Implementation of Whisper-based Validation at the Hanford Tank Farms

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washington river protection solutions

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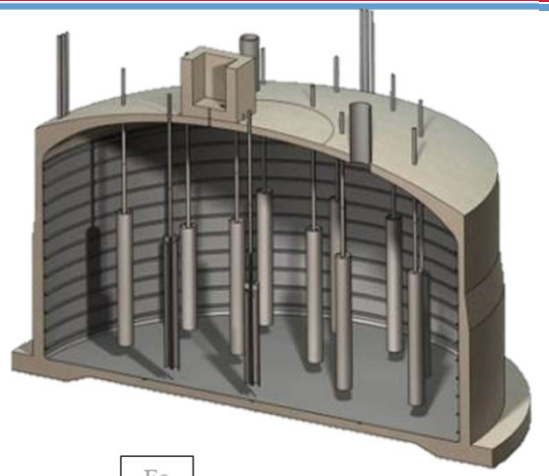
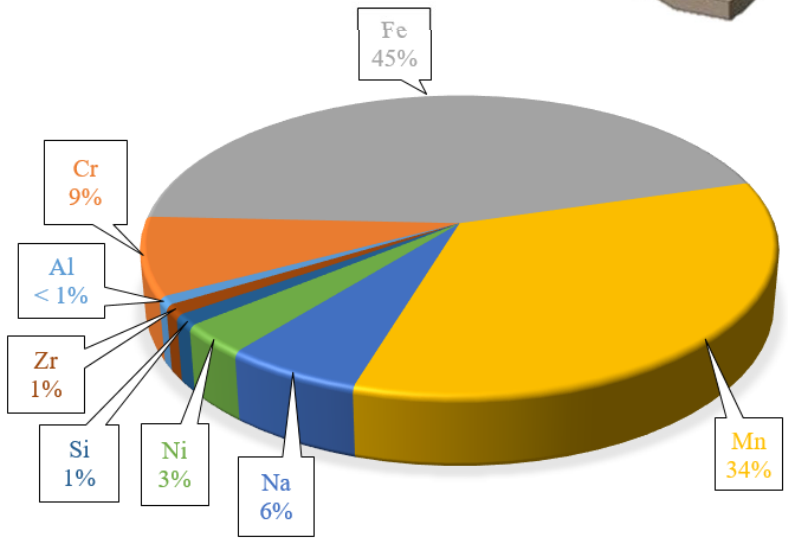
HANFORD TANK WASTE

- **Product of 50 years of plutonium production**
  - Many distinct waste streams and compositions
- **56 million gallons of waste in 177 tanks, including:**
  - Various metals
  - Fission products
  - Uranium (~600 metric tons)
  - Plutonium (670 kg)
- **NCS analysis mainly based on presence of:**
  - Aluminum
  - Chromium
  - Iron
  - Manganese
  - Nickel
  - Silicon
  - Sodium
  - Zirconium





CRITICALITY SAFETY CALCULATIONS

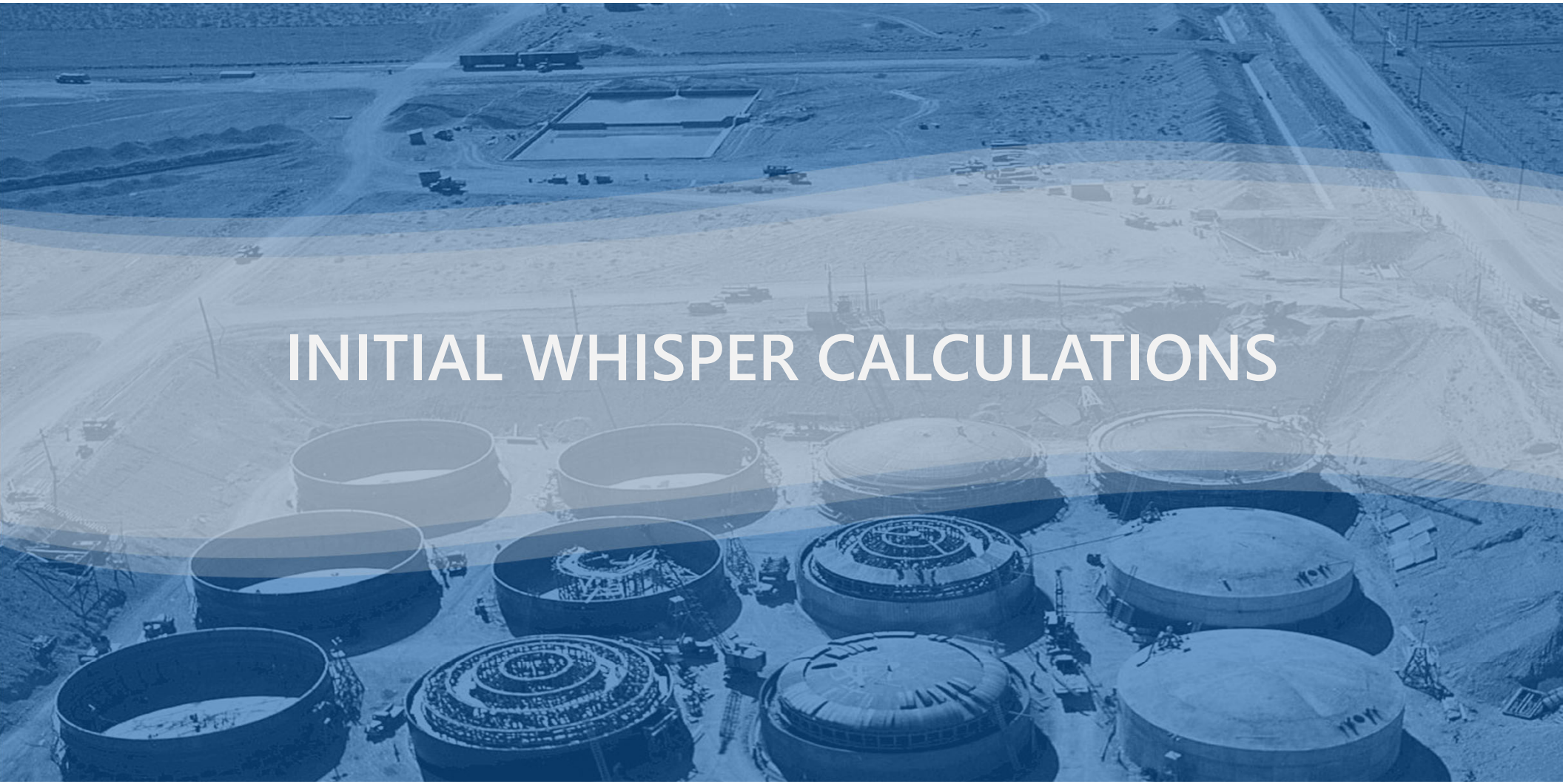
- **Current NCS evaluation is based on Pu-to-absorber ratios:**
  - Infinite, homogenous mixtures of Pu, water, and one absorber metal oxide
  - Absorbers combined proportionally (iron-equivalent mass)
- **Future evaluations will include direct calculation of waste compositions**

…How similar are benchmark experiments to these models?

- Previous recommendations to use sensitivity/uncertainty validation methods

VALIDATION CALCULATIONS

- **MCNP6.2 with Whisper-1.1**
  - ENDF/B-VII.1 cross-sections
- **1,223 total benchmark experiments:**
  - 1,101 distributed with Whisper
    + 122 added locally
  - Added:
    - ✓ Many MIX benchmarks
    - ✓ Available thermal Pu benchmarks with absorbers of interest
- **USL calculations using:**
  - Each absorber over full H-to-X range
  - 'Real' tank compositions [~400 total solids layers], at optimal moderation



INITIAL WHISPER CALCULATIONS

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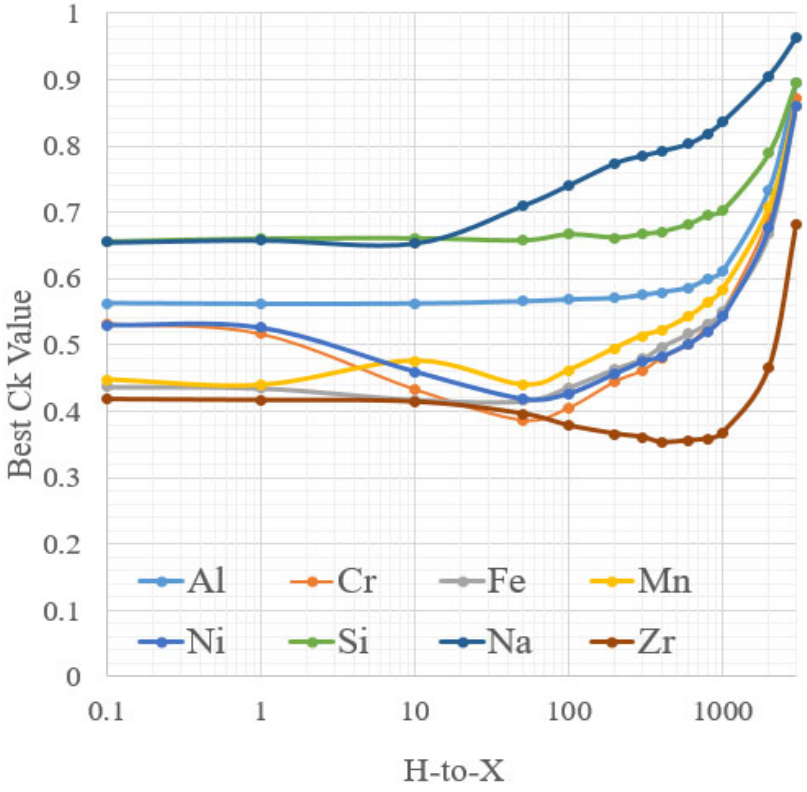
BENCHMARK SIMILARITY

- **Using standard Whisper calculation flow:**
  - Best c_k value typically between 0.4 and 0.6
  - [Good match is c_k > 0.9]
- **Minimal presence of most absorbers in benchmarks:**
  - Structural materials, cladding, or trace contaminants
  - No significant sensitivity in k_{eff}
- **(n,γ) sensitivity in calcs often 100+ times any benchmark**

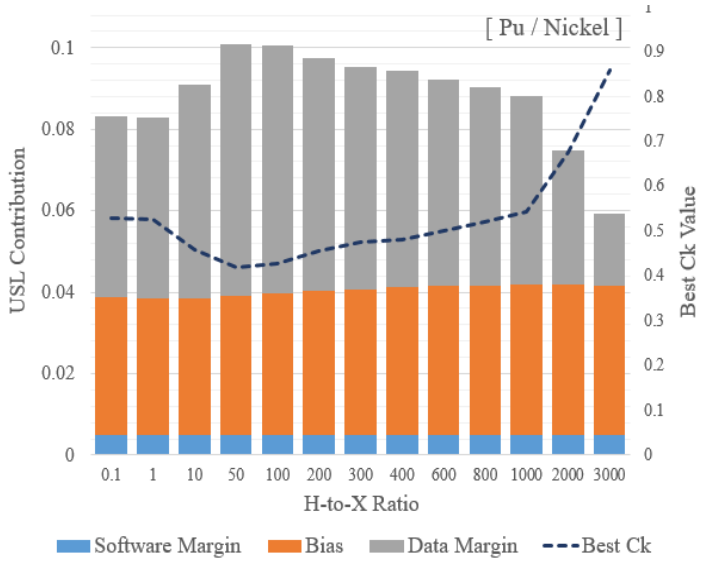


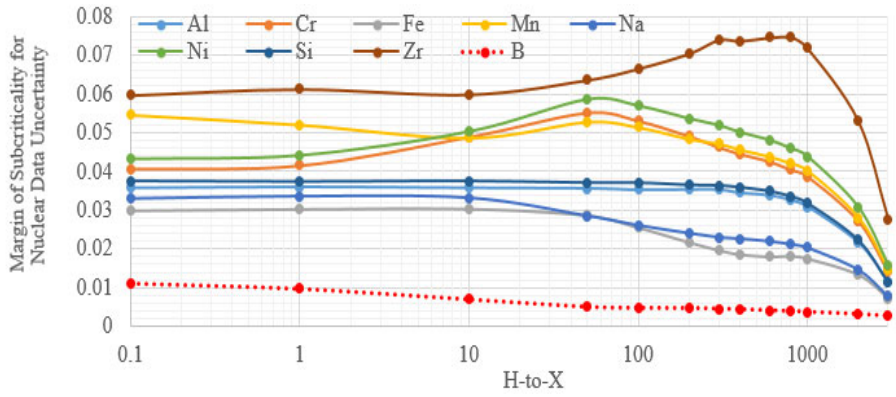
IMPACT ON WHISPER USL

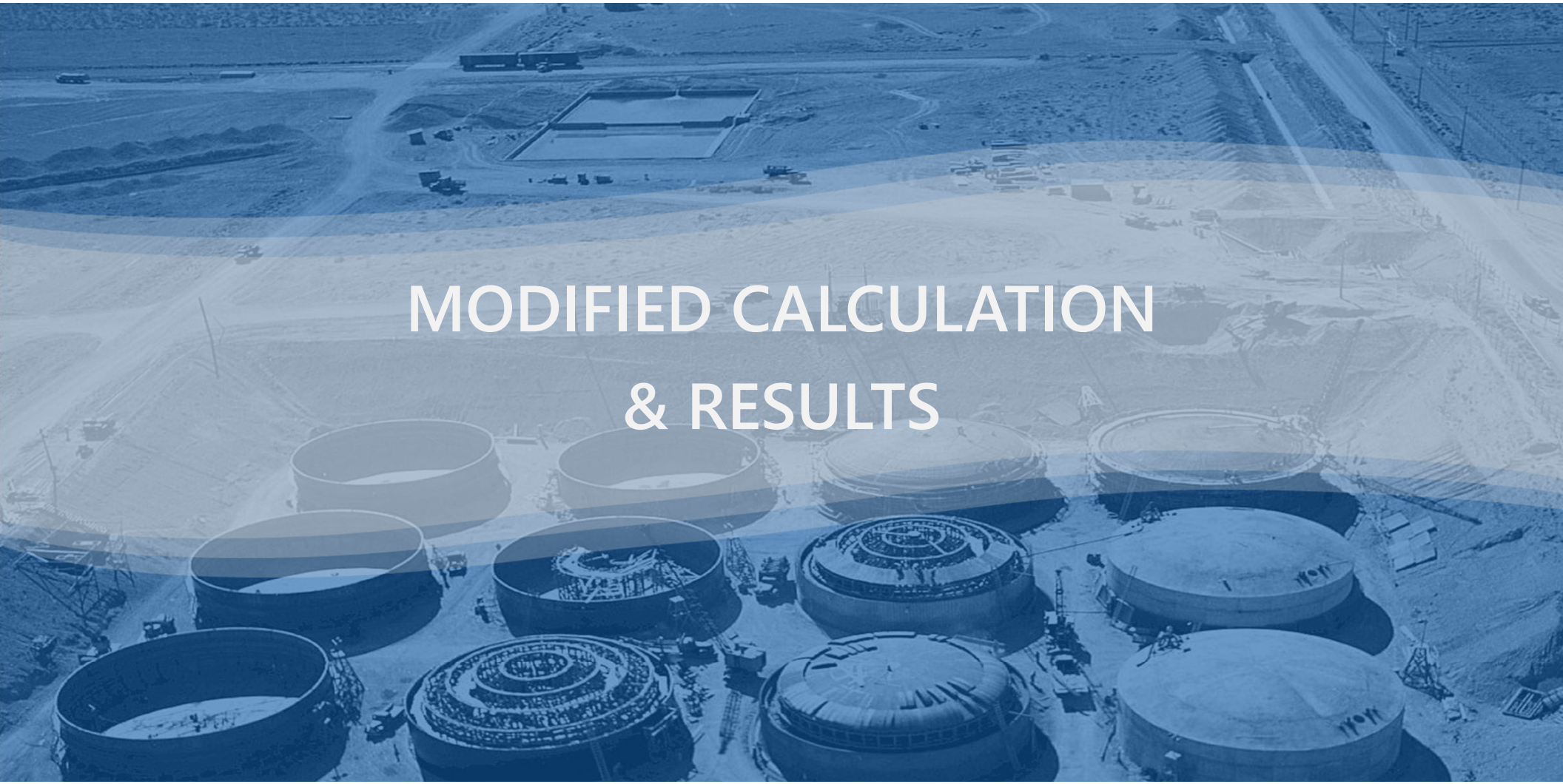
$$USL = 1 - Bias - MOS_{nuclear\ data} - MOS_{software}$$

For initial calculations:

- Bias large and near-constant
  - Low c_k = little variation across H-to-X or elements
  - Near maximum possible for benchmark set
- MOS_{data} largest component of calculated USL
  - Little uncertainty reduction (~few comparison points)
- Produced USLs around 0.87 to 0.90







MODIFIED CALCULATION & RESULTS

SPLITTING USL CALCULATION

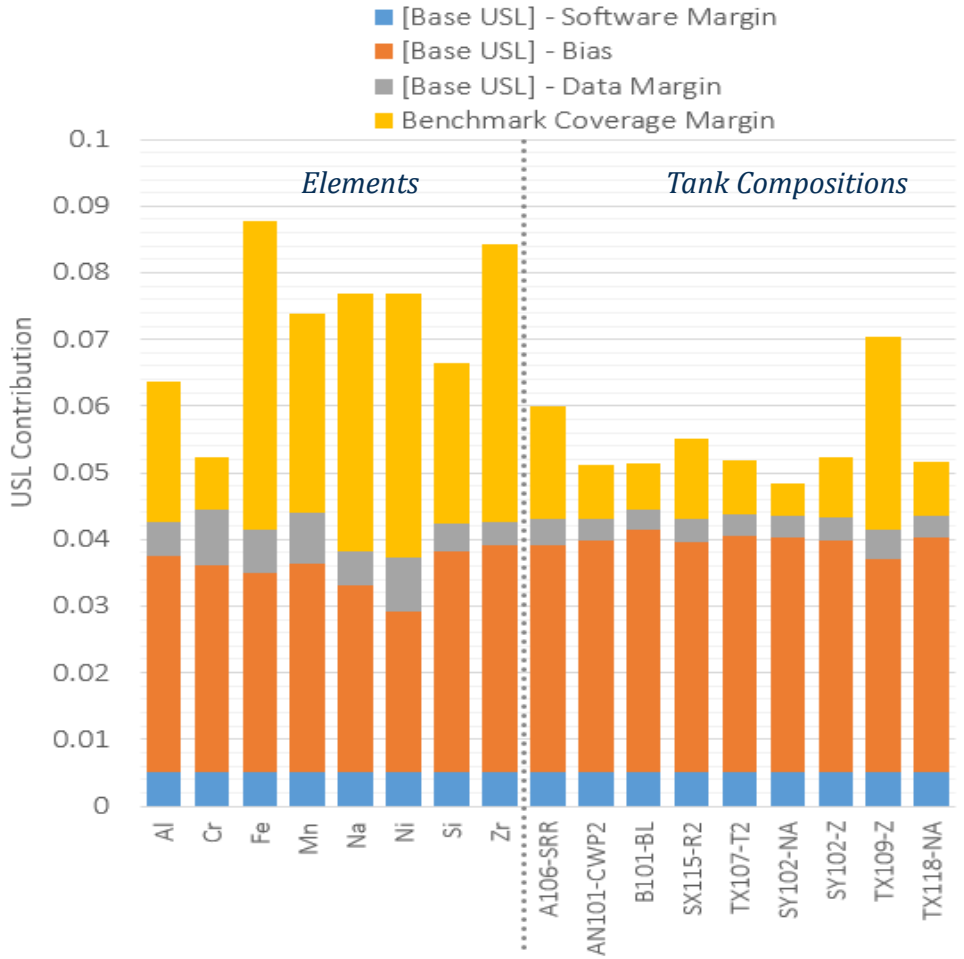
"[It] is possible to bound the computational bias introduced by a particular nuclide, for which little experimental data are available, by examining the keff uncertainties introduced by the uncertainties in that nuclide's nuclear data. … The additional margin should be at least as large as the keff uncertainties introduced by the uncertainties in that nuclide's nuclear data (at the one sigma level."

~ CSSG response 2014-02

- **Final USLs calculated in 2 parts:**
  - A "base USL" calculated with Whisper
    - Sensitivity calculation limited to Pu, U, H, and O
    - Same input file; exact match to spectra
    - C_k shows applicability to isotopes that can be matched
  - An additional margin based on CSSG response 2014-02, "*Validation with Limited Benchmark Data*"
    - Accounting for absorbers without benchmark representation
    - Based on sensitivities calculated for each isotope, and their cross-section uncertainties

CALCULATED MARGINS

- **Calculated bounding single-element margins for all H-to-X**
  - Lowest final USLs for Fe, Zr
- **Smaller total margins for tank waste compositions:**
  - Absorption in ^{238}U – part of "base USL"
  - 8 different absorber elements



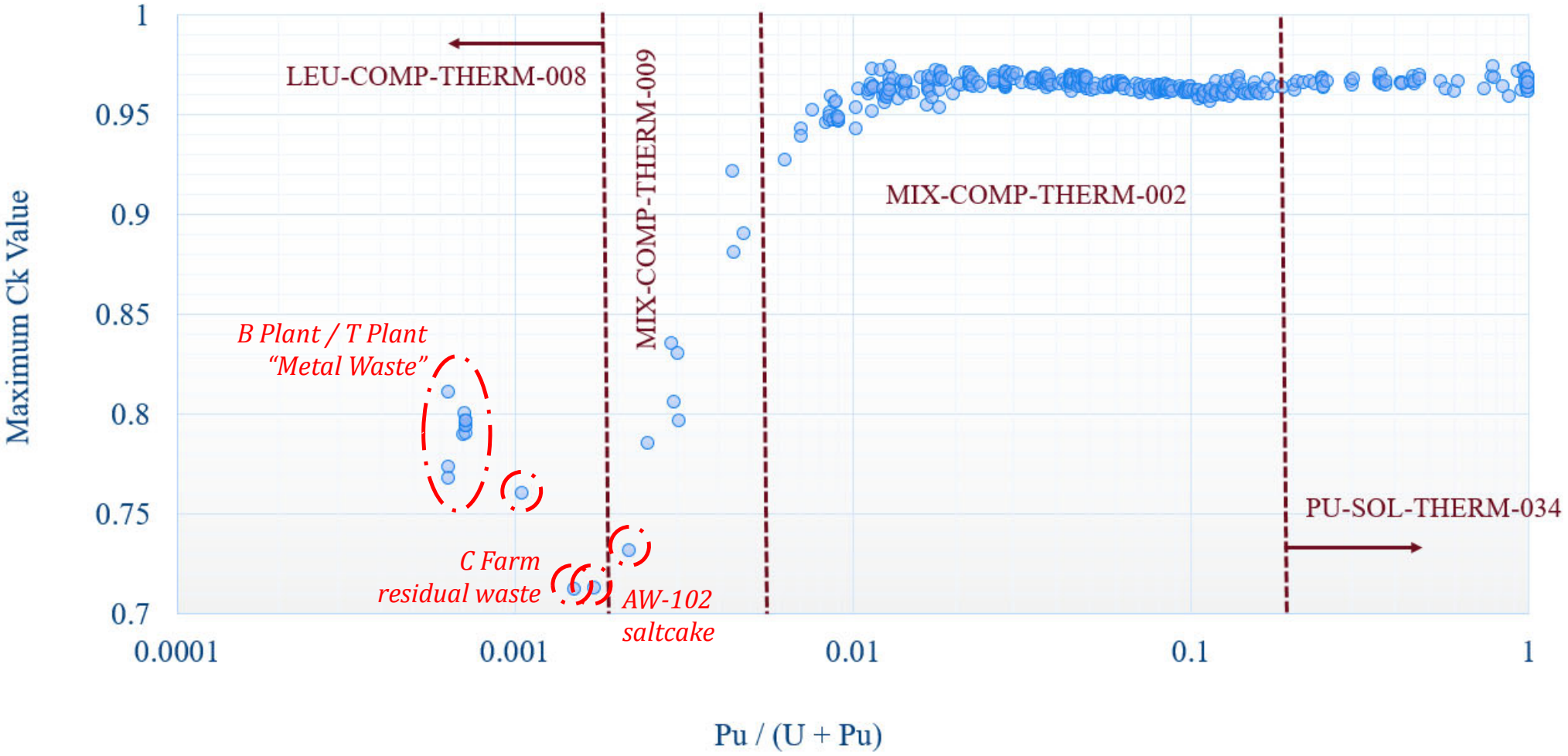
BASE USL – C_K SIMILARITY VALUES

- **Almost all tank layers had excellent c_k values for base USL calculation [c_k > 0.95]**
  - Only 3 kg Pu [0.4%] in layers with c_k <0.8
  - 7½ kg Pu [1%] in layers with c_k < 0.9

- **Clear trends with uranium content**

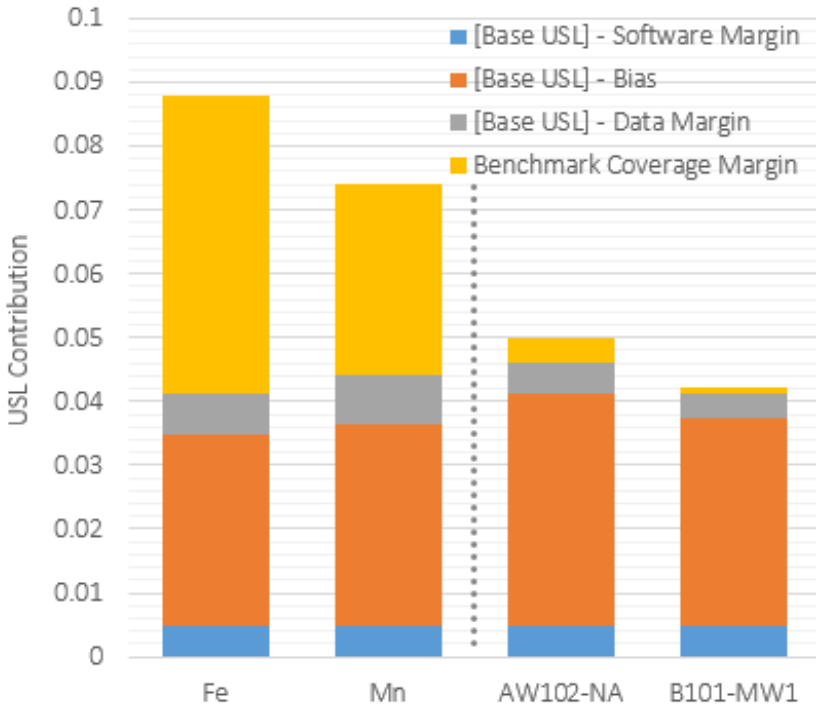
- **Highest-ranked benchmark was always one of four experiments:**
  - ✓PU-SOL-THERM-034 – plutonium solution containing Gd
  - ✓MIX-COMP-THERM-002 – Pu and natural UO_2 in borated water
  - ✓MIX-COMP-THERM-009 – Pu and DU in water
  - ✓LEU-COMP-THERM-008 – 2.5% enriched UO_2 fuel pins in borated water

HIGHEST-RANKED BENCHMARKS



MARGINS IN LOW-C_K BASE USLS

- **Lowest-c_k layers = highest U content**
  - Vast majority of absorption in ^{238}U
  - Much less reliant on absorbers like Fe, Mn, etc.
  - ➢ *Smaller benchmark coverage margins for other absorbers*
- **Future calculations use same USL for all compositions:**
  - Bounding, worst-case single element = Fe, 0.913
  - Significant extra margins for high-U, low-c_k waste layers
- **Majority of low-c_k layers are compositions with lowest NCS concern**
  - Minimal actual Pu
  - Very large absorber masses



CONCLUSIONS & PATH FORWARD

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- **Sensitivity / Uncertainty methods implemented for Tank Farms NCS calculations**
  - Showed that few highly applicable benchmarks were available
- **New MCNP6.2 validation uses variant of standard Whisper method**
  - Additional margins to compensate for absorbers
- **More use of full tank layer calculations**
  - Less reliance on any single absorber element
  - Include absorption from near-natural U in same calculation
- **Development of new thermal Pu benchmarks**
  - Designed for strong absorption from credited elements
  - Fe & Mn versions of TEX experiment


Questions?