SCALE/ORIGEN Sensitivity in Fission Products

June 22, 2021

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SCALE/ORIGEN

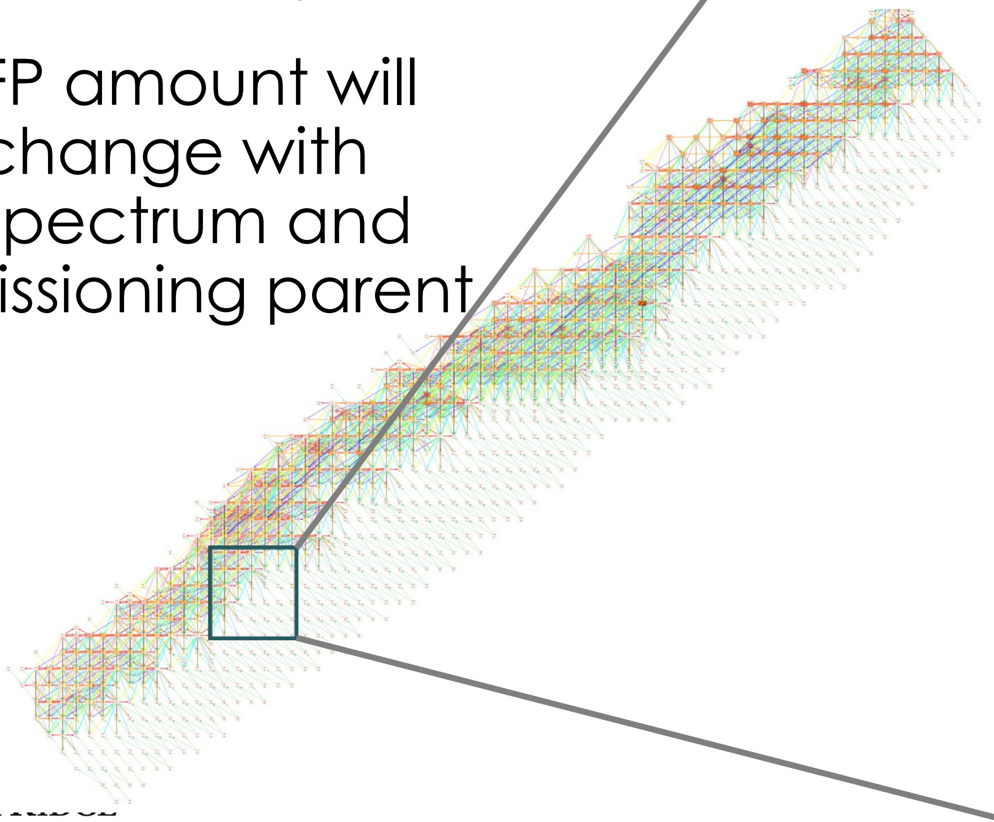
- Transmutation physics based on fundamental ENDF/B data
  - Fission product yields†
  - Cross sections (one-group flux-weighted collapse based on the reactor spectrum)
  - Decay data
  - Supported with activation data from JEFF 3.0/A
- Emerging sensitivity capability and ability to read ENDF/B format yields & decay data directly
- Used in current NRC assessment work on non-LWR severe accident analysis
- Goal of this presentation
  - Summarize data+uncertainty for two promising FPs: Rb-92, Y-96
  - Show sensitivity analysis results for Rb-92 in LWR & non-LWR

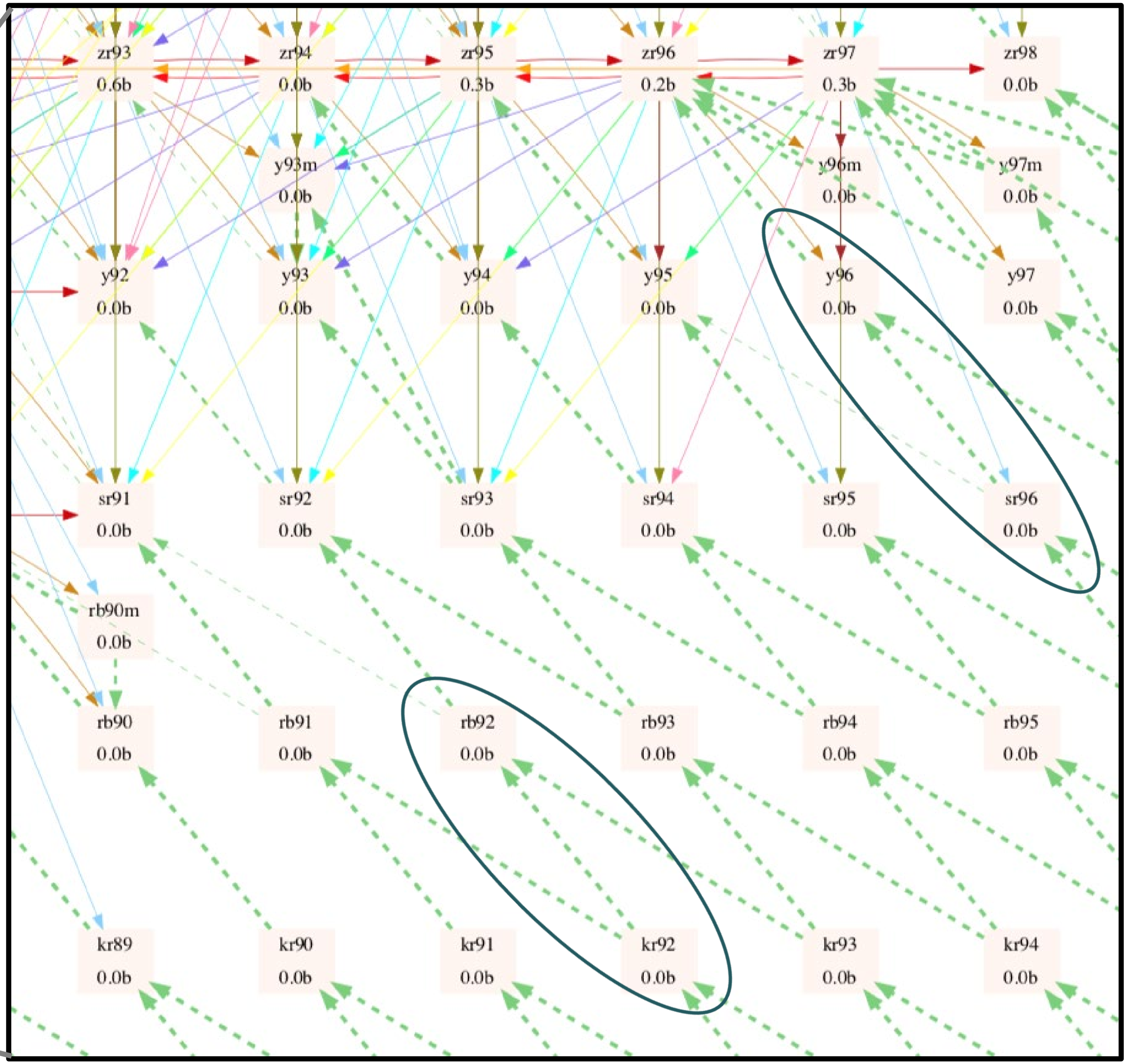
†Based on ENDF/B-VII.1 with consistency fixups for cumulative yield ↔ branching ratio ↔ independent yield

OAK RIDGE National Laboratory

Decay Chains for Rb-92, Y-96

- Direct, short-lived yield fission products
  - Rb-92 half-life 4.5s
  - Y-96 half-life 5.3s
  - No absorption xs
- FP amount will change with spectrum and fissioning parent





Data summary

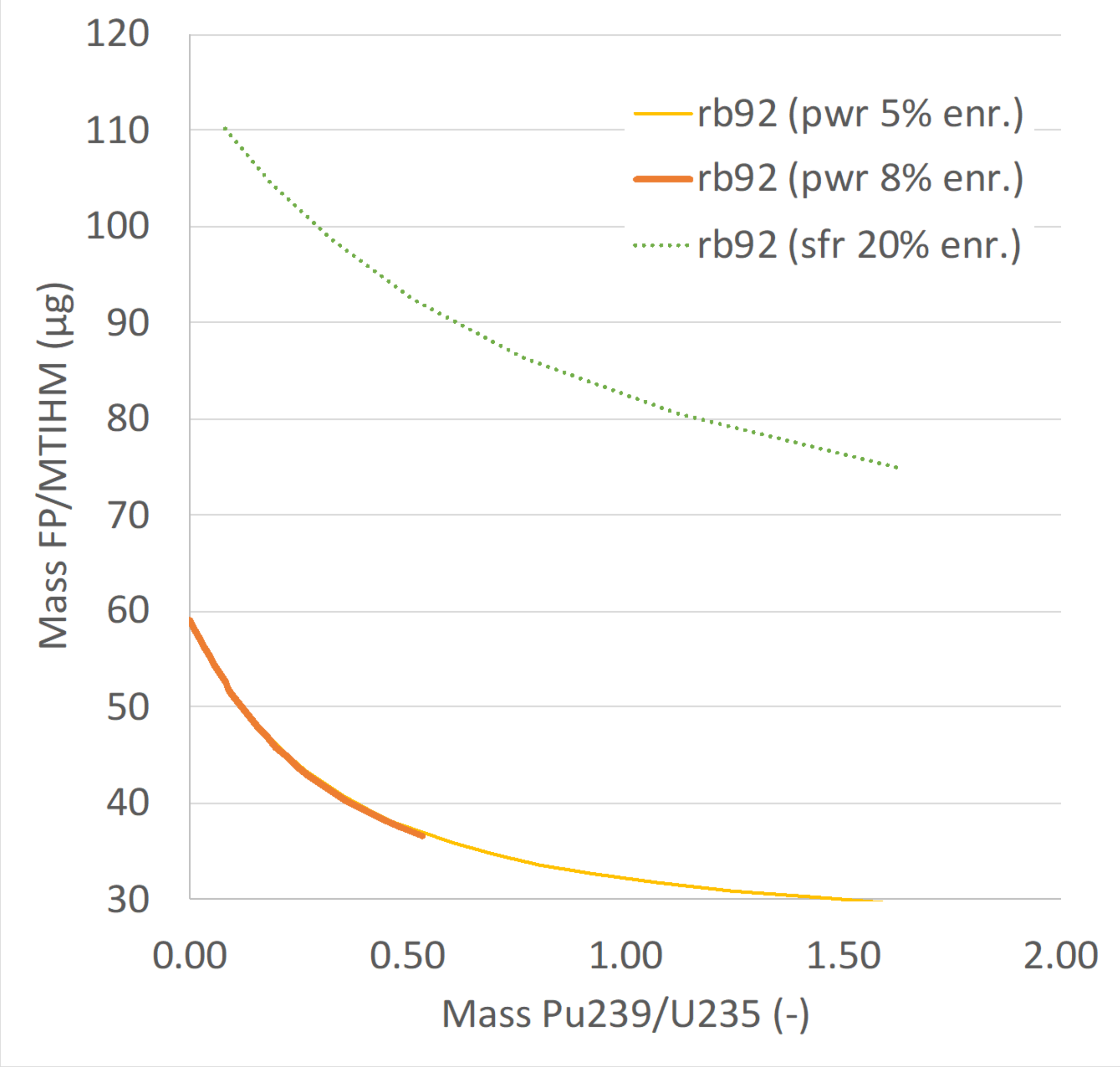
Rb-92	Nominal Value	Uncertainty (%)	Y-96	Nominal Value	Uncertainty (%)
decay constant	4.492 s	0.44 %	decay constant	5.34 s	0.1 %
Kr-92 (parent) branch ratio	100 %	0.0025 %	Sr-96 (parent) branch ratio	100 %	0 %
U-235 FPY (therm)	0.0313	2 %	U-235 FPY (therm)	0.0202	32 %
U-235 FPY (inter)	0.0279	32 %	U-235 FPY (inter)	0.0013	64 %
U-235 FPY (fast)	0.0293	32 %	U-235 FPY (fast)	0.0016	64 %
Pu-239 FPY (therm)	0.0161	6 %	Pu-239 FPY (therm)	0.0025	64 %
Pu-239 FPY (inter)	0.0153	24 %	Pu-239 FPY (inter)	0.0021	63 %
Pu-239 FPY (fast)	0.0150	26 %	Pu-239 FPY (fast)	0.0014	63 %

Recent nuclear data uncertainty/sensitivity analysis work

- Sensitivity/uncertainty analysis with TSUNAMI (perturbation theory):
  - B. L. Broadhead, B. T. Rearden, C. M. Hopper, J. J. Wagschal, and C. V. Parks (2004), "Sensitivity- and Uncertainty-Based Criticality Safety Validation Techniques," *Nucl. Sci. Eng.*, 146(3), pp. 340–366.
  - B. T. Rearden, M. L. Williams, M. A. Jessee, D. E. Mueller, D. Wiarda, (2011). Sensitivity and uncertainty analysis capabilities and data in SCALE. *Nuclear Technology*, 174(2):236–288.
- Depletion perturbation theory (DPT):
  - Keith C. Bledsoe, Germina Ilas, Susan L. Hogle, "Application of Depletion Perturbation Theory for Sensitivity Analysis in the High Flux Isotope Reactor" *Trans. Am. Nucl. Soc.,* 121 Nov. 2019
- Sensitivity/uncertainty analysis with Sampler (random sampling approach):
  - B. L. Broadhead, B. T. Rearden, C. M. Hopper, J. J. Wagschal, and C. V. Parks (2004), "Sensitivity- and Uncertainty-Based Criticality Safety Validation Techniques," Nucl. Sci. Eng., 146(3), pp. 340–366.
  - F. Bostelmann (2020), "Systematic Sensitivity and Uncertainty Analysis of Sodium-Cooled Fast Reactor Systems," École polytechnique fédérale de Lausanne, Switzerland. https://infoscience.epfl.ch/record/274286
  - F. Bostelmann, D. Wiarda, W. Wieselquist (2021), "Extension of SCALE/Samplers' Sensitivity Analysis," Annals of Nuclear Energy, *submitted*.
- Analysis:
  - F. Bostelmann, G. Ilas, and W. A. Wieselquist (2020), "Key Nuclear Data Impacting Reactivity in Advanced Reactors," ORNL/TM-2020/1557, 2020. https://info.ornl.gov/sites/publications/Files/Pub140896.pdf
  - F. Bostelmann, G. Ilas, C. Celik, A. Holcomb, W. Wieselquist (2021), "Nuclear Data Performance Assessment for Advanced Reactors," ORNL/TM-2021/2002, NUREG, *submitted for review to NRC*.

Mass of Rb-92 FP during operation

- Different fuel types
  - Standard PWR fuel at 5% U-235
  - Near-term potential deployed higher enrichment fuel at 8% U-235
  - Sodium Fast Reactor (SFR) with 19.75% enriched U-metal fuel
- Operating history
  - **PWR:** 80GWd/MTU discharge burnup, 40 MW/MTU specific power
  - **SFR:** 200 GWd/MTU, 80 MW/MTU specific power
- Faster spectrum in SFR produces greater amounts of Rb-92
- Minimal difference for PWR with 5% or 8% enrichment



Highlights for Rb-92

- Strongest sensitivity† for decay constant
  - $N(t) = \frac{\gamma(t)\sigma_f(t)\phi(t)}{\lambda}(1 - e^{-\lambda t})$
  - For short half-life:

    $$N(t) = \frac{\gamma(t)\sigma_f(t)\phi(t)}{\lambda}$$

  - $SC = \frac{\partial N}{\partial \lambda}\frac{\lambda}{N} = -1$ as predicted, **high sensitivity** but **uncertainty is low**
- Direct yield of Rb-92 from U-235 & Pu-239 has 0.3 SC independent of reactor type
- Branching ratio also has 0.3 SC
- SC mostly independent of reactor type

ORIGEN Sensitivity analysis performed at end-of-life

Sensitivity coefficient (SC) is % change in Rb-92 per % change in data

parent	daughter	tid	type	pwr 5%	pwr 8%	sfr 19.75% umetal	sfr u+pu metal
942390	370920	18	yield	0.35	0.23	0.25	0.38
922350	370920	18	yield	0.15	0.34	0.31	0.34
360920	370920	-1	bran	0.31	0.33	0.35	0.27
922350	360920	18	yield	0.08	0.18	0.16	0.18
942390	360920	18	yield	0.07	0.04	0.06	0.08
922380	370920	18	yield	0.06	0.04	0.06	0.01
922350	350920	18	yield	0.00	0.00	0.00	0.00
360930	370920	-1	bran	0.00	0.00	0.00	0.00
922350	360930	18	yield	0.00	0.00	0.00	0.00
942390	350920	18	yield	0.00	0.00	0.00	0.00
942390	360930	18	yield	0.00	0.00	0.00	0.00
370920	0	-1	decay	-1.00	-1.00	-1.00	-1.00

^{92}Rb (direct)

^{92}Kr (parent)

^{92}Kr → ^{92}Rb branching

PRELIMINARY SCALE 6.3 BETA RESULTS—FULL VERIFICATION STILL UNDERWAY

† *See:* Keith C. Bledsoe, Germina Ilas, Susan L. Hogle, "Application of Depletion Perturbation Theory for Sensitivity Analysis in the High Flux Isotope Reactor" *Trans. Am. Nucl. Soc.*, 121 Nov. 2019 *for further discussion*

Backup

Mass of Y-96 FP during operation

- Different fuel types
  - Standard PWR fuel at 5% U-235
  - Near-term potential deployed higher enrichment fuel at 8% U-235
  - Sodium Fast Reactor (SFR) with 19.75% enriched U-metal fuel
- Operating history
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