NBSR Spent Fuel Depletion and Decay Heat Determination Using SCALE

D.S. O'Kelly, R.E. Williams,
NIST Center for Neutron Research

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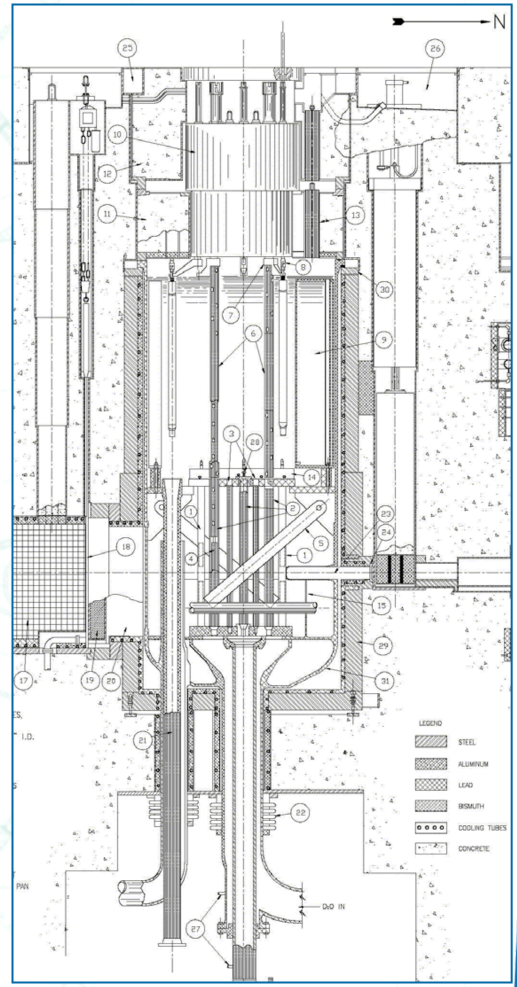
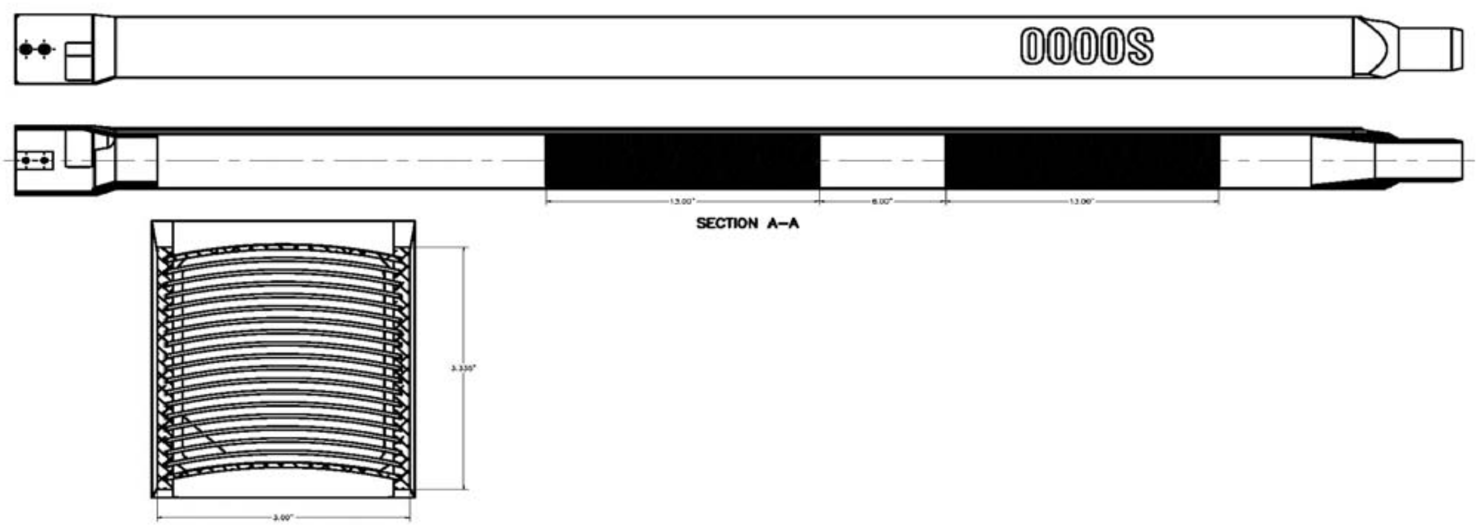
NBSR Coolant Flow

- 20 MW D_2O 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:

$$H = 4.95\times10^{-3}(P)(t_d^{-0.06})(t_d^{-0.02} - (t_i + t_d)^{-0.2})\ \text{Watts}$$

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

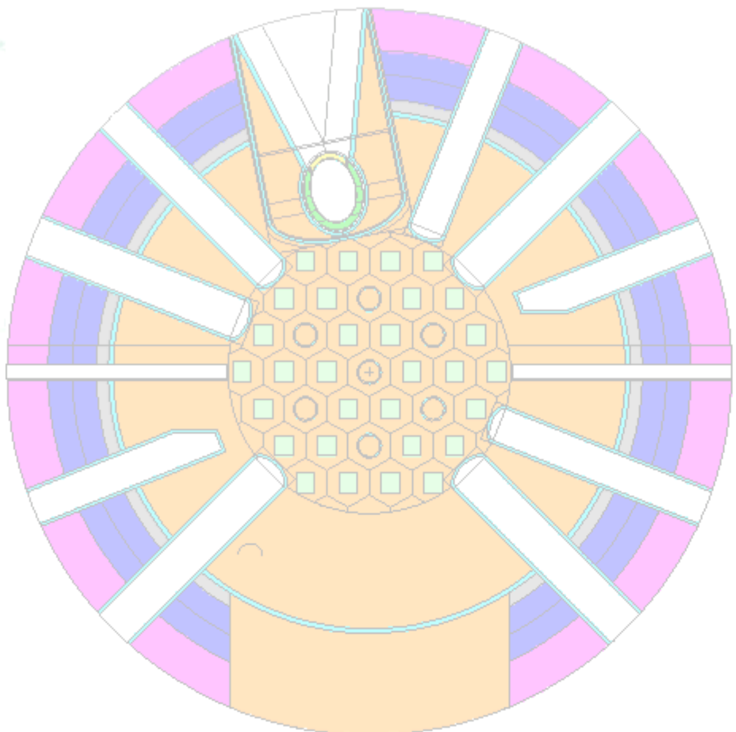
$$H = 0.1(P)[(t_d + 10)^{-0.2}] - 0.087(P)[t_d + 2\times10^7)^{-0.2} - (t_i + t_d + 2\times10^7)^{-0.2}]\ \text{Watts}$$

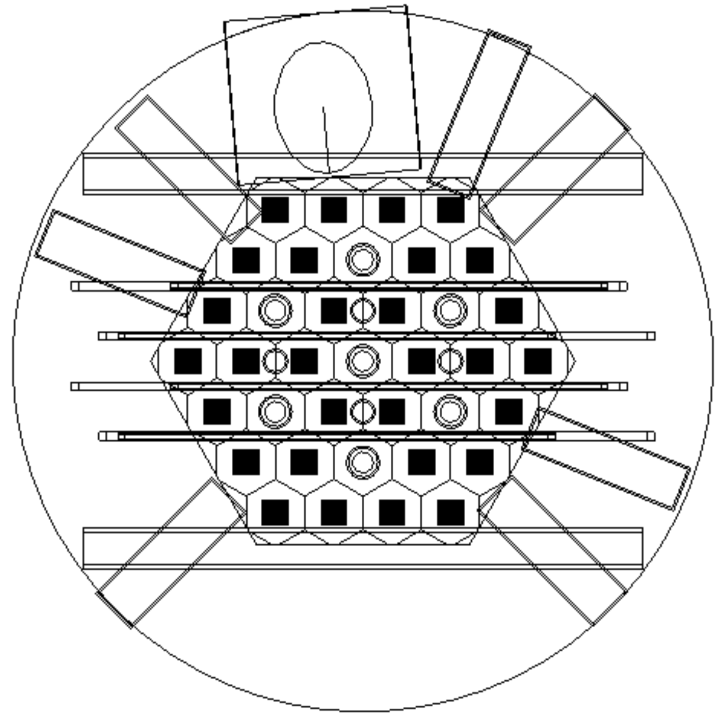
SCALE 6

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.

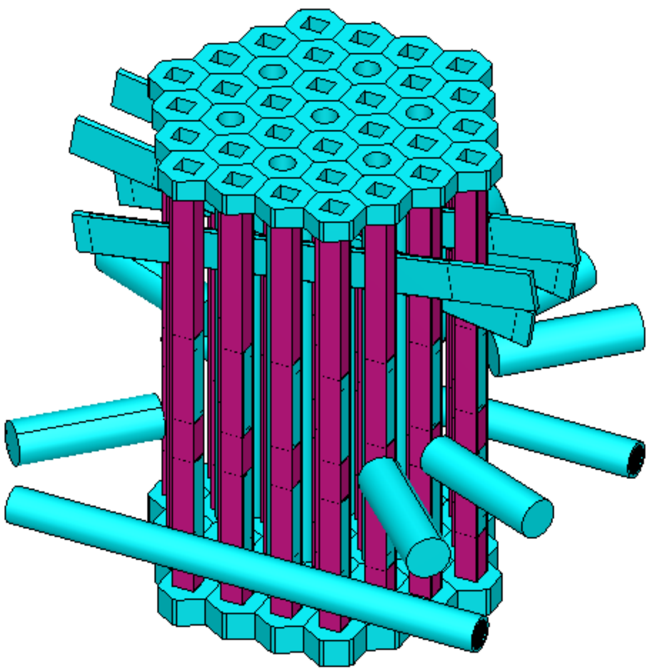
The *TRITON* control module performs 2D or 3D iterative and automatic transport and depletion calculations

MCNP Benchmarked SCALE





SCALE 3D Model of NBSR

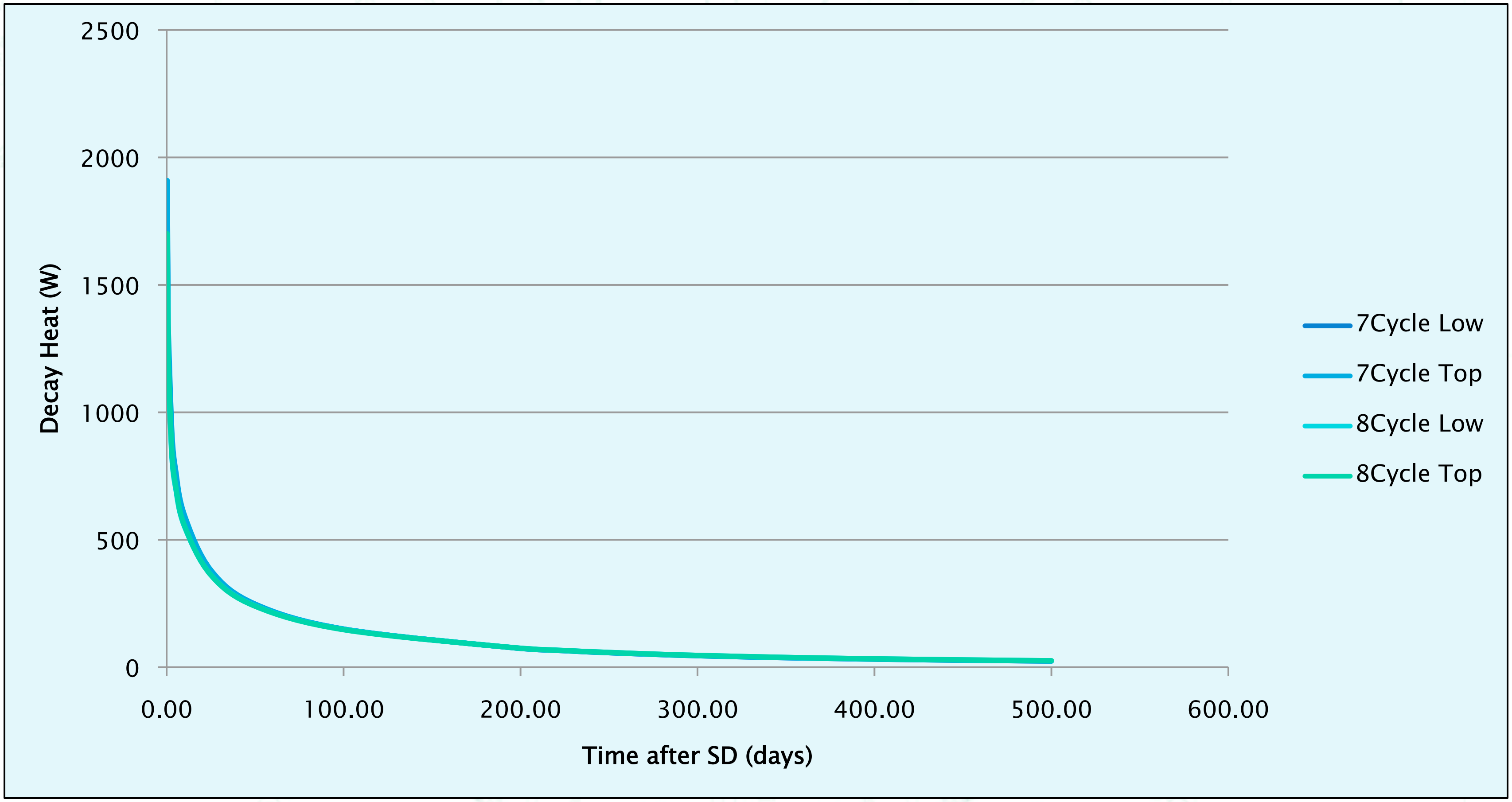


NBSR Model with Heavy Water Removed

•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



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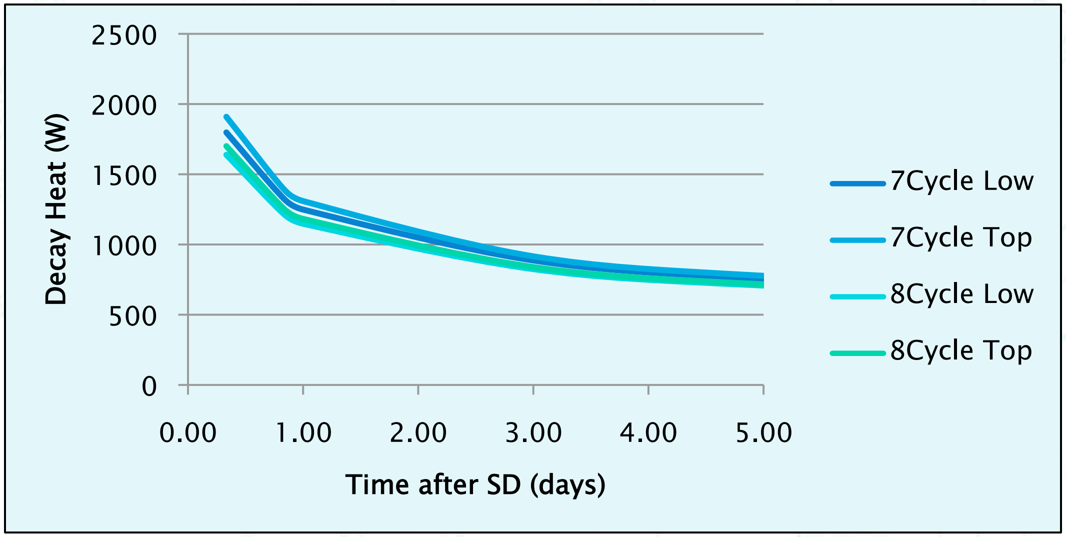
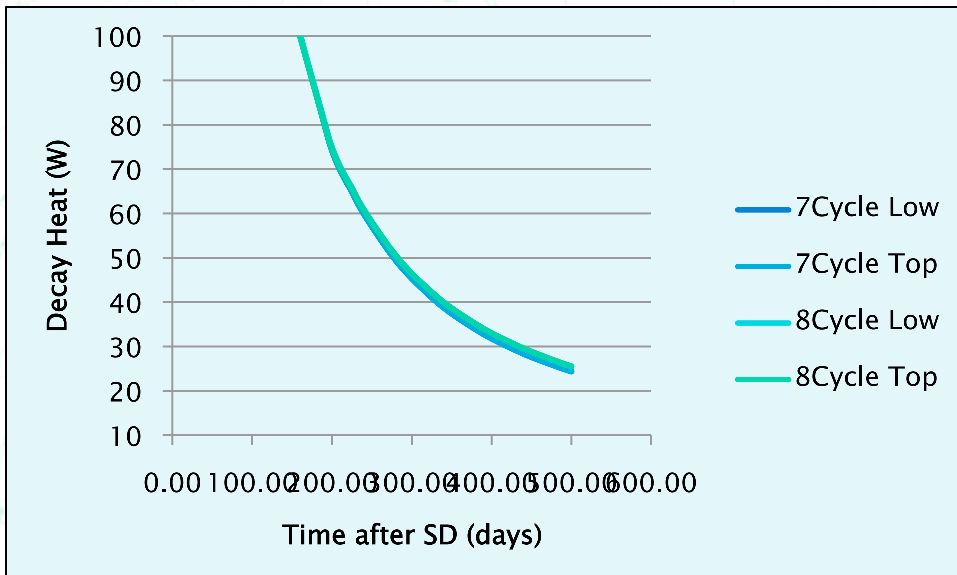
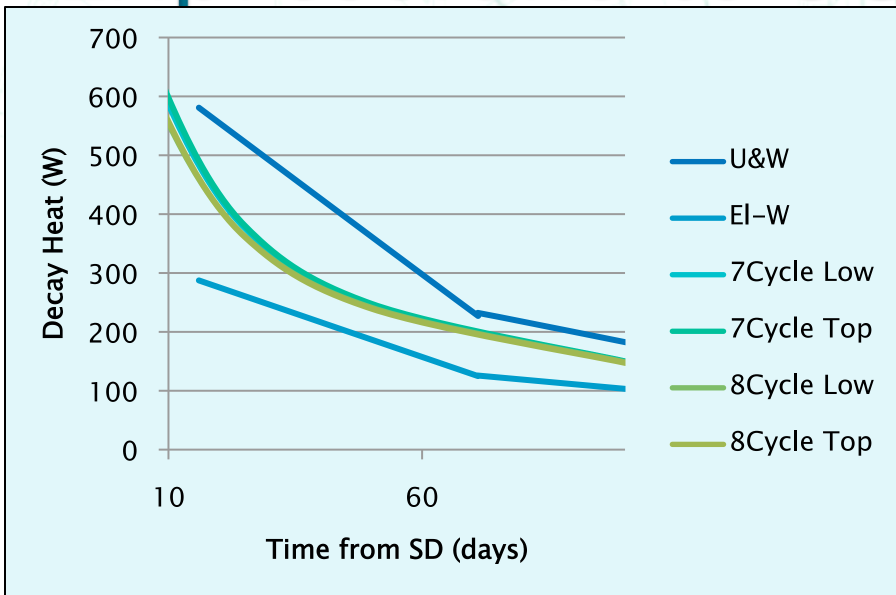
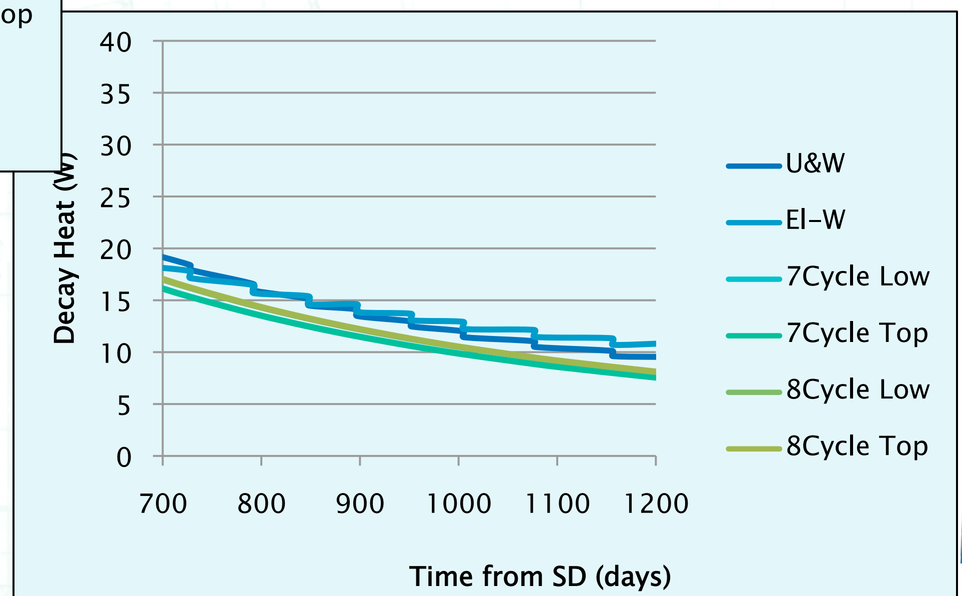

2500
2000
1500
1000
500
0
Decay Heat (W)
0.00
1.00
2.00
3.00
4.00
5.00
Time after SD (days)
7Cycle Low
7Cycle Top
8Cycle Low
8Cycle Top


100
90
80
70
60
50
40
30
20
10
Decay Heat (W)
0.00
100.00
200.00
300.00
400.00
500.00
600.00
Time after SD (days)
7Cycle Low
7Cycle Top
8Cycle Low
8Cycle Top

Comparison of Analytical Expressions to SCALE (TRITON)





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Possible Errors

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:

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

$$A = 1.37 (\overline{P})(t_d^{-0.2} - (t_e + t_d)^{-0.2}) \text{ Curies}$$

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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.