Validation of Chlorine with Limited Experimental Data
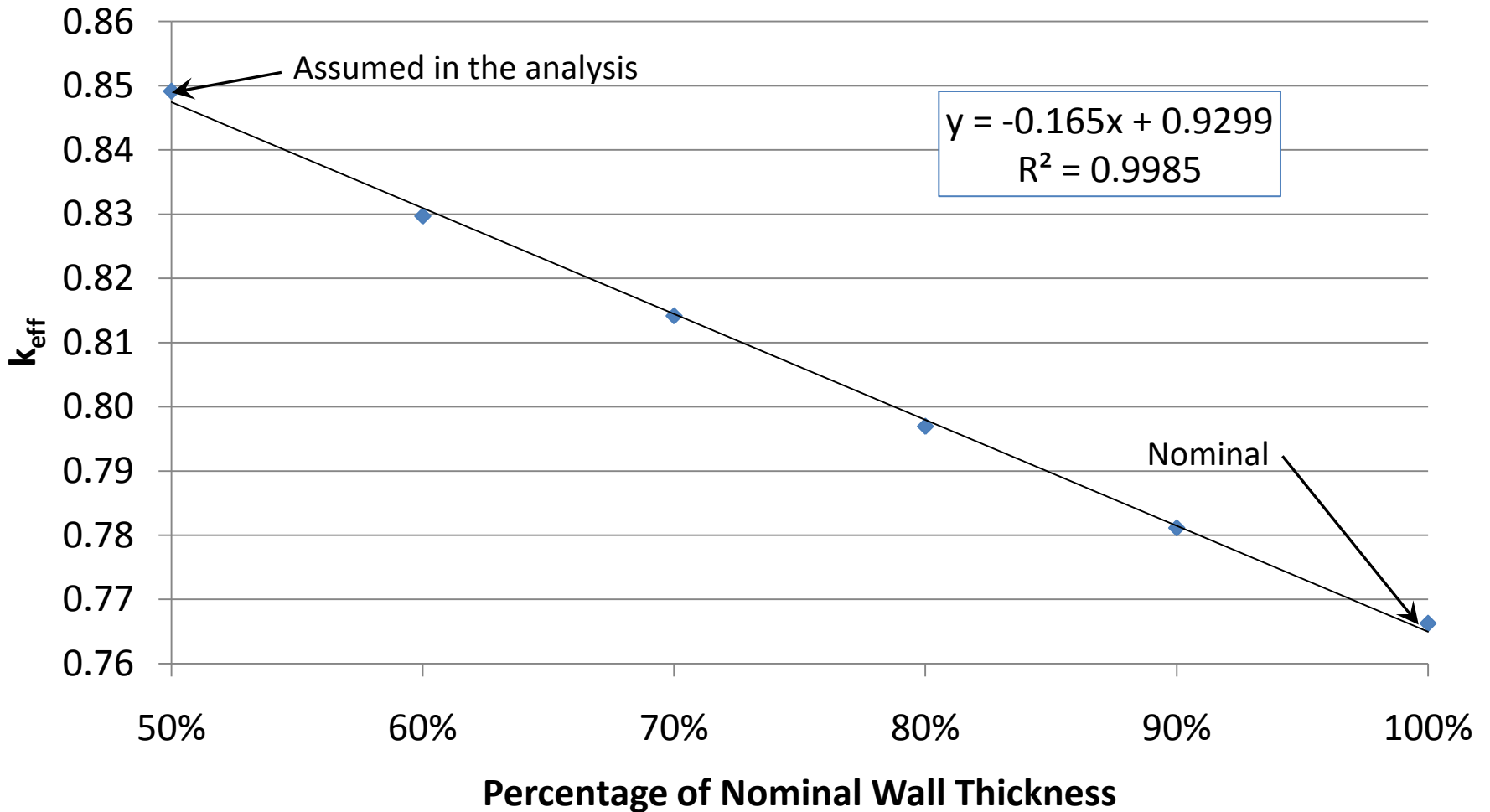
American Nuclear Society Annual Meeting
Hollywood, Florida

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William D. Newmyer, NSA, Inc.
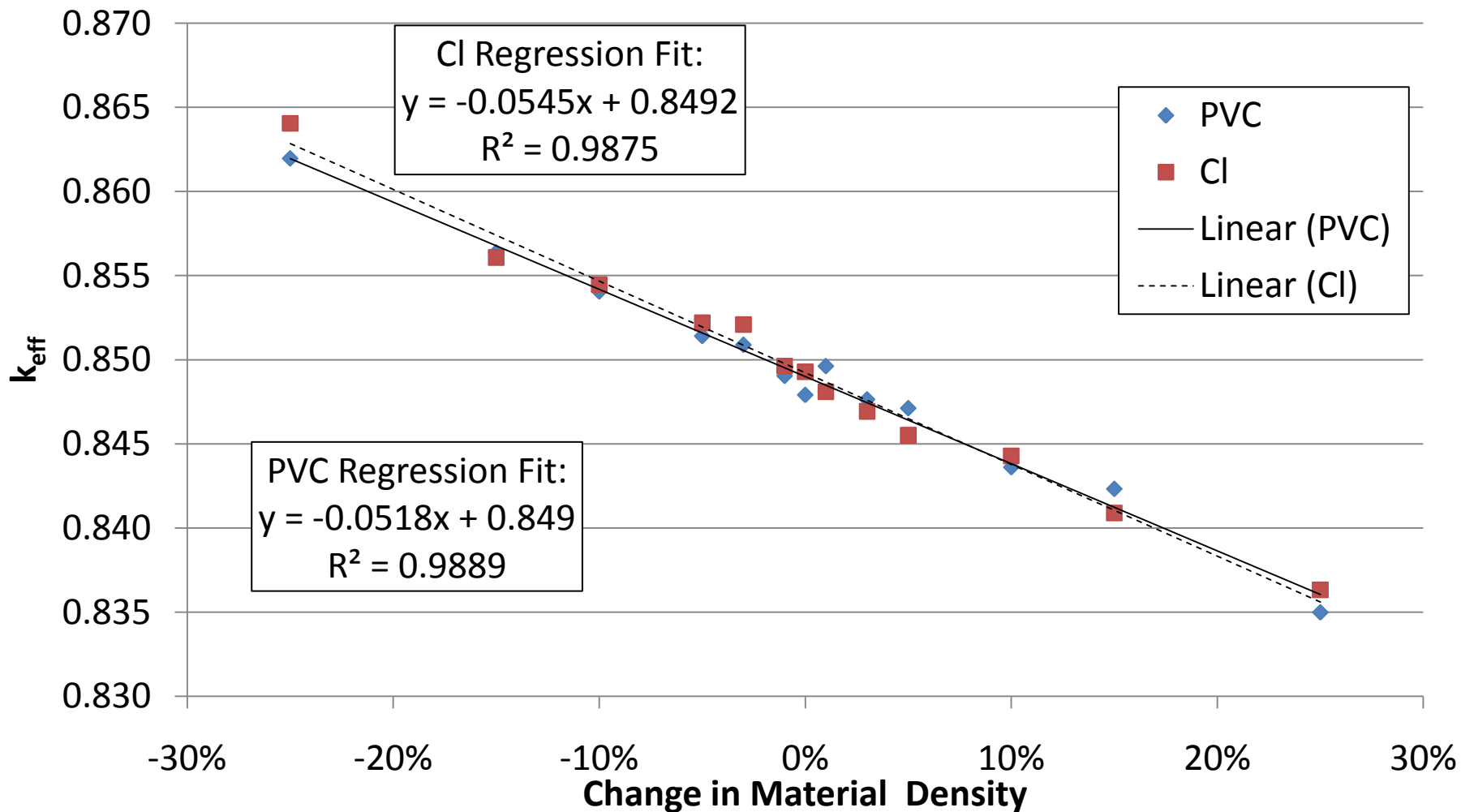
Background

- Polyvinylchloride (PVC) is $CH_2=CHCl$

- Used extensively for piping

- Used by B&W NOG-L for uranium solution processing in Uranium Recovery

- HEU Solutions

- 5 inch Schedule 40

Impact of Wall Thickness

# Impact of Wall Material

Cl Regression Fit:
$y = -0.0545x + 0.8492$
$R^2 = 0.9875$

PVC Regression Fit:
$y = -0.0518x + 0.849$
$R^2 = 0.9889$

Legend:
- PVC
- Cl
- Linear (PVC)
- Linear (Cl)

y-axis: k_{eff}

x-axis: Change in Material Density

Validation

- Traditional approach – select criticals that have PVC

- Problem – only a few exist

  - LEU-COMP-THERM-045 (3 cases)

  - HEU-SOL-THERM-044 (2 cases)

- Processing HEU so only HEU-SOL-THERM-044 is expected to be applicable
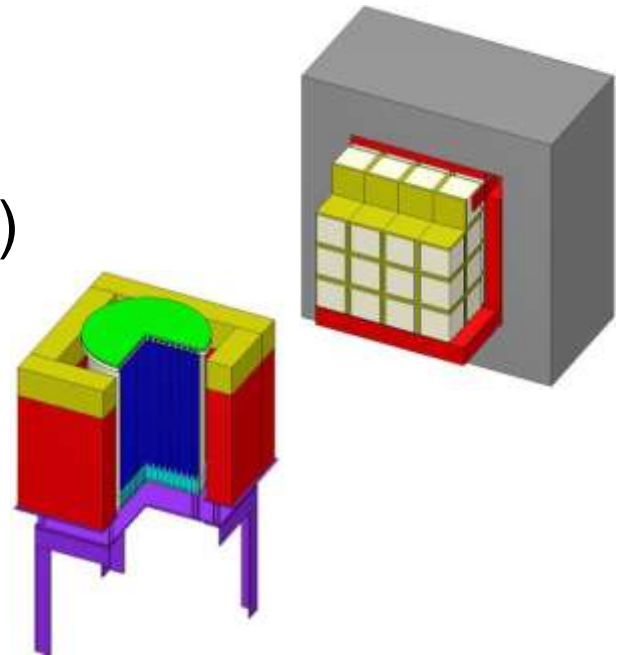
Uncertainty and Sensitivity

- Assess the uncertainty and sensitivity

- TSUNAMI

  - TSUNAMI-3D was used to calculate k_{eff} sensitivity due to cross section variation

  - TSUNAMI-IP was used to calculate k_{eff} sensitivity due to nuclear data uncertainty

- SCALE 5

  - Chlorine covariance data was not included

- SCALE 6

  - Covariance data for natural Cl and ^{35}Cl and ^{37}Cl

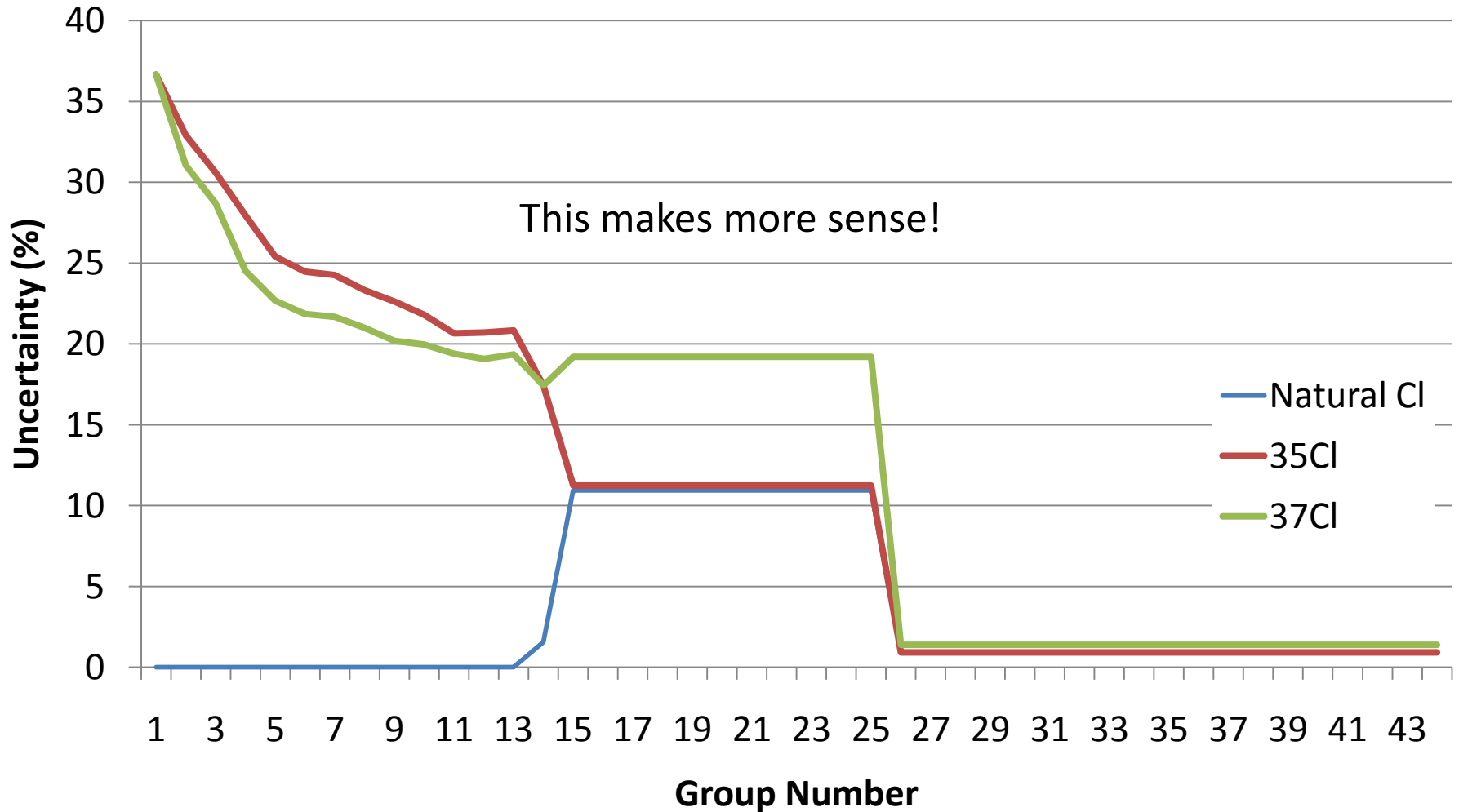# Sensitivity of the System to Cl
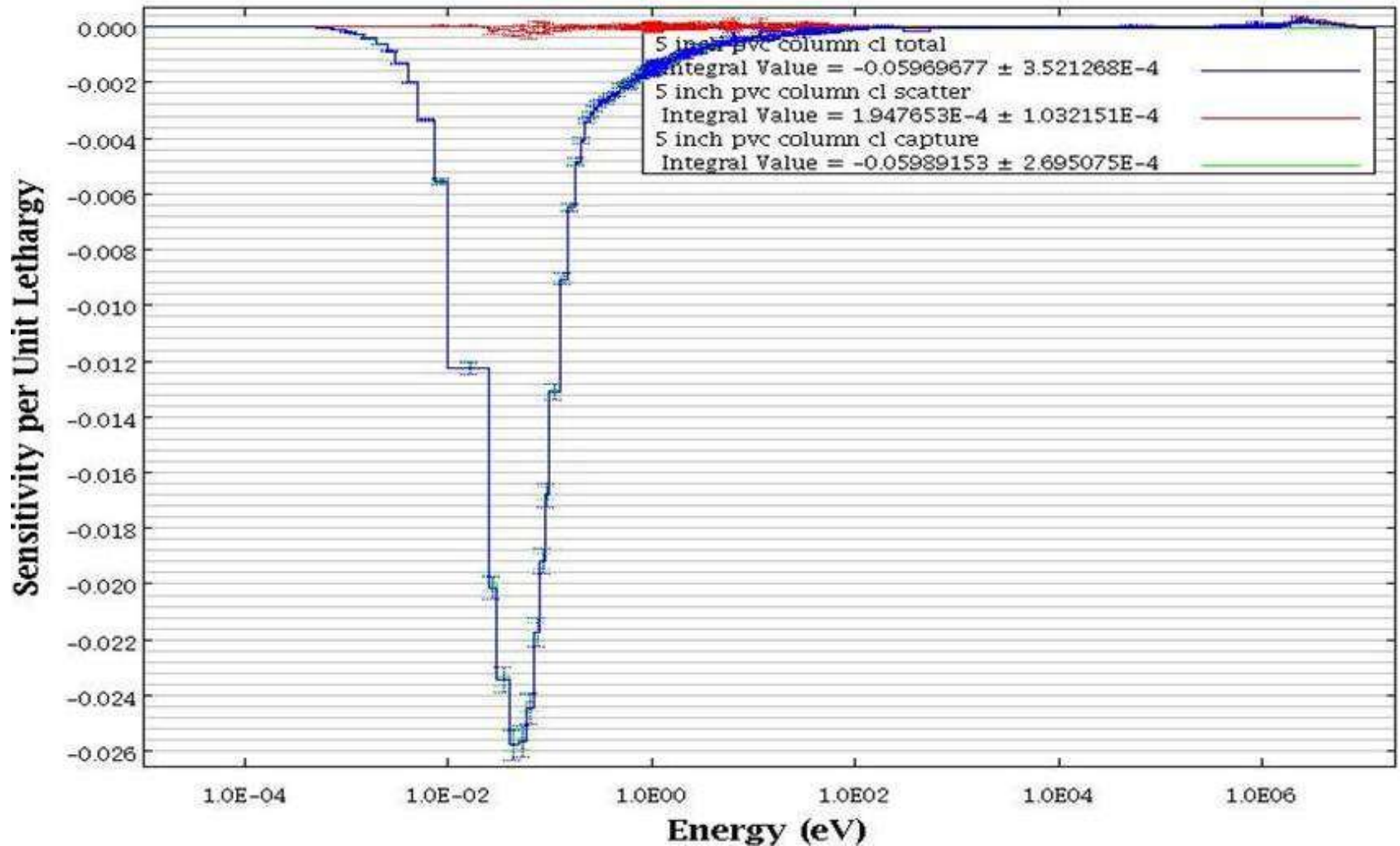
Uncertainty Data (n, gamma)

Uncertainty Data (n, gamma)

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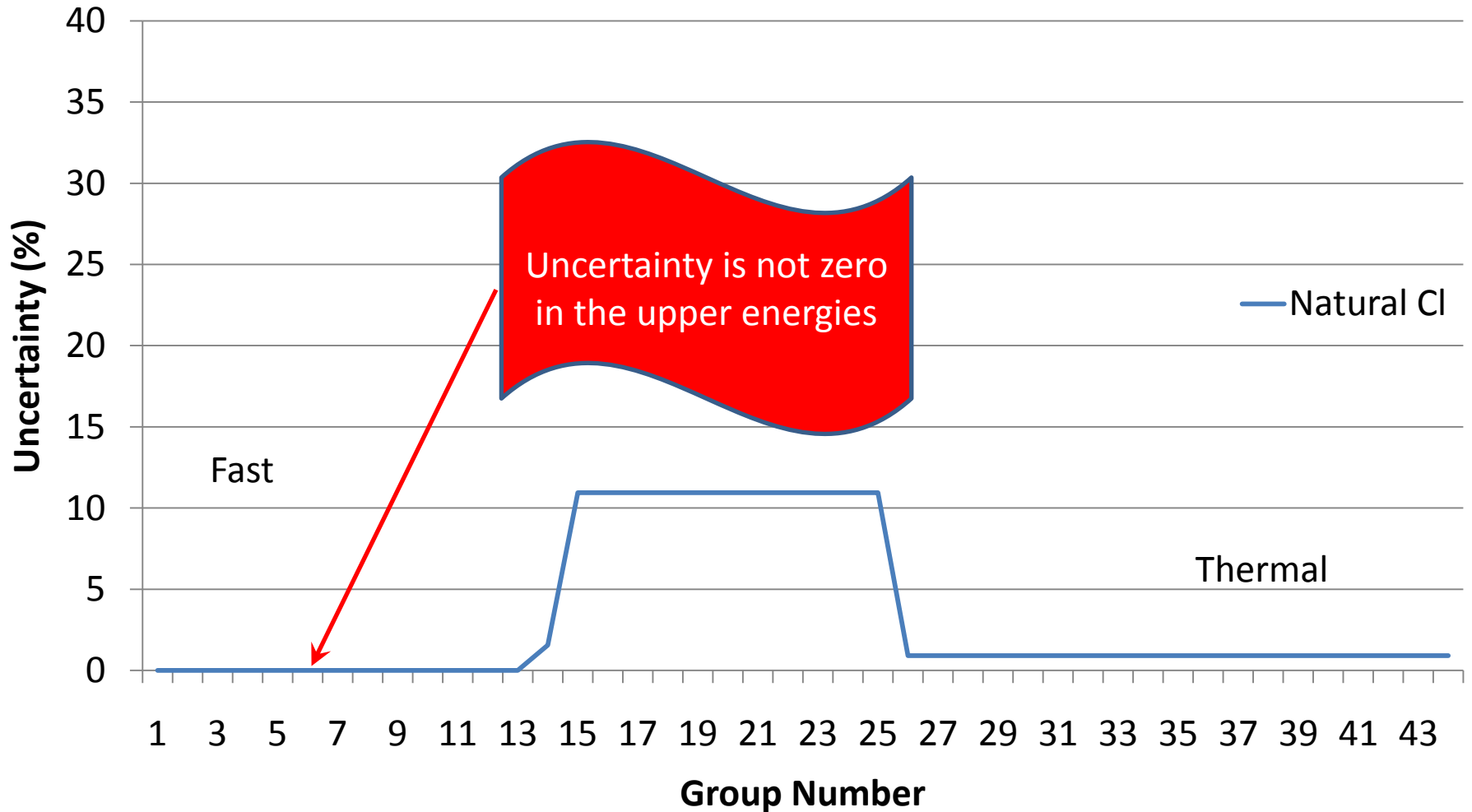
Applicability of Benchmarks

- Test benchmarks against system of interest
  - 5 inch Schedule 40 PVC pipe with inner half of the wall removed containing 400 g ^{235}U/l solution
  - Water reflected
- Test applicability of benchmarks using TSUNAMI
  - LEU-COMP-THERM-045
    - Case 6, c(k) = 0.5750
    - Case 18, c(k) = 0.5549
    - Case 19, c(k) = 0.5569
  - HEU-COM-THERM-044
    - Case 2, c(k) = 0.9645
    - Case 3, c(k) = 0.8430

Alternate Approach

- Use of TSUNAMI to assess the impact of cross section uncertainties on the k_{eff} of the system

- The nuclear data uncertainty is folded into the analysis (case is used as application and experiment)

- Assess the impact of the cross section uncertainties on the bias

  - Run using the SCALE 6 natural CI with input uncertainties

  - Run using the SCALE 6 isotopic data

* D. Mueller, B. Rearden, Using Cross-Section Uncertainty Data to Estimate Biases, *Trans. Am. Nucl. Soc.*, Vol. 96, June 2007, pp. 389-390

Sensitivity by Chlorine Reaction Types

Reaction	Sensitivity ($\delta k/k$)/unit change	Reaction	Sensitivity ($\delta k/k$)/unit change
Total	-0.05942 ± 0.00030	Capture	-0.05964 ± 0.00026
Scatter	0.00022 ± 0.00001	n, gamma	-0.05889 ± 0.00026
Elastic	-0.00002 ± 0.00001	n,p	0.00072 ± 0.00000
n,n'	0.00024 ± 0.00001	n, alpha	0.00003 ± 0.00000

Sensitivity for the Reflected Column

Covariance Matrix		% $\delta k/k$
u-235 chi	u-235 chi	6.8373E-01 ± 4.3167E-04
h-1 elastic	h-1 elastic	3.2322E-01 ± 6.1227E-04
u-235 nubar	u-235 nubar	2.8049E-01 ± 5.5633E-06
u-235 n, gamma	u-235 n, gamma	2.2369E-01 ± 1.5412E-05
u-235 fission	u-235 fission	7.4011E-02 ± 6.2410E-06
cl n, gamma	cl n, gamma	6.2580E-02 ± 5.0005E-06
cl n, p	cl n, p	3.0008E-03 ± 1.6577E-08
cl n, n'	cl n, n'	2.4447E-03 ± 8.9229E-08
cl elastic	cl elastic	1.1017E-03 ± 7.3758E-08
cl n, alpha	cl n, alpha	1.4157E-04 ± 1.5454E-10
cl n,2n	cl n,2n	1.1261E-07 ± 4.6539E-16

Sensitivity for Chlorine

covariance matrix		% $\delta k/k$
cl-35 n,gamma	cl-35 n,gamma	6.3323E-02 ± 2.1580E-07
cl-35 n,p	cl-35 n,p	3.3871E-03 ± 7.8047E-10
cl-35 n,n'	cl-35 n,n'	6.8941E-04 ± 1.6374E-10
cl-35 elastic	cl-35 elastic	6.8321E-04 ± 1.2874E-09
cl-35 n,alpha	cl-35 n,alpha	1.5641E-04 ± 5.9517E-12
cl-37 n,gamma	cl-37 n,gamma	3.3324E-04 ± 5.0981E-12
cl-37 n,p	cl-37 n,p	1.7705E-04 ± 1.0156E-11
cl-37 n,n'	cl-37 n,n'	1.4323E-04 ± 1.5709E-10
cl-37 elastic	cl-37 elastic	2.9783E-06 ± 4.8783E-15
cl-37 n,alpha	cl-37 n,alpha	8.4710E-07 ± 2.1628E-16

Conclusions

- 0.00063 δk uncertainty due to CI data uncertainty
- For high enriched $UO_2(NO_3)_2$ solutions:
  - Bias uncertainty is 0.00240 δk
  - Add in chlorine uncertainty
  - Total uncertainty is 0.0025 δk
- Minimum k_{eff} = 0.99070
- Bias = 1 − Minimum k_{eff} + bias uncertainty
- 0.0118 δk
- Existing bias of 0.015 δk applied to all HEU calculations bounds the chlorine uncertainty for solution processing columns