Functionality Isolation Test for Fuel Cycle Code ORION – MOX Fabrication

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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 isotopes

- 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:

\[ ENP_i = (\bar{\nu}_i - 1) \times \sigma_{f,i} - \sigma_{a,i} \]

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:

- 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) $k_{\text{inf}}$ value
Good MOX Criteria

• Good MOX is set to be MOX with:
  – EOC $k_{\text{inf}} = 1.03$

  – MOX Fuel with 4 different plutonium vectors
    • For each plutonium vector:
      – Search for Pu Content that makes EOC $k_{\text{inf}} = 1.03$
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
Varying Sensitivity to Burnup

![Graph showing change in kinf with burnup (Pu content = 0.18)]

- Pu vector 1 (m=-2.72E-06)
- Pu vector 2 (m=-2.85E-06)
- Pu vector 3 (m=-2.70E-06)
- Pu vector 4 (m=-3.23E-06)
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 \(^{240}Pu\),

\[ESMC_{Pu240} = f(\sigma_{a,Pu240}, \sigma_{f,Pu241})\]
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
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%.

\[
\delta F(\text{TRU}_i) = \frac{F_{\text{EFMC}}(\text{TRU}_i) - F_{\text{FF}}(\text{TRU}_i)}{F_{\text{FF}}(\text{TRU}_i)}
\]
Varying Sensitivity to Burnup

- Each MOX fuel have varying sensitivity to burnup
Background and Motivation

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