2nd Workshop of Spanish Users on Nuclear Data
“the Accident Tolerant Fuels for LWRs”
20 May 2020 (Web-Seminar)

Current neutronics activities on LWR ATF at GRS

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Outline

- **Introduction**
- **Comparative and scoping Analyses**
  - Calculational Methods
  - Generic ATF Model Systems
  - Critical Benchmark Experiments
  - Two-group Cross-Section Generation
  - Preliminary Burnup Calculations
  - Preliminary Activation Calculations
- **Conclusions and Outlook**

Calculational Methods

- Scoping calculations using **SCALE 6.2.3**
  - ✓Monte Carlo using CE → **CSAS5** with **ce_v7.1_endf**
  - ✓Monte Carlo using Multigroup XS → **CSAS5**/**T3D** with **v7.1-252** and v7.1-56
  - ✓Deterministic → **NEWT** with **v7.1-252** and **v7.1-56**
  - ✓Burn-up calculations → **TRITON** (T-DEPL) with **v7.1-56**

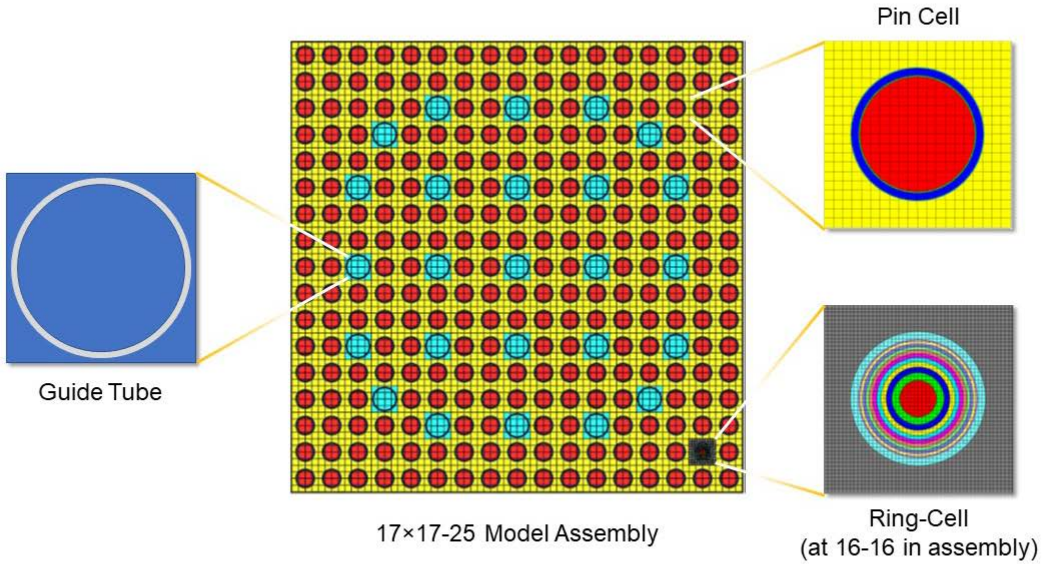
- Comparative calculations (k_{inf}, collapsed HZP two-group XSEC) using
  - ✓**SERPENT** with **CE ENDF/B-VII.0 continuous energy (CE) XSECs**

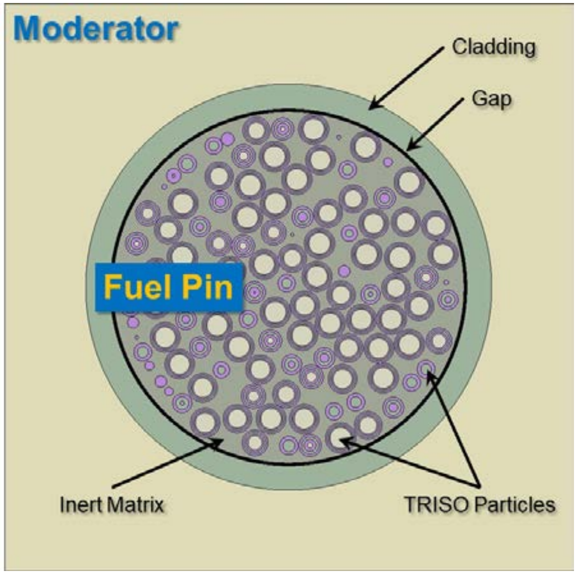
- Pin cell, "Ring cell" (Pin cell in equi-areal rings), ATF pin in standard assembly
  - ➢**Plausibility / consistency checks**

- Select, model, calculate and evaluate **critical benchmark experiments** (ICSBEP) comprising relevant ATF elements, here esp. **Fe**, **Cr**, **Al**, and **Si**

Generic ATF Model Systems – Parameters (2/2)

Pin / Assembly Parameter	Value [cm] cases 1, 3-6 (w/o coating)	Value [cm] case 2 (w/ 50 µm coating)
Pellet diameter	0.8192	0.8192
Gap diameter	0.8356	0.8356
Clad diameter	0.9490	0.9390
Coating diameter	n/a	0.9490
Guide tube inner diameter	0.56134	0.56134
Guide tube outer diameter	0.60198	0.60198
Pitch	1.326	1.326
Assembly Pitch	22.642	22.642





Generic ATF Model Systems – Parameters (1/2)

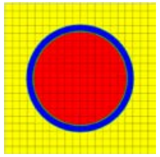
- **Fuel forms** and **cladding materials** under scope (ref.: UO_2/Zr4)

Case	Fuel	Cladding	Coating	Enrichment ^{235}U
1 (ref.)	UO_2	Zr-4	n/a	4.9
2	UO_2	Zr-4	Cr, 50 µm	4.9
3	UO_2	FeCrAl	n/a	4.9
4	UO_2	SiC	n/a	4.9
5	U_3Si_2	FeCrAl	n/a	4.9
6	TRISO/SiC	SiC	n/a	9.9

- **Hot Zero Power (HZP) State**
  - T_{fuel} = 1200K, T_{clad} = 600K, $T_{moderator}$ = 580K
  - Moderator density 0.723 g/ccm, 630 ppm boron
  - Case of irradiation: Burn-up 55 GWd/tHM_{init}

Generic ATF Model Systems – First Results

- SCALE/CSAS5 and v7.1-252: Pin cell k_{inf} and EALF



Case	k_{inf}	EALF
1 (ref.)	1.36423	0.654214
2	1.35228	0.666836
3	1.28203	0.746954
4	1.37293	0.658506
5	1.29312	0.905739
6	1.33567	0.119078

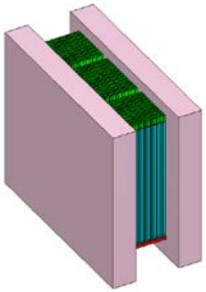
- Further comparisons: Assembly k_{inf} (Update to ICNC Paper!)

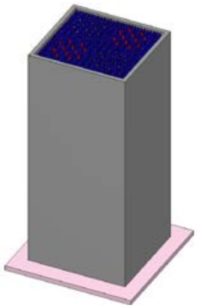
Case	SCALE/T-NEWT 56G VII.1	SCALE/T-NEWT 238G VII.0	SCALE/T-NEWT 252G VII.1	SERPENT CE ENDF/B-VII.0
1 (ref.)	1.37397	1.37238	1.37458	1.37650
2	1.36283	1.36150	1.36342	1.36574
3	1.29030	1.28913	1.29076	1.29366
4	1.38154	1.37992	1.38236	1.38422
5	1.30301	1.30112	1.30319	1.30596
6	1.29604	1.29643	1.29643	1.28907

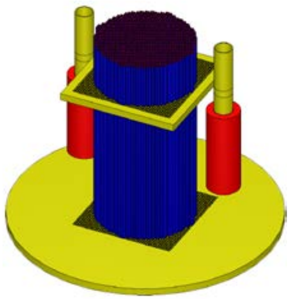
Critical Benchmark Suite – Selection Evaluation

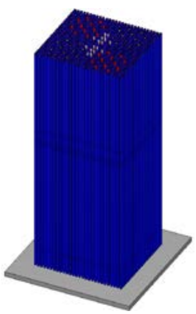
- Overall of **353 critical configurations** from **36 LEU-COMP-THERM** experiment series

- **Examples**
  - LCT42 Case 2 – $k_{eff,calc}$ = 0.99714 ± 0.00011
    - Steel separator, Alu-clad; **Cr, Fe, Al**
  - LCT77 Case 3 – $k_{eff,calc}$ = 1.001621 ± 0.000078
    - Steel rods; **Cr, Fe, Si**
  - LCT80 Case 1 – $k_{eff,calc}$ = 0.99516 ± 0.00021
    - Alu cladded rods; **Al**
  - LCT90 Case 1 – $k_{eff,calc}$ = 1.000758 ± 0.000089
    - Alu cladded rods, Steel rods; **Al, Cr, Fe**





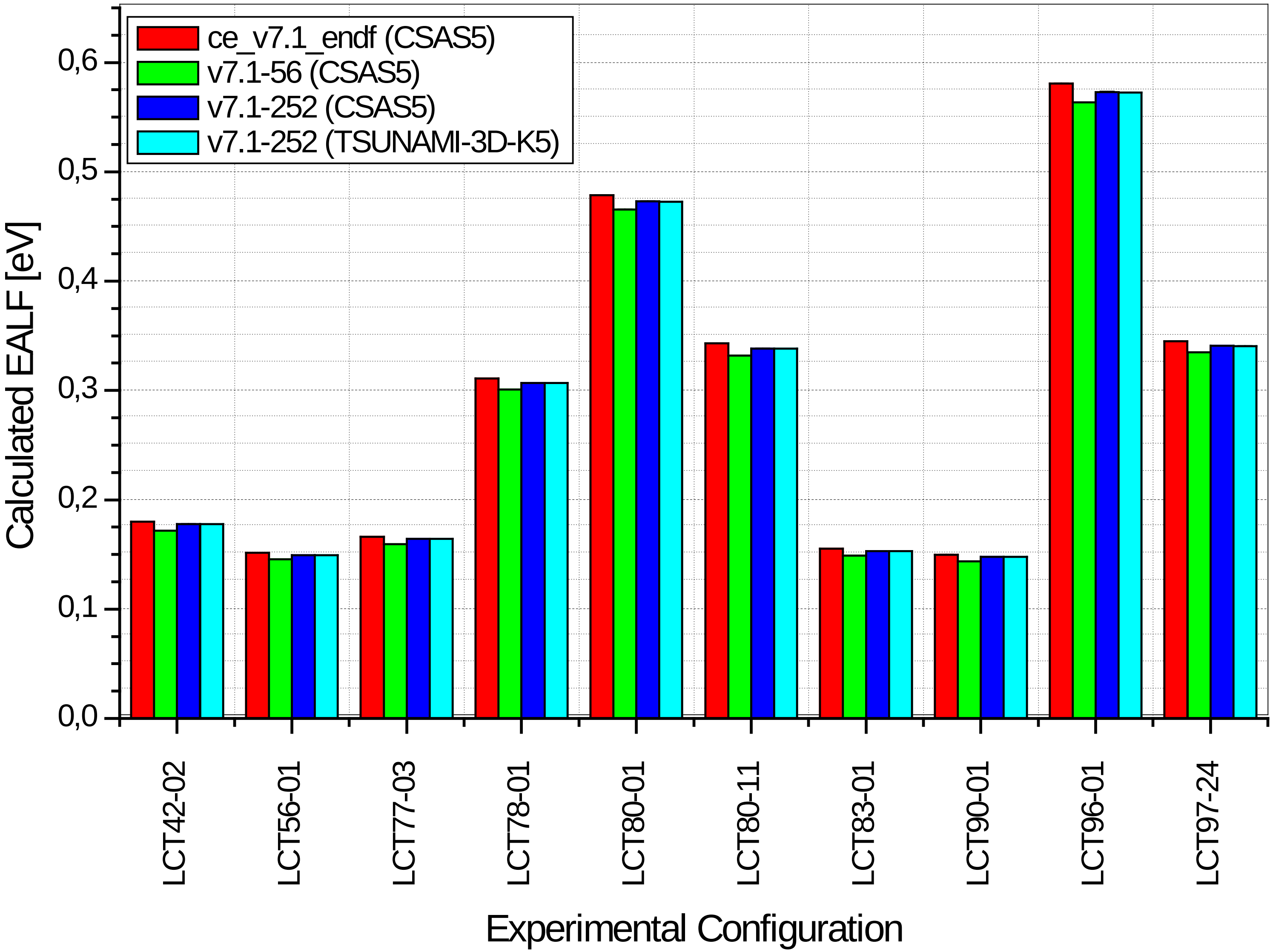




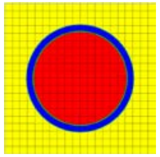
➢ **Only 20/19/1/20/1/na conf.**, respectively, being sufficiently similar acc. to **T-IP $c_K \geq 0.8$**!

➢ **EALF** range from **0.06140 to 2.26570**, **avg. 0.28738** and standard dev. 0.35484

Selected Benchmark Calculation Results – EALF



Two-group Cross-Section Generation

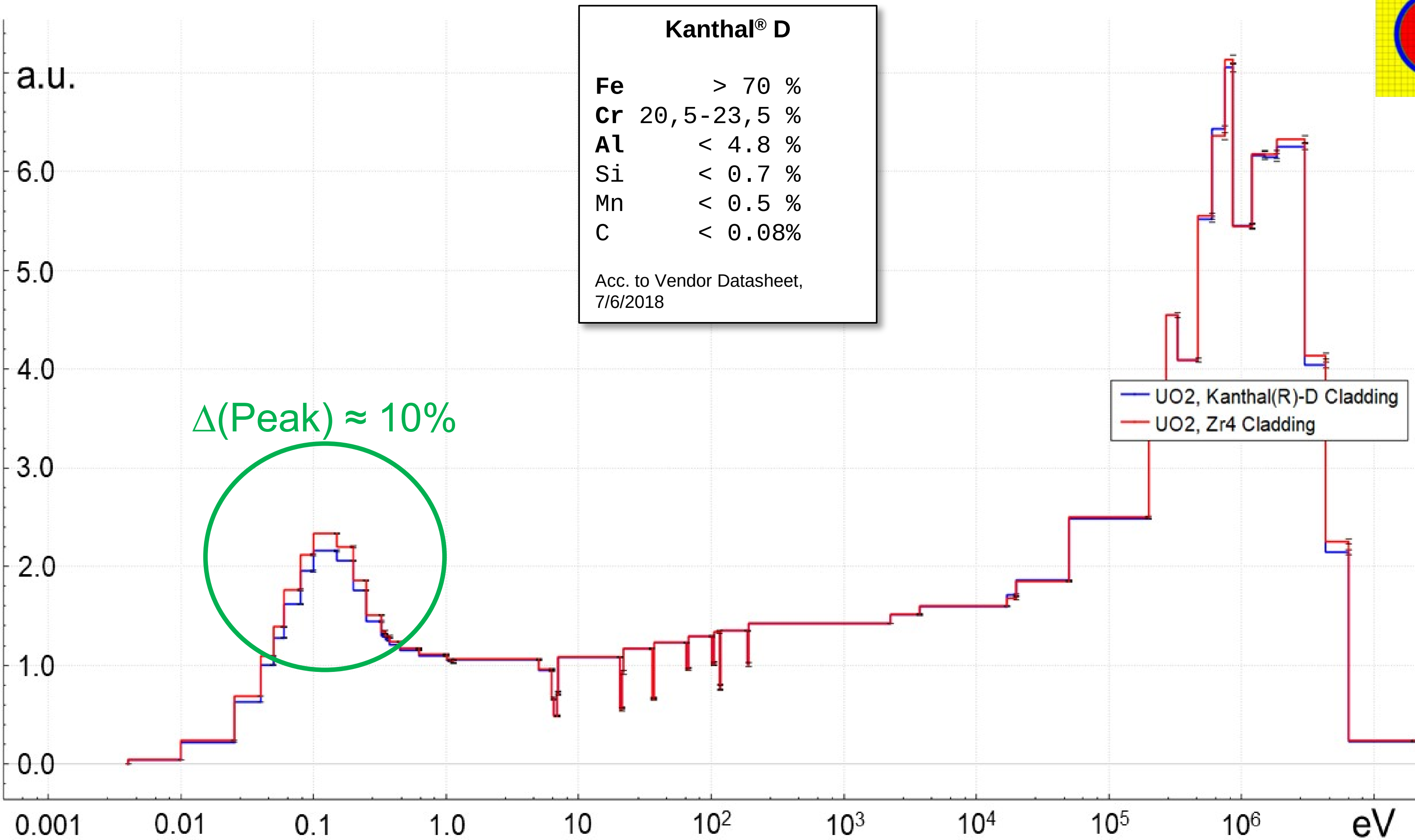


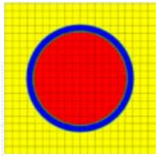
- **Energy boundaries**
  - 5.0 to 2×10^{7} eV for the fast group (upper value in the following table)
  - 10^{-5} to 5.0 eV for the thermal group (lower value) → **split at 5 eV**

- **Two-group cross-sections – unirradiated state (HZP)** (Update to ICNC Paper!)

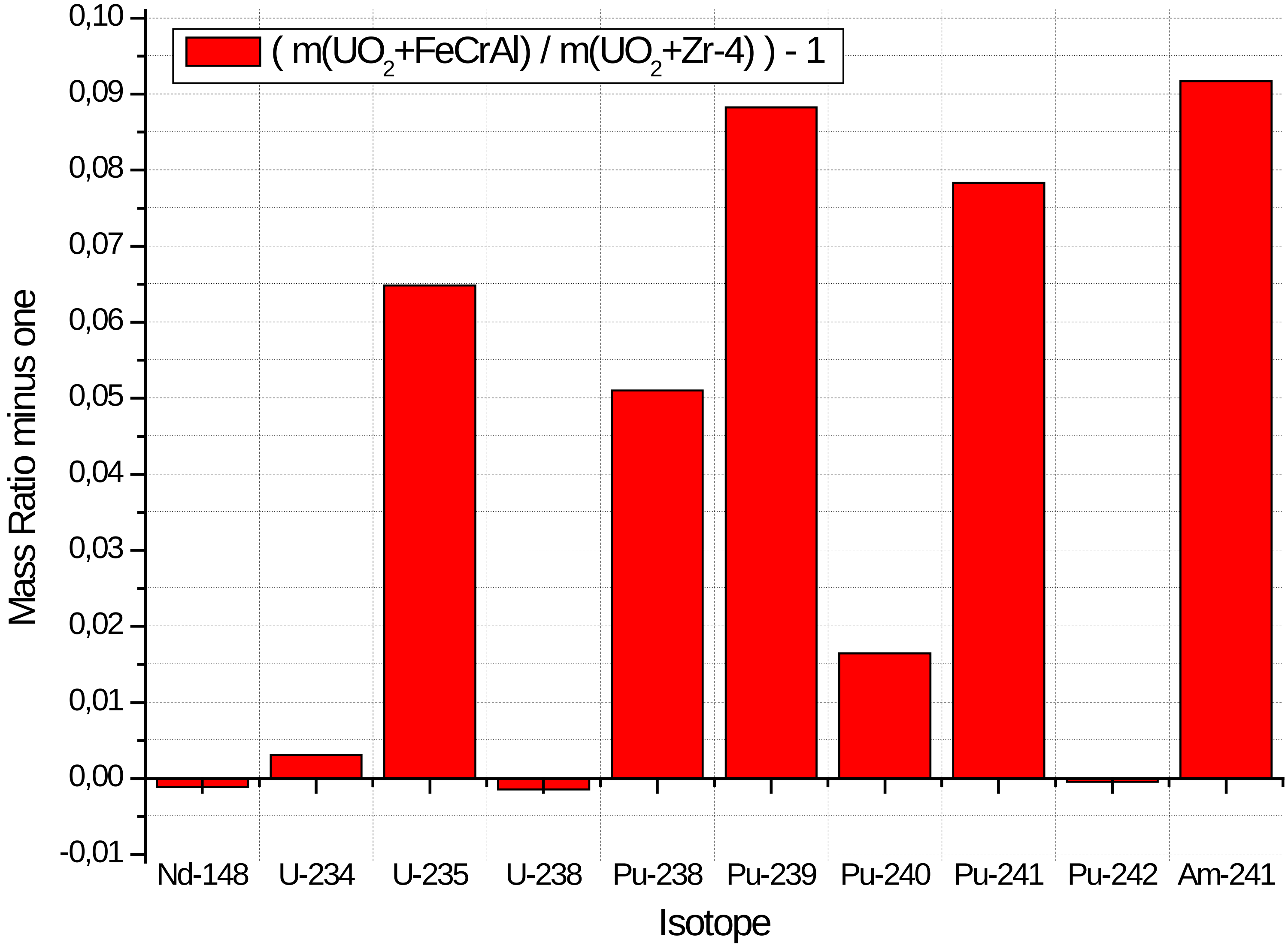
Case	SCALE/NEWT (56G VII.1)	SCALE/NEWT (238G VII.0)	SCALE/NEWT (252G VII.1)	SERPENT CE ENDF/B-VII.0
1 (ref.)	0.52629 1.26078	0.52915 1.26490	0.52541 1.26091	0.53777 1.26691
2	0.52725 1.26033	0.53040 1.26441	0.52937 1.26044	0.53872 1.26633
3	0.53704 1.29359	0.54117 1.29759	0.53928 1.29361	0.54819 1.29859
4	0.51890 1.25878	0.52241 1.26298	0.52129 1.25892	0.53053 1.26504
5	0.51432 1.26003	0.51598 1.26398	0.51438 1.25987	0.51566 1.26168
6	n/a	n/a	n/a	0.50172 1.28907

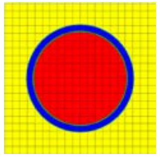
Burnup Calculations – First Results: Neutron Spectra



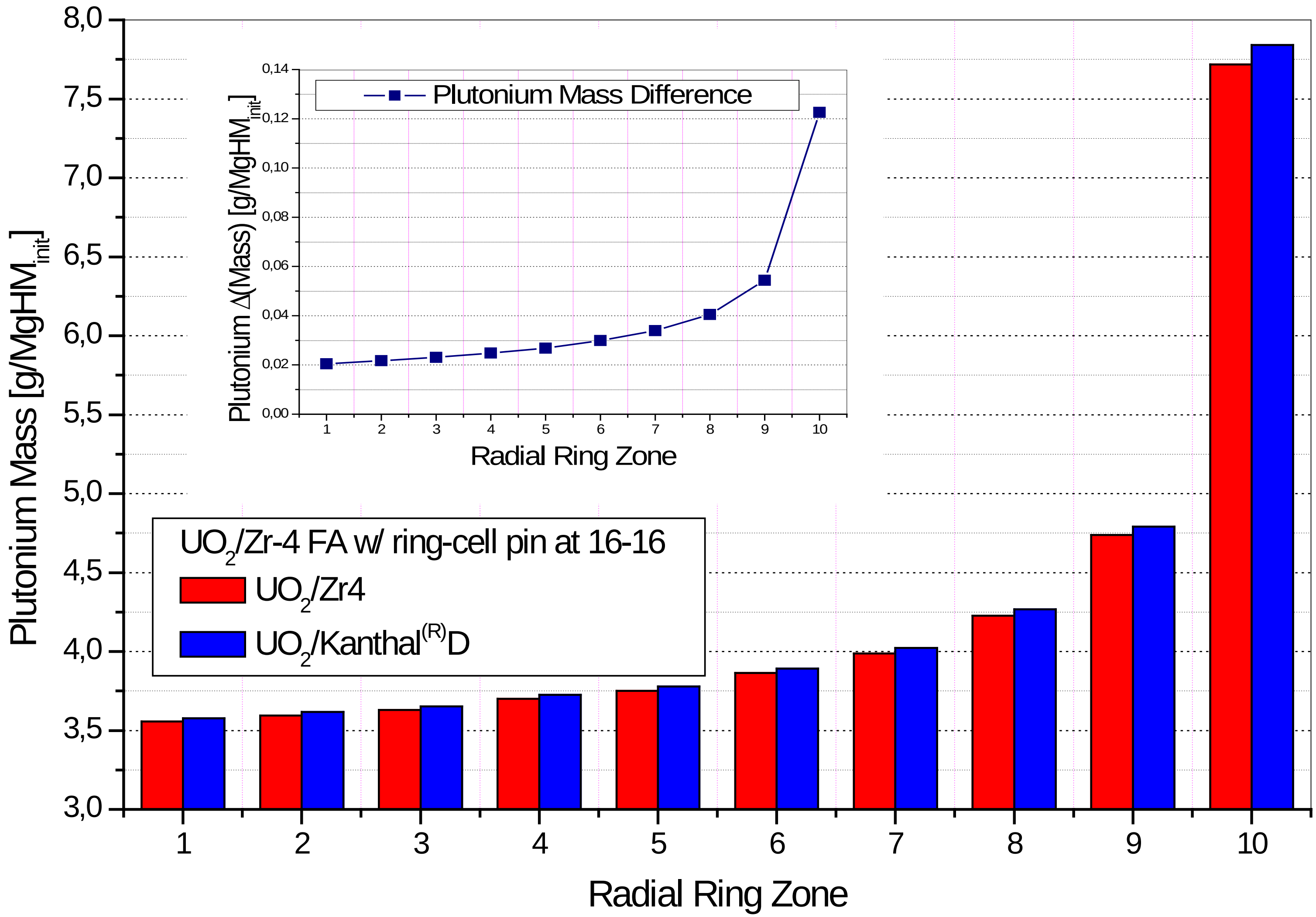


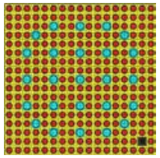
Burnup Calculations – First Results: Plutonium Build-up

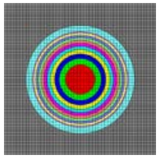




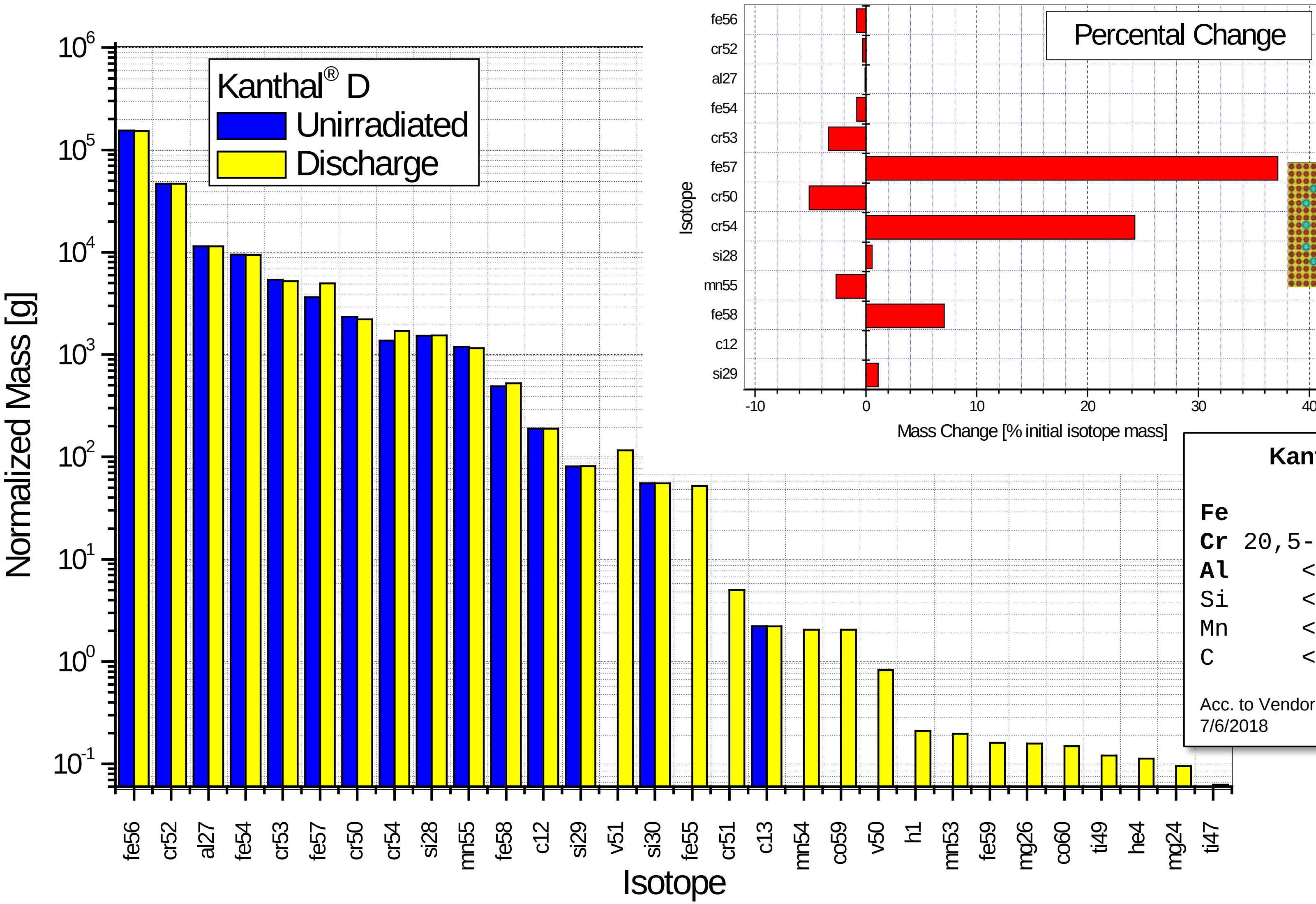
Burnup Calculations – First Results: Rim Effect

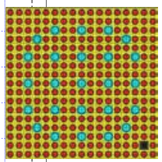






Burnup Calculations – First Results: Clad Activation





Kanthal® D

Fe	> 70 %
Cr	20,5-23,5 %
Al	< 4.8 %
Si	< 0.7 %
Mn	< 0.5 %
C	< 0.08%

Acc. to Vendor Datasheet, 7/6/2018

Summary and Outlook

Current State of ATF Neutronics Test Calculations

- ✓ Critical benchmark experiments calculated
  - ➢ **Issues** found with **experiments' applicability** to ATF systems
- ✓ Scoping calculations for various ATF pin cell / assembly models, including heterogeneous cladding and FCM fuel forms
- ✓ (Few group) cross section generation
  - ➢ **Issues** found in **cross section processing** for systems being **more heterogeneous** than the reference system ► **mainly resolved**
- ✓ First ATF pin / assembly burn-up and activation studies

Future Works

- **Resolving the issues** mentioned above: ► **more Benchmarking**
- Going on the **GRS Nuclear Simulation Chain → Applicability**
  - Burn-up calculations with GRS in-house code **MOTIVE** (currently underway)
  - GRS core simulator **KMACS** (next step)
  - Static and transient core modelling, **coupled neutronic/thermal-hydraulic** systems
  - GRS cross section U/S analysis code **XSUSA**

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Finally…

Thank you very much for your kind attention.

Are there any questions?

Introduction - Accident Tolerant Fuels

- **Accident Tolerant Fuels (ATF)** (*)
  - **Cladding** with improved coolability/resilience under accident conditions (AC) to decelerate degradation ("additional grace time")
  - **Fuel forms** with improved heat conductivity/capacity to reduce overall core heat, and improved corrosion resistance under AC (including moderator contact to fuel)
  - ➢ Modified, amended or replaced fuel and/or cladding material
  - ➢ Neutronic properties not in primary focus of ATF development

- **However**
  - ATF materials may exhibit different neutronic properties being safety relevant
    - ➢ ATF components may feature "unusual" neutron cross sections (qualification status), or require more sophisticated cross section processing
  - **Scope: Apply and test the GRS neutronics calculation capabilities on ATF**
    - ➢ Here: Focus on **Criticality, Cross-sections and Burn-up**

(*) aka "Advanced Technology Fuels"

Introduction – GRS Nuclear Simulation Chain