NBSR Spent Fuel Depletion and Decay Heat Determination Using SCALE

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NBSR Coolant Flow

- 20 MW D$_2$O Cooled and Moderated
  - 30 Fuel Elements
- Reactivity Control
  - 4 Semaphore Shim Arms
  - 1 Regulating Rod
- Operation Cycle of ~38 days
  - 16 Elements are in core 8 cycles
  - 14 Elements are in core 7 cycles
NBSR Fuel Design

- MTR type fuel (17 fuel plates per fuel element (FE))
- $U_3O_8$ sintered with Al (3.6 g/cc)
- Al 6061 cladding
- Split core with 7 inch gap between fuel
Questions for SNF Shipping

- Is there a significant difference in the decay heat between the top and bottom of the NBSR fuel elements at discharge?
- Is there a significant difference in the SNM inventory between the top and bottom of the NBSR fuel elements at discharge?
Calculating SNF Decay Heat

Analytical methods developed by fitting curves to decay heat data may be used to derive decay from power history and cooling time since removal from core. These calculations are conservative and are based on curve fits to experimental data.

El–Wakil (El–W) provides a curve fit to data from ANL–5800:

\[ H = 4.95 \times 10^{-3} (P)(t_d^{-0.06})(t_d^{-0.02} - (t_i + t_d)^{-0.2}) \text{ Watts} \]

Untermyer and Weills (U&W) also have a useful expression:

\[ H = 0.1(P)[(t_d + 10)^{-0.2}] - 0.087(P)[t_d + 2 \times 10^7]^{-0.2} - (t_i + t_d + 2 \times 10^7)^{-0.2} \text{ Watts} \]
The modular code system SCALE (Standardized Computer Analysis for Licensing Evaluation) may be used to perform reactor physics, criticality safety, radiation shielding and spent fuel characterization.

The TRITON control module performs 2D or 3D iterative and automatic transport and depletion calculations.
MCNP Benchmarked SCALE
NBSR was modeled in 3D in order to determine fission product inventory and depletion as a function of core location, location within fuel element, cycle number and power history.

SCALE was programmed to read previous history file half-way through a “cycle” during a depletion operation, withdraw shim arms and begin the second half of the cycle with the new inventories.
Decay Heat for NBSR 7 & 8 Cycle Elements

![Decay Heat Graph](image)

- 7Cycle Low
- 7Cycle Top
- 8Cycle Low
- 8Cycle Top
Comparison of Analytical Expressions to SCALE (TRITON)
ANL/RERTR/TM–26 (2000) *Nuclear Mass Inventory, Photon Dose Rate and Thermal Decay Heat of Spent Research Reactor Fuel Assemblies (Rev. 2)* provides the following equations relating decay heat to fission product activity:

\[ H = 6.85 \times 10^{-3} (\bar{P})(t_d^{-0.2} - (t_e + t_d)^{-0.2}) \text{ Watts} \]

\[ A = 1.37(\bar{P})(t_d^{-0.2} - (t_e + t_d)^{-0.2}) \text{ Curies} \]
Possible Errors

This expression over-estimates actual fission product activity by a factor of 2.

A better (undocumented) expression would be:

\[ H = 0.99(P)(t_d^{-0.06}) (t_d^{-0.2} - (t_i + t_d)^{-0.2}) \text{ Curies} \]

(or you could use SCALE and find it directly in 3D!)
Conclusion

- Calculation of Decay Heat using analytical equations provides reasonable accuracy when “ballpark” is good enough for shipping or a number is required quickly.
- Accurate 3D modeling of decay heat, fuel burnup and fission product inventory using SCALE (or MCNPX) is sometimes preferred.