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

• 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)
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)
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
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

\[
Assemblies / \text{year} = \frac{MW_t \times \text{CapacityFactor} \times 365 \text{days} / \text{year}}{MW \text{days} / \text{MTU} \times \text{MTU} / \text{Assembly}}
\]

– Full core discharge the year after plant shutdown
Calculation Methodology (Cont'd)

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

\[ d_i = c_i \times \frac{b}{a} \times f_i \]

Where:
- \( a = ^{235}\text{U} \) initial concentration
- \( b = ^{235}\text{U} \) 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 \( ^{235}\text{U} \) 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 \( ^{235}\text{U} \) in feed mass
- \( e \) = Weight % of \( ^{235}\text{U} \) in enriched mass
- \( t \) = Weight % of \( ^{235}\text{U} \) in tails mass
Calculation Methodology (Cont'd)

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

\begin{align*}
\omega \%^{\text{New Assembly}}_{U235} &= \omega \%^{\text{Reference}}_{U235} + 0.233 \times (\omega \%^{\text{Reprocessed}}_{U236} \times \frac{\omega \%^{\text{New Assembly}}_{U235}}{\omega \%^{\text{Reprocessed}}_{U235}} \times 0.71)^{0.808} \\
\text{For } 236\textsuperscript{U} \text{ concentrations less than 1.0%:}

\omega \%^{\text{New Assembly}}_{U235} &= \frac{\omega \%^{\text{Reference}}_{U235}}{1 - 0.142 \times \frac{\omega \%^{\text{Reprocessed}}_{U236}}{\omega \%^{\text{Reprocessed}}_{U235}}} \\
\text{For } 236\textsuperscript{U} \text{ concentrations greater than 1.0%:}
\end{align*}

Fig. 1. Dependence of compensation factor on initial 236\textsuperscript{U} content in the fuel of the VVER-440.

Red indicates items added to original figure
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):

  \[ \text{Pu Content}_{\text{ref}} = 2.086622807 \times (\text{Equivalent UOX Enrichment}) + 0.090394737 \]
Calculation Methodology (Cont'd)

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

\[
\text{Pu Content}_{\text{actual}} = \text{Pu Content}_{\text{ref}} \times \frac{\text{Pu Quality}_{\text{ref}}}{\text{Pu Quality}_{\text{actual}}}
\]

where:

\[
\text{Pu Quality} = \sum_{\text{All Pu Nuclides}} \text{Pu Vector}_i \times \text{Effective Fissile Coefficient}_i
\]

• Above calculation assumes 0.2 % \(^{235}\text{U}\) in source uranium. To adjust for a uranium content different from 0.2%:

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


Calculation Methodology (Cont'd)

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

- Mathcad was used to develop function:

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

![Graph showing Low Level Waste Volume for Aqueous Recycling](image.png)
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