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Determination of Repository Loading Values in Fuel Cycle Analysis Codes

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Outline

- Motivation and Goals
- Background
- Model Development
  - Drift wall at emplacement
  - Drift wall at closure
  - Mid-drift at all times
- Model Implementation
- Results
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Motivation and Goals

- Motivation
  - Fuel cycle scenario analysis codes use mass as a metric for loading, cost, and limits
  - No dependence on isotopics → no measure of true repository benefit
- Goals
  - Develop a model to determine repository loading for an arbitrary set of isotopics
  - Implement this model into a fuel cycle scenario analysis code
  - Study the benefit of various reactor combinations with respect to repository loading

Technical Limits of Geologic Repository

- Limits are dose to the public
  - 15 mrem/yr for 10,000 years and 350 mrem/yr out to 1 million years
- Assumption that waste package will fail
- Desire to…
  - Limit the amount of water that enters the repository at one time
  - Ensure that the water takes a long time to travel through the rock

Repository Limits (Cont)

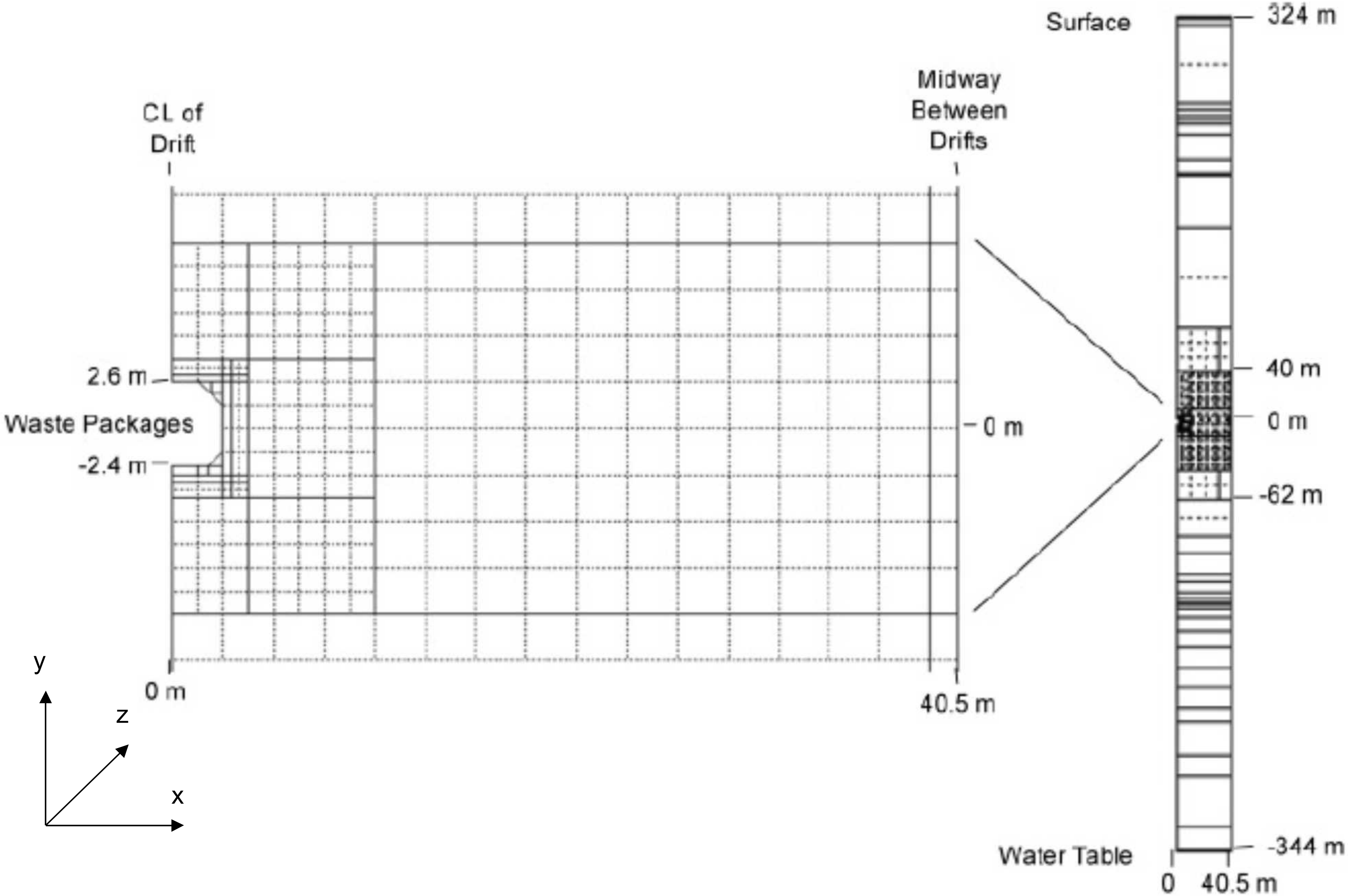
- 2 temperature limits
  - Between drifts < 96˚C
  - Drift wall < 200˚C

- 3 limiting points
  - 200˚C at emplacement – drift wall
  - 200˚C after air flow turned off – drift wall
  - 96˚C thousands of years later – between drifts

Yucca Mountain Thermal Model

- Developed at Argonne by Ted Bauer in the SINDA/G heat transfer code
- Uses current specifications for Yucca Mountain geometry
- Models…
    - Different heat transfer properties for different rock layers
    - Changes in heat transfer properties above boiling
    - Flow of air through the repository
    - Effects of adjacent waste packages

Yucca Mountain Thermal Model



Model Development
Drift Wall Limit at Emplacement

- If the thermal time constant of the rock was shorter than the decay constant of the waste

$$D\rho_{limit}C' = \Delta T$$

- With the decay heat decreasing rapidly

$$\rho_{limit} = \frac{C}{D_{eff}} = \frac{C}{(D_o + a\Delta D)}$$

- From four full cases *C* and *a* were determined to be 7085.9 [W/m] and 0.9023 respectively

Model Analysis
Drift Wall Limit at Emplacement

- Four additional fuel vectors were run in the reference model, for a total of 8 cases

Spent Fuel Composition	Reference Loading (kg/m)	Prediction Accounting for Rate of Change (kg/m)	Difference (%)	Prediction with Constant Limit (kg/m)	Difference (%)
LSF	1100.59	1100.75	0.01	1113.98	1.22
HLW	87.43	88.77	1.53	99.74	14.09
UOX51	1100.65	1100.75	0.01	1113.98	1.21
UOX100	570.17	569.82	-0.06	582.04	2.08
IMF-PNAC	12.90	13.71	6.23	12.05	-6.58
IMF-PNA-2	488.50	488.96	0.09	485.08	-0.70
IMF-PNA-4	437.10	436.88	-0.05	435.28	-0.42
MOX-PN to CFR-2	10.99	11.73	6.73	10.12	-7.94

- Average difference of 4.3% with a maximum of 14.1% with constant limit
- Average difference of 1.8% with a maximum of 6.7% when rate of change of decay heat is accounted for

Model Development
Drift Wall Limit at Closure

- Decay heat not changing quickly

$$\rho_{limit} = \frac{C}{D_C}$$

- Six cases used to determine C
  - 662 W/m (RMS error: 16 W/m, 2.4%)
- Six additional cases were run to test the accuracy
  - RMS error: 21 W/m, 3.2%
- Estimated loading limit
  - Average difference of 2.4%
  - Maximum of -6.4%

Model Analysis
Drift Wall Limit at Closure

Spent Fuel Composition	Predicted Loading (kg/m)	Reference Loading (kg/m)	Difference (%)
SF	1002.74	1045.74	-4.11
UOX33	1929.95	2061.53	-6.38
MOX-PNA-1	108.22	105.61	2.47
MOX-PNA-2	52.13	51.53	1.17
MOX-PNA-3	34.44	34.27	0.49
MOX-PNA-5	22.03	22.08	-0.22
UOX to CFR 1	57.31	55.82	2.67
MOX-PN to CFR-5	12.55	12.26	2.37
UOX to 25 Fr-2	56.73	56.23	0.89
IMF-PN to BFR-1	52.71	54.29	-2.91
UOX to BFR-3	292.34	284.81	2.64
IMF-PN to BFR-4	157.65	160.82	-1.97

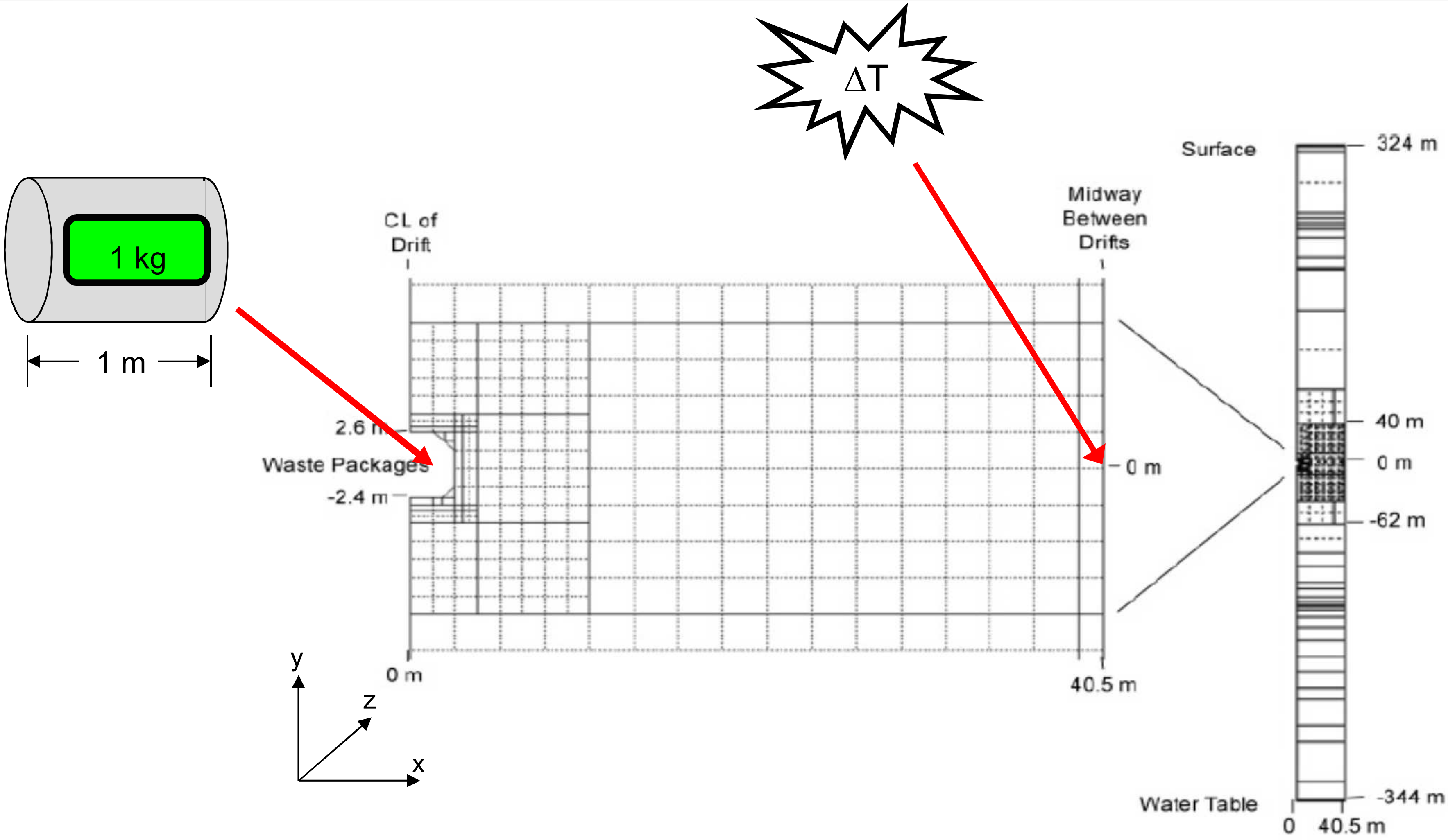
Model Development Between Drift Limit

- Very isotope dependent
  - peaks at different times
  - hard to predict
- Used reference model to obtain vectors of specific temperature change (STC) in time, in units of K/(kg/m)

$$\rho_{limit} = \frac{\Delta T}{\max\left(\sum_{isos} MF_i * \Delta\bar{T}_i(t)\right)}$$

- Select the maximum value as the time the peak temperature is reached

Model Development Between Drift Limit



Model Development Between Drift Limit

- Temperature vector in time

$$\left[20.55^\circ C, 22.55^\circ C, 24.55^\circ C, \ldots\right]$$

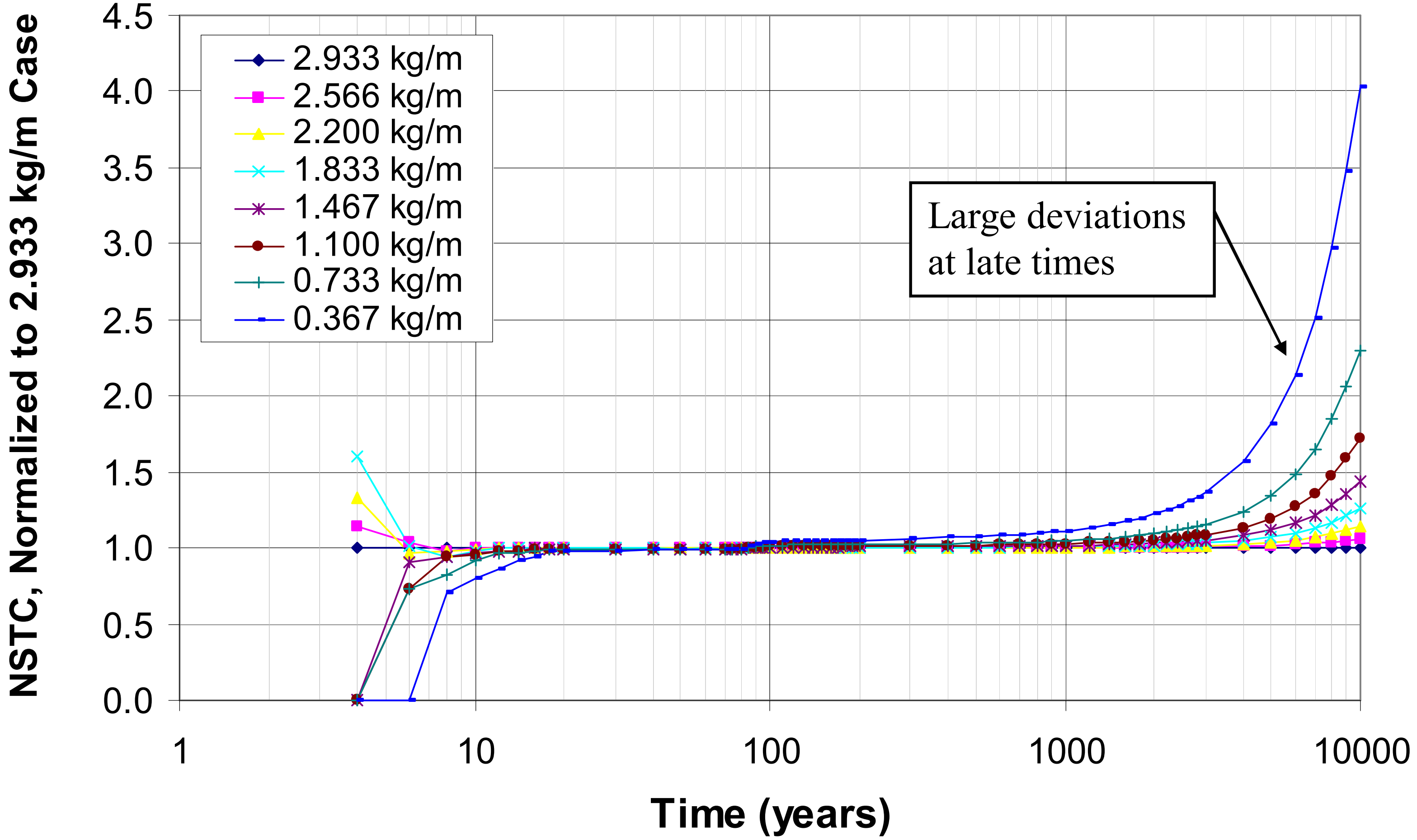
- Subtract starting temperature ➔ change in temperature

$$\left[0.0K, 2.0K, 4.0K, \ldots\right]$$

- Divide by the mass loading ➔ STC

$$\left[0.0K, 2.0K, 4.0K, \ldots\right] \div 2.0\frac{kg}{m} = \left[0.0\frac{K}{(kg/m)}, 1.0\frac{K}{(kg/m)}, 2.0\frac{K}{(kg/m)}, \ldots\right]$$

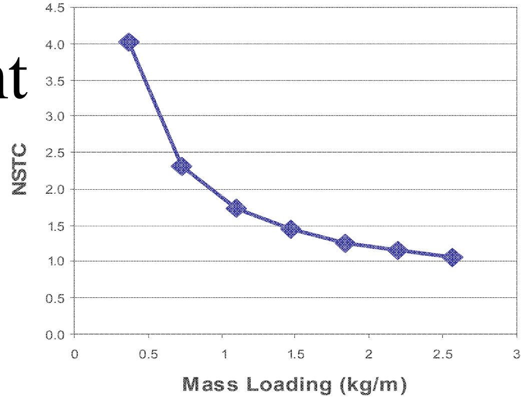
Between Drift Limit
Superposition Analysis – Single Isotope



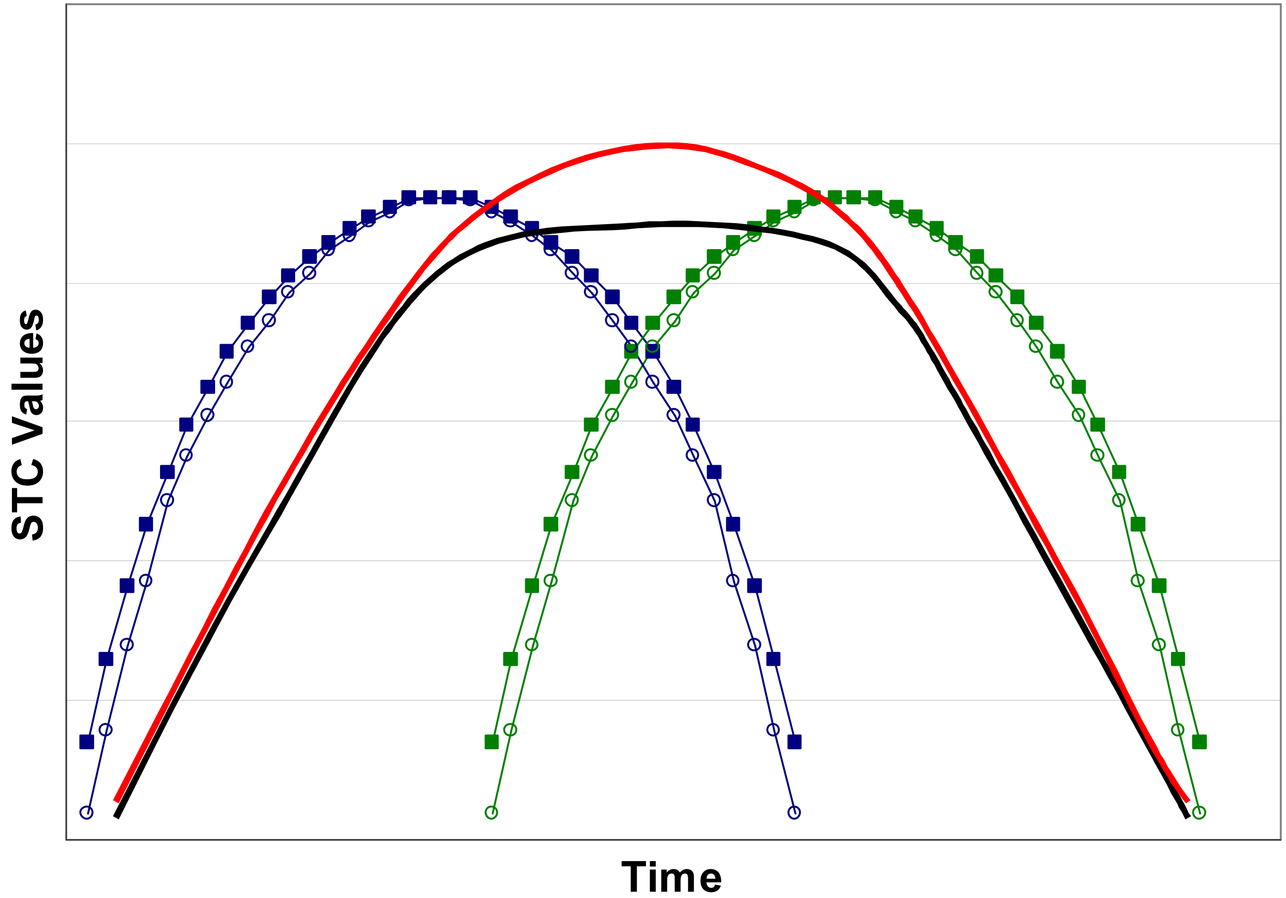
Between Drift Limit
Superposition Analysis – Single Isotope

- Single isotope summary
  - Underlying current effects STC vectors
  - Less effect is seen at higher temperatures
  - Boiling shifts peak to later times

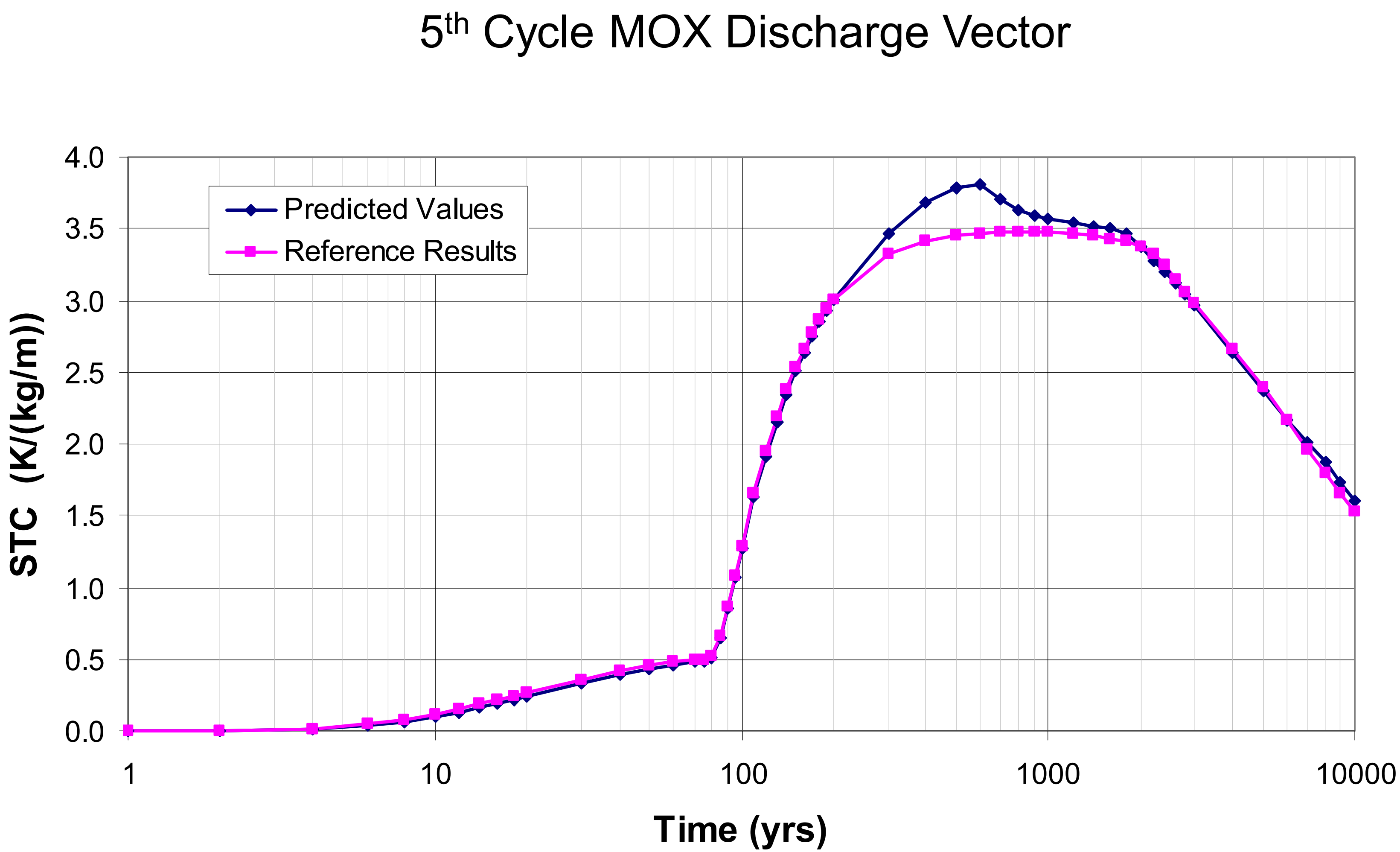
- "Running at the limit"
  - Minimize effect of underlying current
  - Effect of boiling included



Between Drift Limit
Superposition Analysis – Two Isotopes

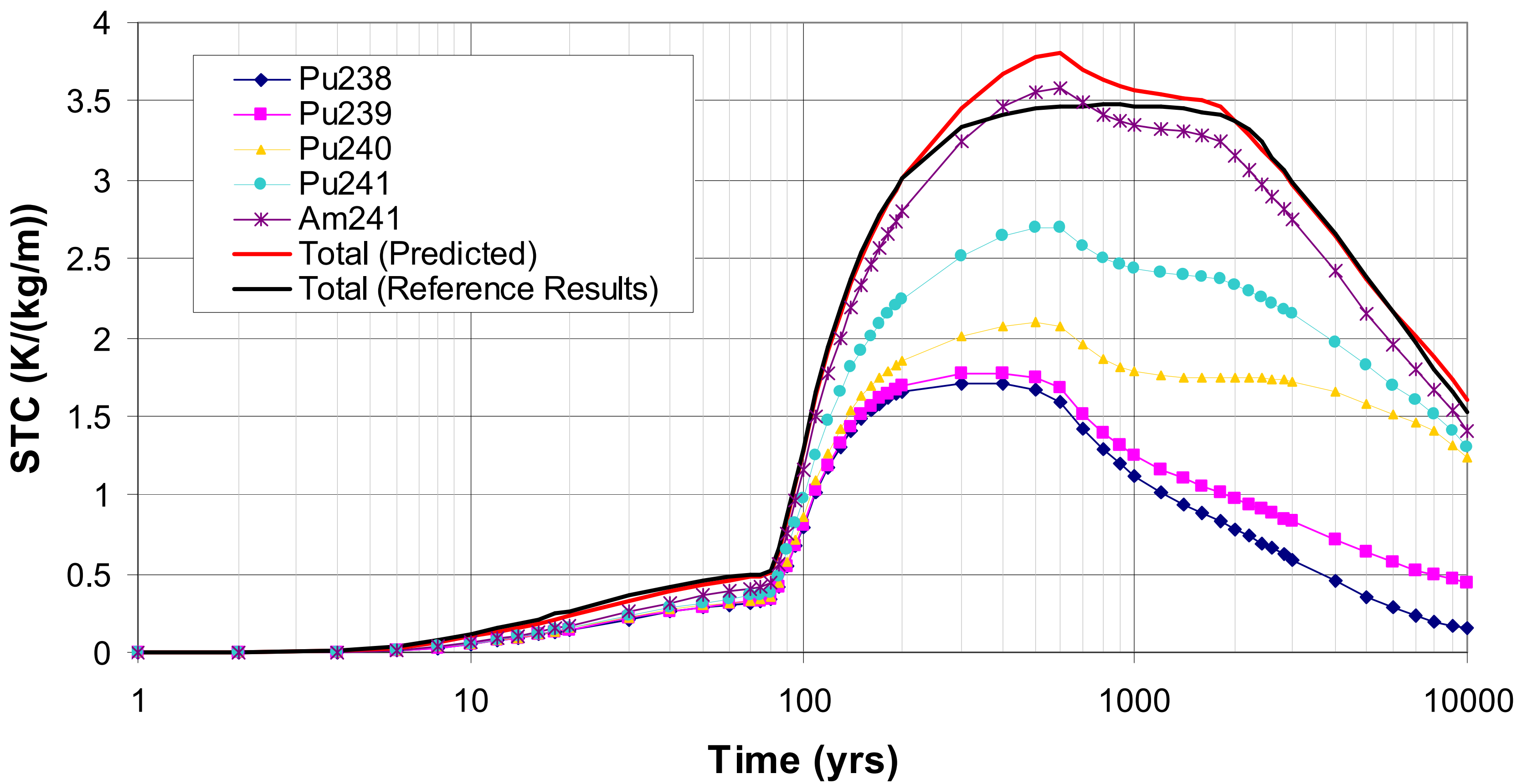


Between Drift Limit
Superposition Analysis – Full Fuel Isotopics

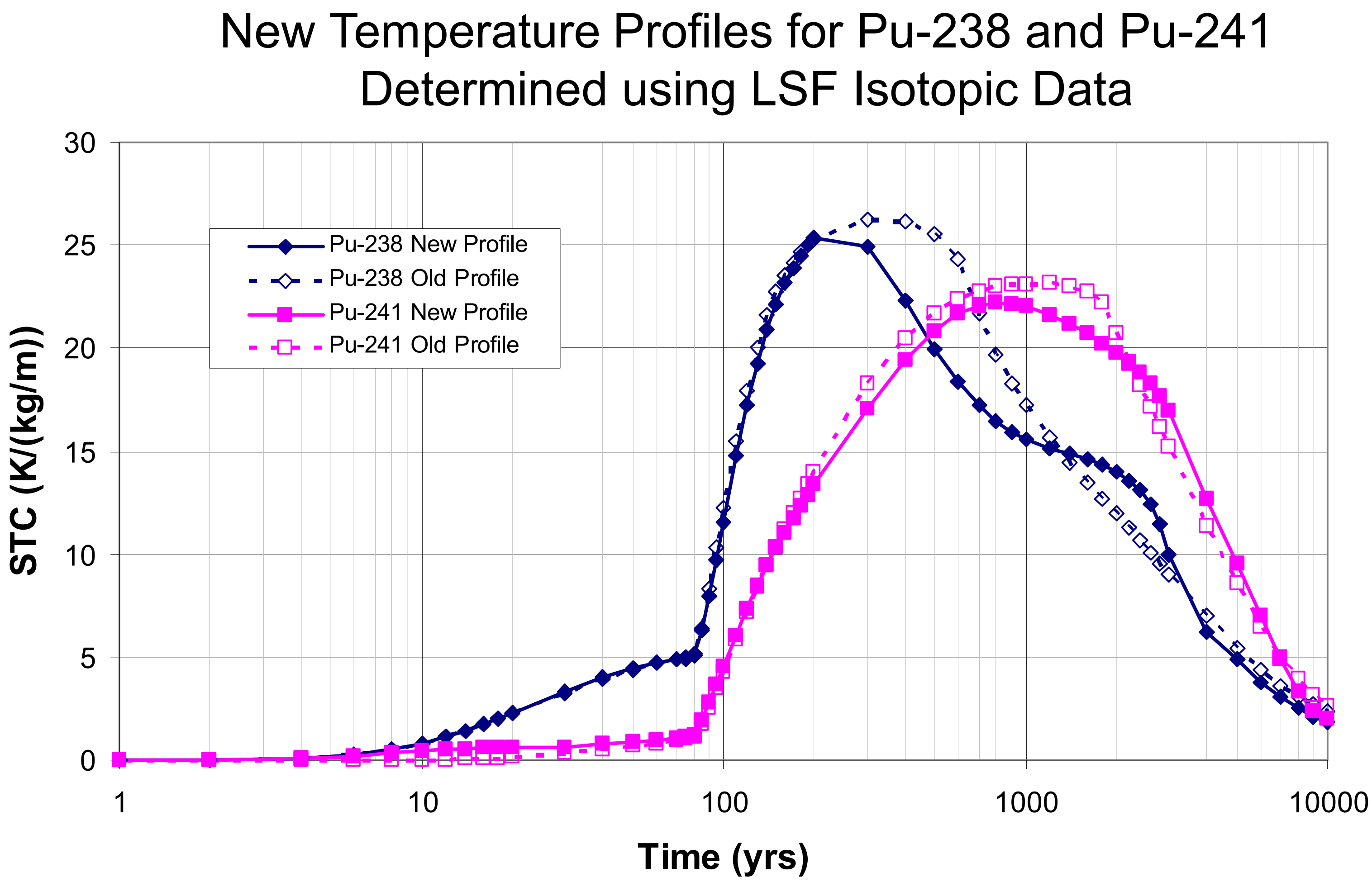


Between Drift Limit
Superposition Analysis – Full Fuel Isotopics

5th Cycle MOX Discharge Vector

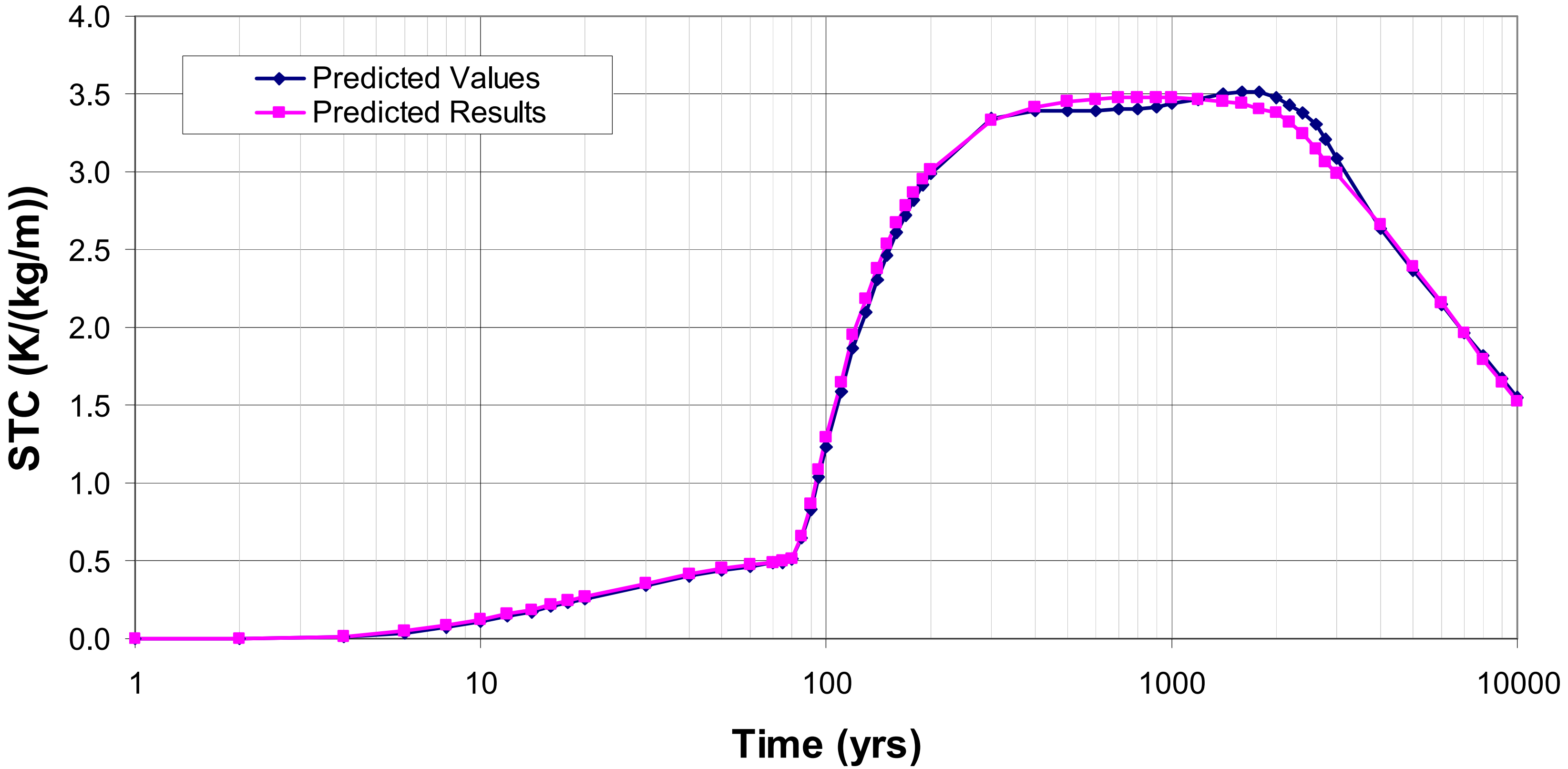


Between Drift Limit
Superposition Analysis – Full Fuel Isotopics



Between Drift Limit Superposition Analysis – Full Fuel Isotopics

5th Cycle MOX Discharge Vector



Model Analysis Between Drift Limit

- Average difference of 2.9% with a maximum difference of -7.6% for 21 full fuel vectors
- Differences correspond with time of peak
  - Largest difference when peak is after 1400 years
- New profiles run with LSF case which peaks around 1000 years

Model Implementation
General

- Seven waste streams entering or leaving the repository in kg/yr
  - HLW, LSF, and SF entering retrievable repository
  - LSF and SF from retrievable to permanent repository
  - LSF and SF out of repository to reprocessing
- Each of the three limits calculated separately
- Maximum length rate [m/yr] selected from the three

Model Implementation
Drift Wall Limit at Emplacement

- Isotopic decay heat values at 0 and 0.3 years were added to VISION

$$\dot{L} = \frac{\dot{m}D_{eff}}{C} = \frac{\dot{m}\left[\dfrac{\sum_i \dot{m}_i D_{eff_i}}{\sum_i \dot{m}_i}\right]}{C} = \frac{\sum_i \dot{m}_i D_{0,i} + a\left(\sum_i \dot{m}_i D_{0.3,i} - \sum_i \dot{m}_i D_{0,i}\right)}{C}$$

Model Implementation
Drift Wall Limit at Closure

- Isotopic decay heat values from 0 to 160 years in 5 year increments were added to VISION
- Year of closure constant added
- Years to closure index
  - (year of closure – current year)/5

$$\dot{L} = \frac{\sum_{isos} \dot{m}_i D_{Yrs2Close,i}}{C}$$

Model Implementation Between Drift Limit

- STC vectors added to VISION
  - 57 values at times from 1 to 10,000 years
- ΔT is difference between ambient temperature and boiling 75.443 °C

$$\dot{L} = \frac{MAX\left(\sum_{isos} \dot{m}_i \Delta \overline{T}_i(t)\right)}{\Delta T}$$

- Maximum selected as the limiting point in time

Model Implementation
Additional Calculations

- Mass loading factor (MLF)

$$MLF = \frac{\text{mass in repository}}{\text{length in repository}}$$

- Energy loading factor (ELF)

$$ELF = \frac{\text{mass of FPs in repository} * \text{conversion factor}}{\text{length in repository}}$$

$$\frac{1\_mole\_U_{235}}{232.4\_g\_FPs} \times \frac{6.022\times10^{23}\,atoms}{1\_mole} \times \frac{193MeV}{1\_atom\_U_{235}} = 5.00\times10^{23}\frac{MeV}{g} = 0.925\frac{GWd}{kg}$$

- Calculated for five repository stocks and overall
- Increase in calculation time of 5 seconds, to 110 seconds

Results
Base Cases

- – Separation efficiencies of 0.2% and 99.8%
- – Closure date of 2130
- – Base cases include 57 reactor combinations

- Cases involving UOX had lower ELFs
- Largest ELF benefit over UOX-UOX was 2.4 times
  - Initially 5 time better, but limited by temperature at closure late in the simulation

Results
Sensitivities

- Separation efficiency
  - Factor of ten increase in efficiency (to 0.02% and 99.98%) resulted in less than 1% improvement in ELF
- Date of Closure
  - Delay of 20 years (to 2150) resulted in a 50% increase in ELF for some cases
- Separation of Cs & Sr to different waste stream
  - ELF increases to over 285 times that of UOX-UOX with 0.2% of Cs & Sr being sent to HLW

Summary

- Models were developed to accurately predict repository loading based on the three limits
- Module implemented into VISION to calculate repository loading at every timestep
- Results show importance of closure date and separation of Cs & Sr
- Module will be included in VISION 1.6.0

Questions

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