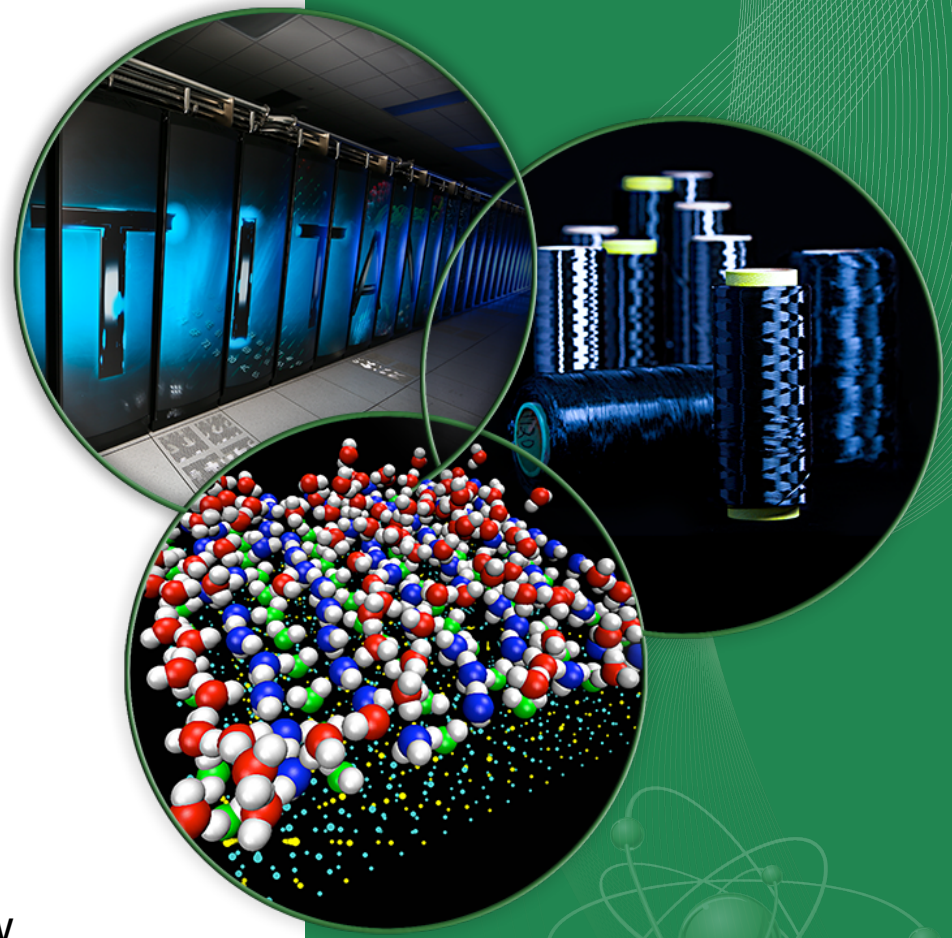
Generation and Testing of Sensitivity Profiles for Benchmark Experiments in the ICSBEP Handbook



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and Ivan Maldonado

NCSP Annual Technical Program Review
Lawrence Livermore National Laboratory
March 18-19, 2015

ORNL is managed by UT-Battelle
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OAK RIDGE National Laboratory

Outline

- Project Objective
- Description of Selected Experiments
- Results
- Conclusions
- Future Work

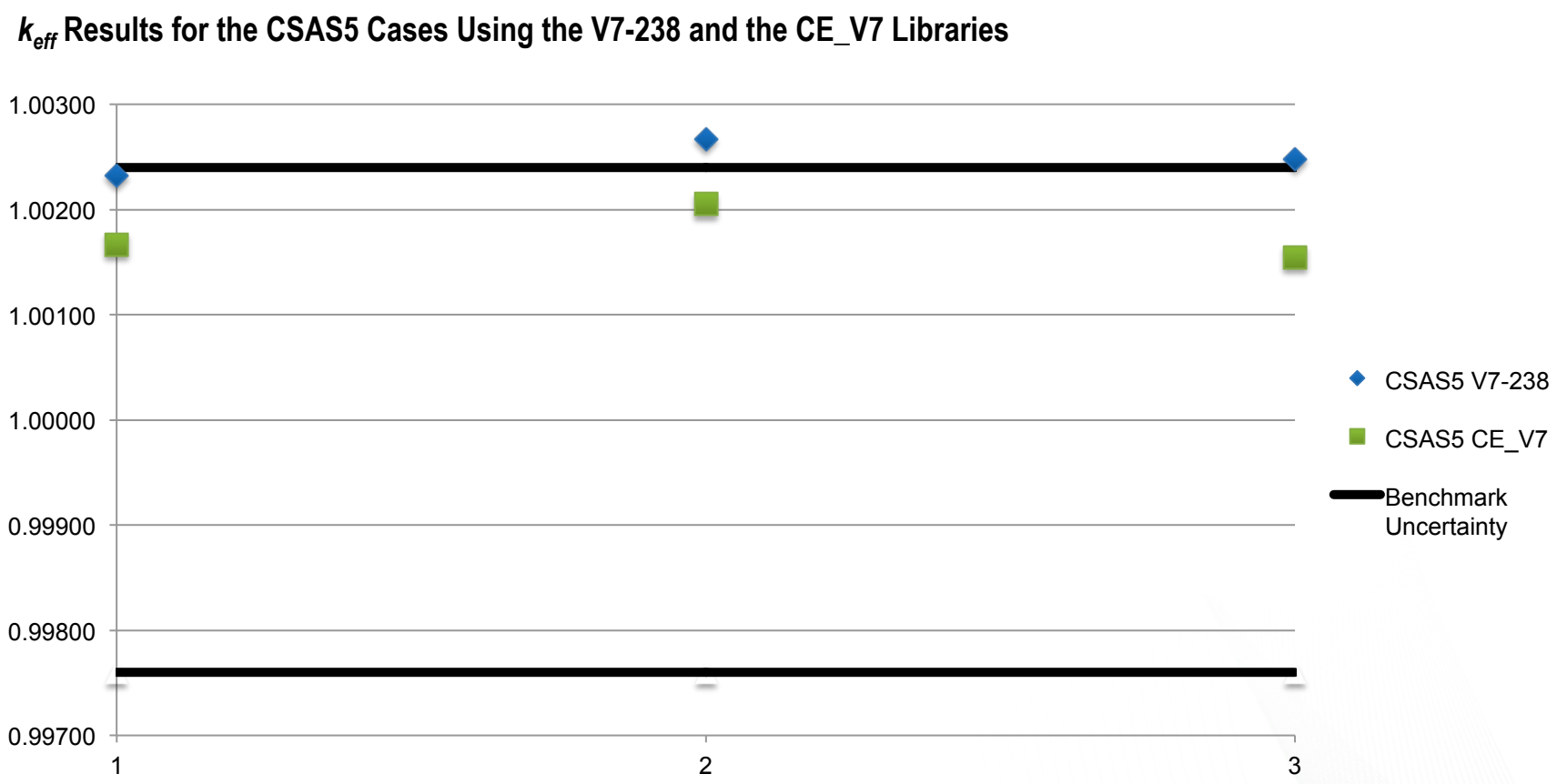
Project Objective

- Selection of documented International Criticality Safety Benchmark Evaluation Project (ICSBEP) evaluations for sensitivity analysis
- Completion of Sensitivity Evaluations with the VALID Procedure Documentation Review
- Submission to Supplement ICSBEP data
- The reactivity and sensitivity calculations constitute calculations performed using the CSAS (MG and CE) and TSUNAMI-3D (MG only) modules of SCALE, respectively
- The CSAS and TSUNAMI-3D calculations
  - SCALE 6.1.2
  - Performed using the ENDF/B-VII.0 multigroup library (V7-238) and continuous-energy (CE_V7)

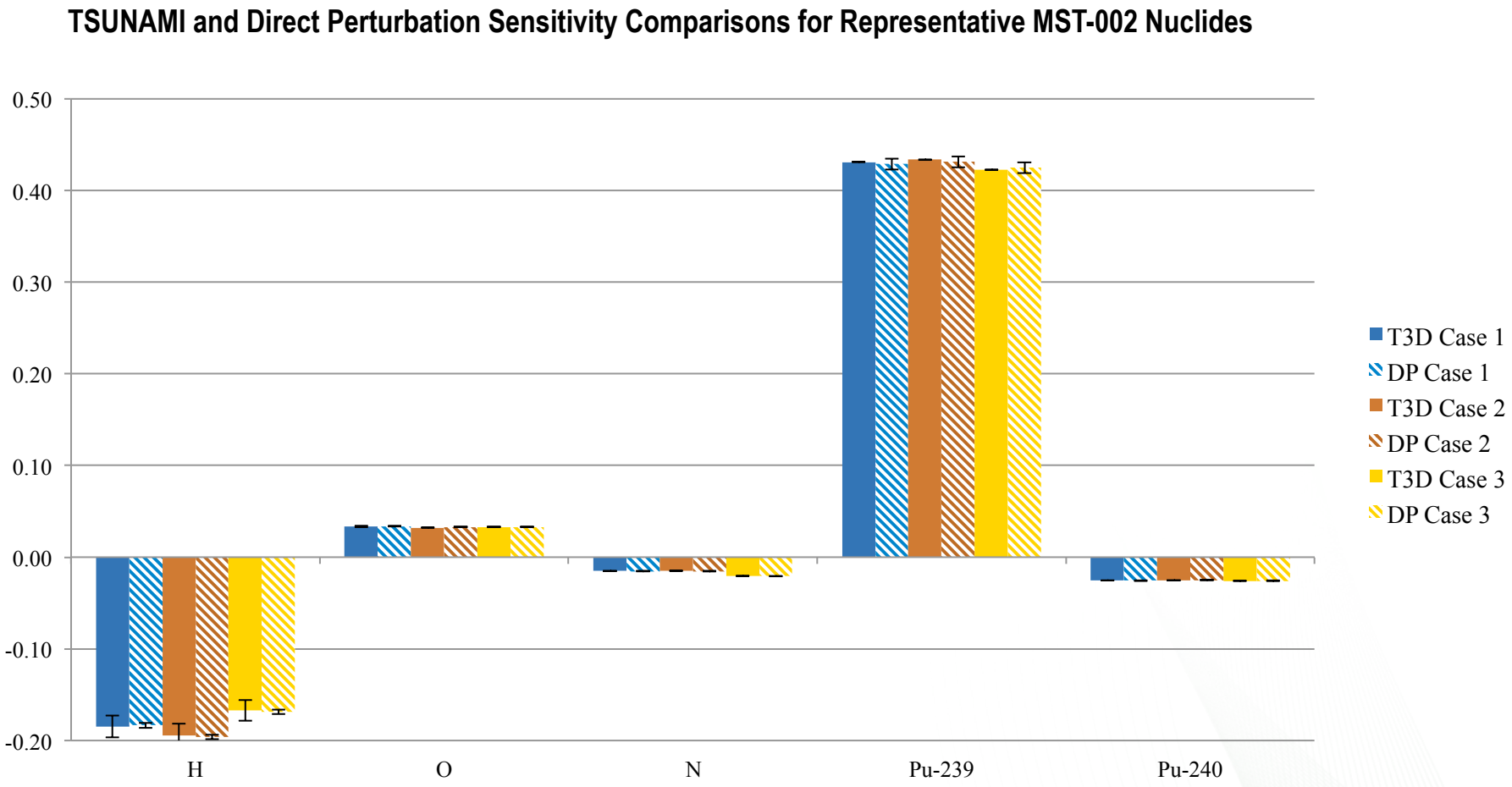
Description of Selected Experiments

- MST-002, -004, -005, -007, -010
  - No MST evaluations in VALID
- HMF-052 and HMM-017
  - Interest in evaluations containing tungsten
- LCT-008
  - Similar to BWR fuel
- The HEU, LEU and MIXED fuel benchmark models are found in Volumes II, IV and VI of the IHECSBE, respectively.
- All models were developed based on information contained in Section 3 of the respective IHECSBE report.

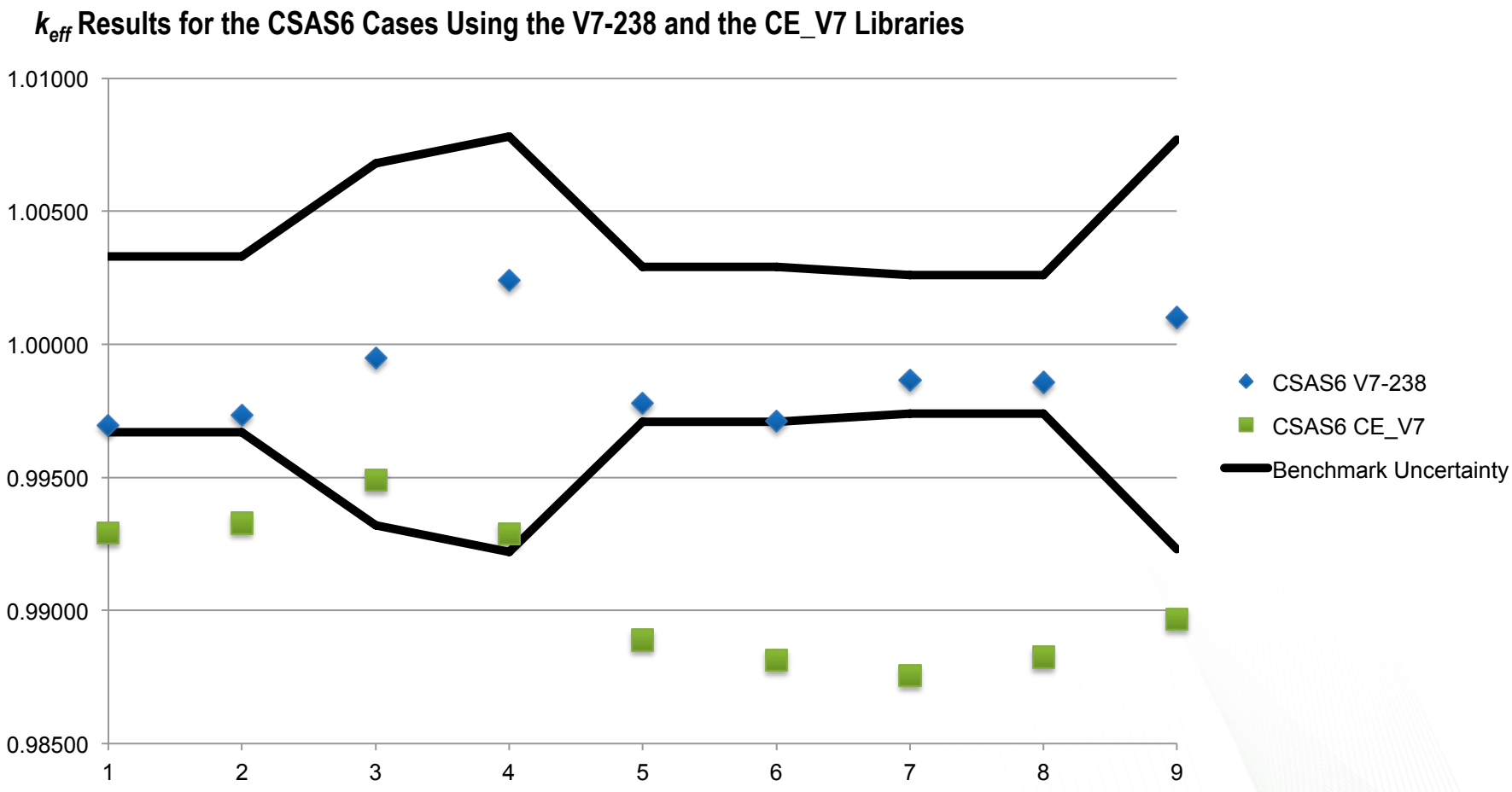
MST-002 k_{eff} Results



Results for MST-002

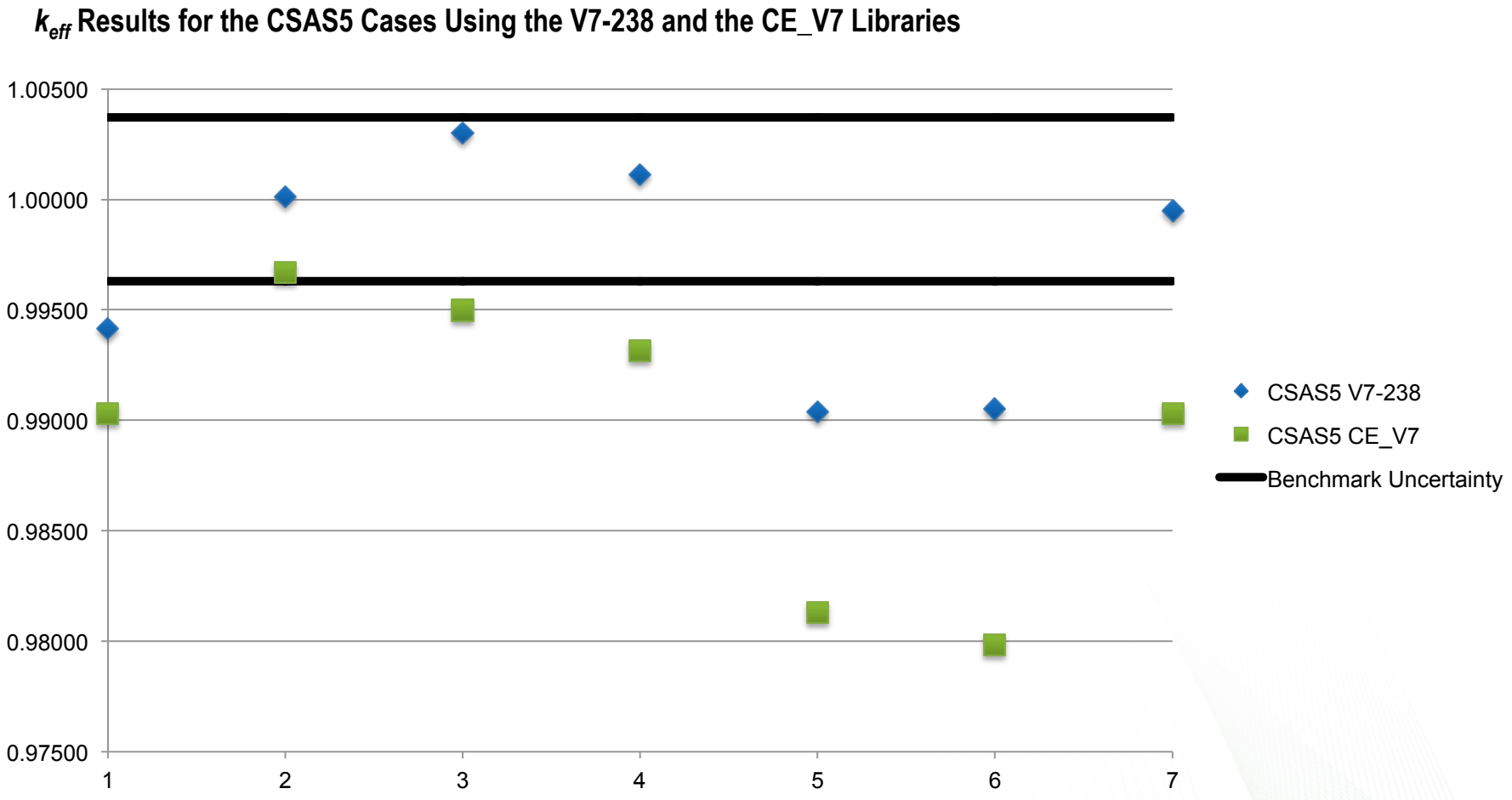


MST-004 k_{eff} Results



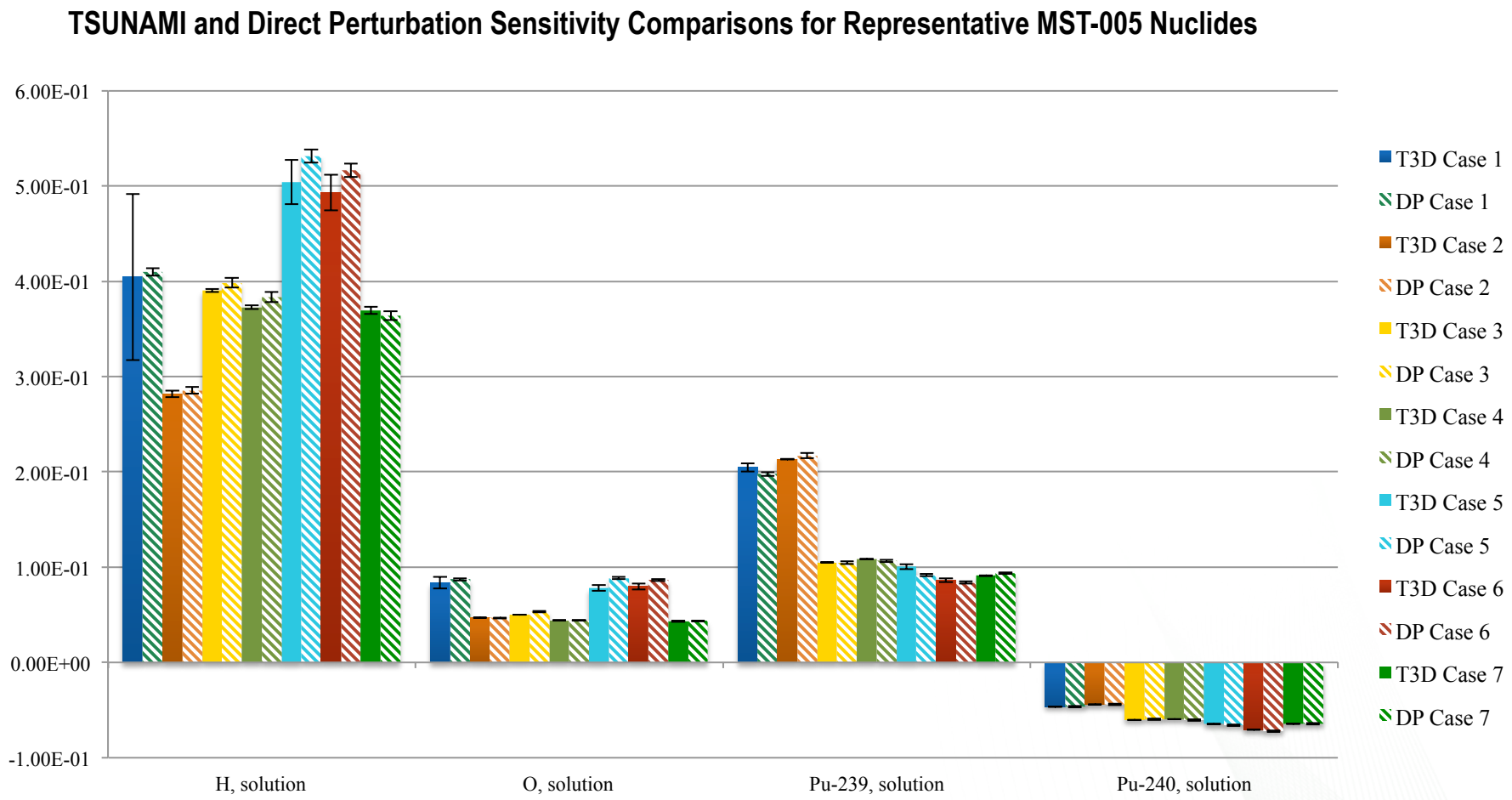
- Improved agreement between MG and CE results in SCALE 6.2b3

MST-005 k_{eff} Results

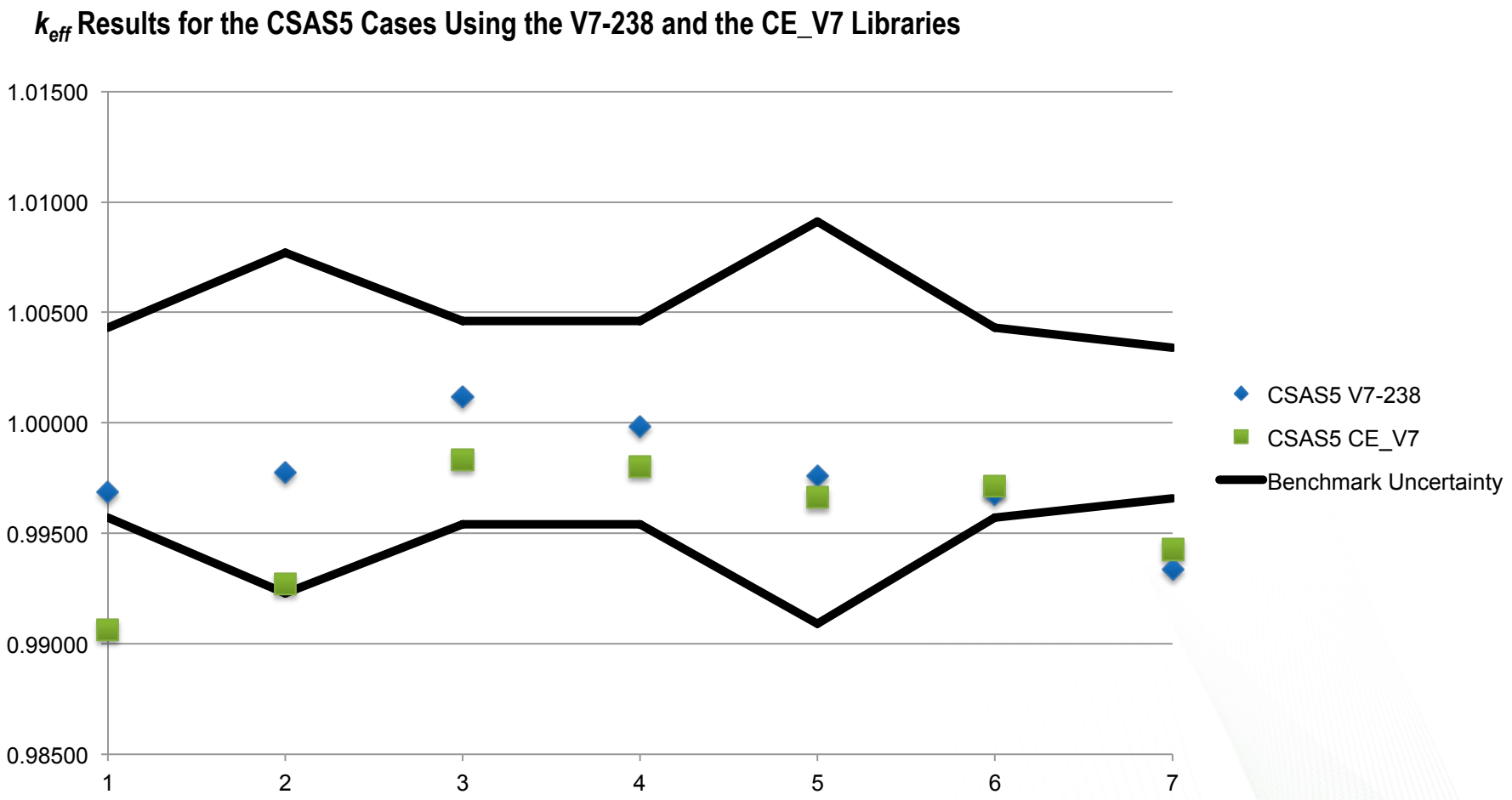


- Improved agreement between MG and CE results in SCALE 6.2b3

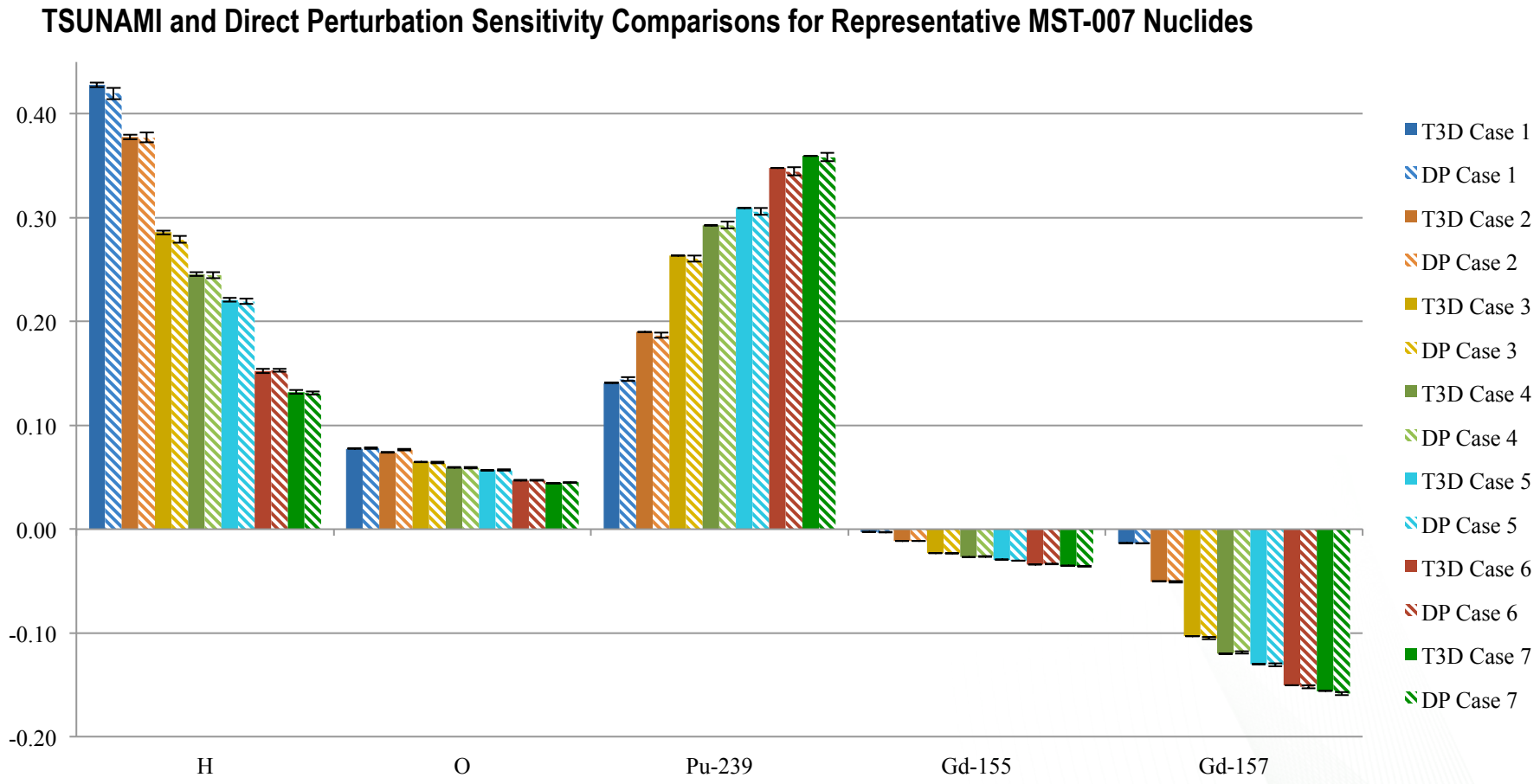
Results for MST-005



MST-007 k_{eff} Results

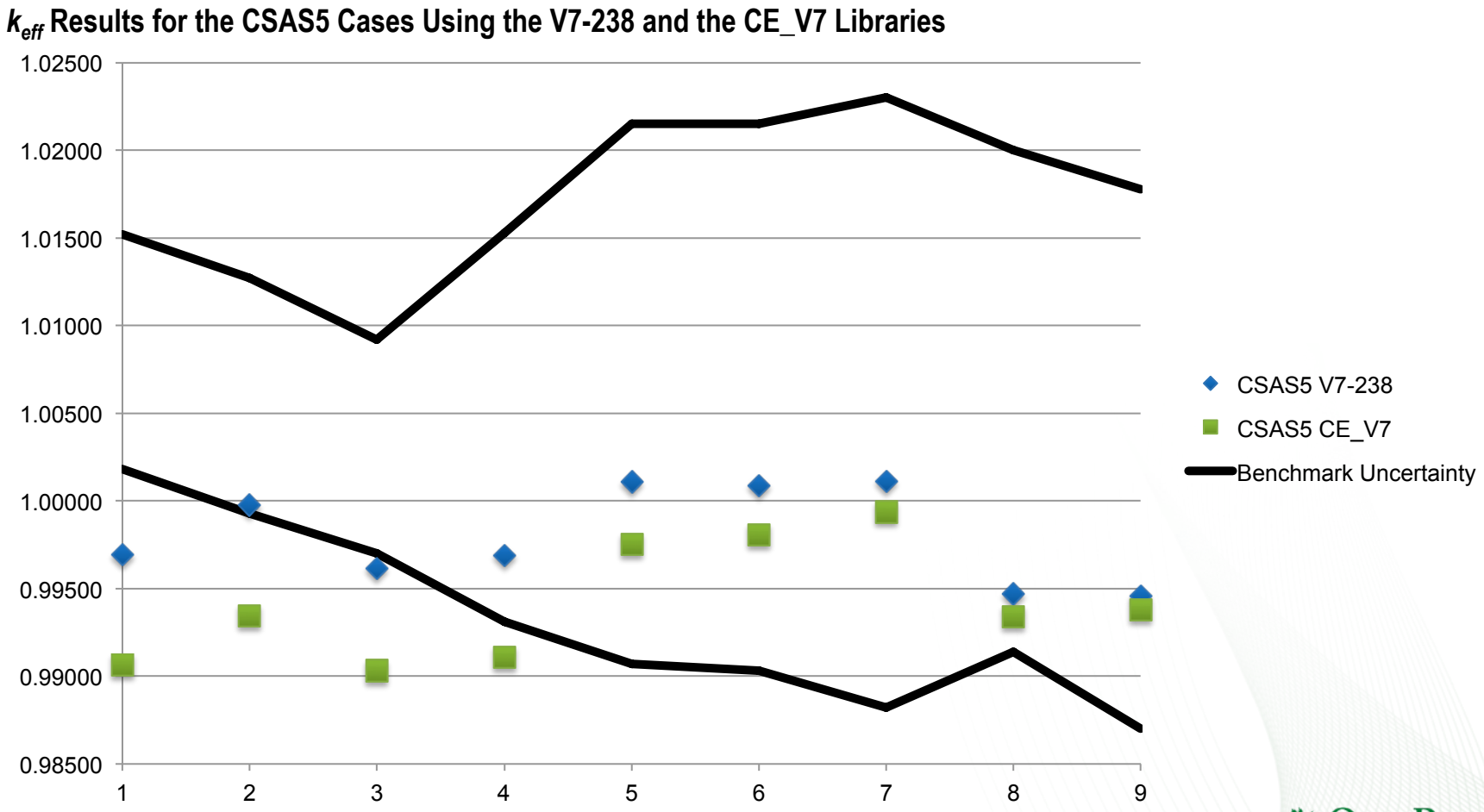


Results for MST-007



MST-010 k_{eff} Results

- The expected k_{eff} values are suspect based on CSAS5 results and an examination of the determination of the expected k_{eff} value from IHECSBE (ranges from 1.002-1.009).

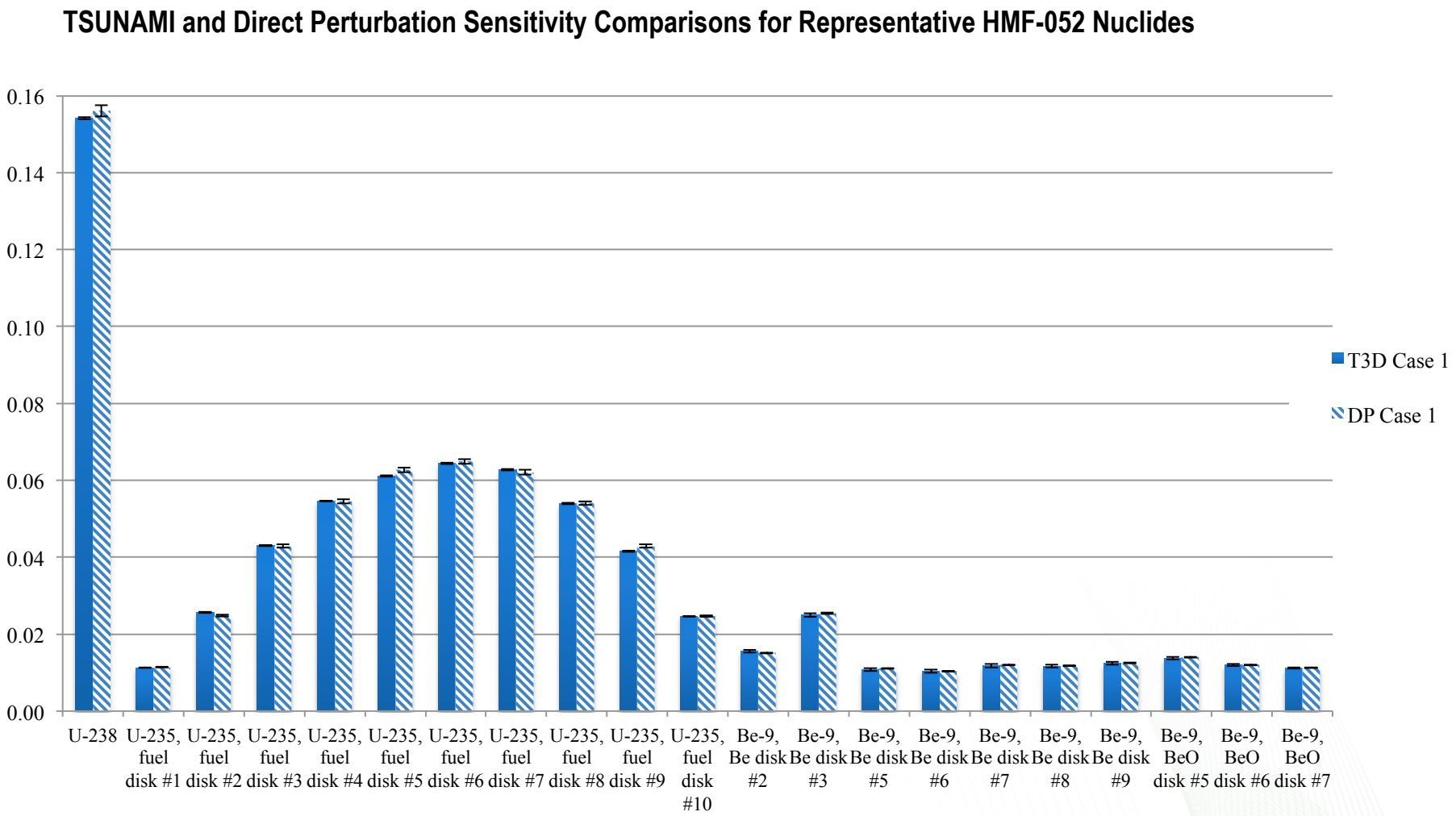


HMF-052 k_{eff} Results

k_{eff} Results for the CSAS5 Cases Using the V7-238 and the CE_V7 Libraries

Case (HEU-MET-FAST-052-)	Benchmark Model Values		CSAS5 V7-238 Result		Calculated/Experimental		Δk_{eff} (CSAS - Benchmark)	
	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	0.9993	0.0011	1.00860	0.00010	1.00931	0.00112	0.00930	0.00110
Case (HEU-MET-FAST-052-)	Benchmark Model Values		CSAS5 CE_V7 Result		Calculated/Experimental		Δk_{eff} (CSAS - Benchmark)	
	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	0.9993	0.0011	1.00050	0.00010	1.00120	0.00111	0.00120	0.00110

Results for HMF-052

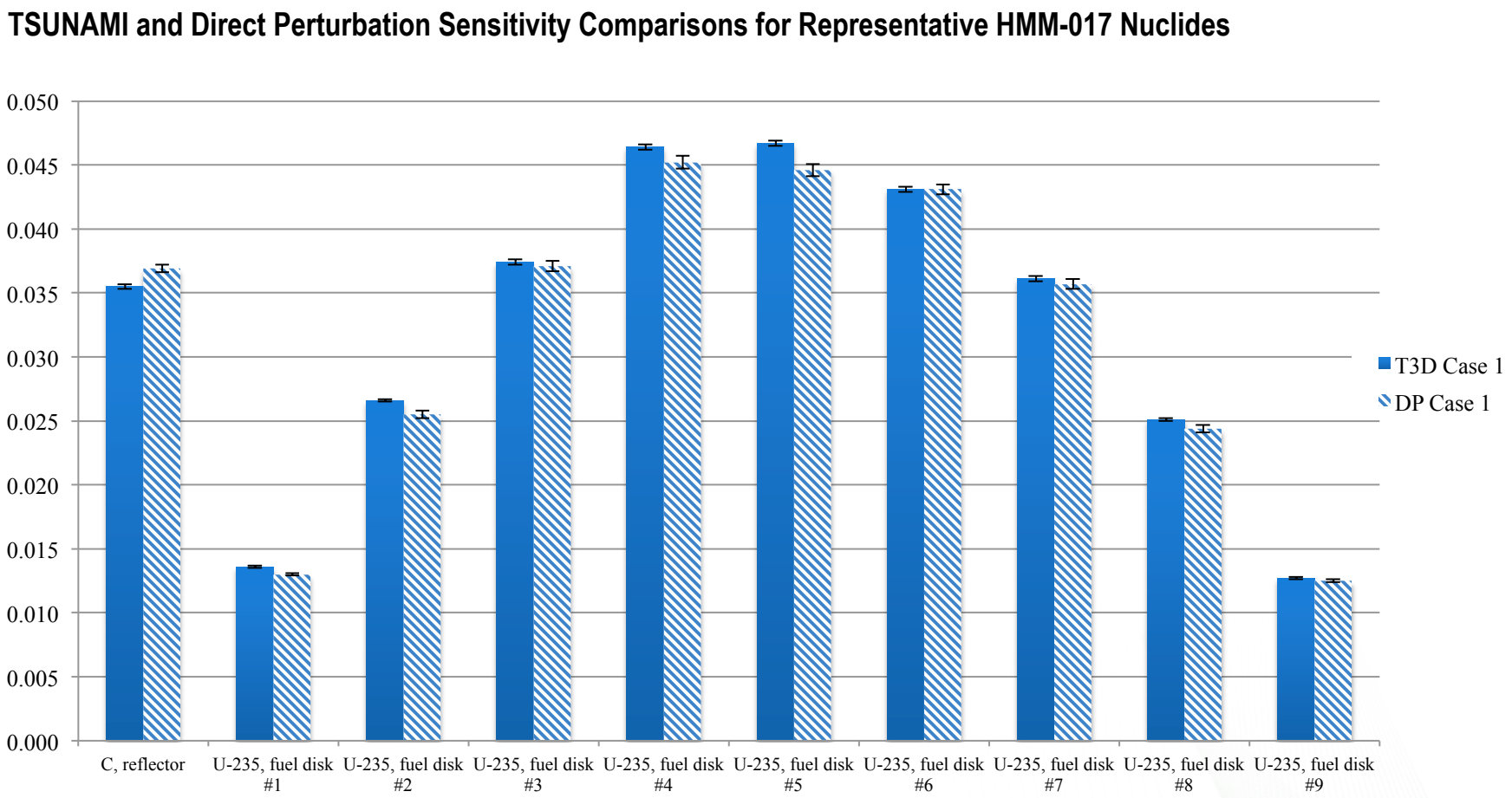


HMM-017 k_{eff} Results

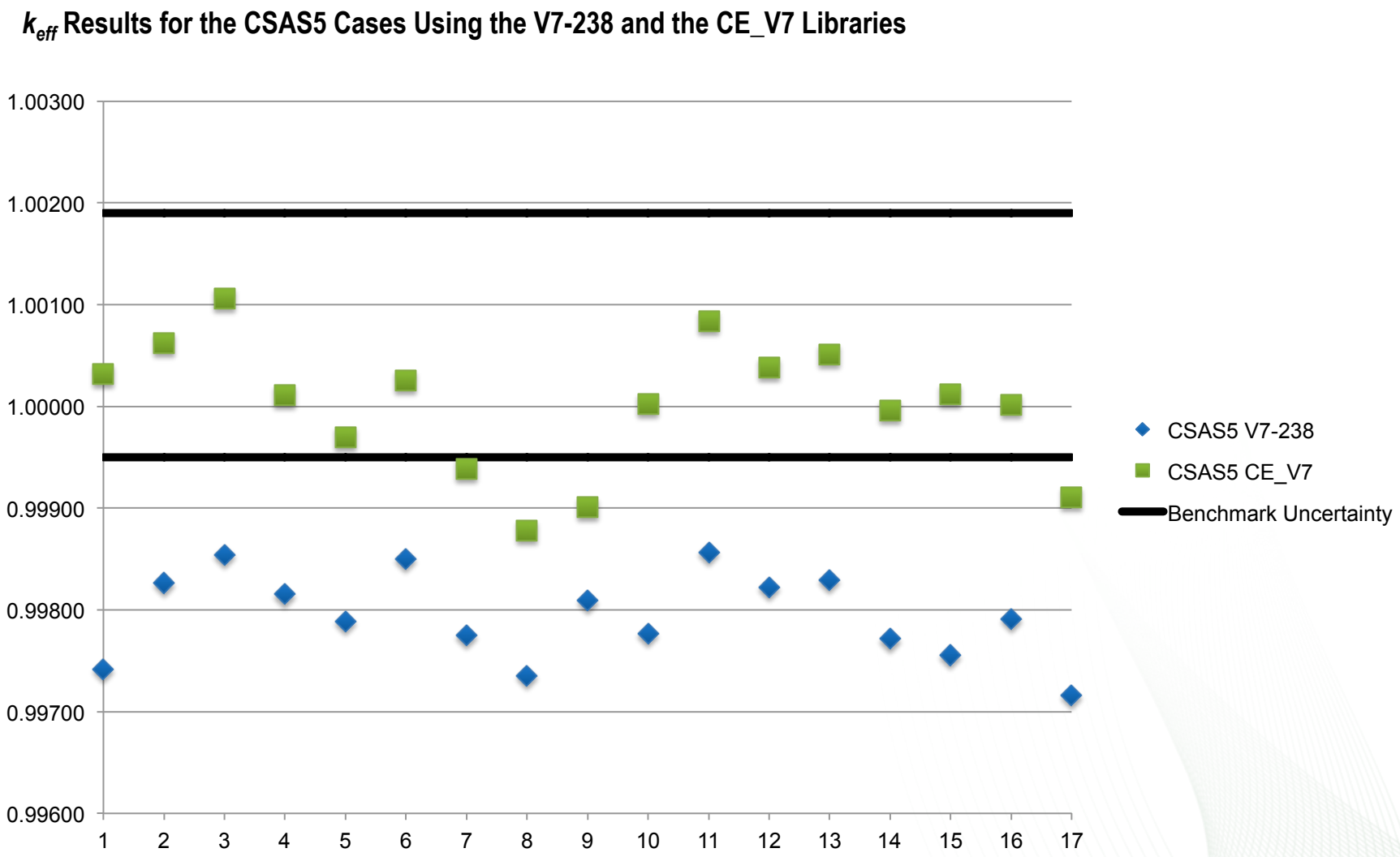
k_{eff} Results for the CSAS5 Cases Using the V7-238 and the CE_V7 Libraries

Case (HEU-MET-MIXED-017-)	Benchmark Model Values		CSAS5 V7-238 Result		Calculated/Experimental		Δk_{eff} (CSAS - Benchmark)	
	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	1.0000	0.0008	0.99758	0.00010	0.99758	0.00080	0.00242	0.00081
Case (HEU-MET-MIXED-017-)	Benchmark Model Values		CSAS5 V7-238 Result		Calculated/Experimental		Δk_{eff} (CSAS - Benchmark)	
	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	1.0000	0.0008	0.99626	0.00010	0.99626	0.00080	0.00374	0.00081

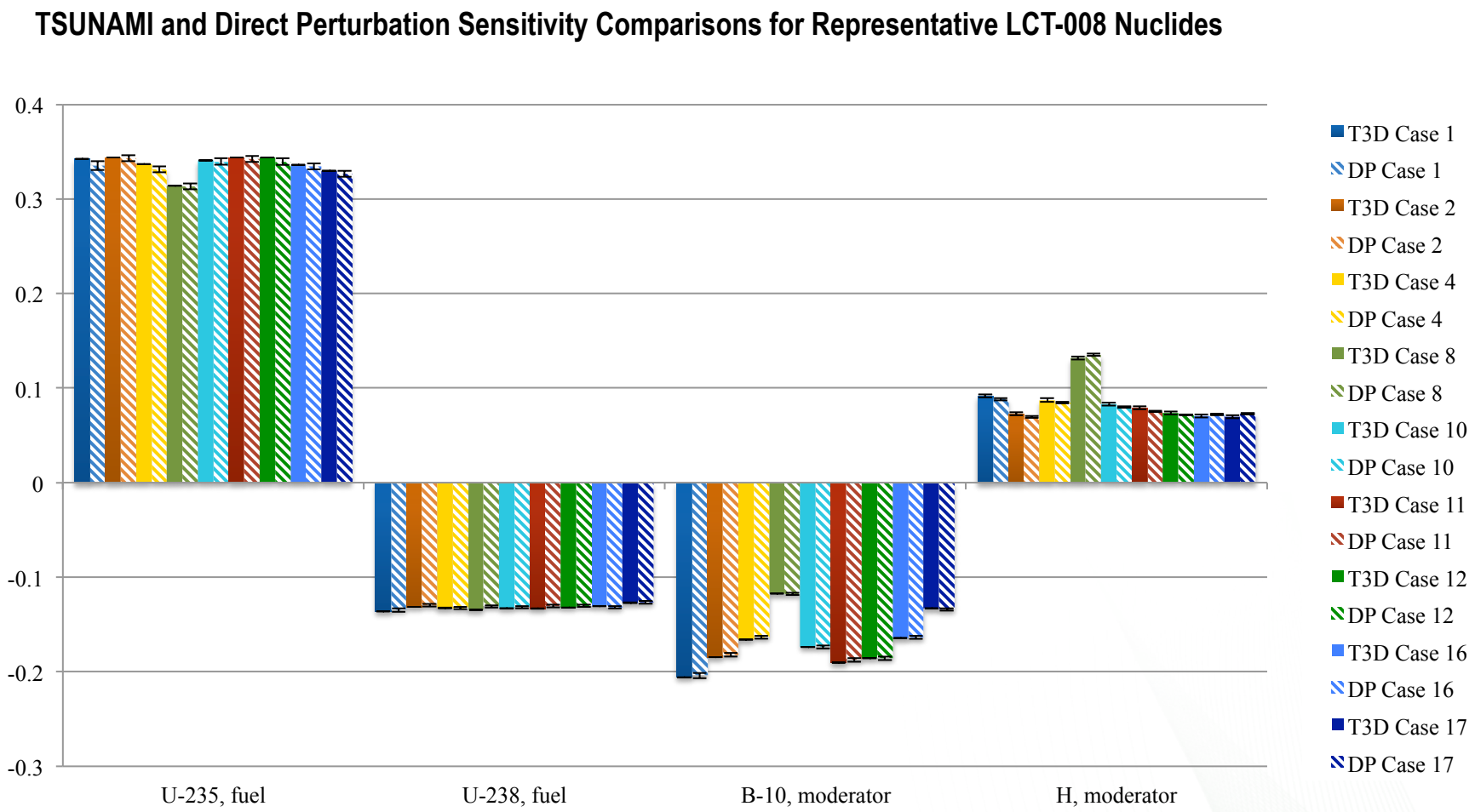
Results for HMM-017



LCT-008 k_{eff} Results



Results for LCT-008



Conclusions

- MST-002
  - 3 experiments
  - Complete, in VALID
- MST-004
  - 9 experiments
  - In progress, performing calculations
- MST-005
  - 7 experiments
  - Did not yield satisfactory results
- MST-007
  - 7 experiments
  - In progress, documentation underway

- MST-010
  - 9 experiments
  - In progress, performing calculations
- HMF-052
  - 1 experiments
  - In progress, awaiting review
- HMM-017
  - 1 experiments
  - In progress, documentation underway
- LCT-008
  - 17 experiments
  - In progress, awaiting review

Additional Accomplishments

- 2014 ANS Winter Meeting Summary
  - "Mixed Uranium-Plutonium Solution Validation of KENO V.a and KENO-VI in SCALE 6.1.2 and 6.2b3 Using Multigroup and Continuous-Energy ENDF/B-VII.0 Libraries"

- Currently analyzing the new capability and applicability of the CE TSUNAMI-3D CLUTCH method

Future Work

- Additional IHECSBE benchmark evaluations
  - MMT-001
- Once SCALE 6.2 is released, revisit MST-004 and MST-005 for VALID purposes
- Perform review on SDFs then add evaluations to the VALID library
  - SDF for each case in VALID distributed with IHECSBE

Acknowledgements

This work was supported by the Department of Energy (DOE) Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration.

Questions?

VALID procedure and library contents

- Verified, Archived Library of Inputs and Data procedure is a SCALE project computational procedure at ORNL
- Critical experiments currently in library and used in validation effort:

Sequence	Experiment class	IHECSBE case numbers	Number of configurations
CSAS5/KENO V.a	HEU-MET-FAST	15, 16, 17, 18, 19, 20, 21, 25, 30, 38, 40, 65	18/22[a]
	HEU-SOL-THERM	1, 13, 14, 16, 28, 29, 30	52
	IEU-MET-FAST	2, 3, 4, 5, 6, 7, 8, 9	8/11[a]
	LEU-COMP-THERM	1, 2, 10, 17, 42, 50, 80	108
	LEU-SOL-THERM	2, 3, 4	19
	MIX-MET-FAST	5, 6	2
	MIX-COMP-THERM	1, 2, 4	21
	PU-MET-FAST	1, 2, 5, 6, 8, 10, 18, 22, 23, 24	10
	PU-SOL-THERM	1, 2, 3, 4, 5, 6, 7, 11, 20	81
CSAS6/KENO-VI	HEU-MET-FAST		24
	IEU-MET-FAST	19	2
	MIX-COMP-THERM	8	28

[a]The larger number includes simplified cases that are duplicate cases for which detailed models are also available in the library.

- 326 cases with KENO V.a
- 54 cases with KENO-VI

Validation methods

- Performance reported in terms of calculated-to-experiment ratio (C/E)
- Expected (experiment) value is determined in the IHECSBE evaluation for each experiment
- TSUNAMI-3D used to generate sensitivity coefficients and uncertainty in overall system k_{eff} due to cross section uncertainties
  - Currently TSUNAMI uses only multigroup data because of the use of adjoint perturbation theory
- TSUNAMI-3D sensitivities are compared to the direct perturbation sensitivities, which are calculated by hand

MST-002 k_{eff} Results

k_{eff} Results for the CSAS5 Cases Using the V7-238 and the CE_V7 Libraries

Case (MIX-SOL-THERM-002-)	Benchmark Model Values		CSAS5 V7-238 Result		Calculated/Experimental		Δk_{eff} (CSAS - Benchmark)	
	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	1.000	0.0024	1.00232	0.00010	1.00232	0.00240	0.00232	0.00240
002	1.000	0.0024	1.00267	0.00010	1.00267	0.00240	0.00267	0.00240
003	1.000	0.0024	1.00248	0.00010	1.00248	0.00240	0.00248	0.00240
Case (MIX-SOL-THERM-002-)	Benchmark Model Values		CSAS5 CE_V7 Result		Calculated/Experimental		Δk_{eff} (CSAS - Benchmark)	
	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	1.000	0.0024	1.00167	0.00010	1.00167	0.00240	0.00167	0.00240
002	1.000	0.0024	1.00205	0.00010	1.00205	0.00240	0.00205	0.00240
003	1.000	0.0024	1.00155	0.00010	1.00155	0.00240	0.00155	0.00240

MST-004 k_{eff} Results

k_{eff} Results for the CSAS5 Cases Using the V7-238 and the CE_V7 Libraries

Case	Benchmark Model Values		CSAS5 V7-238 Results for 6.1.2		Calculated/Experimental		Δk_{eff} (CSAS - Benchmark)	
THERM-004-)	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	1.000	0.0033	0.99681	0.00010	0.99681	0.00329	0.00319	0.00330
002	1.000	0.0033	0.99747	0.00010	0.99747	0.00329	0.00253	0.00330
003	1.000	0.0068	0.99952	0.00010	0.99952	0.00680	0.00048	0.00680
004	1.000	0.0078	1.00240	0.00010	1.00240	0.00782	0.00240	0.00780
005	1.000	0.0029	0.99793	0.00010	0.99793	0.00290	0.00207	0.00290
006	1.000	0.0029	0.99726	0.00010	0.99726	0.00289	0.00274	0.00290
007	1.000	0.0026	0.99870	0.00010	0.99870	0.00260	0.00130	0.00260
008	1.000	0.0026	0.99867	0.00010	0.99867	0.00260	0.00133	0.00260
009	1.000	0.0077	1.00108	0.00010	1.00108	0.00771	0.00108	0.00770
Case	Benchmark Model Values		CSAS5 CE_V7 Results for 6.1.2		Calculated/Experimental		Δk_{eff} (CSAS - Benchmark)	
(MIX-SOL-THERM-004-)	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	1.000	0.0033	0.99304	0.00010	0.99304	0.00328	0.00696	0.00330
002	1.000	0.0033	0.99321	0.00010	0.99321	0.00328	0.00679	0.00330
003	1.000	0.0068	0.99506	0.00010	0.99506	0.00677	0.00494	0.00680
004	1.000	0.0078	0.99292	0.00010	0.99292	0.00775	0.00708	0.00780
005	1.000	0.0029	0.98896	0.00009	0.98896	0.00287	0.01104	0.00290
006	1.000	0.0029	0.98815	0.00010	0.98815	0.00287	0.01185	0.00290
007	1.000	0.0026	0.98777	0.00010	0.98777	0.00257	0.01223	0.00260
008	1.000	0.0026	0.98830	0.00010	0.98830	0.00257	0.01171	0.00260
009	1.000	0.0077	0.98987	0.00010	0.98987	0.00762	0.01013	0.00770

MST-005 k_{eff} Results

k_{eff} Results for the CSAS5 Cases Using the V7-238 and the CE_V7 Libraries

Case (MIX-SOL-THERM-005-)	Benchmark Model Values		CSAS5 V7-238 Result		Calculated/Experimental		Δk_{eff} (CSAS - Benchmark)	
	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	1.000	0.0037	0.99414	0.00010	0.99414	0.00368	0.00586	0.00370
002	1.000	0.0037	1.00013	0.00010	1.00013	0.00370	0.00012	0.00370
003	1.000	0.0037	1.00301	0.00010	1.00301	0.00371	0.00301	0.00370
004	1.000	0.0037	1.00113	0.00010	1.00113	0.00371	0.00113	0.00370
005	1.000	0.0037	0.99039	0.00010	0.99039	0.00367	0.00961	0.00370
006	1.000	0.0037	0.99051	0.00010	0.99051	0.00367	0.00949	0.00370
007	1.000	0.0037	0.99947	0.00010	0.99947	0.00370	0.00053	0.00370

Case (MIX-SOL-THERM-005-)	Benchmark Model Values		CSAS5 V7-238 Result		Calculated/Experimental		Δk_{eff} (CSAS - Benchmark)	
	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	1.000	0.0037	0.99032	0.00010	0.99032	0.00367	0.00968	0.00370
002	1.000	0.0037	0.99671	0.00010	0.99671	0.00369	0.00329	0.00370
003	1.000	0.0037	0.99498	0.00010	0.99498	0.00368	0.00502	0.00370
004	1.000	0.0037	0.99317	0.00010	0.99317	0.00368	0.00683	0.00370
005	1.000	0.0037	0.98133	0.00010	0.98133	0.00363	0.01868	0.00370
006	1.000	0.0037	0.97984	0.00010	0.97984	0.00363	0.02016	0.00370
007	1.000	0.0037	0.99030	0.00010	0.99030	0.00367	0.00970	0.00370

MST-007 k_{eff} Results

k_{eff} Results for the CSAS5 Cases Using the V7-238 and the CE_V7 Libraries

Case (MIX-SOL-THERM-007-)	Benchmark Model Values		CSAS5 V7-238 Result		Calculated/Experimental		Δk_{eff} (CSAS - Benchmark)	
	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	1.000	0.0043	0.99685	0.00010	0.99685	0.00429	0.00315	0.00430
002	1.000	0.0077	0.99776	0.00010	0.99776	0.00768	0.00225	0.00770
003	1.000	0.0046	1.00118	0.00010	1.00118	0.00461	0.00117	0.00460
004	1.000	0.0046	0.99983	0.00010	0.99983	0.00460	0.00017	0.00460
005	1.000	0.0091	0.99760	0.00010	0.99760	0.00908	0.00240	0.00910
006	1.000	0.0043	0.99674	0.00010	0.99674	0.00429	0.00326	0.00430
007	1.000	0.0034	0.99335	0.00010	0.99335	0.00338	0.00665	0.00340
Case (MIX-SOL-THERM-007-)	Benchmark Model Values		CSAS5 CE_V7 Result		Calculated/Experimental		Δk_{eff} (CSAS - Benchmark)	
	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	1.000	0.0043	0.99064	0.00010	0.99064	0.00426	0.00936	0.00430
002	1.000	0.0077	0.99274	0.00010	0.99274	0.00764	0.00726	0.00770
003	1.000	0.0046	0.99833	0.00010	0.99833	0.00459	0.00167	0.00460
004	1.000	0.0046	0.99802	0.00010	0.99802	0.00459	0.00199	0.00460
005	1.000	0.0091	0.99662	0.00010	0.99662	0.00907	0.00338	0.00910
006	1.000	0.0043	0.99714	0.00010	0.99714	0.00429	0.00286	0.00430
007	1.000	0.0034	0.99426	0.00010	0.99426	0.00338	0.00574	0.00340

MST-010 k_{eff} Results

k_{eff} Results for the CSAS5 Cases Using the V7-238 and the CE_V7 Libraries

Case (MIX-SOL-THERM-010-)	Benchmark Model Values		CSAS5 V7-238 Results for 6.1.2				Δk_{eff} (Benchmark - CSAS)	
	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	1.009	0.0067	0.99691	0.00010	0.98851	0.00657	0.01159	0.00670
002	1.006	0.0067	0.99977	0.00010	0.99380	0.00662	0.00623	0.00670
003	1.003	0.0061	0.99617	0.00010	0.99309	0.00604	0.00693	0.00610
004	1.004	0.0111	0.99690	0.00010	0.99273	0.01097	0.00730	0.01110
005	1.006	0.0154	1.00111	0.00010	0.99504	0.01523	0.00499	0.01540
006	1.006	0.0156	1.00086	0.00010	0.99499	0.01543	0.00504	0.01560
007	1.006	0.0174	1.00113	0.00010	0.99555	0.01723	0.00447	0.01740
008	1.006	0.0143	0.99472	0.00010	0.98908	0.01406	0.01099	0.01430
009	1.002	0.0154	0.99457	0.00010	0.99219	0.01524	0.00783	0.01540
Case (MIX-SOL-THERM-010-)	Benchmark Model Values		CSAS5 CE_V7 Results for 6.1.2				Δk_{eff} (Benchmark - CSAS)	
	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	1.009	0.0067	0.99065	0.00010	0.98230	0.00653	0.01786	0.00670
002	1.006	0.0067	0.99344	0.00010	0.98751	0.00658	0.01256	0.00670
003	1.003	0.0061	0.99032	0.00010	0.98726	0.00600	0.01278	0.00610
004	1.004	0.0111	0.99110	0.00010	0.98695	0.01091	0.01310	0.01110
005	1.006	0.0154	0.99752	0.00010	0.99148	0.01518	0.00858	0.01540
006	1.006	0.0156	0.99811	0.00010	0.99225	0.01539	0.00779	0.01560
007	1.006	0.0174	0.99937	0.00010	0.99380	0.01720	0.00623	0.01740
008	1.006	0.0143	0.99341	0.00010	0.98778	0.01405	0.01229	0.01430
009	1.002	0.0154	0.99380	0.00010	0.99142	0.01523	0.00860	0.01540

LCT-008 k_{eff} Results

k_{eff} Results for the CSAS5 Cases Using the V7-238 and the CE_V7 Libraries

Case (LEU-COMP-THERM-008-)	Benchmark Model Values		CSAS5 V7-238 Result		Calculated/Experimental		Δk_{eff} (CSAS - Benchmark)	
	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	1.0007	0.0012	0.99741	0.00010	0.99672	0.00120	0.00398	0.00120
002	1.0007	0.0012	0.99827	0.00010	0.99757	0.00120	0.00313	0.00120
003	1.0007	0.0012	0.99854	0.00009	0.99784	0.00120	0.00286	0.00120
004	1.0007	0.0012	0.99815	0.00010	0.99745	0.00120	0.00325	0.00120
005	1.0007	0.0012	0.99789	0.00010	0.99719	0.00120	0.00351	0.00120
006	1.0007	0.0012	0.99850	0.00010	0.99780	0.00120	0.00290	0.00120
007	1.0007	0.0012	0.99775	0.00010	0.99705	0.00120	0.00365	0.00120
008	1.0007	0.0012	0.99735	0.00010	0.99666	0.00120	0.00404	0.00120
009	1.0007	0.0012	0.99809	0.00010	0.99739	0.00120	0.00331	0.00120
010	1.0007	0.0012	0.99776	0.00010	0.99707	0.00120	0.00363	0.00120
011	1.0007	0.0012	0.99856	0.00010	0.99786	0.00120	0.00284	0.00120
012	1.0007	0.0012	0.99822	0.00010	0.99753	0.00120	0.00317	0.00120
013	1.0007	0.0012	0.99829	0.00010	0.99759	0.00120	0.00311	0.00120
014	1.0007	0.0012	0.99772	0.00009	0.99702	0.00120	0.00368	0.00120
015	1.0007	0.0012	0.99755	0.00010	0.99686	0.00120	0.00384	0.00120
016	1.0007	0.0012	0.99791	0.00010	0.99721	0.00120	0.00349	0.00120
017	1.0007	0.0012	0.99716	0.00010	0.99646	0.00120	0.00424	0.00120

Case (LEU-COMP-THERM-008-)	Benchmark Model Values		CSAS5 CE_V7 Result		Calculated/Experimental		Δk_{eff} (CSAS - Benchmark)	
	k_{eff}	σ	k_{eff}	σ	C/E	σ	Δk_{eff}	σ
001	1.0007	0.0012	1.00032	0.00010	0.99962	0.00120	0.00038	0.00120
002	1.0007	0.0012	1.00063	0.00010	0.99993	0.00120	0.00007	0.00120
003	1.0007	0.0012	1.00106	0.00010	1.00036	0.00120	0.00036	0.00120
004	1.0007	0.0012	1.00011	0.00010	0.99941	0.00120	0.00059	0.00120
005	1.0007	0.0012	0.99970	0.00010	0.99900	0.00120	0.00100	0.00120
006	1.0007	0.0012	1.00025	0.00010	0.99955	0.00120	0.00045	0.00120
007	1.0007	0.0012	0.99939	0.00010	0.99869	0.00120	0.00131	0.00120
008	1.0007	0.0012	0.99878	0.00010	0.99808	0.00120	0.00192	0.00120
009	1.0007	0.0012	0.99901	0.00010	0.99831	0.00120	0.00169	0.00120
010	1.0007	0.0012	1.00003	0.00010	0.99933	0.00120	0.00067	0.00120
011	1.0007	0.0012	1.00084	0.00010	1.00014	0.00120	0.00014	0.00120
012	1.0007	0.0012	1.00038	0.00010	0.99968	0.00120	0.00032	0.00120
013	1.0007	0.0012	1.00051	0.00010	0.99981	0.00120	0.00019	0.00120
014	1.0007	0.0012	0.99996	0.00010	0.99926	0.00120	0.00074	0.00120
015	1.0007	0.0012	1.00012	0.00010	0.99942	0.00120	0.00058	0.00120
016	1.0007	0.0012	1.00002	0.00010	0.99932	0.00120	0.00068	0.00120
017	1.0007	0.0012	0.99911	0.00010	0.99841	0.00120	0.00159	0.00120