Reproducibility of Subcritical Measurements: Five Years of Plutonium Sphere Data

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Overview

- Regular measurements have taken place with the BeRP ball since 1980.
- This work compiles all measurements of the BeRP ball that have taken place at the DAF.
  - Measurements from 18 campaigns over 5 years
- Comparison of these data is useful in assessing reproducibility and measurement uncertainties

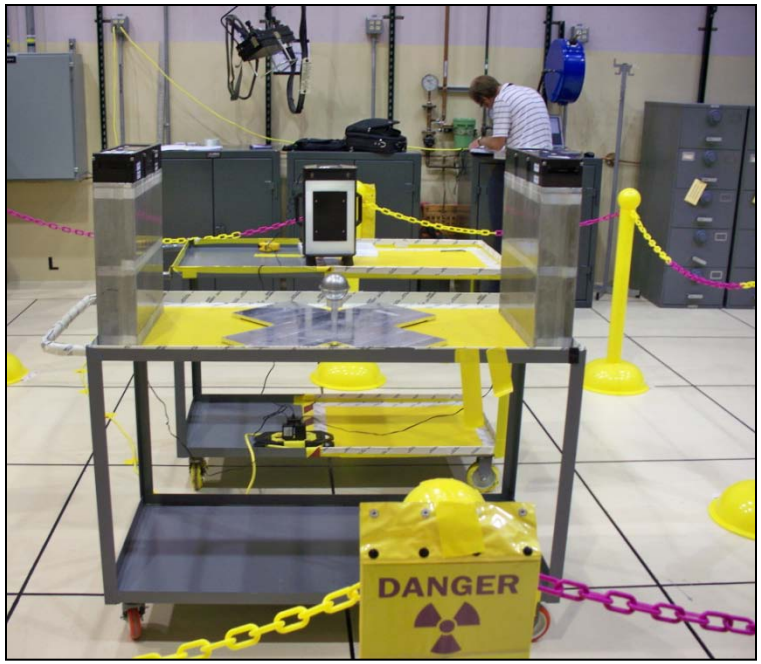
List of measurement campaigns

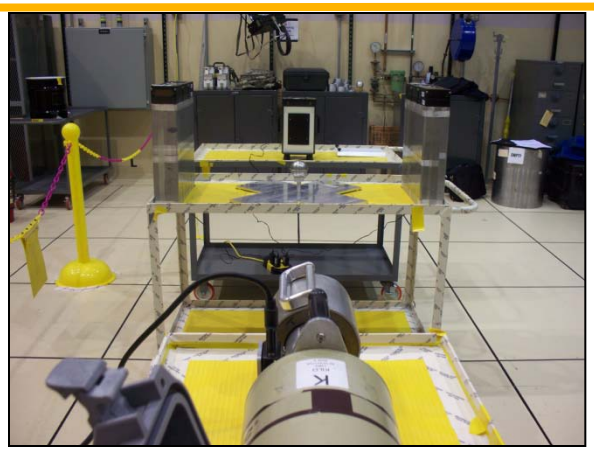
start date	organization	detectors present
07/26/07	LANL	1 NPOD, SNAP
01/17/08	LANL	1 NPOD, SNAP
09/25/08	LANL	1 NPOD, SNAP
10/20/08	LLNL, LANL	Fission meter extreme, short 14s, Det EX, gamma camera, NPOD, SNAP
11/18/08	LANL	2 NPODs
11/18/08	LANL	1 NPOD, SNAP
01/05/09	SNL,LANL	1 NPOD, SNAP, K
01/05/09	SNL,LANL	1 NPOD, SNAP, K
03/11/09	LANL	2 NPODs
06/10/09	LANL	1 NPOD, SNAP
02/08/10	LANL	2 NPODs
05/26/10	LANL	2 NPODs, SNAP, K, portable neutron spec
07/26/10	LANL	2 NPODs, SNAP
09/13/10	LANL	2 NPODs, SNAP
01/24/11	LANL,RSL	Infield, mini-Infield, PackEye, RadPack, RSI, RSL
03/23/11	LANL	2 NPODs
06/06/11	LANL	2 NPODs (1 w/o Cd), Fission meter
08/23/11	LANL	2 NPODs
08/23/11	LANL	2 NPODs (1 w/o Cd), SNAP
08/23/11	SNL, LANL	Det EX-100, gr-135, identifinder, NPOD, uDet, Fission Meter
12/13/11	LANL	NPOD, SNAP
12/14/11	LANL	NPOD, SNAP
05/14/12	LANL	1-4 NPODs, SNAP
09/05/12	LANL, SNL	LM15, EJ309
09/17/12	LANL	2 NPODs, SNAP, K

List of measurement campaigns

- The measurements were performed for different sponsors for multiple applications.
- The detector setups were slightly different for many of the measurements.
- This work compiles all “similar” measurements for the SNAP and NPOD detector systems.

Measurement Setups

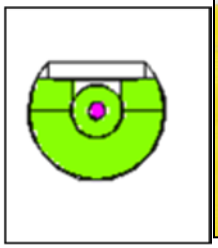




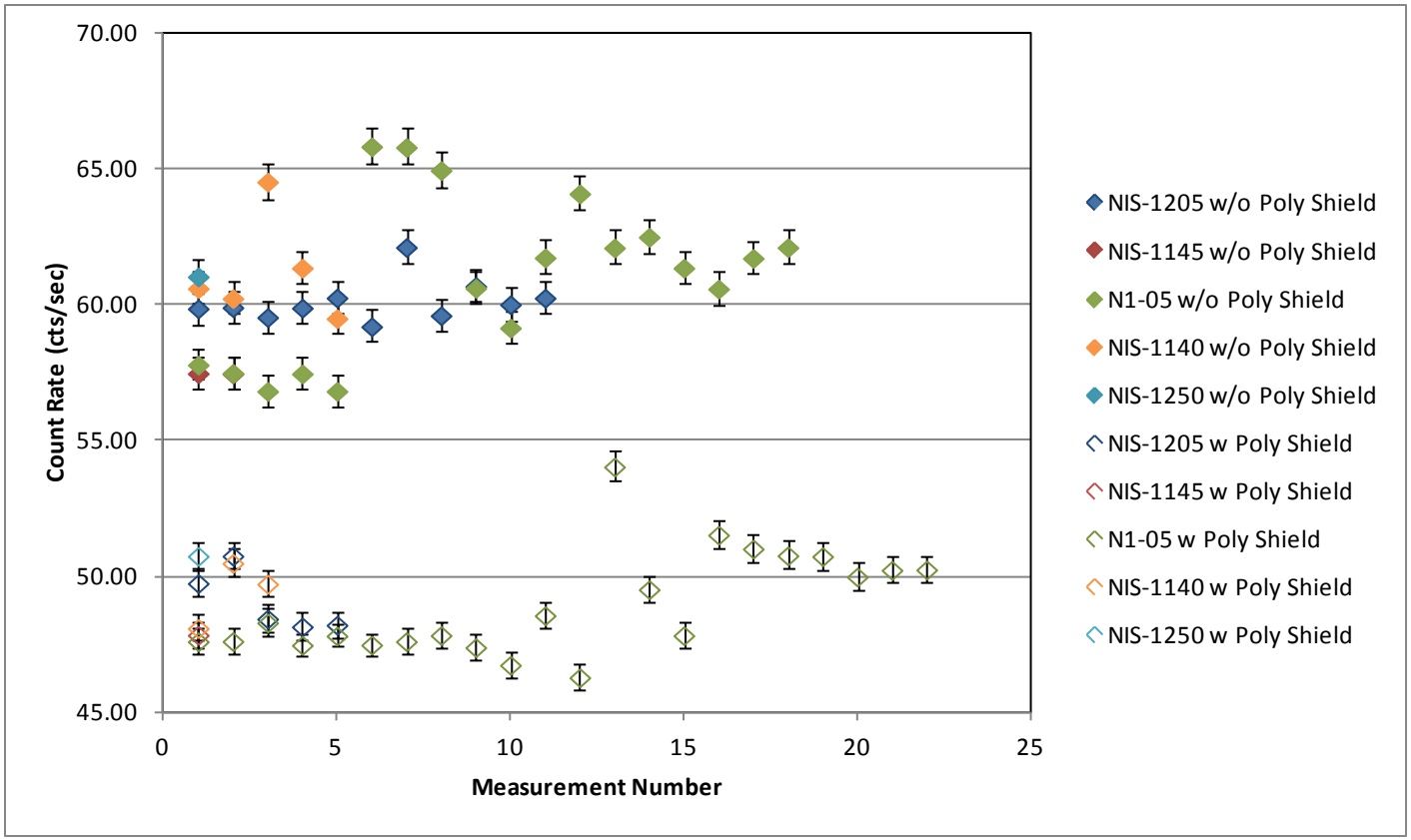
Measurement Setups

SNAP detector

- Shielded Neutron Assay Probe
- Single ^{3}He tube
- Removable polyethylene shield
- Provides count rate information
- Given a “known” efficiency, the Neutron Source Strength (NSS) is approximated
- Data from 5 different SNAP models are presented



SNAP Results

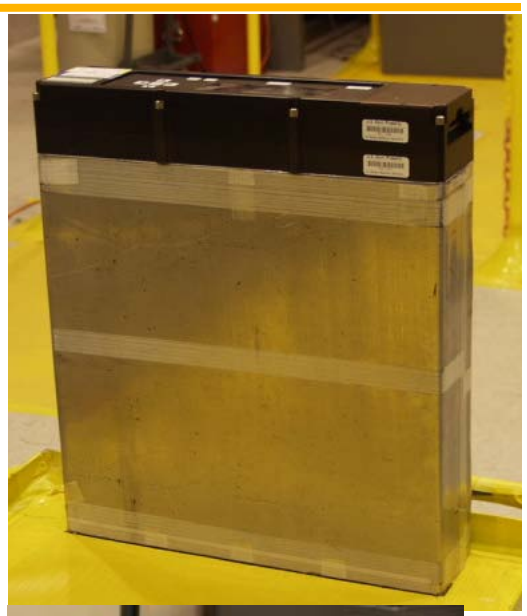


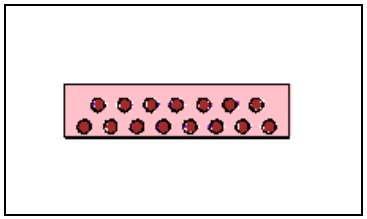
SNAP Results

Reflector	Thickness (inches)	No. of measurements (no poly)	No. of measurements (with poly)	SNAP Count rate (no poly)			SNAP Count rate (with poly)		
Bare	0	37	32	60.63	±	2.33	49.05	±	1.68
Poly (LANL)	0.5	14	9	81.26	±	2.24	57.49	±	1.41
	1	11	9	104.35	±	2.93	65.37	±	1.45
	1.5	16	11	122.97	±	2.57	71.37	±	1.62
	3	17	12	103.61	±	2.25	56.87	±	1.05
	6	9	8	26.41	±	0.86	15.36	±	0.56
Poly (SNL)	0.5	4	7	75.95	±	0.25	54.67	±	0.46
	1	2	2	98.10	±	0.96	61.36	±	0.38
	1.5	7	5	116.18	±	1.56	68.81	±	0.47
	3	5	11	96.81	±	1.70	54.22	±	0.89
	6	4	7	24.29	±	0.35	14.21	±	0.40
Acrylic	0.5	5	1	78.04	±	0.46	57.15		
	1	4	1	97.86	±	0.79	65.39		
	1.5	3	1	115.89	±	0.66	70.93		
	3	9	4	129.42	±	1.80	69.92	±	0.75
Nickel	0.5	3	1	76.38	±	0.49	62.51		
	1	4	1	94.64	±	0.38	75.21		
	1.5	5	1	110.70	±	1.01	85.50		
	2	4	1	125.84	±	0.78	97.16		
	2.5	4	1	140.93	±	1.40	107.66		
	3	4	1	153.94	±	2.36	112.37		
Tungsten	0.5	3	1	87.78	±	0.65	68.97		
	1	3	1	112.87	±	1.21	87.79		
	1.5	3	1	140.29	±	0.87	105.39		
	2	3	1	171.63	±	1.34	121.96		
	2.5	3	1	200.19	±	0.03	140.93		
	2.75	3	1	210.17	±	1.99	142.91		
	3	3	1	222.36	±	0.11	149.58		

NPOD detector

- 15 ^{3}He tubes
- Produces list-mode data (time list of each detected event)
- Used for correlated neutron analysis
- Data with 16 different NPOD detectors are presented

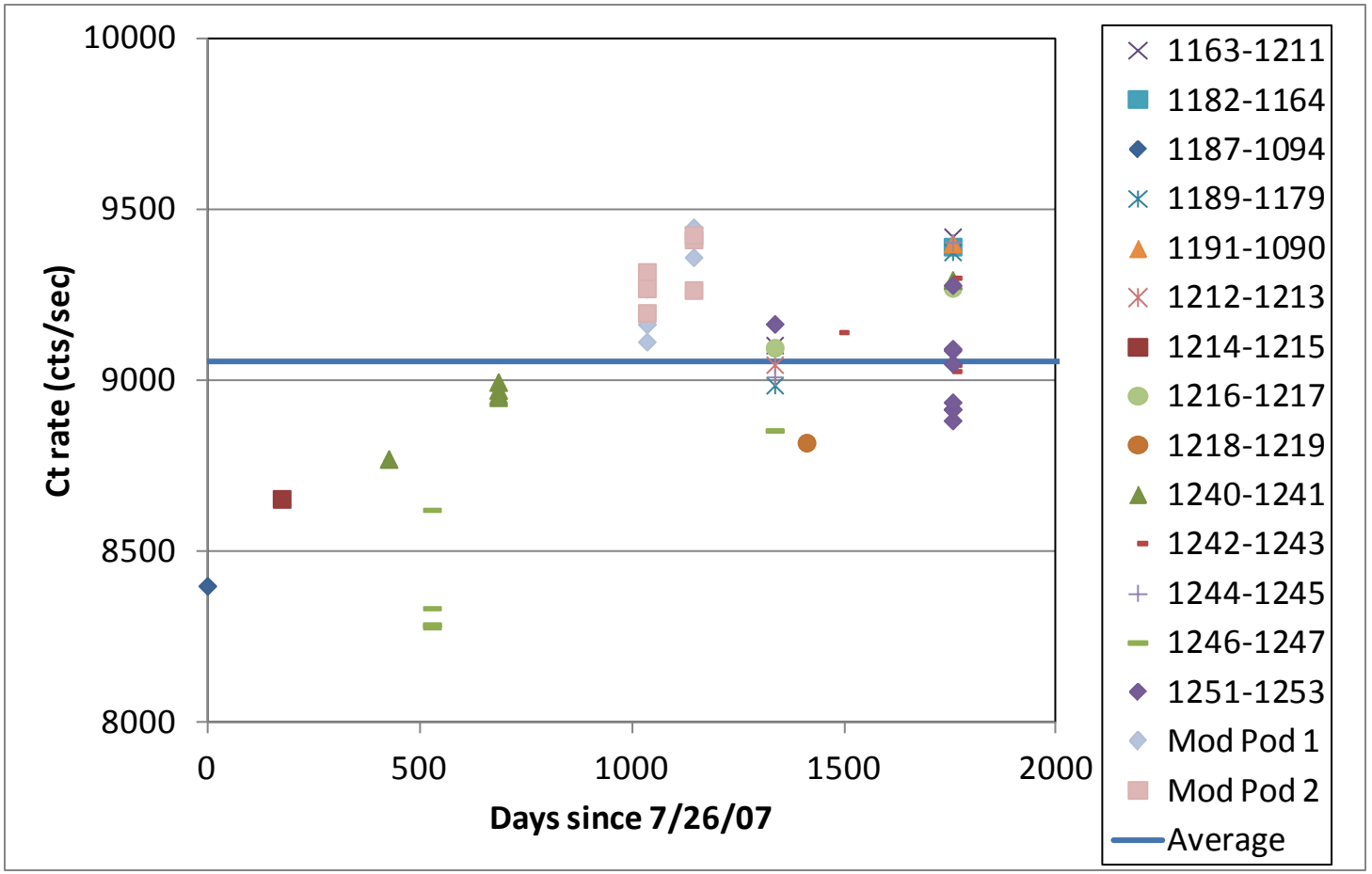




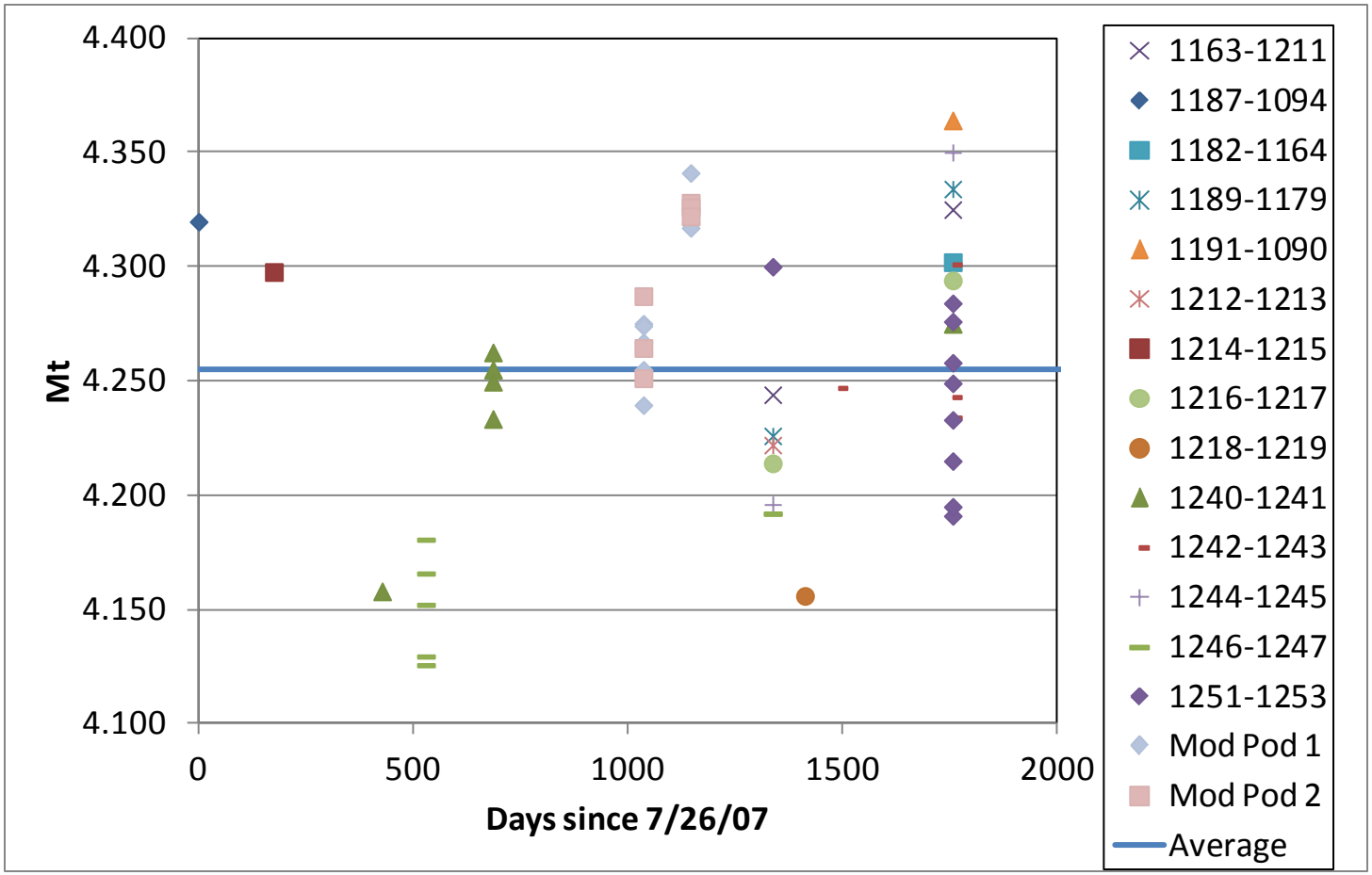
NPOD results

- All data were analyzed using:
  - The Hansen-Dowdy formulism
  - Sequential binning with a gate width of 256 micro-seconds
  - The same set of nuclear data information (nu-bar, Diven's parameters)
- These things do not strongly influence the spread of measured results

NPOD results



NPOD results



NPOD results

Reflector	Thickness (inches)	No. of campaigns	No. of files	Lifetime			Count Rate		
Bare	0	11	53	41.00	±	1.47	9054	±	311
Poly (LANL)	0.5	3	14	40.29	±	0.63	12118	±	255
	1	3	14	43.95	±	0.54	15628	±	281
	1.5	3	14	58.10	±	0.78	18415	±	271
	3	4	26	121.46	±	3.51	15686	±	416
	6	2	14	136.26	±	7.73	3751	±	89
Poly (SNL)	0.5	1	4	40.48	±	0.15	11132	±	21
	1	1	8	43.67	±	0.62	14567	±	136
	1.5	1	4	58.27	±	0.18	17485	±	64
	3	1	4	127.48	±	0.64	14687	±	43
	6	1	3	149.28	±	1.06	3646	±	50
Acrylic	0.5	1	1	40.03			11131		
	1	1	1	40.56			13886		
	1.5	1	1	47.67			16539		
	3	2	10	113.58			18661		
Nickel	0.5	1	1	41.00			11614		
	1	1	1	40.86			24512		
	1.5	1	1	40.08			16742		
	2	1	1	40.28			19091		
	2.5	1	1	40.35			21339		
	3	1	1	40.22			23518		
Tungsten	0.5	1	3	40.11	±	0.27	12026	±	2
	1	1	3	40.46	±	0.56	15551	±	23
	1.5	1	2	40.52	±	0.74	19314	±	5
	2	1	4	40.39	±	0.54	23435	±	161
	2.5	1	4	40.17	±	0.32	27098	±	177
	2.75	1	4	40.59	±	0.31	30149	±	69
	3	1	4	40.35	±	0.33	32128	±	15

NPOD results

Reflector	Thickness (inches)	No. of campaigns	No. of files	C2bar			Ym			Mt			Ml		
Bare	0	11	53	8.393	±	0.490	0.300	±	0.011	4.255	±	0.058	3.102	±	0.054
Poly (LANL)	0.5	3	14	14.277	±	0.528	0.498	±	0.010	5.412	±	0.092	3.870	±	0.082
	1	3	14	23.279	±	0.752	0.816	±	0.014	6.611	±	0.059	4.651	±	0.063
	1.5	3	14	32.372	±	0.875	1.151	±	0.019	8.509	±	0.113	5.888	±	0.105
	3	4	26	24.419	±	1.178	1.062	±	0.028	11.659	±	0.159	7.947	±	0.096
	6	2	14	2.126	±	0.080	0.253	±	0.008	10.139	±	0.132	6.956	±	0.083
Poly (SNL)	0.5	1	4	12.271	±	0.047	0.456	±	0.003	5.075	±	0.012	3.593	±	0.008
	1	1	8	20.472	±	0.359	0.760	±	0.010	6.688	±	0.022	4.632	±	0.014
	1.5	1	4	29.399	±	0.199	1.092	±	0.005	8.533	±	0.006	5.821	±	0.004
	3	1	4	21.662	±	0.119	1.002	±	0.004	12.232	±	0.015	8.206	±	0.010
	6	1	3	2.037	±	0.042	0.249	±	0.003	12.773	±	0.042	8.554	±	0.027
Acrylic	0.5	1	1	12.250			0.449			5.024			3.560		
	1	1	1	18.610			0.680			6.229			4.336		
	1.5	1	1	26.234			0.962			7.756			5.321		
	3	2	10	33.631			1.262			12.205	±	0.066	8.188	±	0.042
Nickel	0.5	1	1	13.348			0.516			5.439			3.828		
	1	1	1	50.915			0.839			6.606			4.580		
	1.5	1	1	27.182			1.056			7.610			5.227		
	2	1	1	35.420			1.360			8.607			5.869		
	2.5	1	1	44.443			1.673			9.504			6.447		
	3	1	1	54.327			2.003			10.234			6.918		
Tungsten	0.5	1	3	14.197	±	0.007	0.533	±	0.001	5.727	±	0.009	4.013	±	0.006
	1	1	3	23.316	±	0.062	0.876	±	0.001	7.215	±	0.011	4.972	±	0.007
	1.5	1	2	35.940	±	0.038	1.325	±	0.005	8.724	±	0.028	5.945	±	0.018
	2	1	4	53.400	±	0.702	1.901	±	0.014	10.411	±	0.021	7.032	±	0.014
	2.5	1	4	72.568	±	1.030	2.524	±	0.035	11.953	±	0.041	8.026	±	0.027
	2.75	1	4	90.281	±	0.429	2.979	±	0.012	12.706	±	0.020	8.512	±	0.013
	3	1	4	103.761	±	0.143	3.391	±	0.008	13.541	±	0.019	9.049	±	0.012

Results

Parameter	Relative Standard Deviation			
	Multiple Campaigns		Single Campaign	
	Average	Maximum	Average	Maximum
Lifetime	1.32%	5.67%	1.04%	1.90%
Count Rate	0.90%	3.44%	0.59%	1.66%
Cbar	0.90%	3.44%	0.59%	1.66%
C2bar	1.59%	5.83%	1.07%	2.78%
Ym	1.05%	3.51%	0.76%	1.67%
Mt	0.52%	1.70%	0.33%	0.82%
Ml	0.55%	2.13%	0.30%	0.76%
SNAP Count rate (no poly)	1.27%	3.84%	0.82%	1.76%
SNAP Count rate (with poly)	1.96%	3.64%	1.33%	2.84%

Conclusions

- Data from approximately 18 measurement campaigns were presented
  - Data taken over a 5 year span for different applications
  - ~325 SNAP data points with 5 detector systems
  - ~200 NPOD data files with 16 detector systems
- “Similar” data points and files were compared
  - No obvious trends were found (single detector high or low)
- The mean and standard deviations of several parameters were determined to assess the reproducibility of these measurements
- These results will be used to assist in determining the uncertainties associated with subcritical measurements