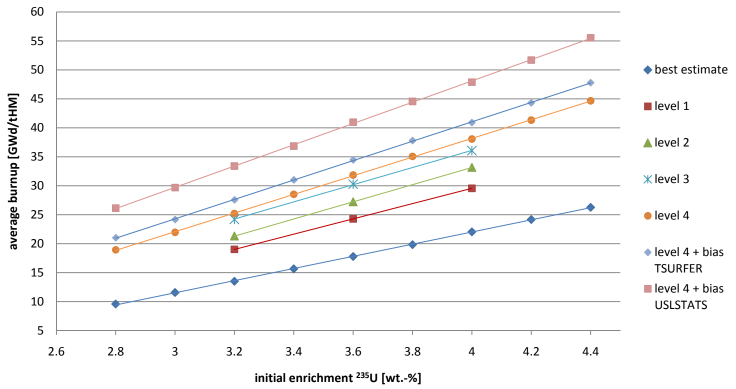
- k_{eff} for ^{235}U enrichment of 4.0 %:



Code bias is not considered is this plot!

Loading curve

- Loading curve of generic transport cask:
  - Represents minimum required burnup as a function of enrichment, which results in an acceptable k_{eff}
  - I.e. minimal burnup is defined by $k_{eff} = 1 - \Delta k_s - \Delta k_u$



Conclusion

- For generic transport cask:
  - Validation (isotopic corrections factors, code bias) has largest impact on k_{eff} and loading curve
  - Uncertainties of physical parameters and burnup profiles (after applying isotopic correction factors) have only moderate impact on k_{eff} and loading curve
- Similarity between experiment and application depends on burnup
  - → Validation depends on burnup
    - → Significant reduced number of suitable experiments
    - → increased 95 % confidence band of code bias
  - → more sophisticated tools like TSURFER to gain additional information
- More public available PIE experiments and critical experiments needed

Summary & outlook

- A criticality safety analysis for a generic transport cask model on the basis of DIN 25712 was presented
- Neutron multiplication factors and loading curves were determined for ^{235}U enrichments between 2.8 % and 4.4 %, and for burnups up to 60 GWd/tHM
- Impact of conservative assumptions and bounding values on k_{eff} and loading curves were estimated

- Outcome of this generic analysis:
  - Needs for further studies and (tool) developments:
    - Dedicated studies on sensitivity and uncertainty analysis, e.g. method to estimate 95%/95% tolerance limits

      → Presentation 5.01 of Matthias Kirsch
    - Dedicated efforts on code validation

      → Issues: BUC and limited public available experimental data

      → Depletion code: estimation of isotopic correction factors

      → Criticality code: estimation of code bias as function of burnup