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Title: Used Fuel Cask Identification through Neutron Profile

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Fuel Cycle Technologies

Used Fuel Cask Identification through Neutron Profile

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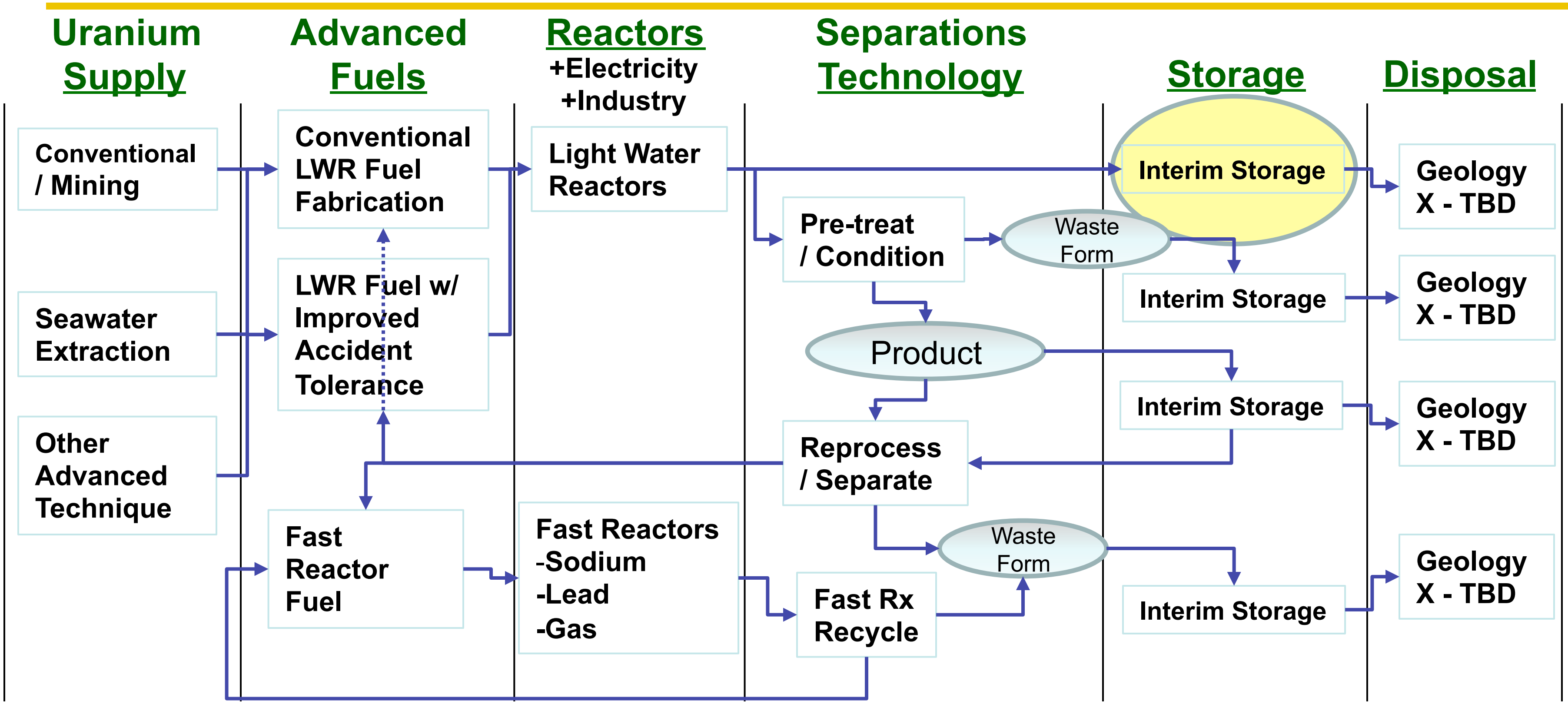
Fuel Cycle as a System

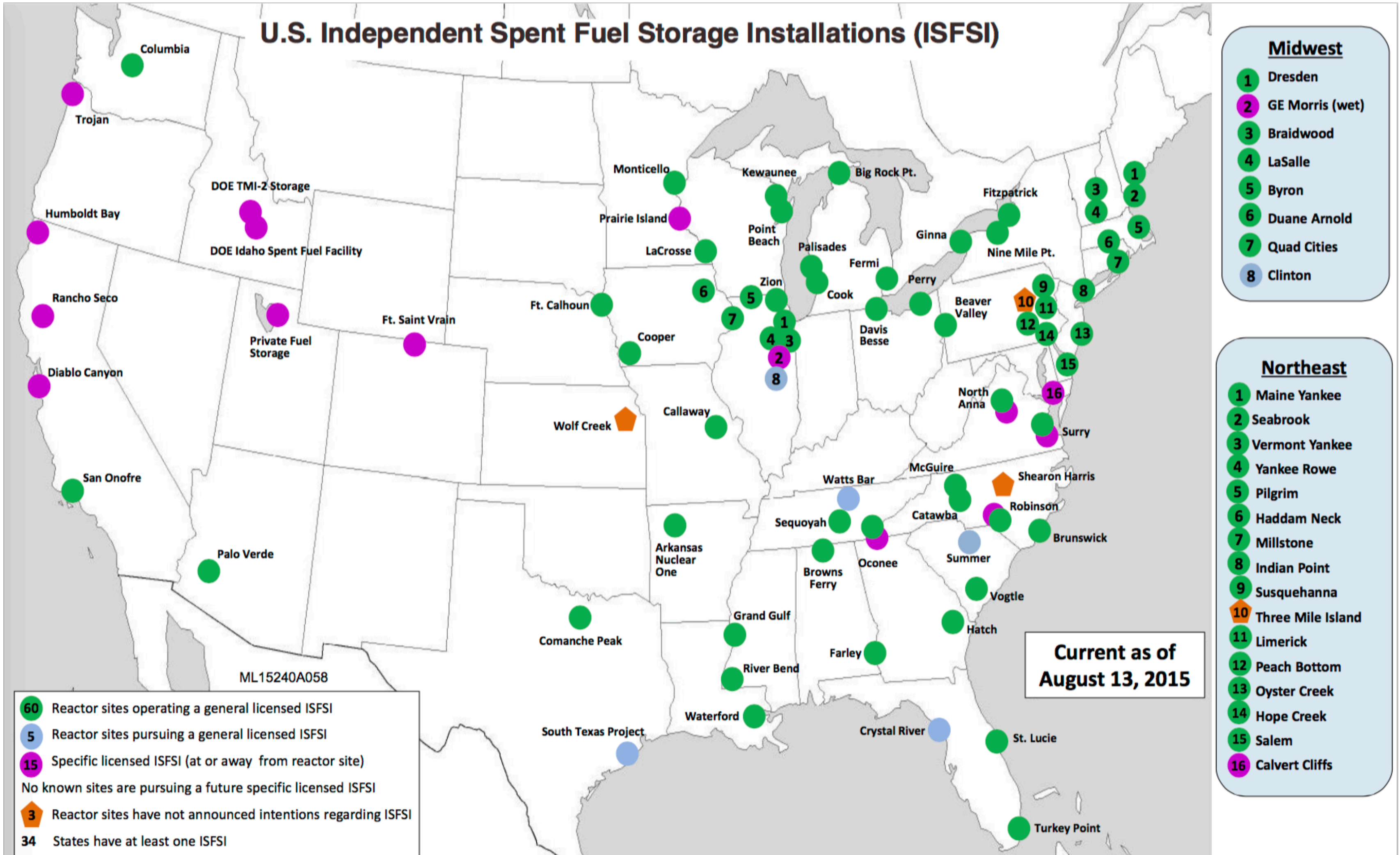


- **Optimized System**: We want the best performance for each step in harmony with other parts of the system
- **Near-Term/Long-Term Balance**: Seek near-term applications while maintaining the long-term objective of a sustainable fuel cycle

Overview

- Introduce the problem
- Proposed signature
- Description of models
- Simulation Results

Current Used Fuel Storage Strategy



Source: http://pbadupws.nrc.gov/docs/ML1524/ML15240A058.pdf

Interim Consolidated Storage Facility

- Receive fuel from multiple sites, weekly shipping
- Long term storage in casks
- Fuel stored for decades on site
- Need a way to restore continuity of knowledge if lost
- Need a method that will indicate state of fuel inside the cask

Proposed signature

- Used nuclear fuel is identifiable by its radiation emission, both gamma and neutron.
- Used nuclear fuel contains most of the fissile material of fresh fuel.
- Neutron emission from fission products, multiplication from remaining fissile material, unique distribution of both in each cask produces a unique neutron signature.
- The neutron signature around the outside of the cask will vary due to specific arrangement of fissile material and neutron sources of a specific cask.
- For these simulations, 100 points around the cask were sampled to generate a profile at the axial mid-point of the fuel

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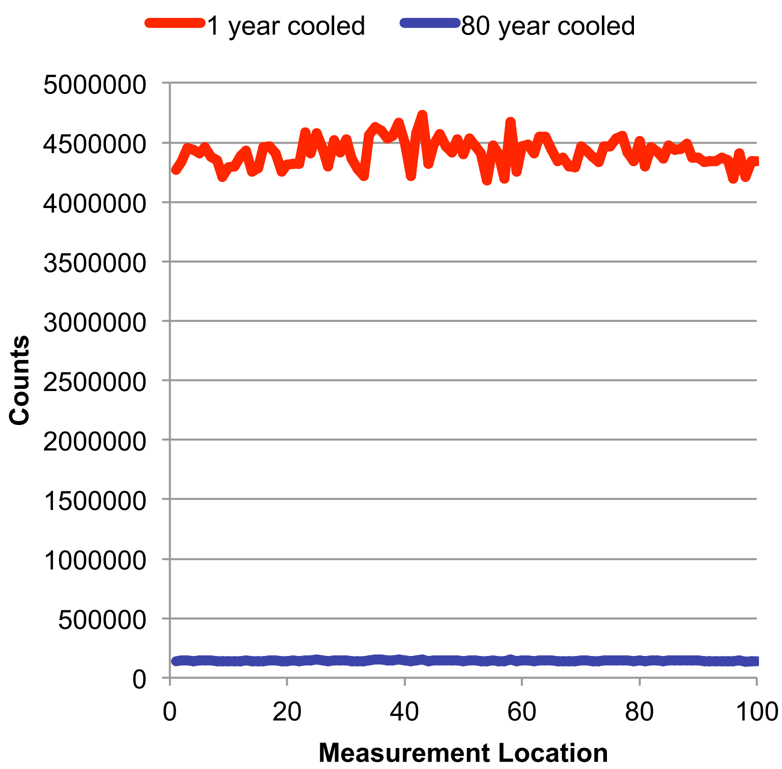
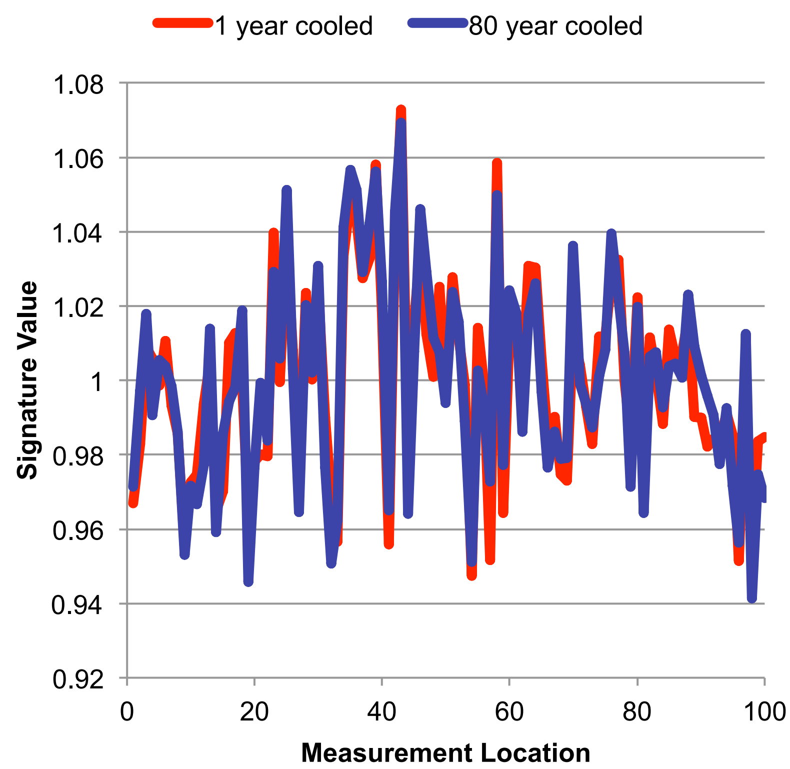
Taking a Measurement

Raw Measurement



Normalized by Average



Matching Signatures

- Normalized Signatures should be constant over time
- With 2 signatures from the same cask, a ratio of the points that make up the signatures should all approach 1
- Significant deviation from a ratio of 1 indicates something has changed in the distribution of sources and fissile material
- Only two things can make that happen, changes within the fuel content or misidentification of a cask
- Matching signatures should only have a small number of ratios that do not approach 1

Example

Present Day

Cell	ftc901	ftc902	ftc903	ftc904	ftc905
201	0.884548	0.835042	0.763931	0.699625	0.927967
202	1.07409	1.043721	0.867333	0.81919	1.186605
203	1.026387	1.040131	0.950534	0.873292	1.062191
204	1.188567	1.123793	1.054175	1.009176	1.236628
205	0.923331	0.849819	0.7975	0.713087	0.926715
206	1.028171	1.006883	0.970193	0.865605	0.967905
207	1.097575	1.179101	1.051269	1.011554	1.056284
208	1.002986	1.159869	0.977997	0.910055	0.944972
209	1.09638	1.210749	1.005695	0.940112	0.994656
210	1.066123	1.205031	1.091817	1.054766	1.030288

100 Years From now

Cell	ftc901 decayed	ftc902 decayed	ftc903 decayed	ftc904 decayed	ftc905 decayed
201	0.897353	0.836949	0.789733	0.692214	0.944112
202	1.079095	1.043142	0.884016	0.822175	1.180405
203	1.058843	1.052898	0.964998	0.839931	1.078843
204	1.199351	1.138983	1.080828	0.990391	1.269484
205	0.912433	0.843377	0.788991	0.689122	0.938768
206	1.043891	1.01354	0.976548	0.866698	0.99442
207	1.063737	1.198932	1.045523	1.016346	1.076974
208	0.994923	1.159735	0.986313	0.915362	0.94033
209	1.089526	1.226178	1.014467	0.940453	0.973417
210	1.054643	1.217528	1.092983	1.066082	1.052753

Future/Present

Cell	ftc901 ratio	ftc902 ratio	ftc903 ratio	ftc904 ratio	ftc905 ratio
201	1.014476	1.002283	1.033775	0.989407	1.017398
202	1.00466	0.999446	1.019236	1.003645	0.994775
203	1.031621	1.012274	1.015217	0.961799	1.015677
204	1.009072	1.013517	1.025283	0.981386	1.026569
205	0.988197	0.99242	0.98933	0.966393	1.013006
206	1.015289	1.006612	1.00655	1.001262	1.027393
207	0.96917	1.016819	0.994535	1.004737	1.019588
208	0.991961	0.999884	1.008503	1.005832	0.995088
209	0.993748	1.012743	1.008722	1.000363	0.978647
210	0.989232	1.01037	1.001068	1.010728	1.021805

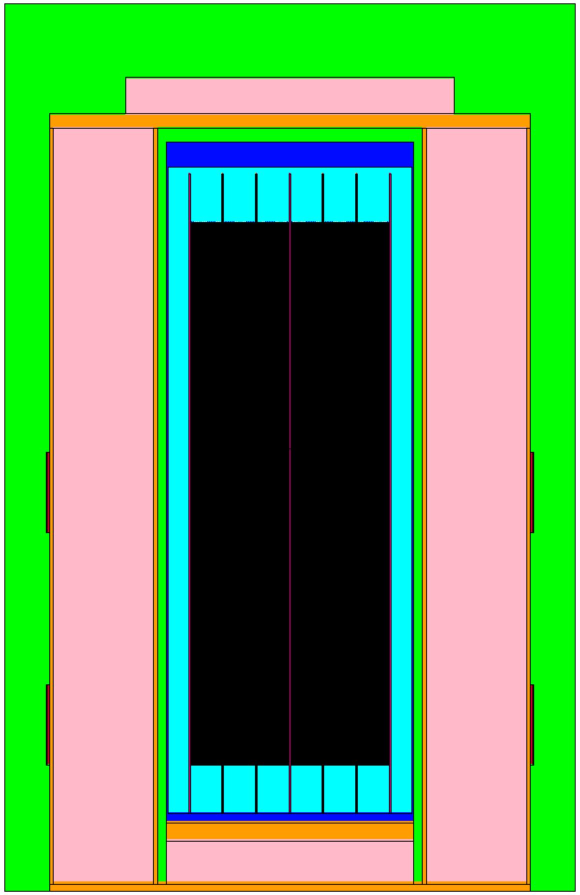
Compared to FTC901

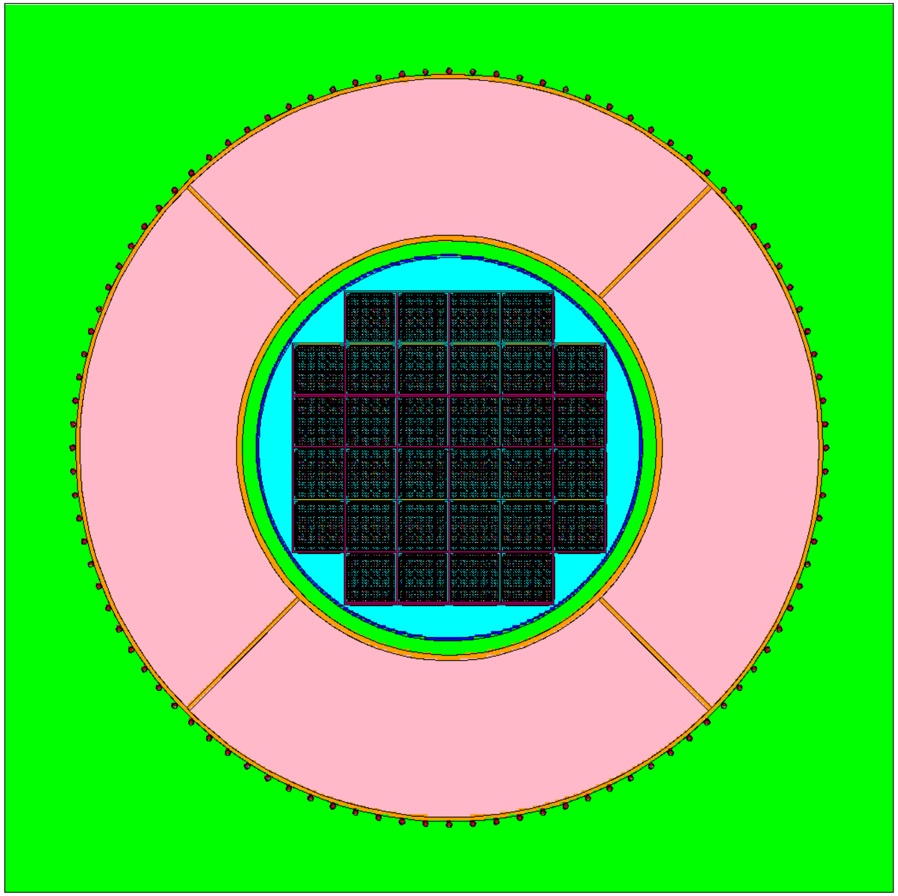
Cell	ftc901/ftc901	ftc901/ftc902	ftc901/ftc903	ftc901/ftc904	ftc901/ftc905
201	1.014476	1.07462	1.174652	1.28262	0.967009
202	1.00466	1.033893	1.244154	1.317272	0.909397
203	1.031621	1.01799	1.113945	1.212473	0.996848
204	1.009072	1.067234	1.137715	1.188445	0.969856
205	0.988197	1.073679	1.144116	1.279554	0.984588
206	1.015289	1.036755	1.075961	1.205966	1.078505
207	0.96917	0.902159	1.01186	1.051586	1.007056
208	0.991961	0.857789	1.017306	1.093256	1.05286
209	0.993748	0.899877	1.083356	1.158932	1.095379
210	0.989232	0.8752	0.965952	0.999883	1.023639

Description of Models

- Using Safety Analysis Reports from multiple cask designs, MCNP models of casks were created
- The Next Generation Safeguards Initiative had produced a library of simulated used fuel with varying burnup and cooling time
- Using the library to generate different loadings for multiple casks, the proposed signature could be tested
- The initial tests showed strong identification trends

HI-STORM 100S with MPC-32 Canister





Real Data from 3 actual MPC-32 Canisters

- Data provided by ORNL
- Neutron emission rates and energy spectrum with axial profiles for 96 assemblies
- Loading patterns provided
- Combined with spent fuel library, 3 simulations were created in MCNP and run

Loading 1

	29 R68 1.229E+08	30 R60 1.255E+08	31 R49 1.273E+08	32 R51 1.280E+08	
23 R66 1.226E+08	24 D60 1.484E+08	25 T10 1.498E+08	26 T12 1.508E+08	27 D05 1.501E+08	28 D17 2.009E+08
17 D27 1.561E+08	18 T09 1.492E+08	19 T11 1.500E+08	20 S45 1.266E+08	21 S67 1.274E+08	22 D01 1.510E+08
11 D53 1.561E+08	12 S75 1.286E+08	13 R43 1.546E+08	14 F56 1.484E+08	15 F18 1.298E+08	16 D29 1.569E+08
5 D55 1.548E+08	6 D31 1.593E+08	7 F01 1.298E+08	8 R64 1.227E+08	9 D18 1.604E+08	10 D11 1.560E+08
	1 D24 1.569E+08	2 D52 1.614E+08	3 D36 1.667E+08	4 D40 1.691E+08	

- **Max – 2.009e08 n/s**
- **Min – 1.226e08 n/s**
- **Average – 1.468e08 n/s**
- **Total – 4.698e09**

Top number is position, Middle value is Assembly Name, Bottom value is neutron emission rate from assembly

Loading 2

	29 F35 1.361E+08	30 F60 1.372E+08	31 F37 1.394E+08	32 F63 1.356E+08	
23 F26 1.070E+08	24 F32 1.073E+08	25 J44 7.303E+07	26 J53 7.153E+07	27 F05 1.080E+08	28 P05 1.006E+08
17 S77 1.126E+08	18 J15 7.175E+07	19 J09 7.328E+07	20 J41 7.337E+07	21 J17 7.465E+07	22 S76 1.141E+08
11 E28 1.266E+08	12 J23 7.170E+07	13 D15 1.247E+08	14 D66 1.643E+08	15 G05 1.129E+08	16 E03 1.312E+08
5 E12 1.336E+08	6 F08 1.619E+08	7 G14 1.132E+08	8 G09 1.131E+08	9 F22 1.620E+08	10 F27 1.639E+08
	1 F33 1.441E+08	2 P21 8.974E+07	3 D47 1.993E+08	4 F68 1.472E+08	

- **Max – 1.993e08 n/s**
- **Min – 7.153e07 n/s**
- **Average – 1.186e08 n/s**
- **Total – 3.795e09**

Loading 3

	29 R41 1.216E+08	30 R55 1.234E+08	31 R53 1.215E+08	32 R50 1.219E+08	
23 R52 1.232E+08	24 R67 1.213E+08	25 D38 1.568E+08	26 R44 1.566E+08	27 P29 1.972E+08	28 P11 1.961E+08
17 P63 1.156E+08	18 E01 1.635E+08	19 F23 1.572E+08	20 F13 1.582E+08	21 E52 1.674E+08	22 R46 1.195E+08
11 R48 1.207E+08	12 F11 1.603E+08	13 F25 1.653E+08	14 E02 1.772E+08	15 R42 1.213E+08	16 D28 1.861E+08
5 D32 1.904E+08	6 D67 1.833E+08	7 R57 1.225E+08	8 R56 1.228E+08	9 D07 1.967E+08	10 D37 1.951E+08
	1 N45 1.126E+08	2 N32 1.162E+08	3 N47 1.537E+08	4 M39 1.870E+08	

- **Max – 1.972e08 n/s**
- **Min – 1.126e08 n/s**
- **Average – 1.510e08 n/s**
- **Total – 4.832e09**

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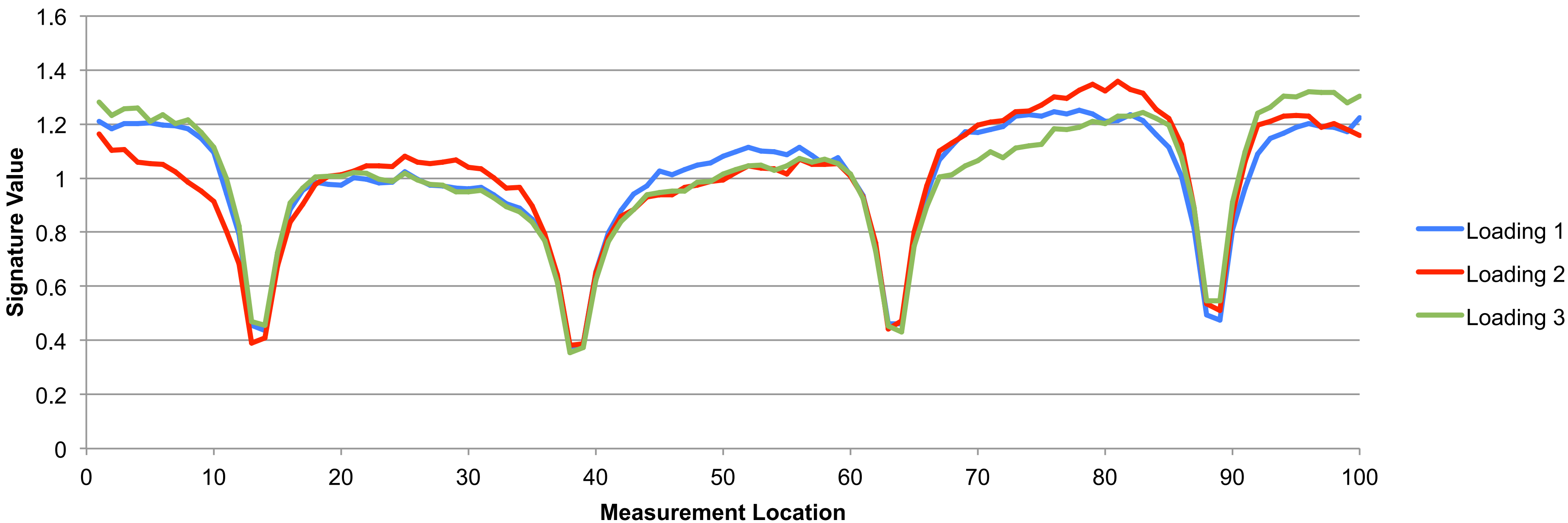
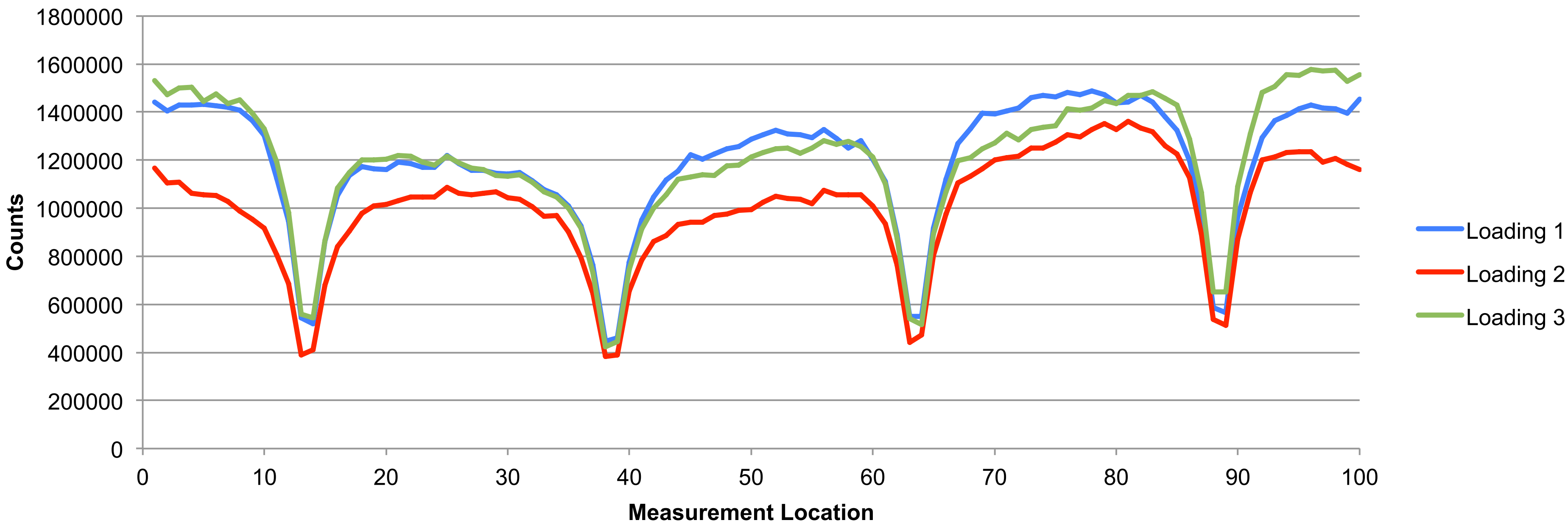
Initial Results



Visible differences in the profile are evident. If more than 5 SV are greater than 5% different in comparison to another measurement, no match.

Simulated Measurement Results



Loading 2 produces significantly lower measurements. Lower measurements expected due to older fuel, with lower neutron emission rates.

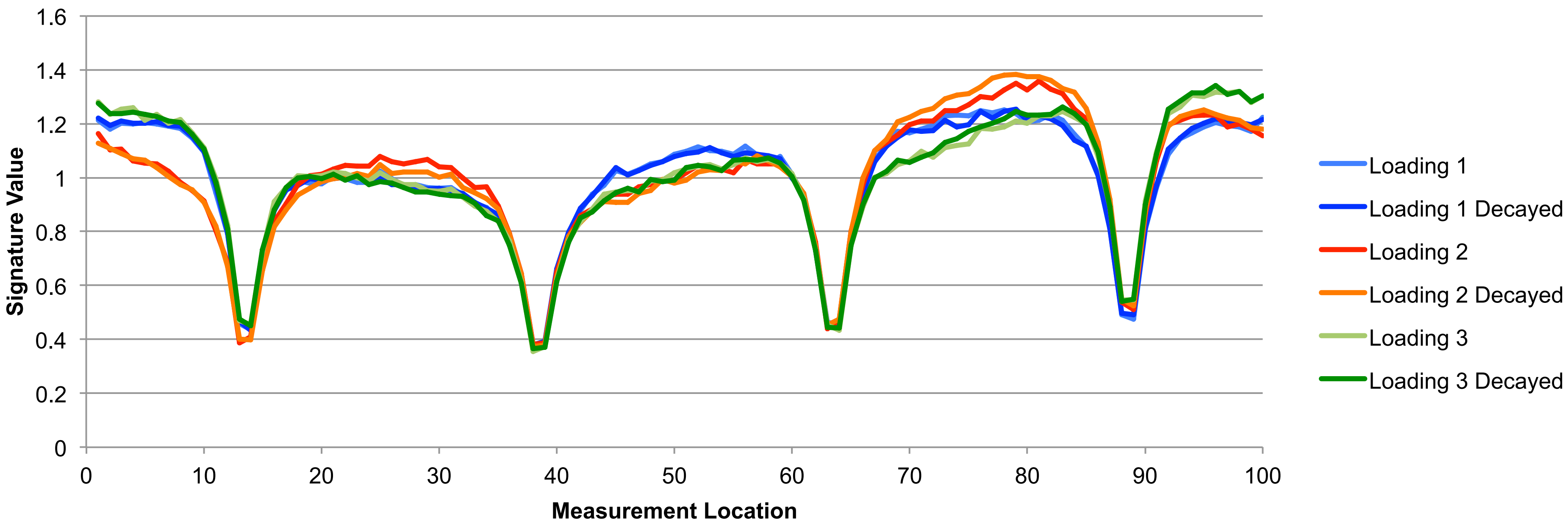
Findings

- Identification of cask loadings works well through the profile of emitted neutrons in simulated real casks
- Even casks with similar overall neutron emission or average counts around the circumference can be distinguished from each other by analyzing the profile
- Collecting profile provides other potentially useful information

Aging Casks

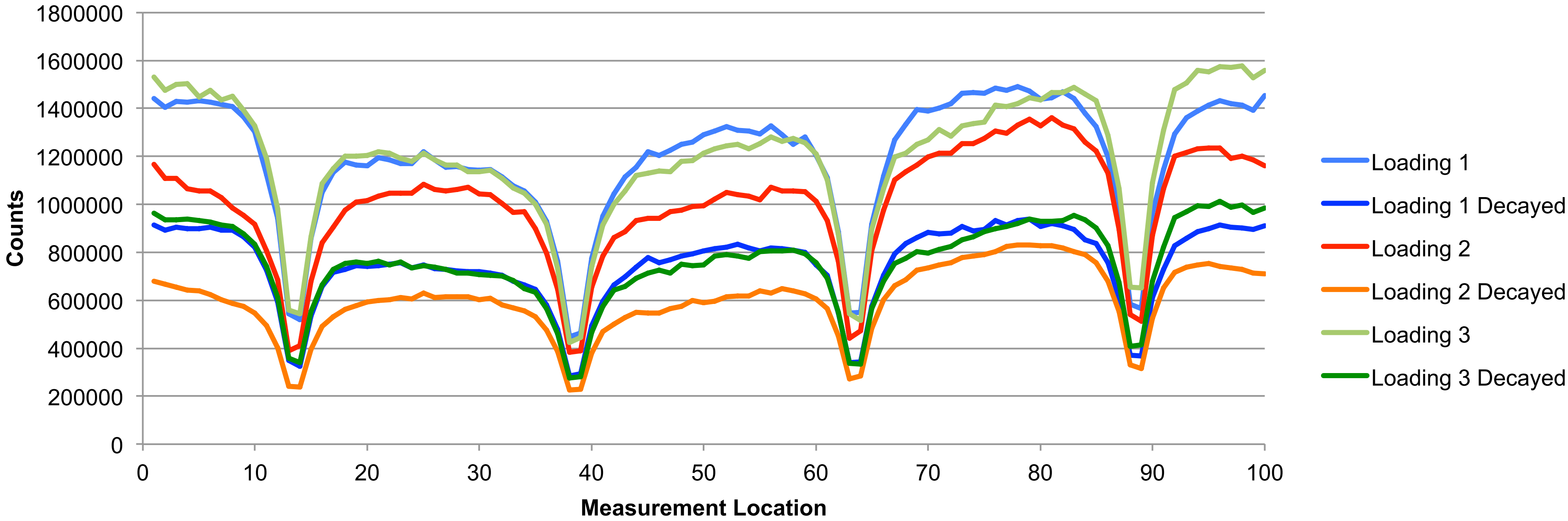
- Using the discharge date and initial in-service date and an equation developed to estimate used fuel activity over time, each assembly in all 3 loadings was aged by 20 years.
- Fuel material compositions were also updated for 20 years of decay using the used fuel library

Results



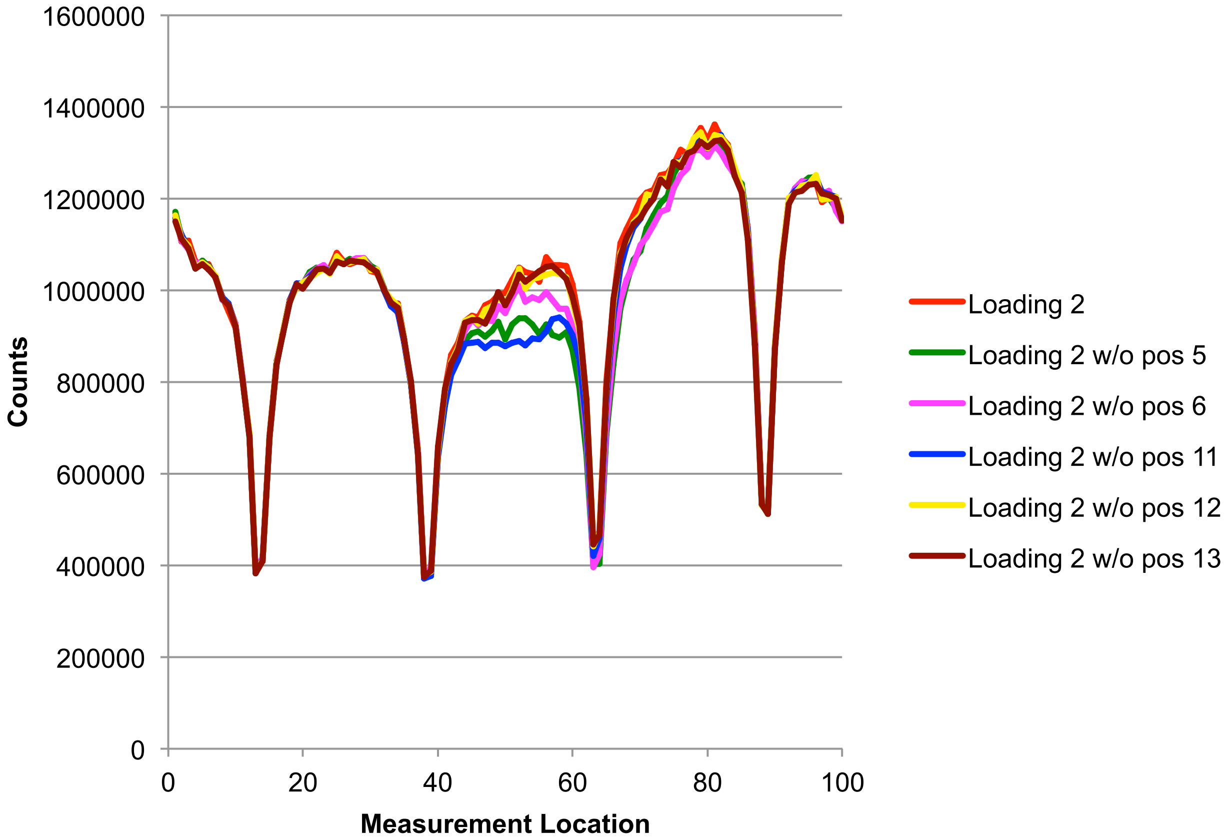
The decayed signatures from Loadings 1 and 3 follow their respective original signatures. Loading 2 does have some variability when compared to its original signature, but falls within the Acceptance Criteria previously outlined.

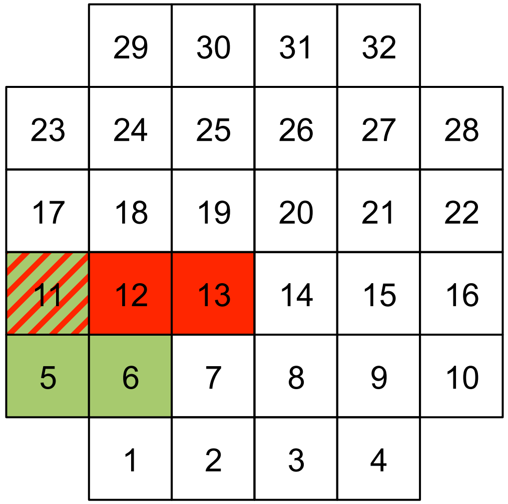
Measurement Results



20 years worth of decay dramatically lowers the count rates, so the normalization is needed for comparison of profiles, but count rates can be indicative of missing assemblies if assembly source strength can be estimated reliably over time.

Removal of an Assembly





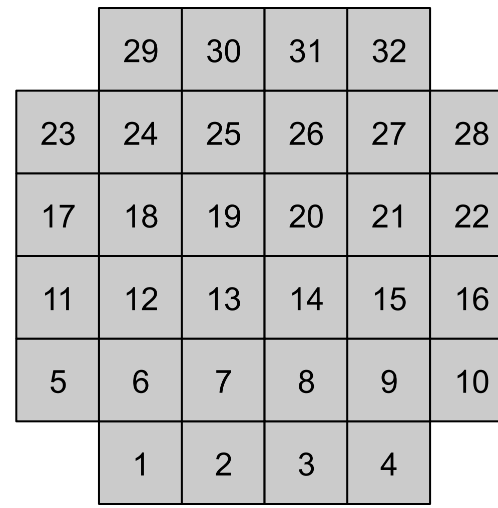
Real Data Missing Assembly Findings

- Signature is less reliant on multiplication than previous studies indicated
- There is a significant change in counts with removal of assemblies
- Looking at percent decrease over time per detector could still offer insight on state of fuel inside cask

Removal of 1 or more Assemblies

	Decayed	Pos 5 removed	Pos 6 removed	Pos 11 removed	Pos 12 removed
Average	63.18%	60.27%	61.63%	62.09%	62.35%
Max	65.89%	64.68%	65.09%	65.40%	65.09%
Min	61.17%	49.22%	55.67%	58.36%	57.24

	Pos 13 removed	Center 4 removed	Center 16 removed	Center 12 removed
Average	62.69%	60.81%	44.33%	52.41%
Max	64.94%	64.36%	46.57%	55.76%
Min	60.16%	58.52%	41.75%	48.99%



Final Simulation Results

- Identification of unaltered casks through neutron signature profile is viable
- Collecting the profile provides insight to the condition and intactness of the fuel stored inside the cask
- Signature profile is stable over time

Thanks

Thanks to DOE-NE and the MPACT campaign for supporting this work.

Special thanks to Mike Miller, Scott Demuth, and Jim Sprinkle.