Test Report for Cricket Radiation Detection System Used In EPA Port Installations

June 2004

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**TEST REPORT FOR CRICKET RADIATION DETECTION SYSTEM
USED
IN EPA PORT INSTALLATIONS**

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June 2004

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U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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EXECUTIVE SUMMARY

Oak Ridge National Laboratory conducted field radiological measurements at two port locations at the request of the Environmental Protection Agency (EPA). The radiological measurements were performed on five radiation detection systems at the port of Darrow, Louisiana and three systems at the port of Charleston, South Carolina. Darrow was visited on January 20-23, 2004 and Charleston on May 25, 2004.

All tested systems are designed to detect radioactive material that might be present in scrap metals as the scrap is being unloaded from ships. All eight systems are commercially known as the Cricket and manufactured by RAD/COMM Systems. Each radiation detection system consists of a detector with two channels and a wireless transmitter, both mounted on the grapple, and a controller located in the crane cab. The cranes at both locations are operated by the Cooper T. Smith Company.

The purpose of the radiological measurements was to evaluate the performance of the radiation detection systems in terms of their ability to detect elevated radiation levels, and to develop a routine testing method for all EPA Cricket systems.

1.0 INTRODUCTION

Oak Ridge National Laboratory (ORNL) conducted field radiological measurements at two port locations at the request of the Environmental Protection Agency (EPA). The radiological measurements were performed on five radiation detection systems at the port of Darrow, Louisiana (Darrow) and three systems at the port of Charleston, South Carolina (Charleston). Darrow was visited on January 20-23, 2004 and Charleston on May 25, 2004. All tested systems are designed to detect radioactive material that might be present in scrap metals as the scrap is being unloaded from ships. All eight Cricket systems are commercially available and manufactured by RAD/COMM Systems. Each radiation detection system consists of a two-channel (A & B) detection unit and a wireless transmitter, both mounted on the grapple, and a controller located in the crane cab. The cranes at both locations are operated by Cooper T. Smith Company.

Radiological measurements were made to evaluate the performance of the radiation detection systems in terms of their ability to detect elevated radiation levels in scrap steel, and to develop a routine testing method for all the EPA Cricket systems.

Two sets of data were collected for each system. One set is used for analyzing the alarm response of the detection system in order to compare it with a description of the alarm algorithm provided by RAD/COMM. The other set is used to analyze the detectors' sensitivity across its surface area.

Flow charts, developed by ORNL based on the RAD/COMM alarm algorithm are shown in Appendix A.

The alarm response and sensitivity measurements at Darrow were taken using a sealed ^{137}Cs (1.07 μCi as of August 8, 1984) source provided by the EPA. The alarm response and sensitivity measurements at Charleston were obtained using thoriated welding rod sources fabricated by Cooper T. Smith (~50 $\mu\text{rem/hr}$ on contact).

Data collected from both sites are listed in Appendix B. Darrow data are listed in tables B1-B10, and Charleston data are listed in tables B11-B12.

2.0 FIELD TEST LOCATIONS & CRICKET SYSTEMS

The following is a list of the Cricket systems tested at each location:

- Darrow – Five Cricket systems installed on five grapples, and controlled and monitored by one control unit (RC/5) mounted in the cabin of crane # 1. Figure 1 is a functional block diagram illustrating the five Cricket radiation detection systems' arrangement.
 - Grapple # B3 (size 8 yards)
 - Grapple # B5 (size 11 yards)
 - Grapple # B6 (size 11 yards)
 - Grapple # B14 (size 17 yards)
 - Grapple # B51 (size 8 yards)

Figure 1. Block Diagram Describing the Cricket Radiation Detection Systems at Darrow

- Charleston - Three Cricket systems installed on three grapples, and controlled and monitored by one control unit (RC/5) mounted in the cabin of crane # 3. Figure 2 is a functional block diagram illustrating the three Cricket radiation detection systems' arrangement.
 - Grapple # 1 (size 10 yards)
 - Grapple # 2 (size 12 yards)
 - Grapple # 3 (size 12 yards)

Figure 2. Block Diagram Describing the Cricket Radiation Detection Systems at Charleston.

3.0 TEST RESULTS

3.1 ALARM RESPONSE

The Cricket system is designed to provide the crane operator with seven alarm types as illustrated by the logic flow charts in Figures A1-A7. As shown in Appendix A, four of the alarms can be triggered with the grapple tines open or closed (R1, R2, RTK, RAB). The other three alarms are triggered upon the closing of the grapple tines (DAB, DSA, DAA). In addition, each alarm type is displayed along with its level which identifies the exposure rate in mR/hr. The Cricket detection system has five different levels (LVL1: less than 0.5mR/hr, LVL2: between 0.5 mR/hr and 1.0 mR/hr, LVL3: between 1.0 mR/hr and 2.0 mR/hr, LVL4: between 2.0 mR/hr and 5.0 mR/hr, LVL5: greater than 5.0 mR/hr) [1]. According to the number of levels (5) and the alarm types (7), it can be interpreted that the Cricket can generate 35 different alarms.

During alarm response testing, only one of the seven alarms was activated for all eight systems. This alarm was indicated as LVL1 # RAB and was triggered with the grapple tines in the open or closed position. The other six alarms were never observed during the tests described in this report.

At Darrow, the alarm response was tested for all five systems using a ^{137}Cs source that produced alarms at an average of 400 net counts per second (cps). In an attempt to activate other alarms, 10 welding rods were used in addition to the ^{137}Cs source to raise the count rate up to approximately 1400 cps. The same LVL1 # RAB alarm was triggered. This was tried on one system only.

At Charleston, the alarm response was tested for all three systems using 2 welding rod sources fabricated specifically for testing the Cricket systems. The average net count rate for the LVL1 # RAB alarm was 600 cps.

The background count rate and alarm type and count rate for Darrow and Charleston are tabulated in Table 1. In addition, the detectable limit (DL) for each location has been computed and shown in Table 1. The DL is a measure of the statistical significance of the detection process at each location based on the background. A measured net count rate higher than the DL value indicates a high confidence level, typically 90% according to the way DL is computed [2]. This quantity is not related to the quality of the detection system but to the statistically random nature of radioactive decay and the measurement itself. The DL for Darrow based on the measured ambient background (62 cps) is 40 cps. The DL for Charleston based on the measured ambient background (51 cps) is 36 cps. Accordingly, the estimated sensitivity level in activity should be expressed by taking into consideration the detection efficiency as follows:

$$\text{Activity level (dps)} = \text{Net Counts (cps)} / E$$

Where,

E is the detection efficiency of the Cricket system, and
dps is the activity in disintegration per second which can be converted to Curie (Ci) by the relation:

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ dps.}$$

3.2 OBSERVATIONS

1. The measured ambient background at Darrow and Charleston, which is in the range of 60 cps, can be considered as the normal ambient for both locations. Background significantly higher than 60 cps can be considered abnormal and should be investigated.
2. The background for channel B associated with the Cricket system installed on Grapple B3 at Darrow was high. The background for this channel was 238 cps which is approximately four times higher than channel A of the same system as well as the four other systems.
3. The position of the RC/5 controller inside the crane cabin requires the operator to turn his attention away from operating the crane during loading/unloading scrap in order to observe the alarm display. There is also the potential of background noise masking the audible alarm which would prevent the operator from hearing the alarm.
4. Analysis of the alarm algorithm for the Cricket system shows a high degree of complexity for the intended operation as illustrated by the flow diagrams (Figure A1-A7). The flow diagrams were developed by ORNL from a written description of the alarm algorithms provided by RAD/COMM. The system has seven alarm types and five alarm levels associated with each alarm type. It is not clear as to why they are needed and for what purpose. During the entire testing effort only one alarm type was observed (LVL1 #RAB) at both locations. Considering the operators' interaction with the Cricket system and the need to know, these various alarms are confusing and don't add any value. The operator only needs to know if the load of scrap has an elevated radiation level. This can be presented to the operator in a simple go/no-go fashion. Interaction with the RC/5 controller requires someone who is more technically oriented.
5. Careful consideration should be given to interpreting the exposure rates indicated by the alarm levels (LVL1-LVL5). Exposure rates in R/hr are typically measured at a certain distance from the radiation source. Varying the distance between the source and the measurement point will certainly vary the exposure. Such a relationship is governed by the inverse square law:

$$\text{Exposure at distance } d2 = \text{Exposure at } d1 \left(\frac{d1}{d2} \right)^2$$

3.3 MEASUREMENT SENSITIVITY

The analysis of the sensitivity data collected from both sites (Tables B1-B13) indicates that optimal measurement can be obtained at the center of each detector channel. As shown by Figure 3, placing the radioactive source at location A2 and B2 provides the highest count rate compared to the other locations (A1, A3, B1, B3, and C). Unfortunately, readings from the center will not provide a complete indication of the detector's status. In order to detect changes in detection quality it is critical to challenge the detector by placing the source at the farthest point from the photomultiplier tube. Cracks or other degradations would be indicated by reduced count rates when tests are performed at that location. These changes may not be as apparent when testing the detector by placing the source at a location that is nearer to the photomultiplier tube (PMT).

Figure 3. Cricket Detector Assembly Illustrating Sensitivity Measurements Locations

Therefore, ORNL recommends using location A1 & B1 for routine testing of the Cricket systems. Measurement points A1 & B1 are located along the center line of each channel at 6 inches from the edge of the detector's housing farthest from the PMT as illustrated by Figure 3.

Table 1. Darrow & Charleston Alarm Data

Measurement (CPS)	Darrow	Charleston
Average Background*	62	51
Average Alarm Total Count**	465	650
Average Alarm Net Count*	403	599
Alarm Type	LVL1 # RAB	LVL1 #RAB
Detectable Limit (DL)***	40	36

* Excluding channel B for Grapple B3

** Average count for all systems per location *** $DL = (3 + 4.65 * \sqrt{BKG}) / \text{Count Time}$ [2]

4.0 RECOMMENDATIONS

Based on the test results, observations by ORNL during testing, and discussions with Cooper T. Smith operators, ORNL offers the following recommendations:

- It is recommended to place the test source at points A1 & B1 shown in Figure 3 to obtain the best results for routine testing of detectors' performance. ORNL has developed a routine test tracking web site (<http://public.ornl.gov/estd/qc/>) that could be used as a simple tracking method for response results. It is recommended that response tests be performed at least weekly. The range should be based on the average reading from each detector with a tolerance of $\pm 20\%$.
- Sources should be standardized for testing the Cricket systems installed at both locations (Darrow and Charleston), as well as any future applications at other EPA sites. It is recommended to use a source similar to that being used at Charleston. This would mitigate the need for special training and certification required for handling radioactive sources, maintaining survey meters, and establishing site specific QA procedures to handle and store sources.
- The high background reading for channel B for the Cricket system installed in Grapple B3 needs to be investigated to determine the cause. The background reading for channel B was 238 counts. This is four times higher than all other detectors.
- Wiring connectors from the battery box to the detector at Darrow need to be replaced with connectors similar to those used at Charleston to prevent corrosion. This will help in reducing maintenance efforts and the spare parts inventory.
- Consideration should be given to provide a simple visual indication for the crane operator with the RC/5 acting as the controller (see Figure 4). The display unit could be as simple as a visual display with two indicators, red and green, located in the vicinity of the crane's operator console. Red would indicate an increase in radiation levels and green would indicate clean load. The RC/5, on the other hand, can be used by a technical person.

Figure 4. ORNL Suggested Operator Interaction Configuration

- The alarm algorithm for the Cricket system needs to be simplified. Operationally, the Cricket should provide the crane operator with a simple alarm telling the operator how to process the load of scrap. Any further details concerning the nature of the radiation should be undertaken by someone other than the crane operator.

REFERENCES

1. RAD/COMM, 'Cricket Operations Manual'
2. University of Toronto, 'Module6: Radiation Detection and Measurements',
<http://www.utoronto.ca/safety/RadTraining/Module6.htm>

APPENDIX A
ALARM FLOW DIAGRAM FOR THE CRICKET SYSTEM

Figure A1. Logic Flow Diagram for Initializing Alarm Algorithms

Figure A2. Logic Flow Diagram for Real Time Alarms (R1, R2, RTK)

Figure A3. Logic Flow Diagram for RAB Alarm Routine.

Figure A4. Logic Flow Diagram for Invoking Alarms (DAB, DSA, DAA) Initiated Upon Tines Closing.

Figure A5. Logic Flow Diagram for Triggering DAB Alarm

Figure A6. Logic Flow Diagram for Triggering DSA Alarm.

Figure A7. Logic Flow Diagram for Triggering DAA Alarm.

APPENDIX B
TEST RESULTS FOR DARROW AND CHARLESTON

Figure B1. DARROW Alarm Response Test (Grapple B3)

Date: 1/22/04

Cricket System ID: Darrow/Bill Hines/Grapple B3/Transmitter 2

Test Source: Cs-137, Activity 1.07 uCi, Dated 8/8/84

Weather Conditions: Sunny, ~45-50 °F

Performed By: Ayman Shourbaji & Larry Phillips

Back Ground		
Det A	Det B	Total(T)
91	242	300
86	227	318
51	273	316
116	247	312
71	202	308
Average	83	238
		311

Tines Open				Tines Closed			
Alarm Type	A (CPM)*	B (CPM)*	Remarks	Alarm Type	A (CPM)*	B (CPM)*	Remarks
Level 1/RAB	449	606	A & B alarms level 1 /RAB	Level1/RAB	449		A & B alarms level 1 / RAB
	414	717			553	409	
	459	657			485	348	
	510	667			596	338	
	444	591			550	419	
	455	682			556	455	
	505	732			429	444	
	399	707			399	364	
	515	697			449	460	
	510	657			434	455	
Average	466	671		Average	490	410	

* Measurements for A & B were obtained separately

Figure B2. DARROW Sensitivity Test (Grapple B3)

Date: 1/22/04

Cricket System ID: Darrow/Bill Hines/Grapple B3/Transmitter 2

Test Source: Cs-137, Activity 1.07 uCi, 8/8/84

Weather Conditions: Sunny, ~45-50 °F

Performed By: Ayman Shourbaji & Larry Phillips

Back Ground		
Det A	Det B	Total (T)
91	242	300
86	227	318
51	273	316
116	247	312
71	202	308
Average	83	238
		311

See Sketch #1 for Measurement Locations					
A1	A2	A3	B1	B2	B3
495	712	692	611	889	581
424	783	591	722	808	591
530	692	682	621	783	651
510	853	667	616	838	571
449	682	606	601	783	606
389	879	535	581	788	636
444	727	505	566	722	631
510	702	550	657	813	657
359	838	677	722	823	545
419	707	495	662	758	651
453	758	600	636	801	612

See Sketch #1 for Measurement Locations			
C0 (T)	C6 (T)	C12 (T)	C36(T)
611	638	605	380
610	637	611	382
604	638	614	396
610	634	612	395
609	643	608	397
612	639	610	398
610	643	612	394
613	647	608	396
617	645	611	400
614	647	609	395
611	641	610	393

C0 (T) denotes measurement taken at point C w/ source placed against the detector and readings taken from channel T

C6 (T) denotes measurement taken at point C w/ source 6" from the detector and readings taken from channel T

C12 (T) denotes measurement taken at point C w/source 12" from the detector and readings taken from channel T.

C36 (T) denotes measurement taken at point C w/source 36" from the detector and readings taken from channel T.

Figure B3. DARROW Alarm Response Test (Grapple B5)

Date: 1/21/04

Cricket System ID: Darrow/Bill Hines/Grapple B5/Transmitter 1

Test Source: Cs-137, Activity 1.07 uCi, 8/8/84

Weather Conditions: Sunny, ~45-50 °F

Performed By: Ayman Shourbaji & Larry Phillips

Back Ground		
Det A	Det B	Total (T)
66	45	114
71	51	116
51	61	118
101	35	117
36	76	113
Average	65	54
		116

Tines Open				Tines Closed			
Alarm Type	A (CPM)*	B (CPM)*	Remarks	Alarm Type	A (CPM)*	B (CPM)*	Remarks
Level1/RAB	530	460	A & B alarms level 1/RAB	Level 1/ RAB	510	354	A & B alarms level 1/RAB
	505	444			455	424	
	485	414			424	384	
	500	424			434	384	
	485	313			444	348	
	515	374			439	399	
	500	419			465	434	
	601	323			384	313	
	505	485			434	455	
	596	420			430	451	
Average	522	408		Average	442	395	

* Measurements for A & B were obtained separately

Figure B4. DARROW Sensitivity Test (Grapple B5)

Date: 1/21/04

Cricket System ID: Darrow/Bill Hines/Grapple B5/Transmitter 1

Test Source: Cs-137, Activity 1.07 uCi, 8/8/84

Weather Conditions: Sunny, ~45-50 °F

Performed By: Ayman Shourbaji & Larry Phillips

Back Ground		
Det A	Det B	Total (T)
66	45	114
71	51	116
51	61	118
101	35	117
36	76	113
Average	65	54
		116

See Sketch #1 for Measurement Locations					
A1	A2	A3	B1	B2	B3
419	828	626	207	500	394
409	818	682	263	354	424
359	672	681	202	475	364
439	758	687	268	510	303
424	768	581	152	485	294
394	732	758	232	424	333
364	631	651	202	470	364
404	793	768	217	485	419
389	838	763	278	505	308
354	756	667	202	419	333
396	759	686	222	463	354

See Sketch #1 for Measurement Locations		
C0 (T)	C6 (T)	C12 (T)
277	241	331
270	268	319
273	291	323
284	299	324
295	334	336
304	345	361
318	367	386
325	391	412
315	446	440
318	438	456
298	342	369

C0 (T) denotes measurement taken at point C w/ source placed against the detector and readings taken from channel T

C6 (T) denotes measurement taken at point C w/ source 6" from the detector and readings taken from channel T

C12 (T) denotes measurement taken at point C w/source 12" from the detector and readings taken from channel T.

Figure B5. DARROW Alarm Response Test (Grapple B6)

Date: 1/22/04

Cricket System ID: Darrow/Bill Hines/Grapple B6/Transmitter 2

Test Source: Cs-137, Activity 1.07 uCi, 8/8/84

Weather Conditions: Sunny, ~45-50 °F

Performed By: Ayman Shourbaji & Larry Phillips

Back Ground		
Det A	Det B	Total (T)
61	56	88
40	25	89
45	51	90
66	20	92
76	40	94
Average	58	38
		91

Tines Open				Tines Closed			
Alarm Type	A (CPM)*	B (CPM)*	Remarks	Alarm Type	A (CPM)*	B (CPM)*	Remarks
Level1/RAB	419	651	A & B alarms level 1/RAB	Level 1/ RAB	535	449	A & B alarms level 1/RAB
	485	557			566	525	
	394	712			586	495	
	389	631			591	399	
	343	576			495	394	
	364	550			722	323	
	374	586			465	434	
	343	545			475	525	
	429	571			515	404	
	379	672			470	495	
Average	392	605		Average	542	444	

Figure B6. DARROW Sensitivity Test (Grapple B6)

Date: 1/22/04

Cricket System ID: Darrow/Bill Hines/Grapple B6/Transmitter 2

Test Source: Cs-137, Activity 1.07 uCi, 8/8/84

Weather Conditions: Sunny, ~45-50 °F

Performed By: Ayman Shourbaji & Larry Phillips

Back Ground		
Det A	Det B	Total (T)
61	56	88
40	25	89
45	51	90
66	20	92
76	40	94
Average	58	38
		91

See Sketch #1 for Measurement Locations					
A1	A2	A3	B1	B2	B3
217	581	597	490	687	601
152	576	439	626	742	641
182	636	500	545	747	778
202	646	561	576	778	717
217	601	505	439	758	768
222	626	465	384	778	732
242	727	480	449	747	621
207	566	434	434	727	662
167	621	475	505	737	677
177	651	460	419	621	722
199	623	492	487	732	692

See Sketch #1 for Measurement Locations			
C0 (T)	C6 (T)	C12 (T)	C36(T)
468	457	450	212
467	458	451	210
466	465	452	213
468	468	448	212
461	467	449	211
453	466	451	212
441	478	452	213
447	484	434	215
454	481	441	214
466	485	438	212
459	471	447	212

C0 (T) denotes measurement taken at point C w/ source placed against the detector and readings taken from channel T

C6 (T) denotes measurement taken at point C w/ source 6" from the detector and readings taken from channel T

C12 (T) denotes measurement taken at point C w/source 12" from the detector and readings taken from channel T.

C136 (T) denotes measurement taken at point C w/source 36" from the detector and readings taken from channel T.

Figure B7. DARROW Alarm Response Test (Grapple B14)

Date: 1/21/04

Cricket System ID: Darrow/Bill Hines/Grapple B14/Transmitter 5

Test Source: Cs-137, Activity 1.07 uCi

Weather Conditions: Sunny, 45-50 °F

Performed By: Ayman Shourbaji & Larry Phillips

Back Ground	
Det A	Det B
91	76
71	61
56	71
45	66
66	111
Average	66

Tines Open				Tines Closed			
Alarm Type	A (CPM)*	B (CPM)*	Remarks	Alarm Type	A (CPM)*	B (CPM)*	Remarks
Level 1/RAB	424	449	A & B alarms level 1/RAB	Level1/RAB	465	394	A & B alarms level 1/RAB
	338	444			444	409	
	424	566			389	348	
	460	434			470	338	
	444	505			475	419	
	399	465			460	455	
	354	490			384	444	
	389	399			475	364	
	369	465			465	460	
	375	460			462	455	
Average	398	468		Average	449	409	

* Measurements for A & B were obtained separately

Figure B8. DARROW Sensitivity Test (Grapple B14)

Date: 1/21/04

Cricket System ID: Darrow/Bill Hines/Grapple B14/Transmitter 5

Test Source: Cs-137, Activity 1.07 uCi, Dated 8/8/84

Weather Conditions: Sunny, 45-50 °F

Performed By: Ayman Shourbaji & Larry Phillips

Back Ground	
Det A	Det B
91	76
71	61
56	71
45	66
66	111
Average	66
	77

See Sketch #1 for Measurement Locations					
A1	A2	A3	B1	B2	B3
455	636	697	515	823	571
419	621	667	449	576	626
409	682	672	465	778	687
510	727	621	490	803	707
429	692	626	455	914	682
475	631	556	475	848	747
404	693	611	571	838	838
384	702	490	465	798	732
409	742	550	460	727	793
439	752	586	444	894	758
433	688	608	479	800	714

See Sketch #1 for Measurement Locations			
C0 (T)	C6 (T)	C12 (T)	C24 (T)
355	543	566	316
356	542	552	310
355	537	550	312
352	538	553	313
357	537	554	315
354	530	553	319
353	561	551	317
352	558	547	314
350	557	544	315
347	552	542	316
353	546	551	315

C0 (T) denotes data taken at point C w/ source placed against detector and readings taken from Channel T

C6 (T) denotes data taken at point C w/ source placed 6" from detector and readings taken from Channel T

C12 (T) denotes data taken at point C w/ source placed 12" from detector and readings taken from Channel T

C24" (T) denotes data taken at point C w/ source placed 24" from detector and readings taken from Channel T

Figure B9. DARROW Alarm Response Test (Grapple B51)

Date: 1/21/04

Cricket System ID: Darrow/Grapple B51/Transmitter 5

Test Source: Cs-137, Activity 1.07 uCi

Weather Conditions: Sunny, ~ 45-50 °F,

Performed By: Ayman Shourbaji & Larry Phillips

Back Ground		
Det A	Det B	Total (T)
56	45	114
40	51	116
76	40	118
91	56	117
71	51	113
Average	67	49
		116

Times Open				Times Closed			
Alarm Type	A (CPM)*	B (CPM)*	Remarks	Alarm Type	A (CPM)*	B (CPM)*	Remarks
Level1/RAB	530	485	A & B alarms level 1/ RAB	Level 1/ RAB	455	429	A & B alarms level 1/ RAB
	485	429			429	439	
	394	500			424	455	
	444	444			475	490	
	434	399			414	404	
	394	566			455	470	
	480	480			389	510	
	449	439			394	379	
	424	399			449	470	
	395	430			450	440	
Average	443	457		Average	433	449	

* Measurements for A & B were obtained separately

Figure B10. DARROW Sensitivity Test (Grapple B51)

Date: 1/21/04

Cricket System ID: Darrow/Bill Hines/Grapple B51/Transmitter 5

Test Source: Cs-137, Activity 1.07 uCi, 8/8/84

Weather Conditions: Sunny, ~45-50 °F

Performed By: Ayman Shourbaji & Larry Phillips

Back Ground	
Det A	Det B
56	45
40	51
76	40
91	56
71	51
Average	67
	49

See Sketch #1 for Measurement Locations					
A1	A2	A3	B1	B2	B3
359	561	556	258	545	449
338	702	636	202	601	566
450	667	581	318	571	465
313	530	616	232	435	389
374	550	517	187	550	455
268	651	596	253	470	409
328	535	515	308	545	384
389	601	550	278	495	520
318	561	626	247	535	465
283	540	621	258	545	394
342	590	581	254	529	450

See Sketch #1 for Measurement Locations			
C0 (T)	C6 (T)	C12 (T)	C18(T)
415	414	441	338
413	416	404	341
409	414	401	339
408	416	400	335
407	405	398	336
404	408	397	338
406	411	392	336
404	410	390	332
399	408	386	329
401	407	383	330
407	411	399	335

C0 (T) denotes measurement taken at point C w/ source placed against the detector and readings taken from channel T

C6 (T) denotes measurement taken at point C w/ source 6" from the detector and readings taken from channel T

C12 (T) denotes measurement taken at point C w/source 12" from the detector and readings taken from channel T.

C18 (T) denotes measurement taken at point C w/source 18" from the detector and readings taken from channel T.

Figure B11. CHARLESTON ALARM RESPONSE TEST
GRAPPLE #1

Date: 5/26/2004

Cricket System ID Charleston/Crane #3/Grapple #1(10 yards)/Transmitter #2

Test Source 2 Custom Built Thoriated Welding Rods (50 uR/hr each)

Weather Conditions: Sunny, ~90°F

Performed By Ayman Shourbaji & Larry Phillips

Background		
A	B	T
56	35	109
66	56	107
48	46	108
45	56	106
56	51	105
61	61	105
56	71	104
35	35	103
51	25	104
71	35	103
Average	55	47
		105

Tines Open		Tines Closed		Remark
A (Net CPS)	B (Net CPS)	A (Net CPS)	B (Net CPS)	
820	882	678	534	All Alarms LVL1 #RAB
885	806	754	650	
941	857	850	675	
764	897	916	867	
779	928	850	837	
704	918	794	1044	
724	938	769	882	
587	812	724	832	
592	806	623	968	
158	852	315	931	
Average	695	870	727	822

CHARLESTON SENSITIVITY TEST

A1(Net cps)	A2 (Net cps)	A3 (Net cps)	B1(Net cps)	B2(Net cps)	B3 (Net cps)	C0(T) (Net cps)	C6(T) (Netcps)	C12(T) (Net cps)
608	855	542	569	928	835	310	472	340
789	799	592	665	817	716	303	473	345
628	754	577	594	806	837	299	475	345
739	845	496	756	781	568	299	474	350
704	840	512	589	786	620	298	479	354
587	729	572	610	892	655	296	481	356
648	835	547	645	913	700	295	478	359
688	739	557	640	968	574	293	477	366
592	789	567	625	923	736	292	476	369
754	693	512	564	867	690	289	476	375
673	787	547	626	868	693	297	476	356

**Figure B12. CHARLESTON ALARM RESPONSE TEST
GRAPPLE #2**

Date: 5/26/2004

Cricket System ID Charleston/Crane #3/Grapple #2 (12 yards)/Transmitter #2

Test Source: 2 Custom Built Thoriated Welding Rods (50 uR/hr each)

Weather Conditions: Sunny, ~90 °F

Performed By Ayman Shourbaji & Larry Phillips

Background		
A	B	T
56	35	109
66	56	107
48	46	108
45	56	106
56	51	105
61	61	105
56	71	104
35	35	103
51	25	104
71	35	103
Average	55	47
		105

Average

Tines Open		Tines Closed		Remark
A (Net CPS)	B (Net CPS)	A (Net CPS)	B (Net CPS)	
668	428	683	453	All Alarms LVL1 #RAB
643	519	623	443	
623	478	618	423	
587	498	496	428	
486	503	512	468	
507	256	446	301	
461	317	446	231	
451	342	385	337	
582	382	456	307	
527	428	491	302	
Average	553	415	515	369

Average

CHARLESTON SENSITIVITY TEST

A1(Net cps)	A2 (Net cps)	A3 (Net cps)	B1(Net cps)	B2(Net cps)	B3 (Net cps)	C0(T) (Net cps)	C6(T) (Netcps)	C12(T) (Net cps)
224	688	603	332	604	408	254	328	253
163	653	653	357	509	347	259	330	252
183	577	618	413	589	392	261	329	250
219	734	638	377	574	428	263	327	249
289	759	663	473	559	347	267	328	247
178	870	658	367	670	362	271	331	250
239	663	542	372	579	458	273	334	251
284	724	648	408	458	372	274	332	252
289	709	698	367	483	281	272	331	246
305	749	608	423	514	408	269	330	247
237	712	632	389	554	380	266	330	249

**Figure B13. CHARLESTON ALARM RESPONSE TEST
GRAPPLE #3**

Date: 5/26/2004

Cricket System ID Charleston/Crane #3/Grapple #3 (12 yards)/Transmitter #2

Test Source 2 Custom Built Thoriated Welding Rods (50 uR/hr each)

Weather Conditions: Sunny, 90°F

Performed By Ayman Shourbaji & Larry Phillips

Background		
A	B	T
56	35	109
66	56	107
48	46	108
45	56	106
56	51	105
61	61	105
56	71	104
35	35	103
51	25	104
71	35	103
Average	55	47
		105

Tines Open		Tines Closed		Remark
A (Net CPS)	B (Net CPS)	A (Net CPS)	B (Net CPS)	
522	564	522	756	All Alarms LVL1 #RAB
512	675	481	539	
547	700	557	630	
618	615	587	771	
456	625	623	635	
476	685	597	655	
376	594	643	584	
355	579	587	620	
300	640	416	549	
274	519	365	514	
Average	443	620	537	625

CHARLESTON SENSITIVITY TEST

A1 (Net cps)	A2(Net cps)	A3(Net cps)	B1(Net cps)	B2(Net cps)	B3(Net cps)	C0(T)(Net cps)	C6(T)(Net cps)	C12(T)(Net cps)
279	613	474	423	579	610	218	404	221
264	683	562	367	569	579	216	401	288
274	673	436	332	559	579	213	400	284
285	572	476	347	660	675	214	389	283
365	719	562	327	655	498	209	387	284
310	648	633	246	680	578	208	386	287
234	613	502	236	569	630	209	358	285
269	643	512	317	640	610	207	385	284
239	638	582	357	604	604	209	386	285
305	678	491	438	625	660	213	390	287
282	648	523	339	614	602	211	388	278

INTERNAL DISTRIBUTION

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