Decay Heat in Reactor and Fuel Cycle Applications

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❑ Motivation

- ✓ **Short cooling times** (< 1 year) → short-lived FPs dominate
  - o Reactor operators → Shorter refueling times

    Ex.: for EdF, 4% increase in decay heat ⇒ 1 day of shutdown of the French park ~ ½ fuel reload

    ⇒ very strong economic incentive in accurate knowledge of DH

    Target accuracy ~ 10% (2σ) or better

  - o Reactor designers → Better estimation of margins to avoid excessive conservative

    Ex.: Innovative GFR studies at CEA
    - Core definition conditioned by DH at t < 1 minute after shutdown (LOCA) + Very sensitive to it !
    - Further complication with full actinide recycling because of relatively poor knowledge of MA fission yields

❑ Motivation

✓ **Intermediate to long cooling times** (> 1 year) → FPs + actinides

- o Fuel cycle plant operators → Better estimation of margins to avoid excessive conservative

  Ex.: - spent fuel subassembly transfers and transportation
  - fuel reprocessing plant
  - storage of spent fuel or nuclear waste

  ⇒ strong incentive in accurate knowledge of decay heat

  Target accuracy ~ 10% (2σ) or better

❑ Current performance of JEF-2.2 data + CEA codes

✓ Short cooling times

- Validation based on code-to-code comparisons and pulse fission experiments (Akiyama, Dickens)
- Estimated uncertainty for UOX and MOX fuels is ~15% (2σ)
- New experiment at CEA: MERCI $\rightarrow$ fuel rod irradiation in OSIRIS, followed by accurate calorimetric measurements (2007-2010)

✓ Intermediate to long cooling times

- Leading contributors
  - Actinides: Cm244, Cm-242, Pu238, Am241, Pu239, Pu240, Am243
  - FPs: Cs137+Ba137m, Ru106+Rh106, Sr90+Y90, Ce144+Pr144, Eu154, Zr95+Nb95, Cs134
- Validation is only partial as it relies on PIE experiments (fuel rods, irradiated samples)
- Estimated uncertainty for UOX and MOX is ~12% (2σ) for cooling times between 1 and 10 years, and between 4 and 7% for longer cooling times

❑ Recent developments

- ✓ Special effort in Europe over the past years to revise the JEF-2.2 fission yield and decay data files, with support from the French and British nuclear industry

- ✓ **New JEFF-3.1 FY and DD files** released in May 2005
  Also, recently released JENDL-3 decay data file

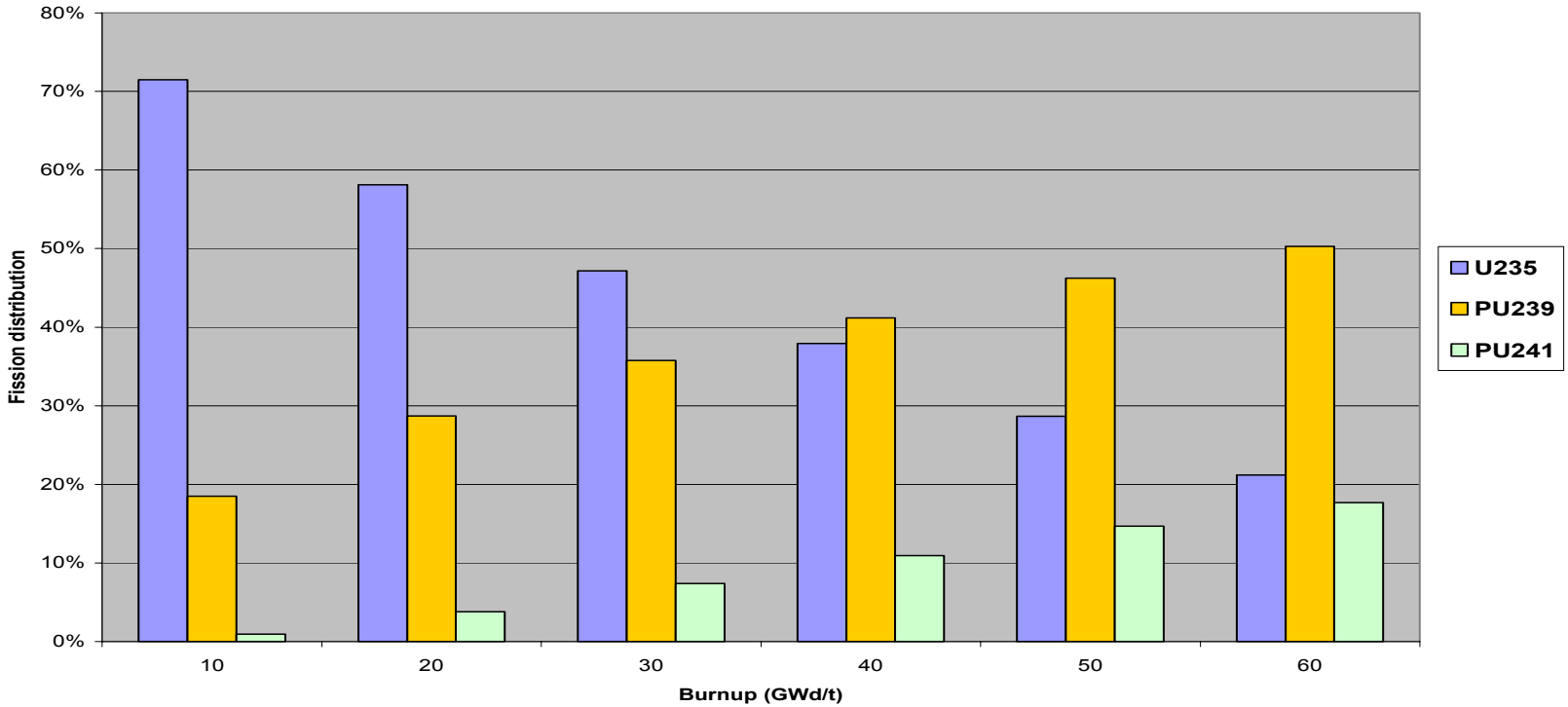
- ✓ Production libraries based on JEFF-3.1 files are currently being prepared
  CEA is committed to
  - o Validating those libraries for its users
  - o Contributing to the future file improvements

- ✓ Some shortcomings already recognized at short cooling times → to be addressed by the international NEA/WPEC/SG25
  - o Pending the availability of JEFF-3.1-based libraries, some preliminary calculations have been done with JEF-2.2
  - o Focus on **JEF-vs-JENDL discrepancies in beta/gamma DH** between ~ 20 s and 2000 s → try to identify the responsible nuclides

Calculations of Irradiated UOX Fuel (4,5% U235) in a PWR

❑ Leading fissile contributions as a function of burn-up

- ✓ Burn-up = 20 and 60 GWd/t
- ✓ Cooling time range = 1 s to 10000 s

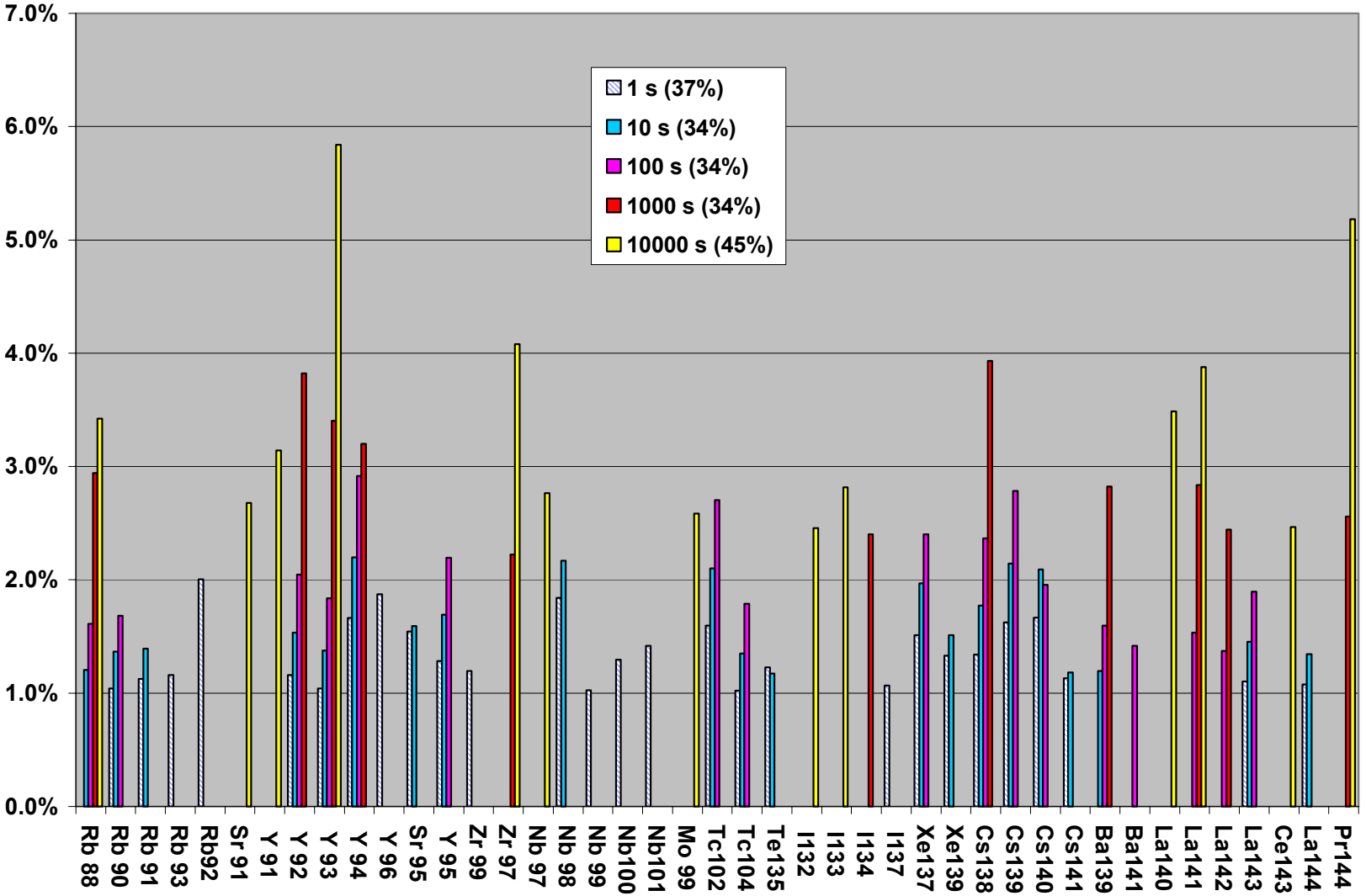


U235, Pu239 and Pu241 relative contributions versus burn-up (UOX fuel)

Although the main contributing actinides change with burn-up, it is essentially **the same** FPs provide the leading contributions to the DH at burn-ups of 20 and 60 GWd/t

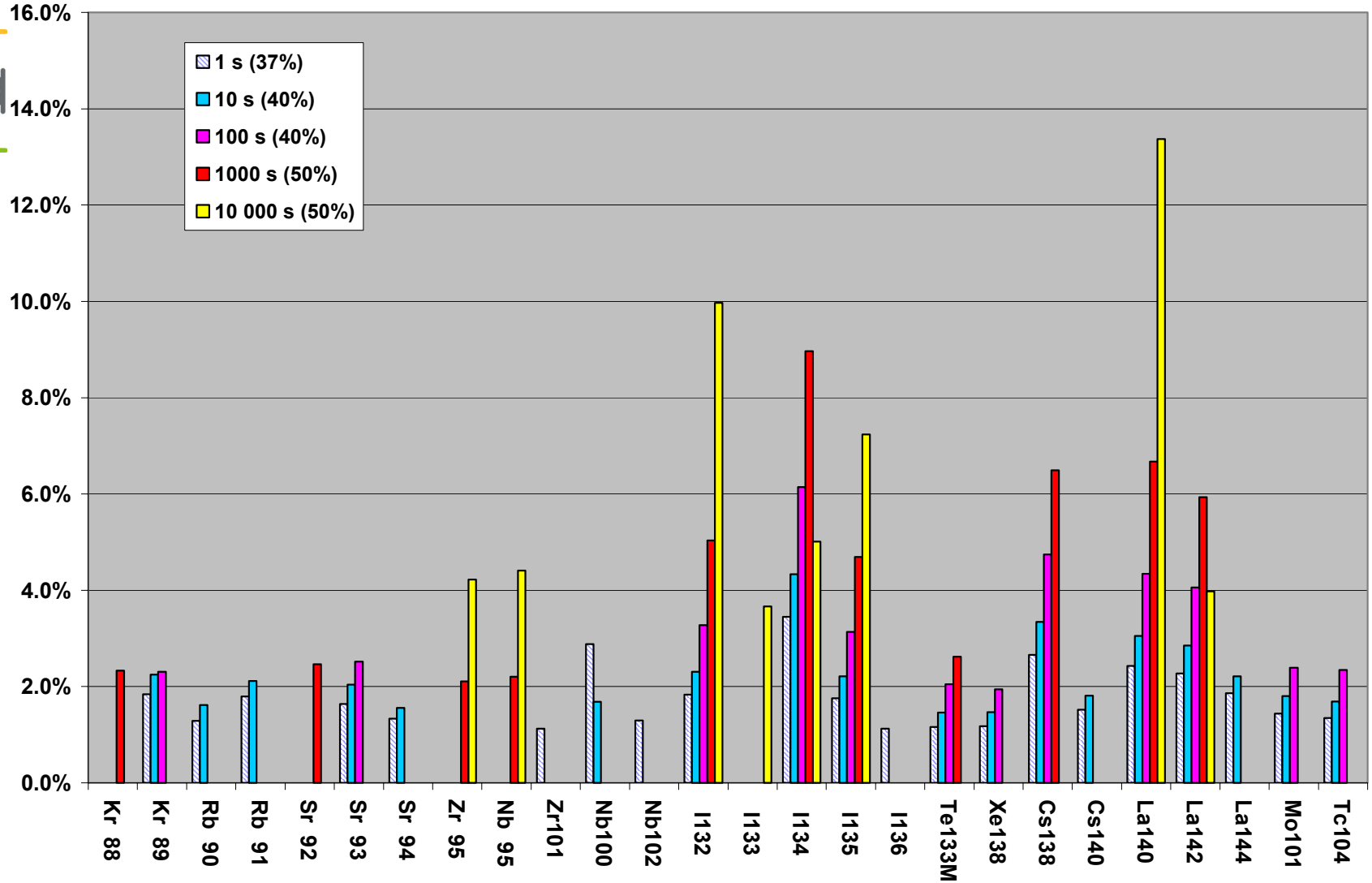
Calculations of Irradiated UOX Fuel (4,5% U235) in a PWR

❑ Main contributions to the total beta DH



Calculations of Irradiated UOX Fuel (4,5% U235) in a PWR

❑ Main contributions to the total gamma DH



Concluding remarks

- **Strong incentive in reducing the uncertainty in DH predictions at all cooling times**
  - ✓ Target ~ 10% (2σ) or better
  - ✓ Is this achievable ?

- **Recent JEFF-3 files have to be further improved to reach this objective**
  - ✓ Which nuclides ? $\rightarrow$ Sensitivity studies, direct substitutions, …
  - ✓ Use of Rudstam average energies ?
  - ✓ New, accurate measurements needed

- **CEA will contribute to the on-going international efforts on this topic**