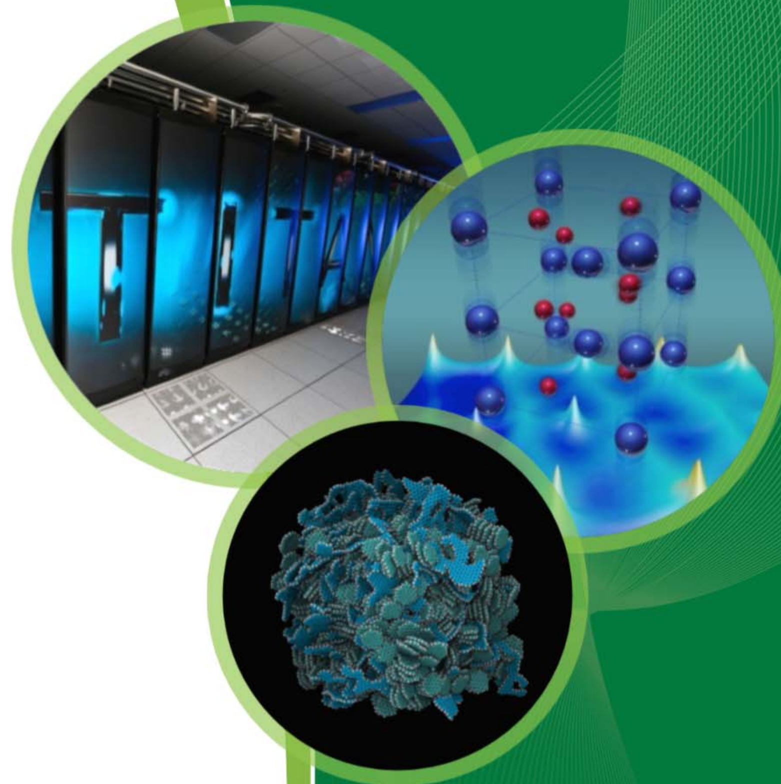
Thermal Loads for Spent Fuel Dry Casks



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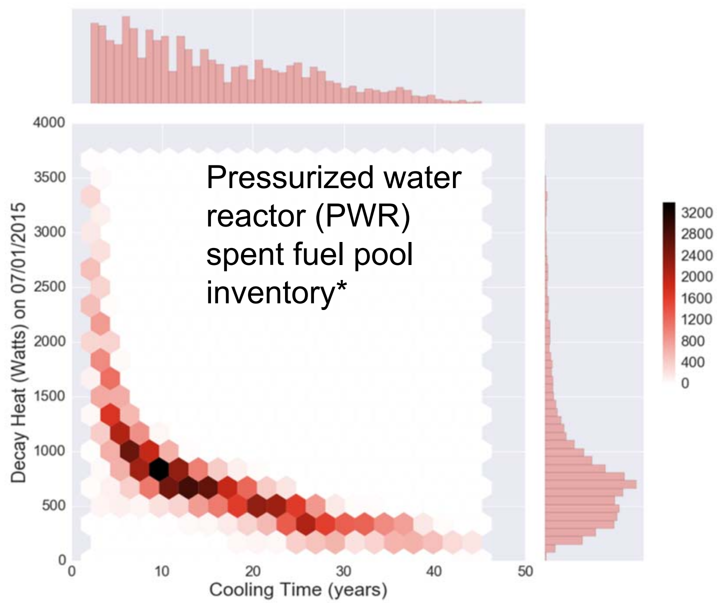
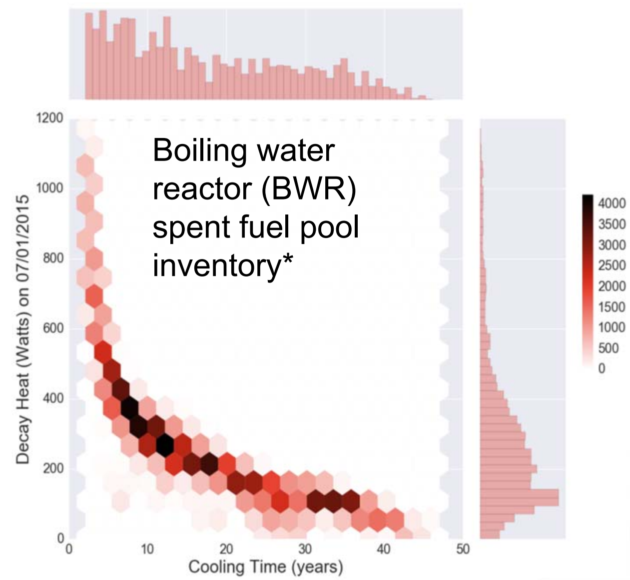
Analysis tools and methods for thermal analyses are mature; accuracy is biased by how they are being applied

- Temperature analysis for dry storage systems is comprised of two primary models
  - Spent nuclear fuel (SNF) assembly decay heat generation rate
  - Heat transfer model
- Current design basis calculations bias the model results to be conservatively hotter
  - Input choices
  - Reverse engineer maximum allowable decay heat to achieve target component temperatures
- Overpredicting temperatures is undesirable when considering aging management
  - Stress corrosion cracking of canisters
  - Seeking the lowest temperatures during transportation after extended storage
- Need to calculate accurate temperatures as they change with time and apply uncertainty appropriately (in positive or negative direction) depending on application of interest

SNF continues to produce decay heat after discharge from the reactor

- Recoverable energy released from the decay of radionuclides in fuel after its discharge from the reactor
- Driven by the isotopic composition in fuel at the end of irradiation
- Changes with decay time after discharge (cooling time)





Nuclear Fuel Data Survey Form GC-859, Energy Information Administration (EIA), US Department of Energy. http://www.eia.gov/survey/form/gc_859/proposed/form.pdf

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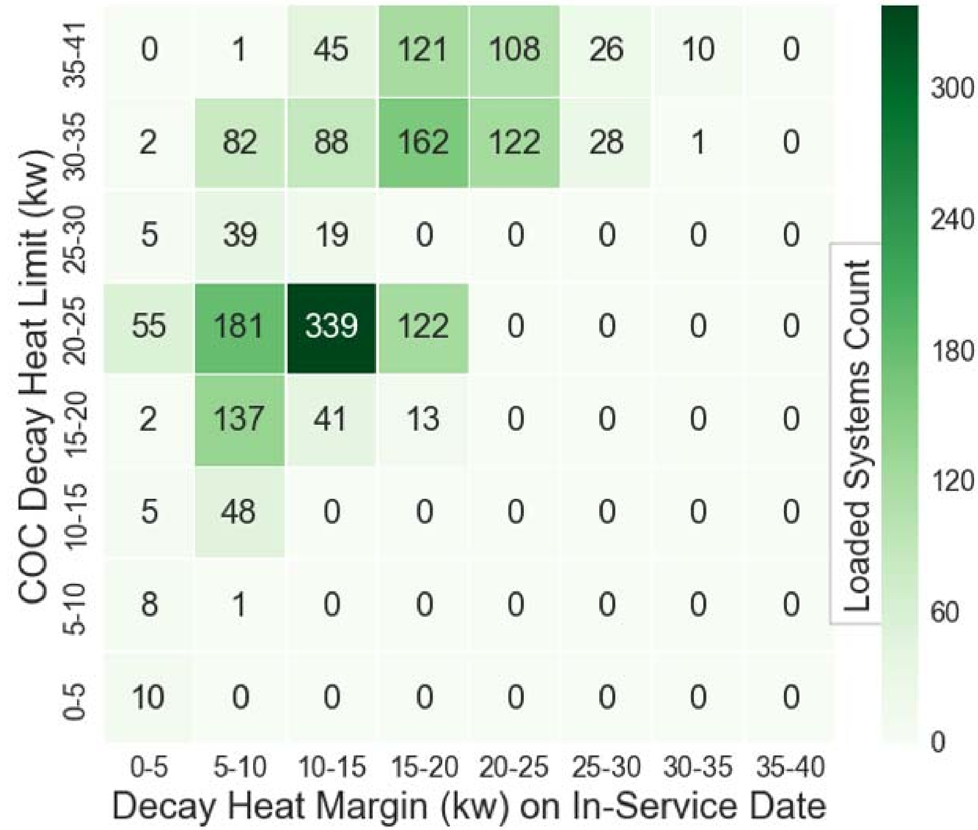
Thermal analyses for dry storage systems use a design basis approach to meet temperature criteria

- Decay heat from SNF is a limiting design boundary condition input for calculating component (e.g., cladding) temperatures for dry storage systems
- Decay heat removal effectiveness depends on system design
- Large margin exists between design basis limits and how casks are loaded



Data extracted from Used Nuclear Fuel-Storage, Transportation & Disposal Analysis Resource and Data System (UNF-ST&DARDS).

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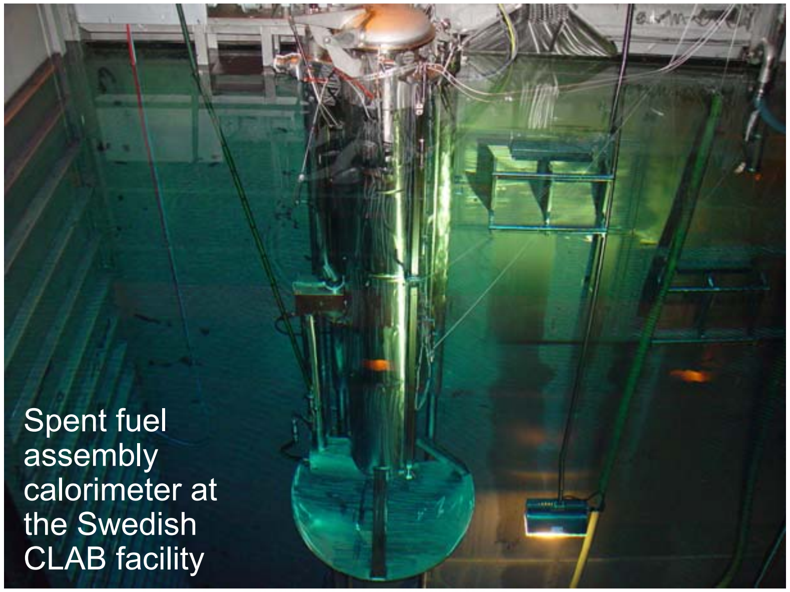
Experimental programs have measured SNF assembly decay heat for years
(>160 assemblies measured*)

- Calorimeters used to measure actual SNF assemblies
  - General Electric Morris Operation
  - Hanford Engineering Development Laboratory
  - Central Interim Storage Facility for Spent Fuel (CLAB) located in Sweden
- Measured assemblies include a wide range of assembly design types, enrichments, burnup, and cooling times
  - CE 14 × 14, W 14 × 14, W 15 × 15, W 17 × 17, GE 7 × 7, ABB 8 × 8, SVEA 64 (8 × 8), ABB 9 × 9, SVEA 100 (10 × 10)
  - Initial enrichment range (wt% ^{235}U): 2.09–3.40
  - Burnup (GWd/MTU): 19.9–51.0
  - Cooling time*: 2–28 years

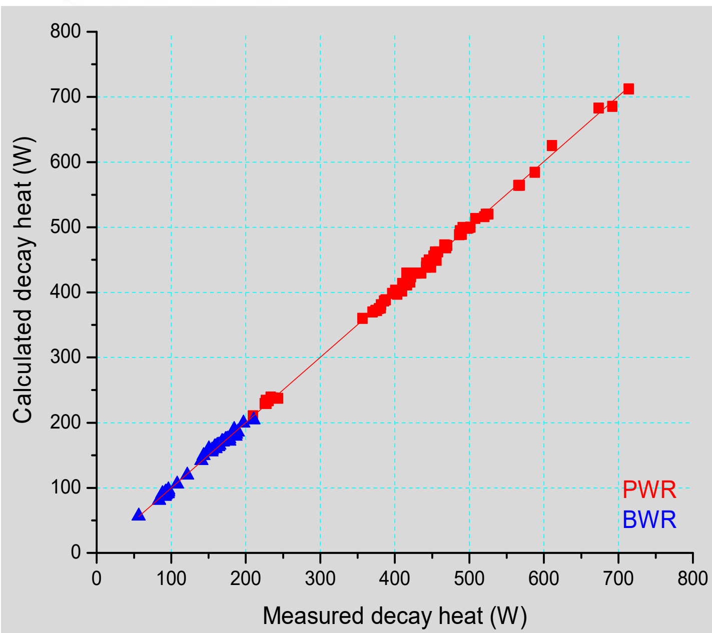


Spent fuel assembly calorimeter at the Swedish CLAB facility

*Small irradiated fuel samples have been used for cooling times less than 1 day and used to support development of decay heat standards for computer code validation (Information summarized from NUREG/CR-6999)

Computational models have been validated using the decay heat measurements

Excellent agreement between measured and calculated results when detailed assembly-specific operating history information is modeled



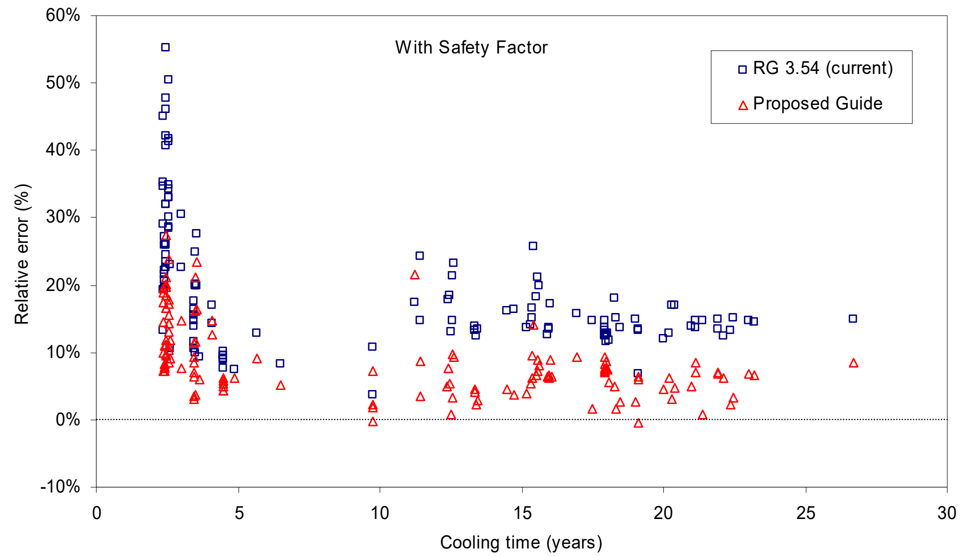
Calculated vs measured decay heat

Summary of SCALE 6.1.3 code system validation results

Data set	No. of measurements	C/E		Residual (W)	
		mean	σ	mean	σ
PWR	71	1.002	0.012	0.57	4.91
BWR	50	0.997	0.024	-0.25	3.36
PWR+ BWR	121	1.000	0.017	0.23	4.34

Different methods are used to estimate assembly decay heat for dry storage loading

- Simplified approaches vs complex models and calculations
  – Regulatory Guide 3.54
  – ANSI/ANS-5.1
  – Branch technical position ASB 9-2
  – ORIGEN
  – Other software
- Trade precision and accuracy to simplify the method
  – Design limits have focused on bounding hot (one-sided tradeoff)
  – Applicability to aging management?



Comparison between measured decay heat values and the methodology in Reg. Guide 3.54 (current and proposed)*

*Safety factor used to account for bias and uncertainty; relative error is higher for shorter cooling times

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Research is underway to reduce application model bias and generate realistic temperature predictions

- High burnup spent fuel data project (EPRI 2014)
  - Integral experiment to validate temperature modeling predictions indirectly via thermocouple lances inserted into an SNF dry storage cask
- BWR cask simulator (SAND2015-10256)
  - Electrical heaters instrumented in a controlled environment
- Uncertainty analysis between application models and detailed models
  - Identification of key parameters that affect accuracy (short-cooled versus long-cooled)
- Enhancement of methods to develop accurate results and apply uncertainty appropriately for the specific application (e.g., storage, transport, aging management)

References

- NUREG/CR-6999. “Technical Basis for a Proposed Expansion of Regulatory Guide 3.54 –Decay Heat Generation in an Independent Spent Fuel Storage installation.” ML100850213.
- Nuclear Technology, Special Issue on UNF-ST&DARDS, Vol. 199, September 2017.
- "Nuclear Fuel Data Survey Form GC-859," Energy Information Administration (EIA), U.S. Department of Energy. http://www.eia.gov/survey/form/gc_859/proposed/form.pdf
- EPRI 2014. High Burnup Dry Storage Cask Research and Development Project: Final Test Plan

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