Nuclear Waste Assessment System for Technical Evaluation (NUWASTE)

Presented to: **NWTRB Workshop on Evaluation of Waste Streams Associated with LWR Fuel Cycle Options**

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Agenda

- Objectives
- Principles
- Structure
- Waste Stream Calculation
- Assembly Processing
- Calculation Methodology

Objectives

- Understand the impacts of potential fuel cycle initiatives on the generation and management of SNF, HLW and other radioactive waste streams.
- Create ability to vary system inputs to represent different initiatives that DOE may consider.
- Evaluate the impact on selected parameters, such as:
    - Number of surface dry storage casks required
    - Number of disposal waste packages generated
    - Mass of natural uranium required
    - New waste streams
    - Proliferation risk
    - Cost

Principles

- Based on simple material balances of assemblies and masses
- Built on fundamental physics concepts and methods
- Covers the full life cycle of US nuclear power production and waste disposition
- Utilizes data from open literature and DOE documents
- Deterministic methodology that enables the user to explore the sensitivity to various inputs
- Currently focused on present light water reactor and reprocessing technology

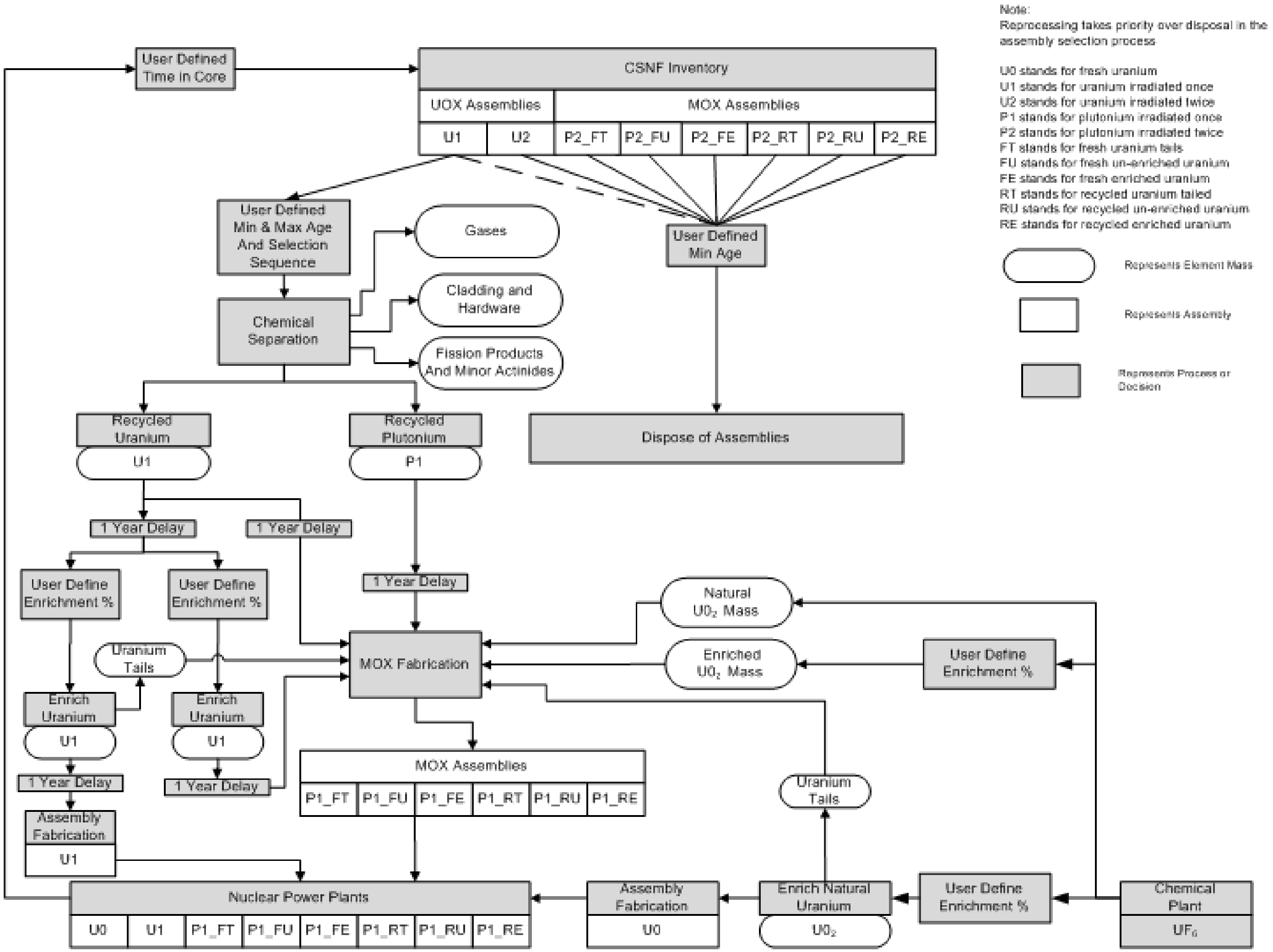
Structure

Isotopes

- Waste Stream Quantities
  - Initial conditions
  - Assembly discharge projections
- Assembly Processing
  - Material balance
    - Mass
    - Assemblies
  - Transitions
    - Mass to assemblies
    - Assemblies to mass
      - Isotopic concentrations determined using ORIGEN/SCALE 6.0
      - NUWASTE uses a linear relationship as a function of burn-up to determine each isotope concentration

NUWASTE Structure (Cont'd)

NUWASTE Functional Diagram



Note:
Reprocessing takes priority over disposal in the assembly selection process

U0 stands for fresh uranium
U1 stands for uranium irradiated once
U2 stands for uranium irradiated twice
P1 stands for plutonium irradiated once
P2 stands for plutonium irradiated twice
FT stands for fresh uranium tails
FU stands for fresh un-enriched uranium
FE stands for fresh enriched uranium
RT stands for recycled uranium tailed
RU stands for recycled un-enriched uranium
RE stands for recycled enriched uranium

Waste Stream Calculation

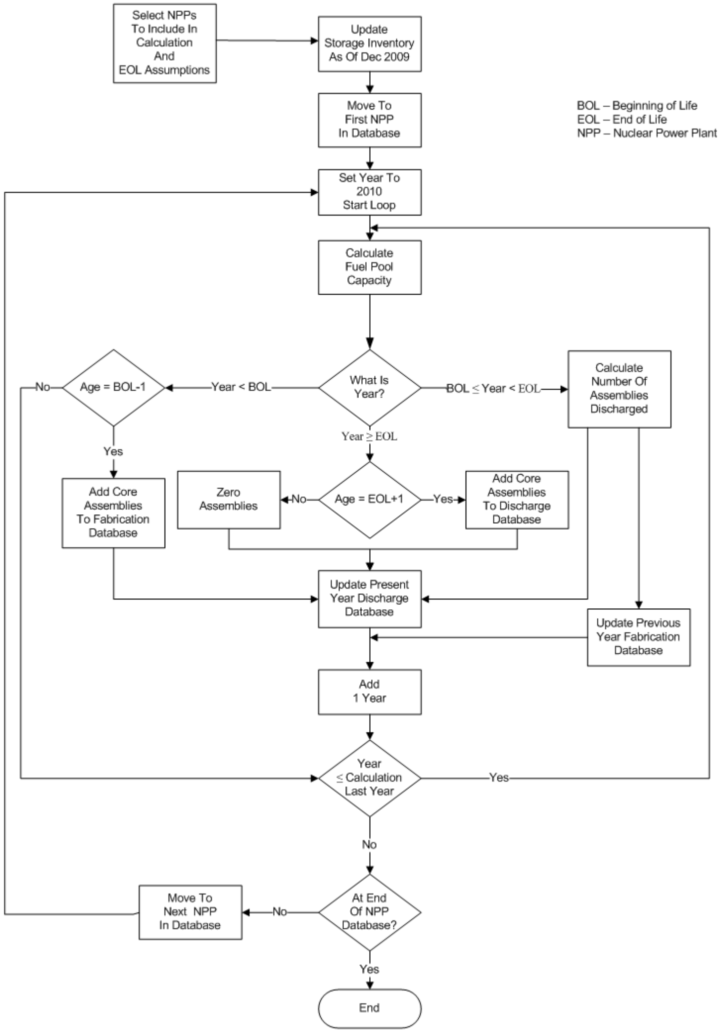
- Initial Conditions
  - Plant parameters
    - MW_t, MW_e, Core size, Fuel pool size, BOL, EOL, Life extension status
  - Assembly storage status as of December 2009
    - Wet storage
      - MTHM
      - Number of assemblies
    - Dry storage
      - MTHM
      - Number of assemblies
      - Number of dry storage casks

Waste Stream Calculation (Cont'd)

- Assembly Discharge Calculation
  - Life extension
    - Life extension status
      - Extended
      - Application submitted
      - No application submitted
    - Life extension duration
      - User input
      - Generally use 20 years
  - Plants to include in calculation
    - Present plants only
    - Present plus planned plants
    - Sufficient plants to maintain present nuclear generating capacity

Waste Stream Calculation (Cont'd)

Waste Stream Flow Chart



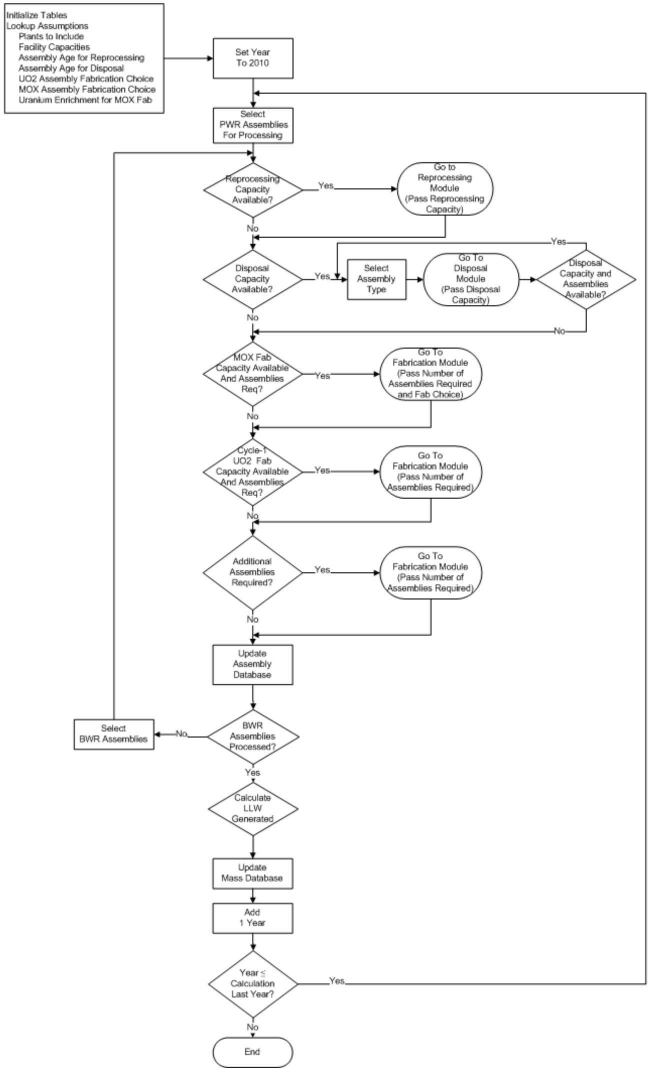
BOL – Beginning of Life
EOL – End of Life
NPP – Nuclear Power Plant

Assembly Processing

- Program Contains Two Nested Loops
  - Primary loop cycles through assembly type (PWR or BWR)
    - PWR assemblies are processed first
    - Processing sequence:
      - Assembly reprocessing (fresh uranium UOX only)
      - Assembly disposal
        - MOX assemblies
        - Fresh uranium UOX assemblies
        - Separated uranium UOX assemblies
      - Assembly fabrication
        - MOX assemblies
        - Fresh uranium UOX assemblies
        - Separated uranium UOX assemblies
  - Secondary loop cycles through years
    - Starts at 2010
    - End date is a user defined variable

Assembly Processing

Assembly Processing Flow Chart



Calculation Methodology

- Calculation of Assembly Fabrication and Core Discharges
  - Full core loading assembly fabrication one year before BOL
  - Assume plants start operation on January 1 of BOL year
  - Assume same number of assemblies discharged each year during plant operation after 2009

$$Assemblies/year = \frac{MW_t \times CapacityFactor \times 365 days/year}{{}^{MWdays}\!/_{MTU} \times {}^{MTU}\!/_{Assembly}}$$

  - Full core discharge the year after plant shutdown

Calculation Methodology (Cont'd)

- Enrichment (Ref: *Management of Reprocessed Uranium*)

Reference 8

$$d_i = c_i \times \frac{b}{a} \times f_i$$

Where:
a = ^{235}U initial concentration
b = ^{235}U final concentration
c_i = Initial concentration of isotope i
d_i = Final concentration of isotope i
f_i = Factor to account for the mass difference between ^{235}U and isotope i

- Feed and Tails Mass (Simple mass balance)

$$T = E \times \frac{(e - f)}{(f - t)}$$

$$F = E \times \frac{(e - t)}{(f - t)}$$

Where:
F = Mass of uranium feed
E = Mass of enriched uranium
T = Mass of tails
f = Weight % of ^{235}U in feed mass
e = Weight % of ^{235}U in enriched mass
t = Weight % of ^{235}U in tails mass

Calculation Methodology (Cont'd)

- 2nd Cycle UOX Assembly Fabrication (Ref: *Compensation for ^{236}U in the Fuel of the VVER-440*)

Reference 9

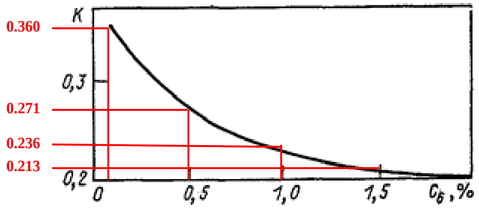


Fig. 1. Dependence of compensation factor on initial ^{236}U content in the fuel of the VVÉR-440.

Red indicates items added to original figure

–For ^{236}U concentrations less than 1.0%:

$$\varpi\%_{U235}^{\text{New Assembly}} = \varpi\%_{U235}^{\text{Reference}} + 0.233 \times \left(\varpi\%_{U236}^{\text{Reprocessed}} \times \frac{\varpi\%_{U235}^{\text{New Assembly}}}{\varpi\%_{U235}^{\text{Reprocessed}}} \times 0.71\right)^{0.808}$$

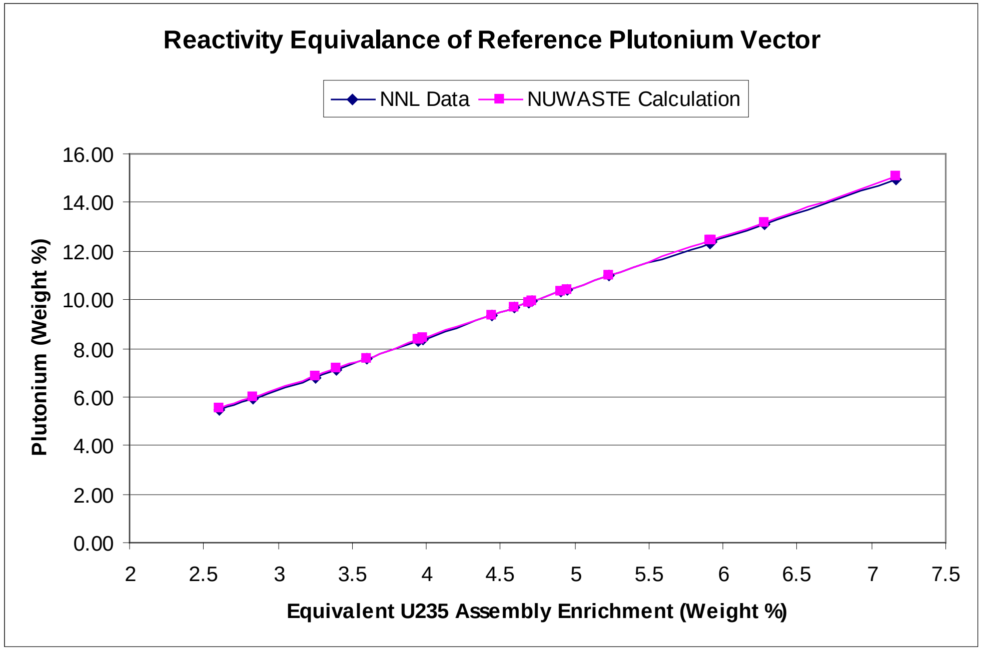
–For ^{236}U concentrations greater than 1.0%:

$$\varpi\%_{U235}^{\text{New Assembly}} = \frac{\varpi\%_{U235}^{\text{Reference}}}{1 - 0.142 \times \dfrac{\varpi\%_{U236}^{\text{Reprocessed}}}{\varpi\%_{U235}^{\text{Reprocessed}}}}$$

Calculation Methodology (Cont'd)

- MOX Assembly Fabrication (Ref: UK NNL memo)
  - For a reference plutonium vector, the plutonium content as a function of equivalent UOX assembly (blue line):

Reference 11



  - Linear function that can be represented by (red line):

$$\text{Pu Content}_{\text{ref}} = 2.086622807 \times (\text{Equivalent UOX Enrichment}) + 0.090394737$$

Calculation Methodology (Cont'd)

- The required plutonium content, assuming a different plutonium vector, can be calculated using:

$$\text{Pu Content}_{\text{actual}} = \text{Pu Content}_{\text{ref}} \times \frac{\text{Pu Quality}_{\text{ref}}}{\text{Pu Quality}_{\text{actual}}} \qquad \text{where:}$$

$$\text{Pu Quality} = \sum_{\text{All Pu Nuclides}} \text{Pu Vector}_{\text{i}} \times \text{Effective Fissile Coefficient}_{\text{i}}$$

- Above calculation assumes 0.2 % ^{235}U in source uranium. To adjust for a uranium content different from 0.2%:

$$\text{Amount Pu Content Must be Adjusted} = \left(\frac{\text{Pu Content}_{\text{actual}}}{\text{Equivalent UOX Enrichment-0.2)}}\right) \times (\%\,^{235}\text{U in MOX Assembly-0.2)}$$

Calculation Methodology (Cont'd)

- LLW (Ref: DOE document *FCRD-USED-2010-000033,* Rev 0)

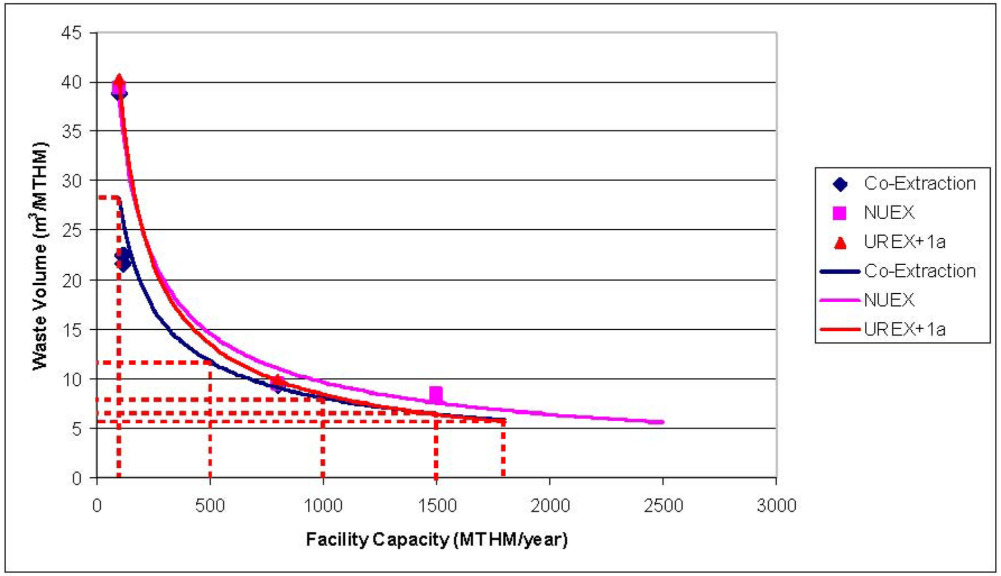


Figure EX-2
Low Level Waste Volume For Aqueous Recycling

  - Mathcad was used to develop function:

$$\text{LLW Volume} = \text{Mass}_{\text{Reprocessed}} \times 406.912 \times \text{Capacity}^{-0.569}$$

Direction for Further Analysis and Development

- Identify and evaluate additional scenarios
  - New data sets
  - Further insights and sensitivity analysis
- Gain feedback from June workshop
- Explore impact of natural uranium mining on nuclear waste generation
- Incorporate additional functionality
  - Facility cost
- Consider extending NUWASTE capabilities
  - Centralized storage capacity needs
  - Transportation requirements at various fuel cycle stages
  - Alternative reprocessing and reactor technologies
  - Disposition of DOE HLW and SNF