Functionality Isolation Test for Fuel Cycle Code ORION – MOX Fabrication

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ORNL is managed by UT-Battelle, LLC for the US Department of Energy

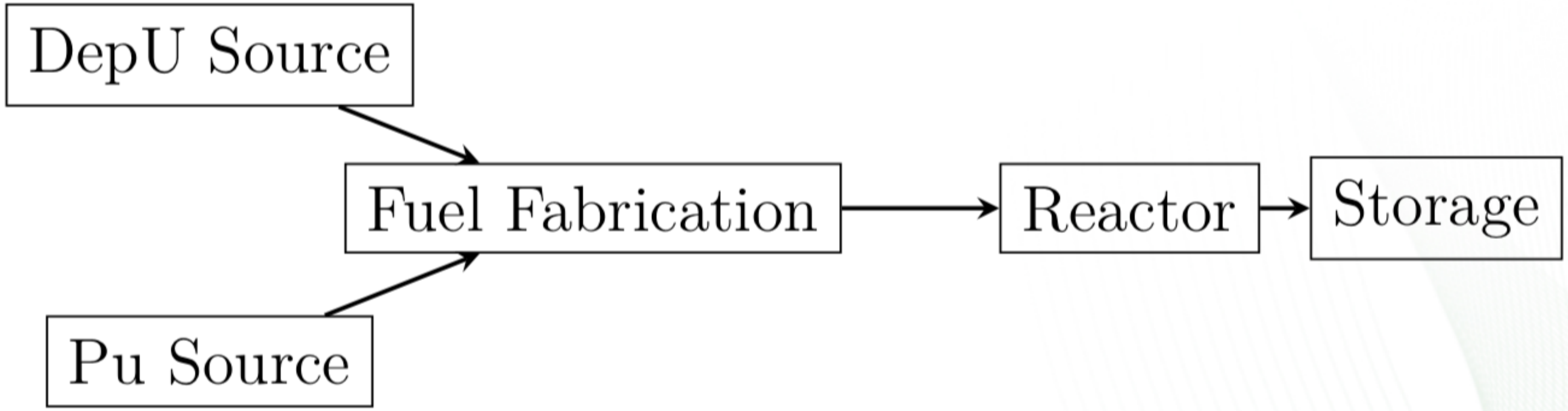
ORION

- Developed and maintained at UK National Nuclear Laboratory (NNL)
- Tracks 2,500 nuclides
- Fleet-based modeling of facilities

Mixed Oxide (MOX) Fuel Fabrication Modeling

- Calculate fissile stream content in MOX fuel given fissile stream isotopics

- What is `good' MOX



ORION Methods

- Fixed Fraction (FF) Method
- Effective Fissile Mass Coefficient (EFMC) Method

FF Method

- Fixed, user-input content
- Simplest method
- Does not take into account fissile stream isotopics (quality)
- Bad approximation for simulations with changing plutonium vector (continuous reprocessing)

EFMC Method

- Used in Sellafield MOX plant
- Two user inputs:
  - One-group collapsed cross section values
    - Absorption
    - Fission
    - Nu-bar (neutrons / fission)
  - Reference Fissile Fraction (RFF) - effective enrichment

EFMC Method

1. Calculate Excess Neutrons Produced (ENP) for each isotope:

$$ENP_i = (\bar{\nu}_i - 1) * \sigma_{f,i} - \sigma_{a,i}$$

2. Calculate EFMC for each isotope:

$$EFMC_i = \frac{ENP_i - ENP_c}{ENP_f - ENP_c}$$

ENP_c = Carrier isotope (U-238) ENP

ENP_f = Fissile isotope (U-235) ENP

EFMC Method

3. Find Actual Fissile Fraction (AFF):

$$RFF(EFMC_i)(RFV_i) + (100 - RFF)(EFMC_i)(RCV) = AFF(EFMC_i)(AFV_i) + (100 - AFF)(EFMC_i)(ACV_i)$$

In this study:

Reference Fissile Vector (RFV) = U-235

Reference Carrier Vector (RCV) = U-238

EFMC Comparison with SCALE/TRITON

Selected four plutonium vectors:

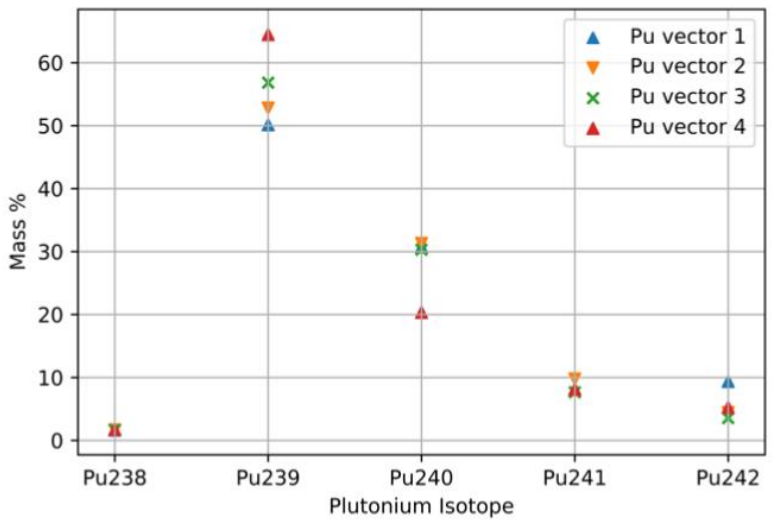


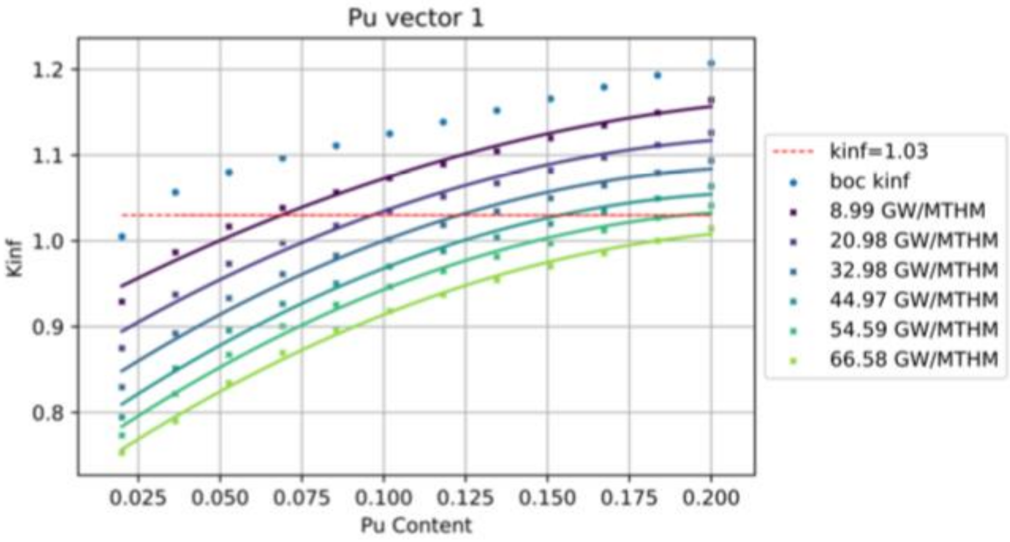
Figure 5: Four plutonium vectors selected for the SCALE/TRITON comparison with ORION's EFMC method.

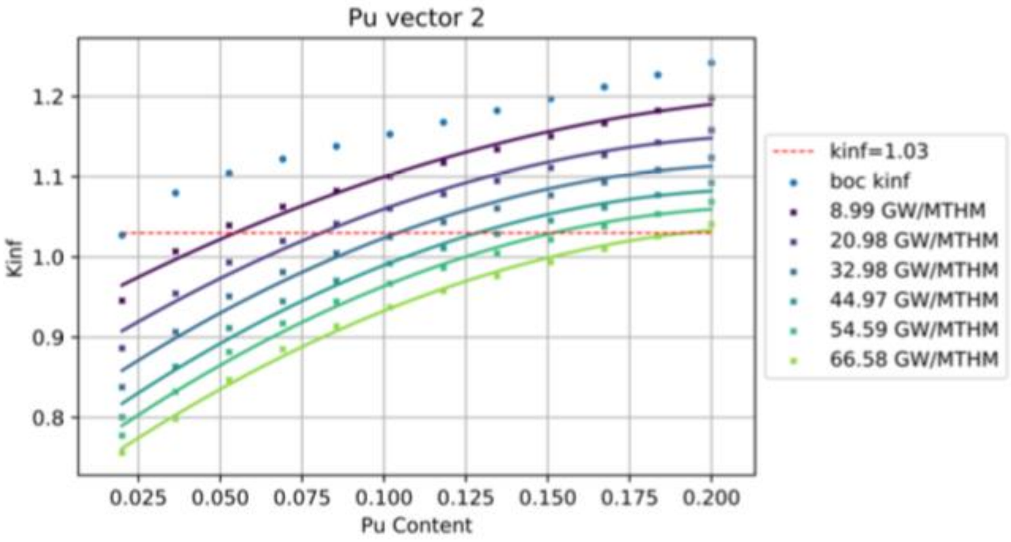
- Create 12 MOX fuel assembly models for each vector
  - 12 evenly spaced points from 2% to 20%
- Find beginning of cycle (BOC) & end of cycle (EOC) k_{inf} value

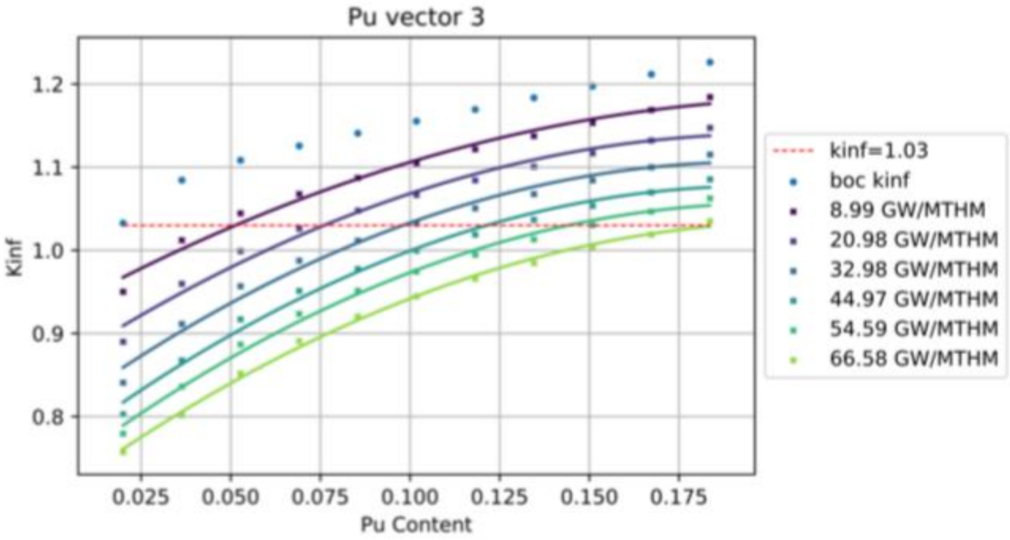
Good MOX Criteria

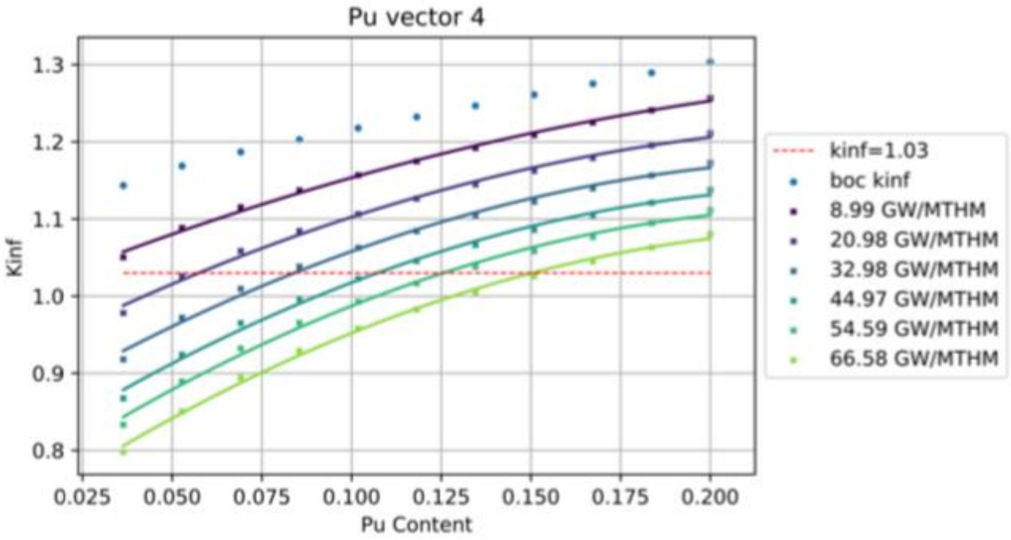
- Good MOX is set to be MOX with:
  - EOC K_inf = 1.03
  - MOX Fuel with 4 different plutonium vectors
    - For each plutonium vector:
      - Search for Pu Content that makes EOC k_inf = 1.03

Good MOX Criteria

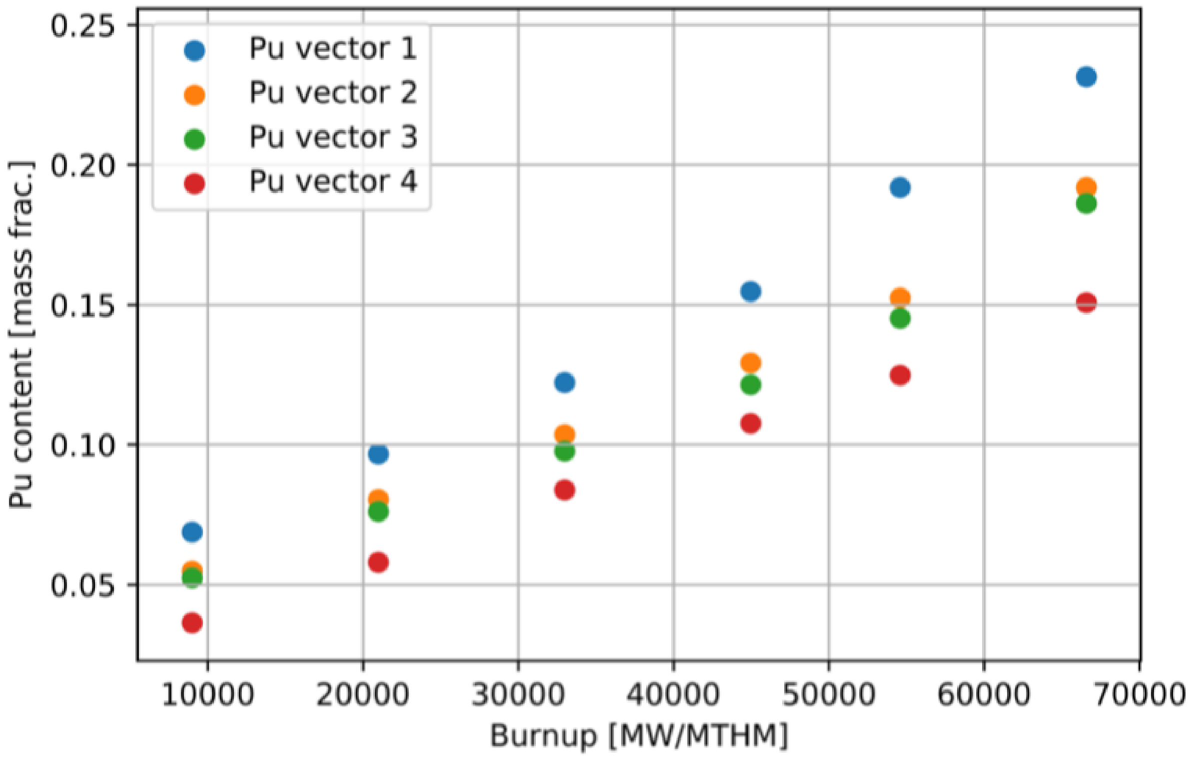








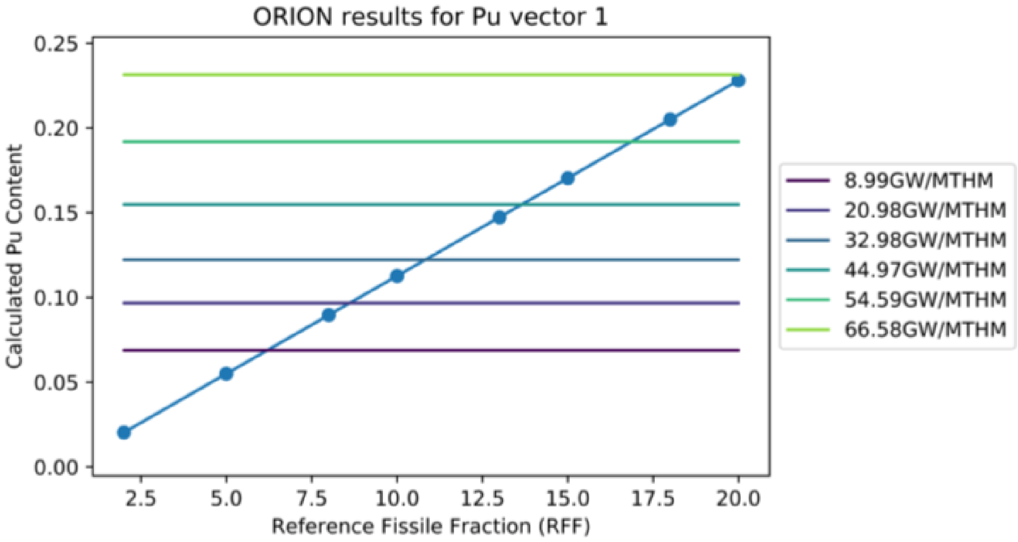
Pu Content for Good MOX

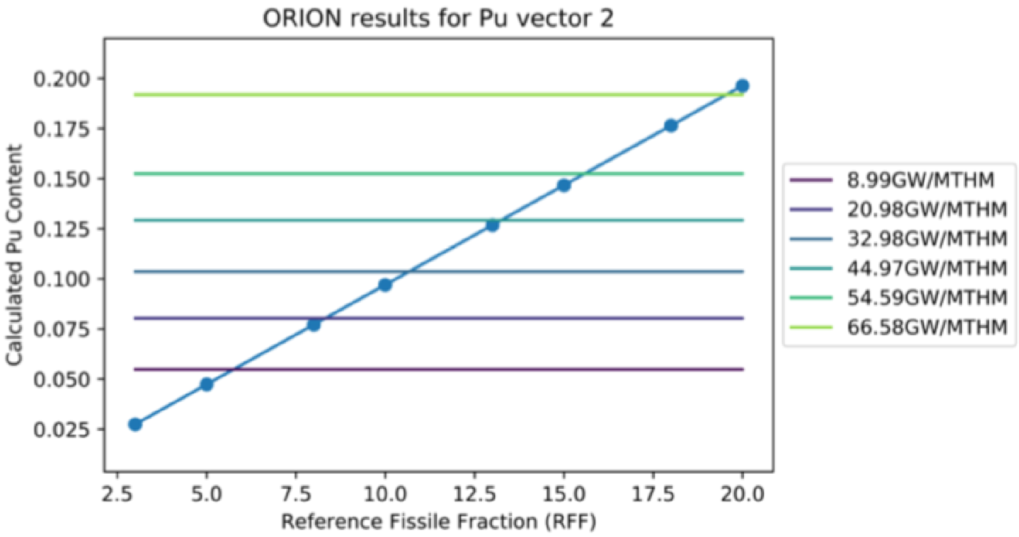


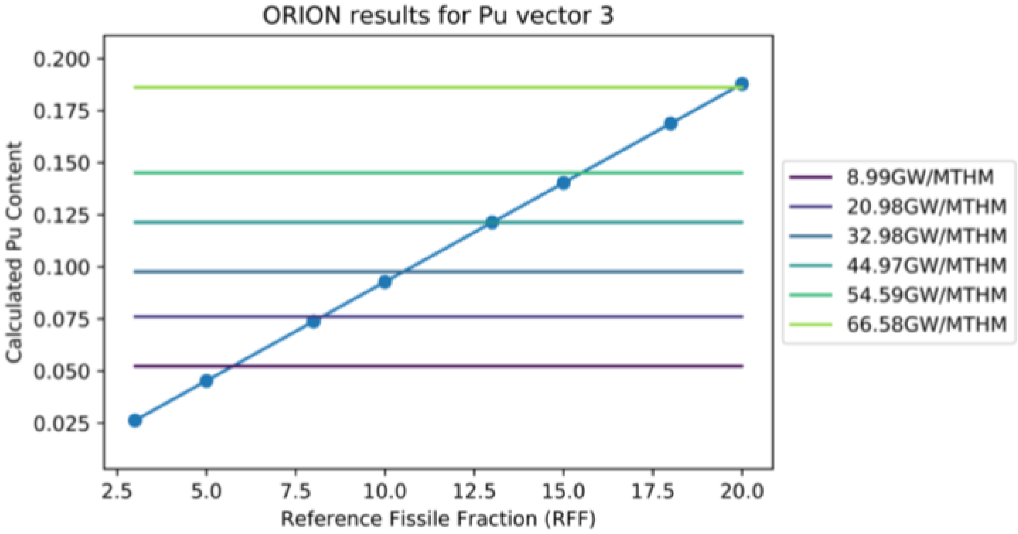
RFF Corresponding to critical Pu Content

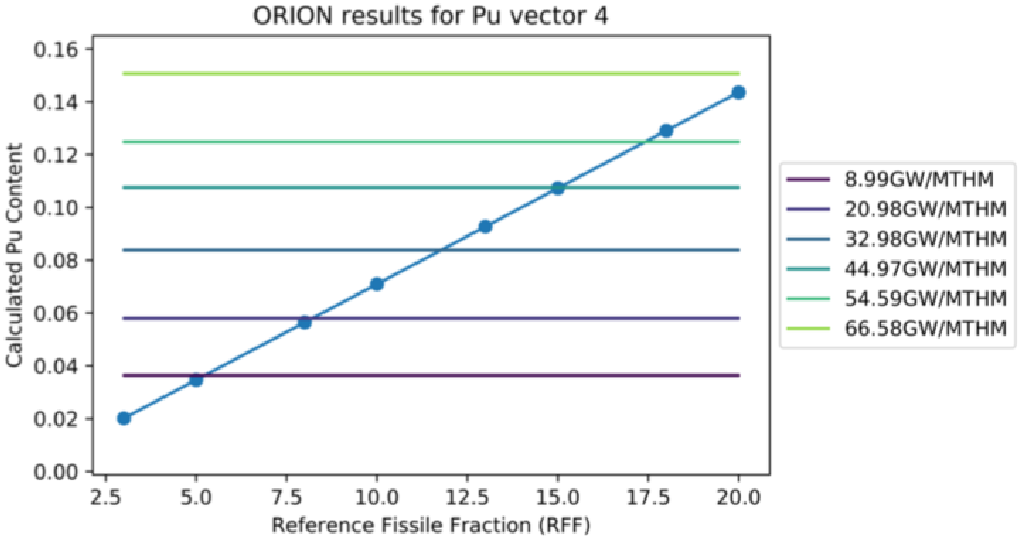
- Finding the Reference Fissile Fraction (RFF) that corresponds to the `good' plutonium content
  - RFF -> (Pu Content) -> `good' MOX
  - Find if RFF is a good indicator of `goodness' of MOX

RFF Corresponding to critical Pu Content



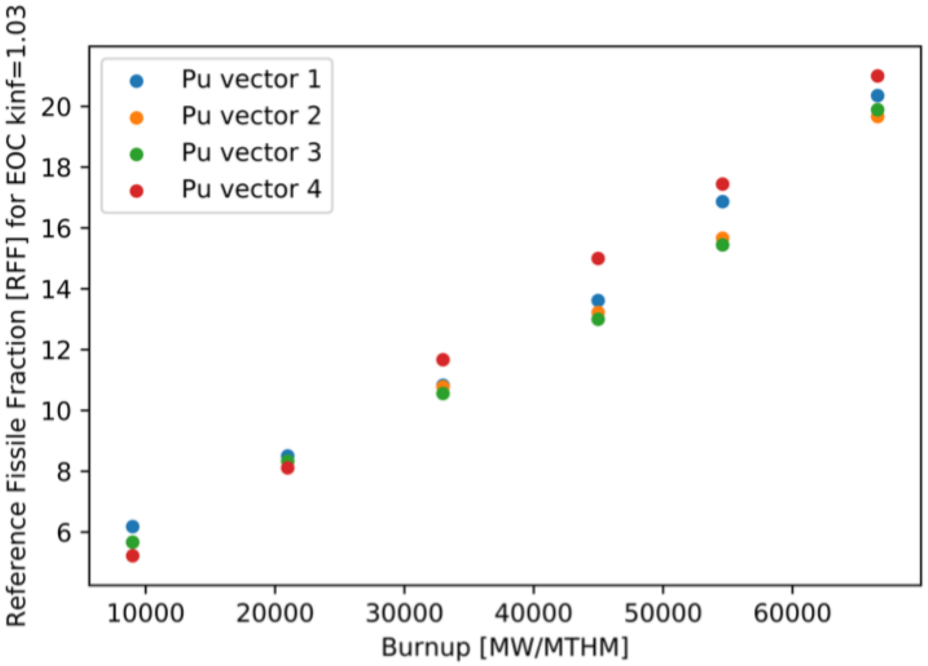






Burnup vs RFF

- Quadratic relationship
- Points deviate in higher burnups



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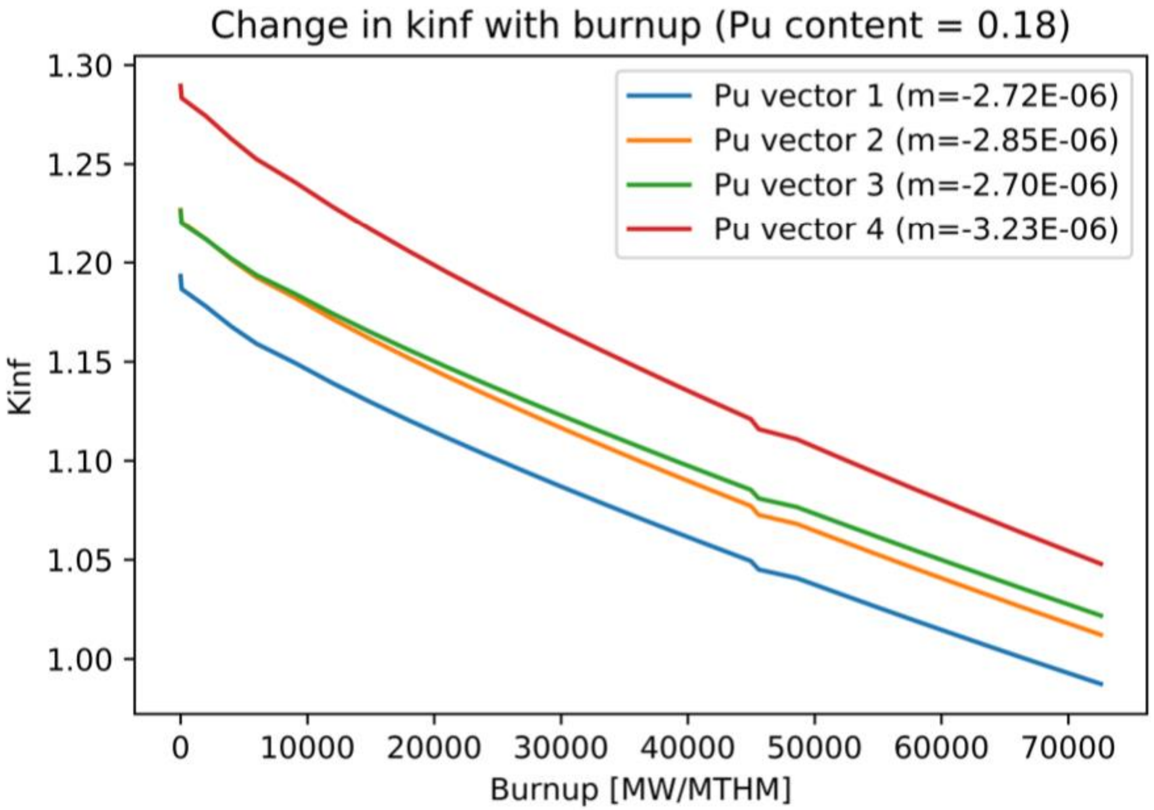
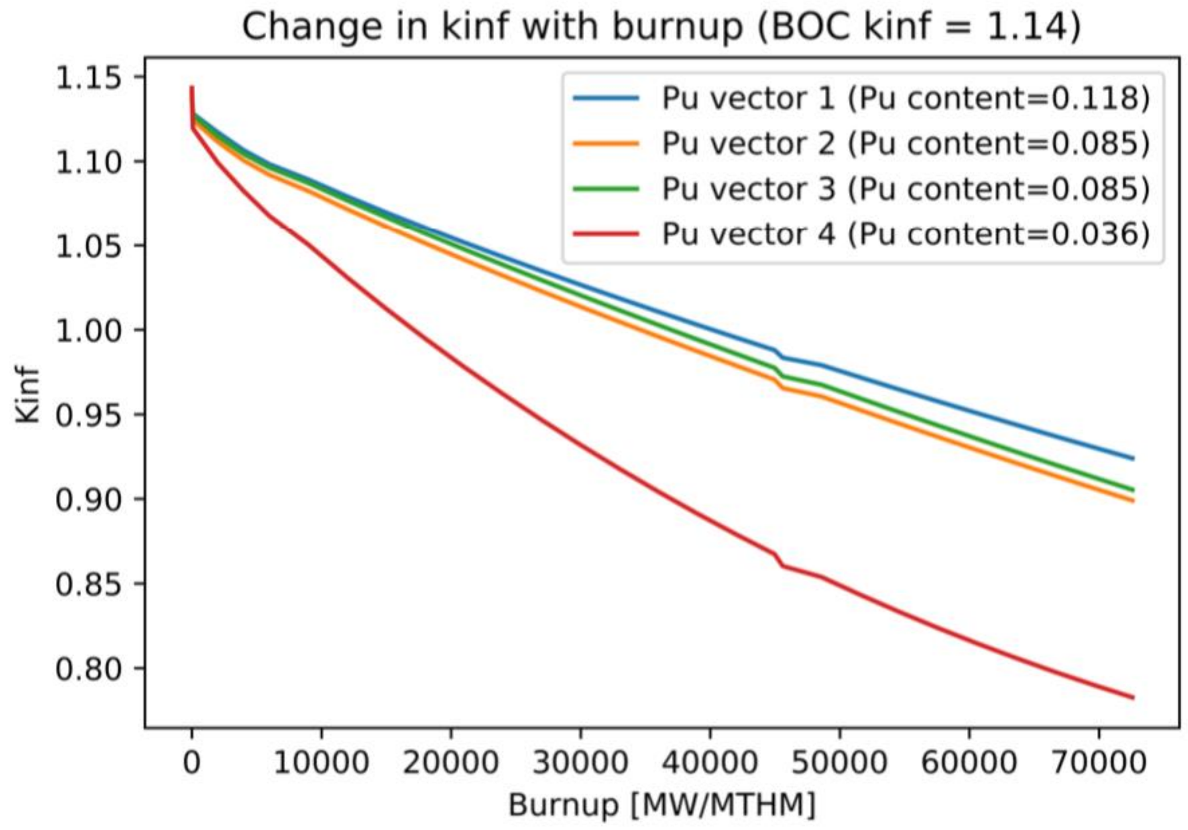
Varying Sensitivity to Burnup



Varying Sensitivity to Burnup



Shortcomings of EFMC

- Problem with current method:
  - RFF is not indicative of the fuel's capability to remain critical after burnup (burnup – scalability)
  - The EFMC method does not account for breeding effects

Improvements to EFMC

- BOC RFF -> EOC RFF
- Cold run to find Pu content so that EOC RFF is a certain value
- Easier to scale with burnup

Improvements to EFMC - 2

- Increase accuracy in higher burnups by adding a second term to calculate fissile value.
- Second term is a function of breeding potential (Effective Secondary Mass Coefficient – ESMC) and burnup.

$$(EMFC_i)(AFV) \rightarrow (EMFC_i)(AFV) + (ESMC_i)\varepsilon(BU)(AFV)$$

For example, for $^{240}\boldsymbol{Pu}$,

$$\mathrm{ESMC}_{Pu240} = f(\sigma_{a,Pu240}, \sigma_{f,Pu241})$$

Alternative

- Neural network approach by Leniau et al

(+) Accurate prediction

(+) Small computational burden

(-) Large data required for training

(-) May lack flexibility

Conclusion

- Fixed Fraction (FF) Method is not enough
- EFMC is a good estimator
- EFMC does not take into account future burnup
- Need for more complex methods

Thanks!

Discussion?

What is a `good' MOX? (Criterion)

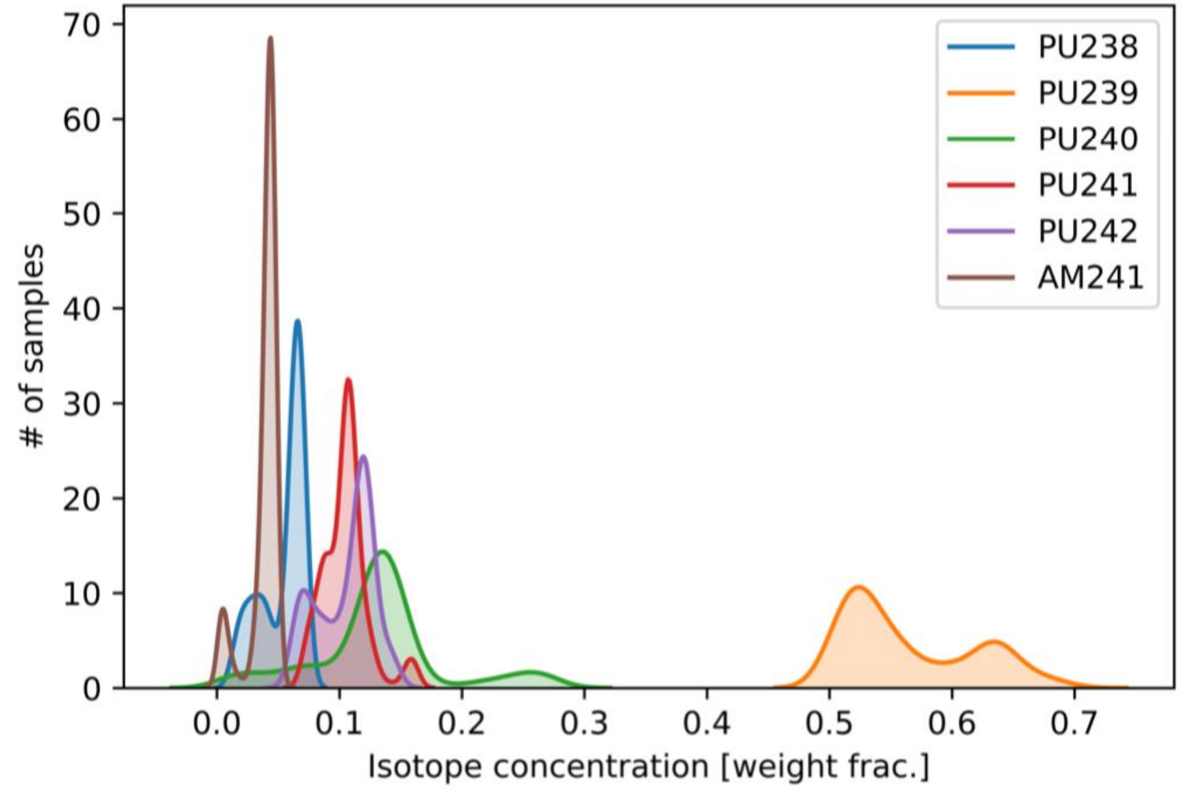
How do we validate fuel cycle simulator functionalities?

(FIT)
What is the most effective, robust way to calculate MOX Fabrication?

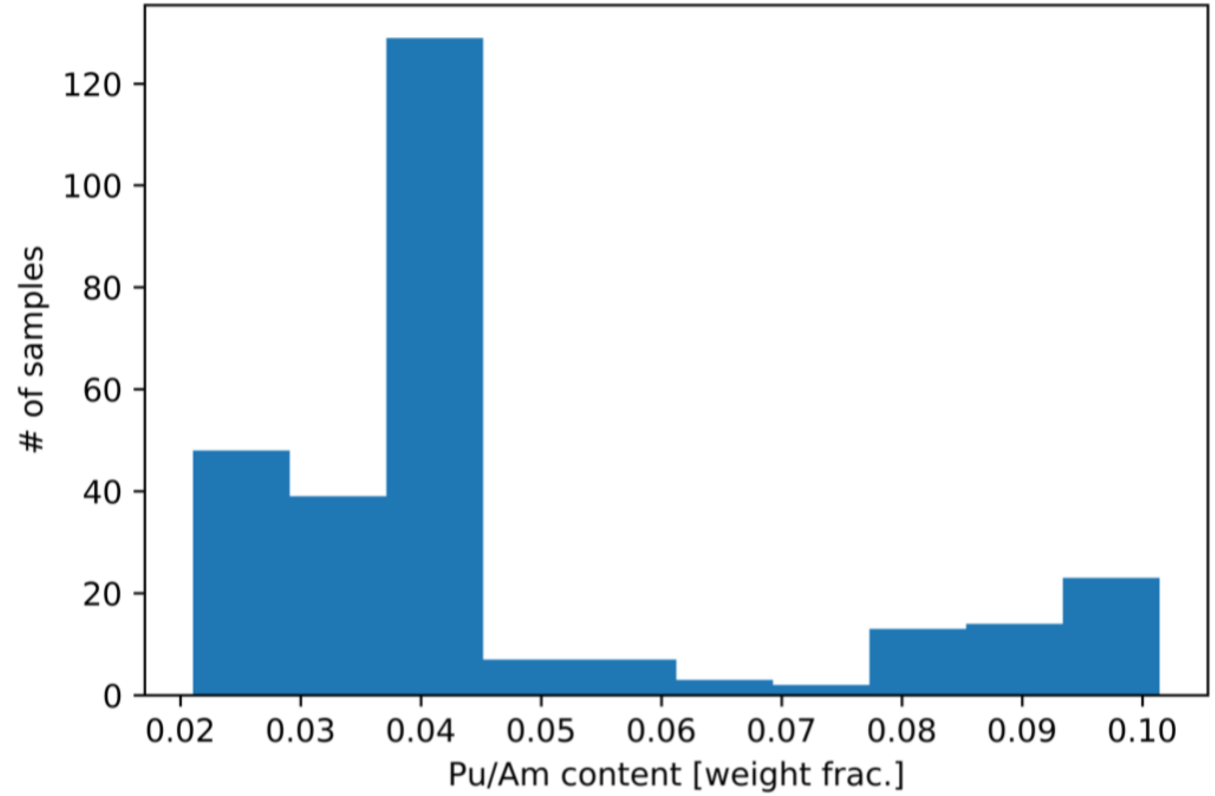
Method

- Compare EFMC vs FF
- Compare EFMC vs SCALE / TRITON

Comparison with FF Method



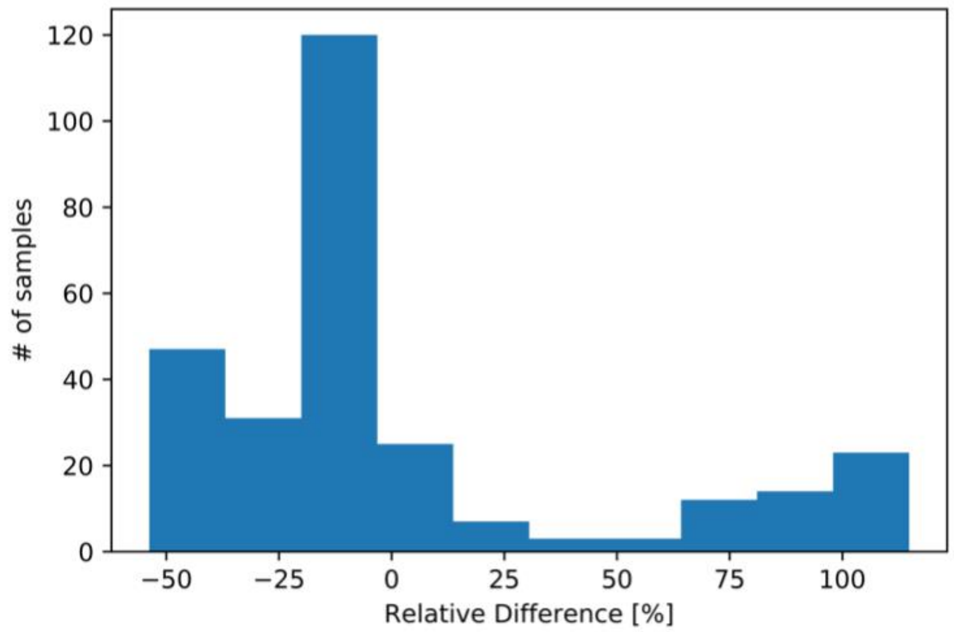
Comparison with FF Method



FF vs EFMC Difference

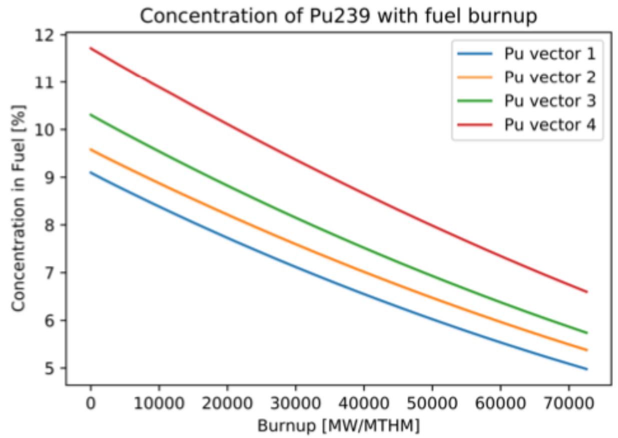
Average TRU content of 4.731%.

$$\delta F(TRU_i) = \frac{F_{EFMC}(TRU_i) - F_{FF}(TRU_i)}{F_{FF}(TRU_i)}$$

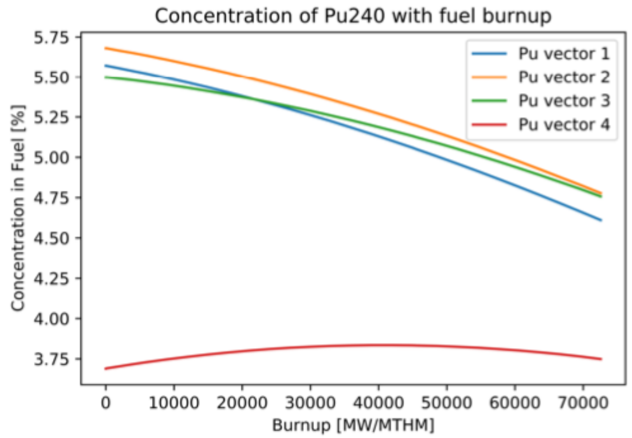


Varying Sensitivity to Burnup

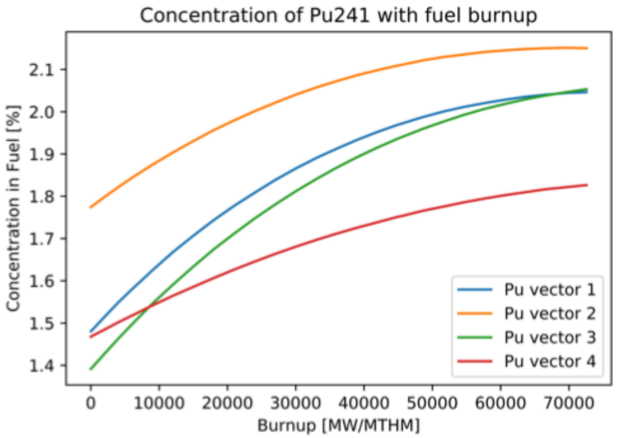
- Each MOX fuel have varying sensitivity to burnup



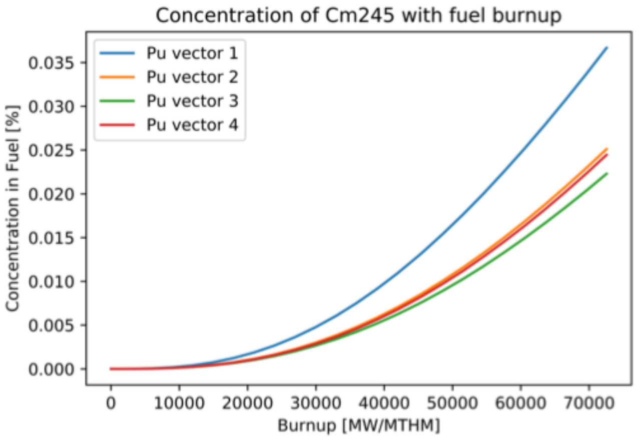
(a) Pu-239



(b) Pu-240



(c) Pu-241



(d) Cm-245

Background and Motivation

- Functionality Isolation Test
- Myriad of nuclear fuel cycle simulators (NFCs)