HI-STORM FW A4
Fuel Qualification Tables (FQTs)
Proposed Approach

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HI-STORM FW A4 FQT

- Background / History
- Proposed Approach – Burnup and Cooling times
- Proposed Approach – Enrichments
- Application
- Path Forward

Background: HI-STORM History

- All HI-STORM CoCs
  - ✓ Maximum Burnup and Minimum Cooling Time
  - ✓ Maximum Decay Heat
    - Uniform, regionalized or cell by cell
    - Fixed value or function of X, which is the ratio between outer region and inner region decay heat
- HI-STORM 100
  - ✓ 18 pages of equation coefficients
  - ✓ Equations determine a burnup limit for the individual assembly as a function of actual heat load, enrichment and cooling time of an assembly
    - This is secondary check on the heat loads, since the CoC already requires to verify the heat load. Redundant, and no longer considered necessary for this purpose. But still retained, in its function to provide a clear definition of permitted burnup/cooling time combinations, so dose rates in Chapter 5 bound those permitted combinations
  - ✓ Dose rates listed in the Chapter are based on the all heat loads, and the corresponding burnup and cooling time combinations
    - Enrichments selected as a function of Burnup, using Table 5.2.24.
- HI-STORM FW
  - ✓ No explicit burnup/cooling time combination limits
  - ✓ Practical limit is the decay heat limit
  - ✓ Dose rates are representative / conservative

Background

- The term Fuel Qualification Table (FQT) is used throughout this presentation. It is used for the summary of requirements that limit burnup/enrichment/cooling time *combinations* that are permitted, and this information may or may not be in the form of tables
- Long history of discussions and approaches, no final agreement yet.
- In our view, the entire issue can and should be separated into the following three questions, each of which may need a different and separate approach to be resolved.
  1. Are FQTs necessary?
  2. If so, should they be in the CoC or in the FSAR?
  3. If so, what is an appropriate form of the FQTs?

Background

1. Are FQTs necessary?
   - Current SRP (NUREG-1536) requires bounding source terms to be specified to define the design basis fuel (Section 5.5.3). This requires some form of FQT.
     - Combinations are only needed for source terms / dose rates evaluations presented in the FSAR, and to qualify fuel assemblies (i.e. to show that they are within the design basis)
     - Combinations are NOT used for site specific dose or dose rate calculations. These use combinations from the actual fuel assemblies, or combinations bounding the actual fuel assemblies by some arbitrary margin.
   - For today's more complex and flexible loading patterns, the bounding approach in determining source terms and dose rates based on every permitted combination (and combinations of combinations for regionalized or cell-by-cell decay heat loading approaches) results in dose rates reported in the FSAR that are disconnected from real loading conditions.
   - To answer/resolve this part would most likely require a revision to the SRP.
     - This is not something to approach in the context of a LAR. Hence no further discussions here, for the purpose of the discussions that follow we consider them necessary

Background

2. Should they be in the FSAR only, or also in the CoC?
   - Ongoing discussion in the context of the Pilot
   - Locating them only in the FSAR would permit changes to the FQTs under 72.48
   - Depending on the structure of the FQTs, specifically if they are sufficiently flexible, it may make not much difference
   - We are awaiting the final conclusion of the Pilot for this, so no further discussions here.

Background

2. What is an appropriate structure of the FQTs?
   - Need to strike a balance between simplicity and conservatism
     - The simplest approach would be a single bounding combination, e.g. 70 GWd/mtU, 1 year cooling time, 0.7% enrichment. But that would be completely unrealistic, and excessively conservative with respect to dose and dose rates
   - Permitted combinations should not be directly linked to decay heats, but in order to result in at least remotely realistic dose rates, they should be informed by decay heats.
   - Approach should be applicable to uniform, regionalized and cell-by-cell decay heat limits

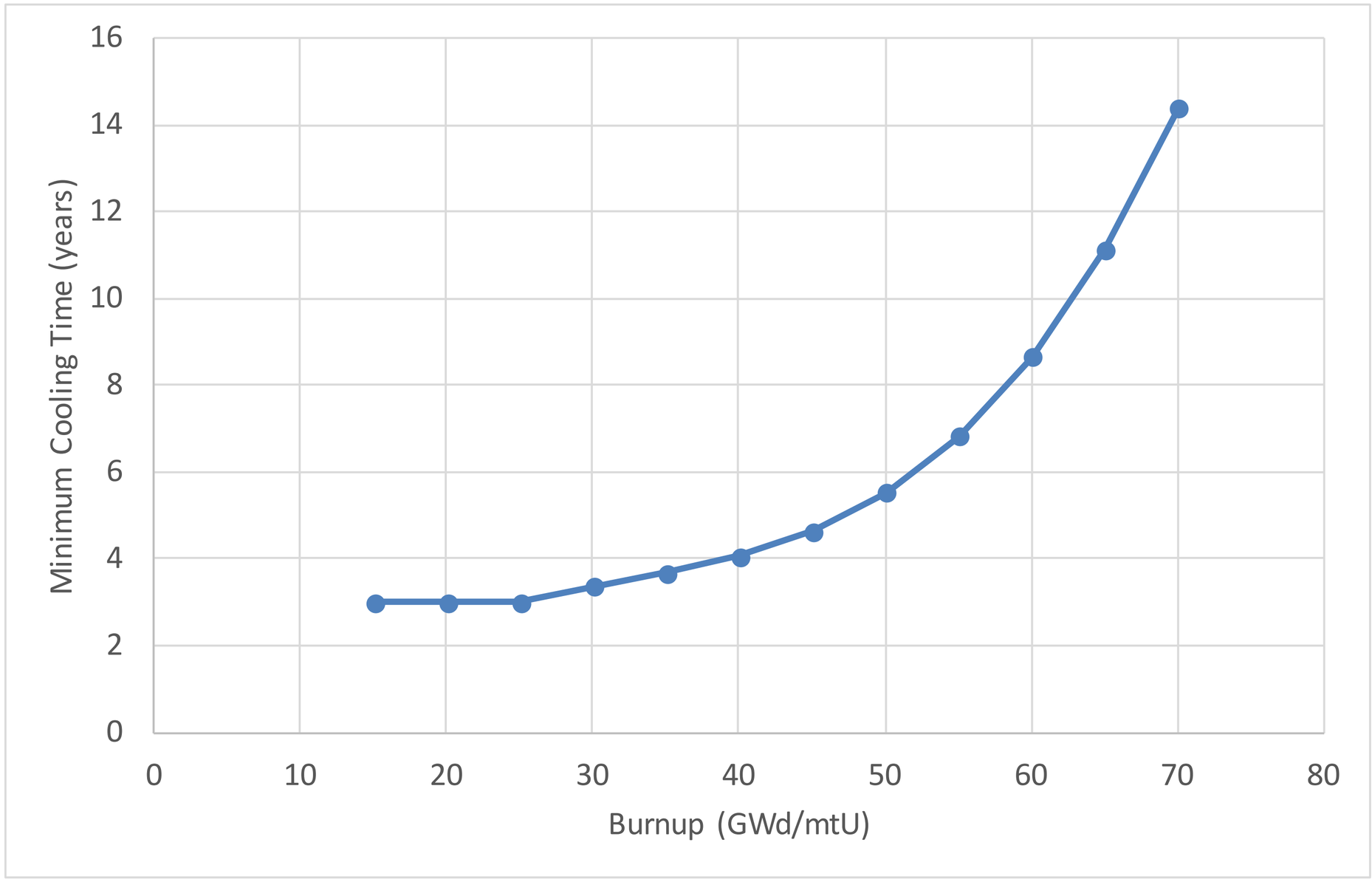
Proposed Approach: Bu/Ct

- For a given individual cell or group of cells in a basket, the minimum cooling time is calculated as a function of burnup, using a third order polynomial, i.e.
  - $Ct = A \times bu^3 + B \times bu^2 + C \times bu + D$

  Where:

  - ***Ct*** Cooling time
    - Cooling time lower limit must also be observed
  - ***bu*** Burnup
  - ***A, B, C*** and ***D*** Tabulated coefficients

Proposed Approach: Bu/Ct Example



Proposed Approach: Bu/Ct

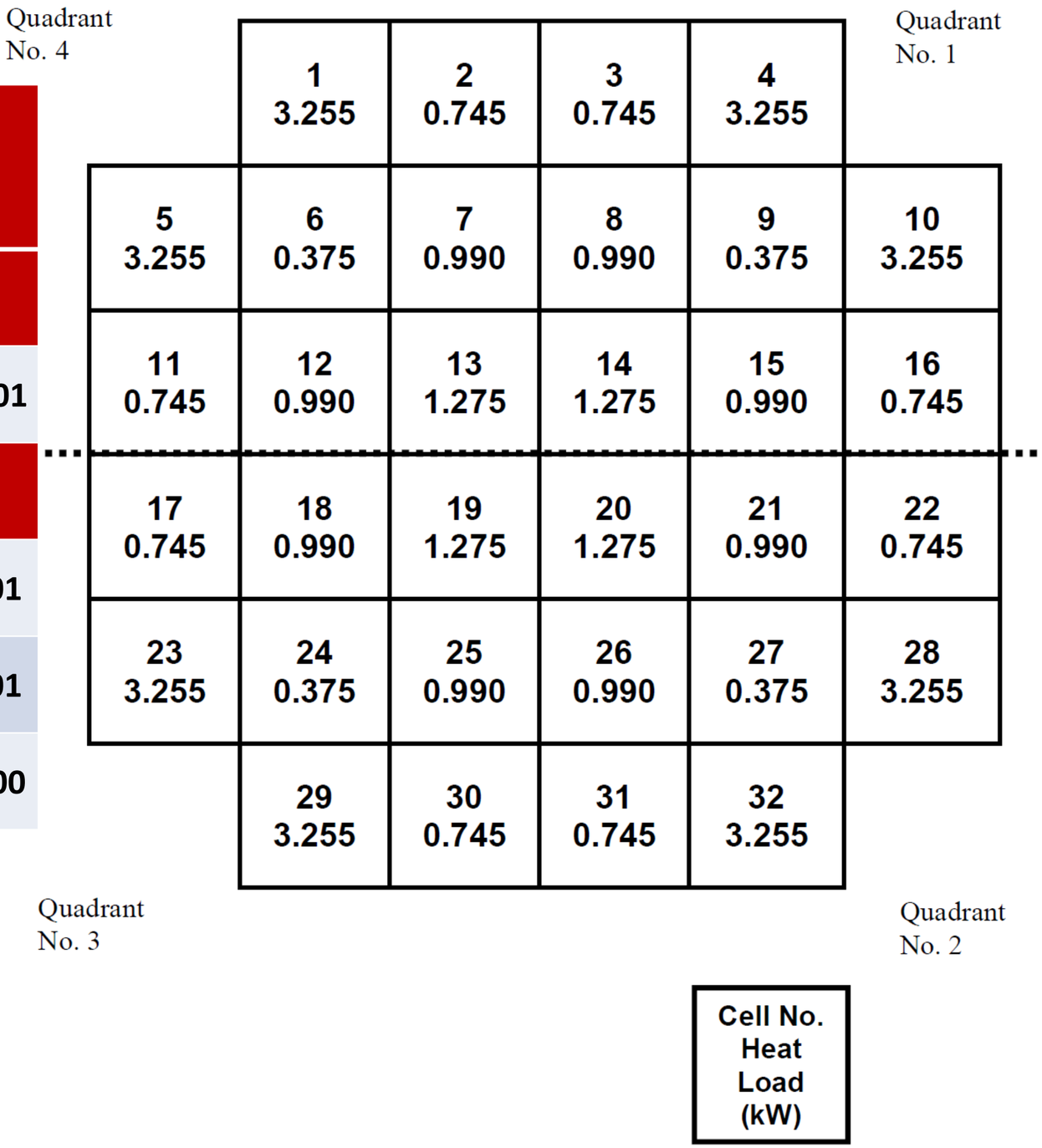
- The function is the design basis for the respective basket / cell(s)
- There may be multiple functions for different baskets / cells
- Functions are informed by heat load limits (i.e. lower permissible cooling time for lower burnups)
- Selected number of points on the curve will be used to calculate dose rates around the cask, in order to determine (reasonably) bounding dose rates

Proposed Approach: Bu/Ct Example for Discussion

Burnup (MWd/mtU)	Initial U-235 Enrichment (wt%)	Cooling Time from Equation (years)	Cooling Time for Dose Rates (years)	Estimated Dose Rate at 1 m from the Side of the HI-STORM FW (mrem/hr)
15000	1.5	1.68	3	71
25000	1.9	3	3	102
30000	2.0	3.36	3	117
35000	2.5	3.68	3.6	95
40000	2.7	4.07	4	89
55000	3.4	6.82	6.8	54
70000	4.4	14.36	14	30

Proposed Approach: Bu/Ct Example for Discussion

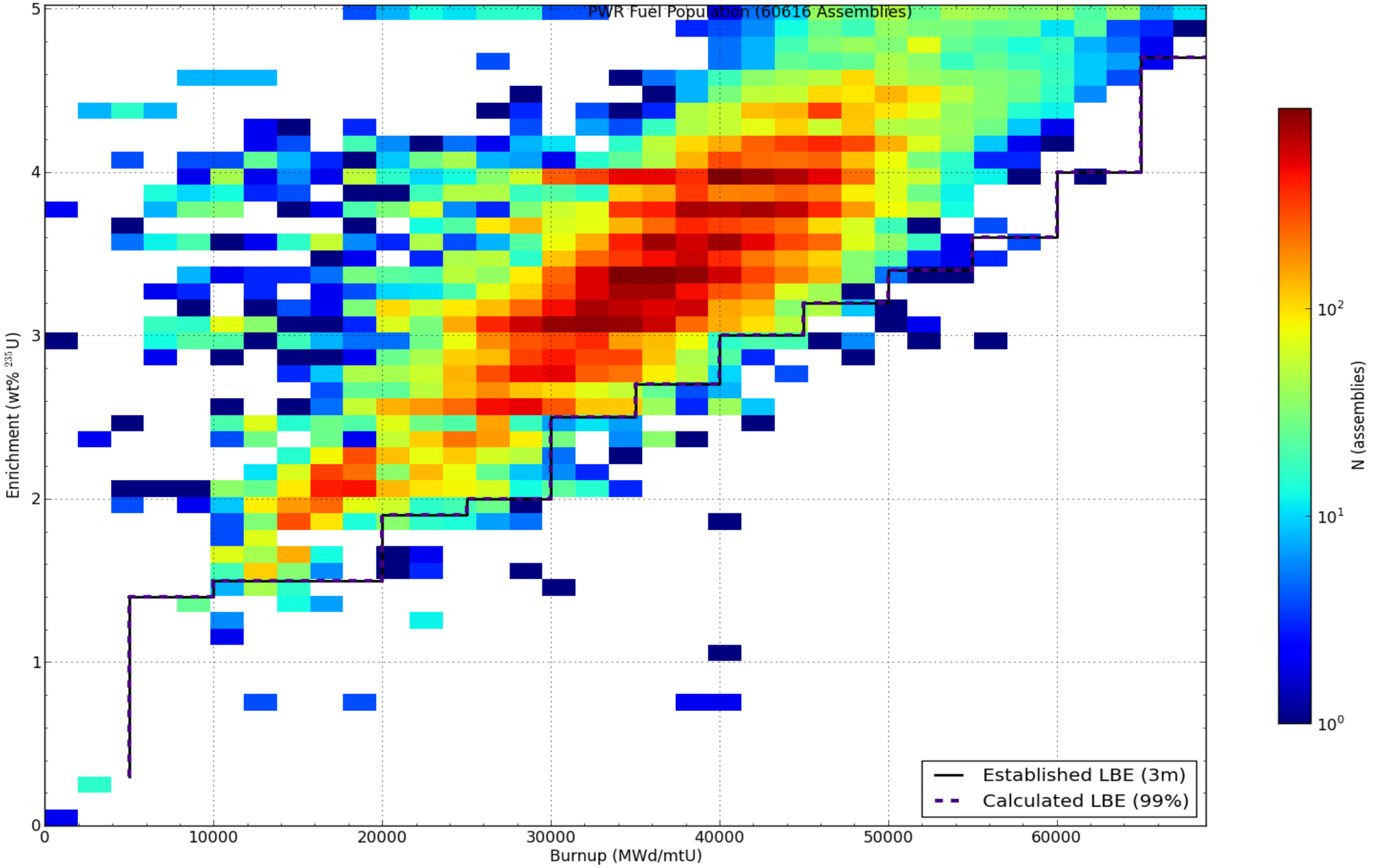
Reference Decay Heat (kW)	A	B	C	D
Uniform Loading				
0 - 1.25	4.11020E-14	-4.62813E-09	2.17444E-04	-5.55545E-01
Regionalized Loading				
0 - 0.83	6.57083E-14	-4.02593E-09	1.47107E-04	8.01647E-01
0.83 - 1.46	1.33649E-14	-1.28418E-09	9.57387E-05	2.97993E-01
1.46 - 3.26	-1.78457E-15	4.60631E-10	-7.26995E-06	1.11390E+00



Proposed Approach, Enrichment

- To avoid the additional complication in adding the enrichment in the function, conservatively low enrichments will be used for the calculations of dose rates reported in the FSAR.
- Evaluation based on Nuclear Fuel Data Survey (RW-859), Energy Information Administration, U.S. Department of Energy, 2002
  - ✔ Will be replaced by 2013 data, just received. No significant differences
- Data divided into ranges of 5 GWd/mtU, then for each range, the enrichment is determined that bounds a certain percentage of the assemblies in that burnup range
  - ✔ Percentage to be discussed
- Due to the low enrichment selected, compared to typical fuel, it is expected that most if not all assemblies in a basket will be above the enrichment, and that this will offset the effect of the potential of a few assemblies being below that enrichment. Therefore, no lower enrichment limits is needed in the definition of the design basis.

Proposed Approach, Enrichment, 99% criteria



Application

- Selected point on the Bu/Ct curve will be used to calculate dose rates around the cask, together with the corresponding enrichment, in order to determine (reasonably) bounding dose rates reported in the FSAR
- Fuel selected for loading must meet the bu/ct requirements from the applicable curve
- Site specific dose and dose rate calculations will continue to use actual burnups, enrichments and cooling times, or values that bound those

Path Forward

- The presented approach will be used in several storage amendments
  - ✔ HI-STORM FW Amendment 4
  - ✔ HI-STORM FW Amendment 5
  - ✔ HI-STORM 100 Amendment 15
- When different sets of coefficients (i.e. different curves) are used for different baskets / cells, they may be identified by ranges of cell numbers or ranges of decay heat limit values

Thank you

Questions ?