Mound Closure Project (MCP)
Pre-Demonstration Test
of INEEL's
Actinide X-ray In-situ Scanning System (AXISS)

Final Report

November 2002

Objective

This pre-test was designed to gather data about the performance of INEEL's actinide scanning detector system, which is a large-area proportional counter (LAPC) type detector referred to as the Actinide X-ray In-situ Scanning System (AXISS). This pre-test gave INEEL an opportunity to analyze Pu-238 spiked Mound soil samples and gather system performance information to use in optimizing the operational parameters of the system prior to an anticipated full-scale field test. The pre-test also allowed the BWXTO Mound testing team to learn more about the current capabilities of this system and its potential use at the Mound site.

Participants

Table 1 is a list of the participants and their roles in the pre-test of the AXISS the week of October 21, 2002 at Mound.

Table 1. Participant Roles in Pre-Test

Participant	Organization	Pre-Test Role
Tom Bechtold	Bechtel BWXT Idaho	Project management/Mound liaison
Mike Carpenter	Bechtel BWXT Idaho	Project management/Mound liaison
Amy Dindal	UT-Battelle (Oak Ridge National Laboratory)	Technical assistance/experimental design/data analysis
John Giles	Bechtel BWXT Idaho	Project Physicist
Steve Howard	BWXTO	Experimental design/sample preparation/facility support
Don Krause	BWXTO	Mound Project Management
Joyce Massie	BWXTO	Mound Project Management
Keith McMahan	BWXTO	Mound Field Operations
Dick Neff	DOE consultant	Experimental design/project management/DOE liaison
Lyle Roybal	Bechtel BWXT Idaho	Software design
Jeff Stapleton	BWXTO	Experimental design/sample preparation/facility support

Sample Description

Prior to the test, the DOE Environmental Measurements Laboratory (EML) was sent approximately 250-mL of uncontaminated, prepared Mound soil for determination of attenuation coefficients. The background soil that was sent to EML was from the same batch of soil that was spiked with Pu-238. The soil was sent dry to EML, with the expectation that the soil would be evaluated at varying moisture levels to determine the appropriate correction factor for moisture during the pre-test trials.

The test plot consisted of a 4' x 4' "sandbox" constructed from plywood, capable of accommodating up to sixteen 1' x 1' trays spiked with known activities of Pu-238 (the trays were cardboard liquid scintillation vial boxes). The spike concentrations were 0, 50 and 500 pCi/g Pu-238. The following describes the methodology used in preparing the blank and spiked soil.

Approximately 80 kg of site background soil was obtained, and a representative aliquot screened via gamma spectroscopy to confirm natural isotopic levels. The soil was placed in milling jars/cans and dried to <1% moisture. Milling was done with Zirconia media and sieved to a maximum particle size of 1 mm. Re-milling was conducted as necessary. This process continued until a sufficient volume of bulk soil stock was obtained. To prepare "blank" (i.e., uncontaminated) samples, individual aliquots of 1.5 kg were added to sample trays and sequentially reconstituted to 18% moisture. Final depth of soil in sample trays was ~1.75 cm. After preparation, each sample tray was labeled with a numeric designation depicting concentration. To prepare spiked soils, Pu-238 aqueous reference standard was added (volume per desired final concentration) to individual 1.5 kg soil aliquots within ball milling cans. The soils were dried to <1% moisture. Spiked soils were ball milled and sieved to particle size of <1 mm. To validate and confirm the spiking methodology, aliquots were taken from ~25% of each concentration batch and analyzed via anion exchange separation and alpha spectroscopy. The average concentration of each spiked batch was within +/- 5% of the target concentration, indicating that the results of the spiked samples were within quality control expectations. After analytical confirmation, the spiked soils were added to sample trays, reconstituted, and labeled in the same manner as the blank samples. All sample trays were covered with a cellophane wrap and secured with tape.

Experimental Description and AXISS Results

The testing of the AXISS was conducted in a trailer located at Mound from October 21 through October 24, 2002. BWXTO arranged multiple test plots, varying the amount and location of the Pu-238 spikes for each test. INEEL knew the potential spiked concentrations, but did not know the test plot configurations. For the stationary measurements, INEEL removed the cart wheels and mounted the system on top of the 4' x 4' box. Figure 1 is a picture of the AXISS during a typical test. The original plan was to conduct testing both inside the trailer and outdoors, as well as some optional walking tests, but insufficient time remained for completing the outdoor and walking tests.

Table 2 contains a summary of the test plots, the calculated average concentration over the 4' x 4' area. It also contains the AXISS reported results, both uncorrected and adjusted for moisture. Measurements were taken for up to 60 min (3600 s), with results recorded at 60 s, 120 s, 300 s, 600 s, 1200 s, 1800 s, 2700 s, and 3600 s. The results in Table 2 are for the longest time scan for each particular test. All data is reported in the Appendix. During the first three days of testing, the test plot concentrations were blind to INEEL. On the fourth day, the Mound testing team shared the results from the first three days of testing, so that the team and INEEL could collaborate on experimental design for the last day of testing. For Tests 18-21 (see Table 2), the wheels were added back to the cart and the plywood box was removed from the layout so that any shielding/interference from the cart wheels could be evaluated. Appendix A contains the AXISS data set as observed from the real-time display during the testing process. These values are slightly different than the record data files stored by the AXISS (included in the INEEL report,"INEEL/EXT-02-01495, INEEL Pu-238 AXISS, Mound Closure Project, Pre-Test Results").

It should be noted that, aside from one test plot analysis, the second day of testing was devoted nearly entirely to trying to resolve noise interference that repeatedly skewed the system's background signal. The team did not resolve the interference issue, but suspected that it was due to a radio frequency (RF) or electromotive force (EMF) sources at the Mound site that had not been encountered during testing at INEEL.

Figures 1-4– INEEL's Actinide X-ray In-situ Scanning System (AXISS)
Pre-Demonstration Soil Test Plot Setups
(Pu-238 spiked Mound soil in trays)

Test in progress

Back view

Without wheels, trays in box

With wheels, box removed

Table 2. Summary of Soil Test Plot Trials and AXISS Results

Tray layout description [a]	Estimated average conc over 4' x 4' plot (pCi/g)	AXISS Result ± Uncertainty (pCi/g) [b]		Approximate scan time (min)	Test #
		Uncorrected	Adjusted for moisture		
500 pCi/g at A, D, M, P	125	-1 ± 6	-1 ± 6.3	60	1
		6 ± 11	6.3 ± 11.5	20	13
500 pCi/g at F, G, J, K	125	310 ± 12 304 ± 12	323 ± 12.5 317 ± 12.5	20 20	2 2 (re-run)
		311 ± 11	324 ± 11.5	20	15
All 16 trays 50 pCi/g	50	15 ± 6	15.6 ± 6.3	60	3
		47 ± 7	49 ± 7.3	45	11
		16 ± 9	16.7 ± 9.4	30	14
		17 ± 6	17.7 ± 6.3	60	21 [c]
500 pCi/g at F, G, J, K All remaining trays 50 pCi/g	162.5	307 ± 12	320 ± 12.5	20	4
500 pCi/g at A, D, M, P All remaining trays 50 pCi/g	162.5	26 ± 10	27.1 ± 10.4	30	5
		46 ± 9	48 ± 9.4	30	12
500 pCi/g at B, C, N, O	125	107 ± 9	111.6 ± 9.4	30	6
		84 ± 9	87.6 ± 9.4	30	16
All blank trays	0	-14 ± 6	-14.6 ± 6.3	60	7
500 pCi/g at E, I, H, L	125	19 ± 6	19.8 ± 6.3	60	8
500 pCi/g at G	31	72 ± 7	75.1 ± 7.3	45	9
		56 ± 9	58.4 ± 9.4	30	17
500 pCi/g at G, J	62	132 ± 9	137.7 ± 9.4	45	10
500 pCi/g at F, G, J, K only	125	290 ± 11	302 ± 11.5	20	18 [c]
500 pCi/g at E, I, H, L only	125	11 ± 8	11.5 ± 8.3	30	19 [c]
500 pCi/g at B, C, N, O only	125	32 ± 8	33.4 ± 8.3	30	20 [c]

[a] Use grid below to determine location of spiked samples. If not denoted, the tray was blank soil.

A	**B**	**C**	**D**
E	**F**	**G**	**H**
I	**J**	**K**	**L**
M	**N**	**O**	**P**

[b] Observed from the real-time display during the testing process. The entire observed AXISS data set is reported in the Appendix.

[c] These trials were performed with the wheels of the cart on and the plywood box removed.

Performance Evaluation

Prior to testing, the Mound team established seven evaluation parameters for the pre-test results. Each is discussed in detail below. Some of these parameters could not be evaluated as originally intended because not all of the tests were carried out in the field. It should be noted that the results reported in Table 2, which are used in the evaluation of the performance parameters below, have not been corrected for moisture.

1) Detectable Concentrations: Can the system detect Pu-238 accurately (+/- 25% of estimated) and in a reasonable amount of time (< 30 min)?

The Pu-238 detection capability of this system was observed to be less than the expected 4' x 4' field of view. This is discussed further in 2) below. Because the detector did not see the contamination in all sixteen trays as anticipated, the comparison of the estimated concentration averaged over 16 ft^2 with the reported AXISS result (see Table 2) is of limited value. However, a few performance assessments can be noted. First, the detector did report increasing amounts of Pu-238 in a linear fashion. For example, one tray of 500 pCi/g soil (Test #9) was reported as 72 pCi/g, two trays of 500 pCi/g (Test #10) was reported as 132 pCi/g, and four trays of 500 pCi/g (Test #2) as ~300 pCi/g. Secondly, the detector rapidly (< 1 min) saw contamination that was placed directly below the detector, but the scanning continued for 2, 5, 10, 20, 30, 45, or 60 min until the reported concentrations were consistent (< 10% difference) and the uncertainty was low (< 5%). The shortest time scan to consistent results, as shown in Table 2, was 20 min. When the lowest concentration spike (50 pCi/g) was placed in all 16 trays, the AXISS's readings were somewhat inconsistent (see 4)).

2) Spatial Effects on Reporting: Does center-weighting of the detector affect the results when distribution and amount of contamination is varied across the 4' x 4' plot when the average results are similar? Does the system report a different result (% difference (%D) > 25%) for tests 1 and 2, and for tests 4 and 5?

Results reported when the contamination was distributed in different areas of the 4' x 4' test plot indicated noticeable spatial effects. Figure 5 is a schematic detailing the position of the detector over the 16 trays of soil. The detector was positioned over much of the center eight trays, as shown in Figure 5, and this 2' x 4' area appears to be where the vast majority of the contamination is detected. For example, when four 500 pCi/g trays were placed in the center of the test block (Test #2), the results were consistently reported around 300 pCi/g for 20 min count times. When the same four trays were in the corners of the grid (Test #1), the results were essentially undetected at 60 min count rates. When the four trays of 500 pCi/g soil were placed at positions B, C, N, and O (Test 6), the response was much greater (107 pCi/g) than when the trays were in the E, I, H, and L positions (Test 8 – 19 pCi/g). The spatial effects are also evident when trays of 50 pCi/g were mixed with the 500 pCi/g trays (Tests 4 and 5). Testing with the wheels on and off did not show significant differences.

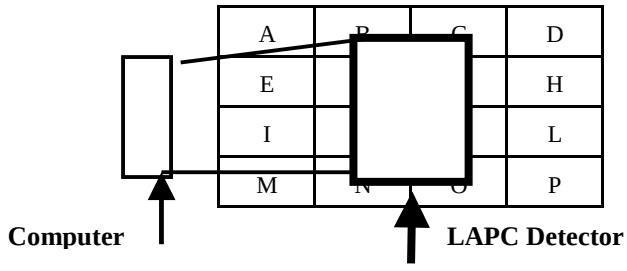

Figure 5. Detector position over soil trays during pre-test trials.

3) Detection of Hot Spots: Is the result for test 9 reported at or near the hot spot action level of 165 pCi/g? Is test 9 reported as > 165 pCi/g due to close proximity of a hot spot to the detector, or is it reported as < 50 pCi/g due to averaging over the 4' x 4' area?

One tray of 500 pCi/g was detected and reported as 72 ± 7 pCi/g. This result was obtained after 45 min of data collection. After one min, the data indicated a result of 80 ± 49 pCi/g, so the data collection continued until the uncertainty was low.

4) Reproducibility: Is the relative standard deviation (RSD) for replicate tests < 25%?

Test 2 was run three times on three different days. The results were 310, 304, and 311 pCi/g, so the RSD value was 1%. The 16 trays of 50 pCi/g were also run three times. The results were 15, 47, and 16 pCi/g, so the RSD value was 70%. The results here are puzzling because the value which seems to be the outlier (47 pCi/g) was the one closest to the estimated value of 50 pCi/g.

Several tests were repeated twice, so the relative percent difference (RPD) between the two was computed between Tests 5 and 12, 6 and 16, and 9 and 17. The RPD values were 55%, 24%, and 25%, indicating that the latter two pairs of tests were fairly consistent. Test 5 was the only test run on Day #2 when INEEL began having significant background issues, so the data from that test may be faulty.

5) Comparability to On-Site Laboratory Results: Is the average concentration within the range of average +/- (3 x std dev) or +/- 25% of alpha spectroscopy results?

As described in the Sample Description section, alpha spectroscopy was used to confirm that the process of preparing the spiked soils was within tolerance limits (± 10% of target value) and not to determine statistically significant laboratory results for each tray, so comparability to alpha spectroscopic results was not the goal of this pre-test series. However, in reference to this evaluation parameter (i.e., were the AXISS results comparable to the alpha spectroscopy results?), in most cases, the data were not comparable.

6) False Positive Error Rate: Are results when evaluating only blank trays reported as non-detects, and what are the reporting limits?

Only one test of all blank soils (Test #7) was performed, and the AXISS did not report a Pu-238 detection. After 60 min, the result was reported as –14 ± 6 pCi/g.

7) Environmental Effects : Are the early morning and late afternoon results comparable (< 25% D)? Are average results reported for tests repeated under indoor and outdoor conditions comparable (< 25% D)?
Mound was not able to evaluate this parameter, since all tests were conducted inside the trailer.

As stated earlier, there was insufficient time to test the detector under indoor and outdoor conditions.

Conclusions

The 4-day pre-test was a successful first evaluation of the AXISS Sytem's ability to detect and measure Pu-238. Both Mound and INEEL learned a significant amount of information about the performance of the system without the expense of a full-scale field deployment. The observations regarding the system include the following:

- It was observed that the field of view was less than 4' x 4'. The pre-test results indicated that it was more like 2' x 4', but this needs to be further investigated by INEEL.
- There were significant unknown sources of interference experienced during the testing which caused blocks of downtime. This needs to be investigated further and remedied by INEEL.
- INEEL indicated that the detector (which they only have one of) is 25 years old. It is known that the sensitivity has been diminished by approximately 15% over the life of the detector. A new detector with a larger surface area (which would afford even greater sensitivity) can be obtained for ~$14,000. In the optimization/re-design of a future instrument, a new or second detector should be considered.
- Evaluation of spiked soils after instrument/software optimization would be recommended before another field test at Mound. If it is possible for INEEL to have the spiked soils on site, it would be ideal for INEEL to use the soils in the evaluation and optimization of instrument performance. For example, tests of the detector's sensitivity, true field of view, real-time scanning performance, and moisture correction factors could be conducted. These are all performance assessments which should be studied in a laboratory prior to field deployment.
- No walking/real-time scanning trials were conducted. Presumably, the GIS/GPS portion of the system is functional, since the configuration is similar that used in other well-proven INEEL systems.

Based on the observations of this pre-test, it is concluded that the AXISS for Pu-238 detection is not mature enough for a full-scale field test. However, it is possible that the system could be viable if the issues highlighted by this pre-test are considered and addressed by INEEL.

After conclusion of these tests and shipment of the equipment back to INEEL, additional data evaluation and tests were conducted. INEEL will include the results of these follow-on activities in a later report, "INEEL/EXT-02-01495, INEEL Pu-238 AXISS, Mound Closure Project, Pre-Test Results."

Appendix – AXISS Scan Observed Concentrations

The box contains the tray layout and soil codes for each test. Codes ending in 0, 1, 2, or 3 were 50 pCi/g, ending in 4, 5, or 6 were 500 pCi/g, and ending in 7, 8, or 9 were blank.

Test 1 - 10/21/02, 2 pm

70 F 50% RH

425	578	179	385
337	339	598	419
197	677	759	218
486	258	699	644

Time (seconds)	Result (pCi/g)[1]	Uncertainty (+/-)
60	-57	53
120	-38	37
300	-15	22
600	-12	16
1200	5	11
1800	4	9
2700	-2	7
3600	-1	6

Test 2 - 10/21/02, 3:12 pm

70 F 49% RH

337	578	339	759
179	644	425	419
197	385	486	699
218	258	677	598

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	379	50
120	365	34
300	306	23
600	312	16
1200	310	12
1800		
2700		
3600		

Test 3 - 10/21/02, 3:45 pm

71 F 47% RH

337	578	339	759
179	644	425	419
197	385	486	699
218	258	677	598

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	37	49
120	-1	37
300	-2	23
600	10	16
1200	2	11
1800	5	9
2700	10	7
3600	15	6

Test 4 - 10/21/02, 4:45 pm

74 F 49% RH

581	541	140	743
980	486	385	120
821	644	425	261
623	420	780	383

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	255	54
120	266	39
300	292	24
600	307	16
1200	304	12
1800		
2700		
3600		

[1] Values obtained from INEEL 11/5/02

Appendix – AXISS Scan Observed Concentrations

Test 5 - 10/22/02, 8:30 am

70 F 53% RH

486	541	140	385
980	581	743	120
821	623	383	261
644	420	780	425

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	52	48
120	44	35
300	49	22
600	41	16
1200	29	12
1800	26	10
2700		
3600		

Test 2- rerun, 10/23/02, 11:15 am

70 F 53% RH

838	218	457	717
699	425	385	917
*663	644	486	677
197	258	578	419

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	315	51
120	344	34
300	307	23
600	299	17
1200	304	12
1800		
2700		
3600		

* 663 was a 50 pCi/g tray. This should have been a blank. This error did not appear to effect the results.

Test 6 - 10/23/02, 11:45 am

70 F 53% RH

457	425	385	218
838	699	917	717
197	*663	677	419
578	644	486	258

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	121	47
120	103	34
300	80	23
600	84	16
1200	96	11
1800	107	9
2700		
3600		

* 663 was a 50 pCi/g tray. This should have been a blank. This error did not appear to effect the results.

Test 7 - 10/23/02, 12:30 pm

581	541	140	743
980	486	385	120
821	644	425	261
623	420	780	383

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60		
120		
300		
600	Ran unattended	
1200		
1800		
2700		
3600	-14	6

Appendix – AXISS Scan Observed Concentrations

Test 8 - 10/23/02, 1:30 pm

70 F 53% RH

457	339	598	218
644	699	917	425
486	759	677	385
578	258	179	419

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	-79	58
120	4	36
300	32	22
600	42	15
1200	17	11
1800	25	9
2700	23	7
3600	19	6

Test 9 - 10/23/02, 2:45 pm

72 F 53% RH

457	339	598	218
197	699	917	838
717	759	385	677
578	258	179	419

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	124	43
120	110	32
300	49	23
600	72	15
1200	74	11
1800	66	9
2700	72	7
3600		

Test 11 - 10/24/02, 7:35 am

70 F 50% RH

383	821	743	541
120	581	780	140
663	241	420	623
363	460	980	261

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	47	47
120	19	35
300	52	21
600	44	15
1200	42	11
1800	40	9
2700	47	7
3600		

Test 12 - 10/24/02, 8:30 am

69 F 52% RH

486	821	743	385
120	521	780	140
663	241	420	623
425	460	980	644

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	83	47
120	61	31
300	53	22
600	44	16
1200	51	11
1800	46	9
2700		
3600		

Appendix – AXISS Scan Observed Concentrations

Test 13 - 10/24/02, 9:00 am

70 F 52% RH

486	578	179	385
337	339	598	419
197	677	759	218
425	258	699	644

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	28	44
120	-3	35
300	28	22
600	28	15
1200	6	11
1800		
2700		
3600		

Test 14 - 10/24/02, 9:30 am

70 F 52% RH

383	821	743	541
120	581	780	140
663	241	420	623
363	460	980	261

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	80	45
120	49	34
300	-3	23
600	23	16
1200	22	11
1800	16	9
2700		
3600		

Test 15 - 10/24/02, 10:10 am

70 F 52% RH

917	218	197	699
419	425	385	337
717	486	644	677
578	759	258	598

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	366	49
120	306	35
300	283	24
600	296	17
1200	311	11
1800		
2700		
3600		

Test 16 - 10/24/02, 10:35 am

71 F 52% RH

917	425	385	699
419	218	197	337
717	759	258	677
578	486	644	598

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	84	51
120	44	37
300	87	22
600	82	16
1200	91	11
1800	84	9
2700		
3600		

Appendix – AXISS Scan Observed Concentrations

Test 17 - 10/24/02, 11:15 am

70 F 52% RH

420	917	699	623
419	218	197	337
578	717	385	677
581	759	258	598

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	60	48
120	65	35
300	45	22
600	44	16
1200	54	11
1800	56	9
2700		
3600		

Test 18 - 10/24/02, 1:30 pm

72 F 50% RH

	486	425	
	644	385	

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	366	44
120	356	32
300	303	22
600	296	16
1200	290	11
1800		
2700		
3600		

Test 19 - 10/24/02, 2:00 pm

72 F 50% RH

486			425
644			385

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	-83	53
120	16	34
300	-7	21
600	-9	15
1200	2	10
1800	11	8
2700		
3600		

Test 20 - 10/24/02, 2:30 pm

72 F 50% RH

	486	644	
	425	385	

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	43	45
120	56	31
300	15	21
600	21	15
1200	28	10
1800	32	8
2700		
3600		

Appendix – AXISS Scan Observed Concentrations

Test 21 - 10/24/02, 3:00 pm

72 F 50% RH

383	821	743	541
120	581	780	140
663	241	420	623
363	460	980	261

Time (seconds)	Result (pCi/g)	Uncertainty (+/-)
60	15	48
120	25	33
300	10	22
600	11	15
1200	3	11
1800	11	9
2700	12	7
3600	17	6