A COMPARISON OF SURVEYING TECHNIQUES FOR RADON 222 IN AIR

by: Janine Guadagno
Radiation Research Group
Materials, Fuels and Lubricants Laboratory
Belvoir Research, Development and Engineering Center
Fort Belvoir, VA 22060-5606

and

Dr. Ramachandra K. Bhat
Radiation Research Group
Materials, Fuels and Lubricants Laboratory
Belvoir Research, Development and Engineering Center
Fort Belvoir, VA 22060-5606

ABSTRACT

In 1988, the Radiation Research Group of the U.S. Army Belvoir Research, Development and Engineering Center was tasked by Fort Belvoir's Department of Engineering and Housing to assess the risk of individual exposure to radon in Fort Belvoir Post facilities. In 1989, the Army Radon Program was created which mandates the testing of all Army facilities using alpha track detectors, regardless of previous survey results using other survey methods. This program created a unique opportunity to compare the findings of the original assessment strategy involving a geologic survey and charcoal canister testing with extensive alpha track detector testing.

The opinions and conclusions expressed herein are those of the authors and do not reflect U.S. Army endorsement/approval.

INTRODUCTION

Two surveying techniques were used to assess radon levels in Fort Belvoir Post facilities. The original survey technique, initiated by Fort Belvoir Department of Engineering and Housing, involved a two-phase assessment plan. The first phase of the assessment was the determination of the region's potential for radon production by conducting a geologic survey. The extensiveness of the second phase of the assessment, charcoal canister testing, was based on the results of the geologic survey. The original assessment was completed in March of 1988, just prior to the creating of the Army Radon Program. This program mandates that all structures on Army facilities be surveyed with alpha track detector (ATDs). Compliance with this program created an opportunity to compare the two survey techniques--geologic surveying coupled with radon charcoal canister testing, and extensive alpha track surveying.

SURVEYING TECHNIQUES

GEOLOGIC SURVEY

Fort Belvoir Post is located in Fort Belvoir, VA. It falls within the boundary of Fairfax County which lies in the physiographic province of the Coastal Plain (see Figure 1). The entire Post is underlain by Coastal Plain sediments and shows negligible geologic variability. Soils in Fort Belvoir have a low radon potential with low aeroradioactivity and low to moderate permeability (see Figure 2). Aeroradioactivity measurements of the soils were conducted by the Soil Conservation Service. This region is not typified by rocks bearing high concentrations of Uranium such as granite, shale, phosphate, and pitchblende; therefore, the geologic survey indicates that Post facilities have a low probability of having indoor radon levels above the Environmental Protection Agency's action levels of 4.0 pCi^{-1}.

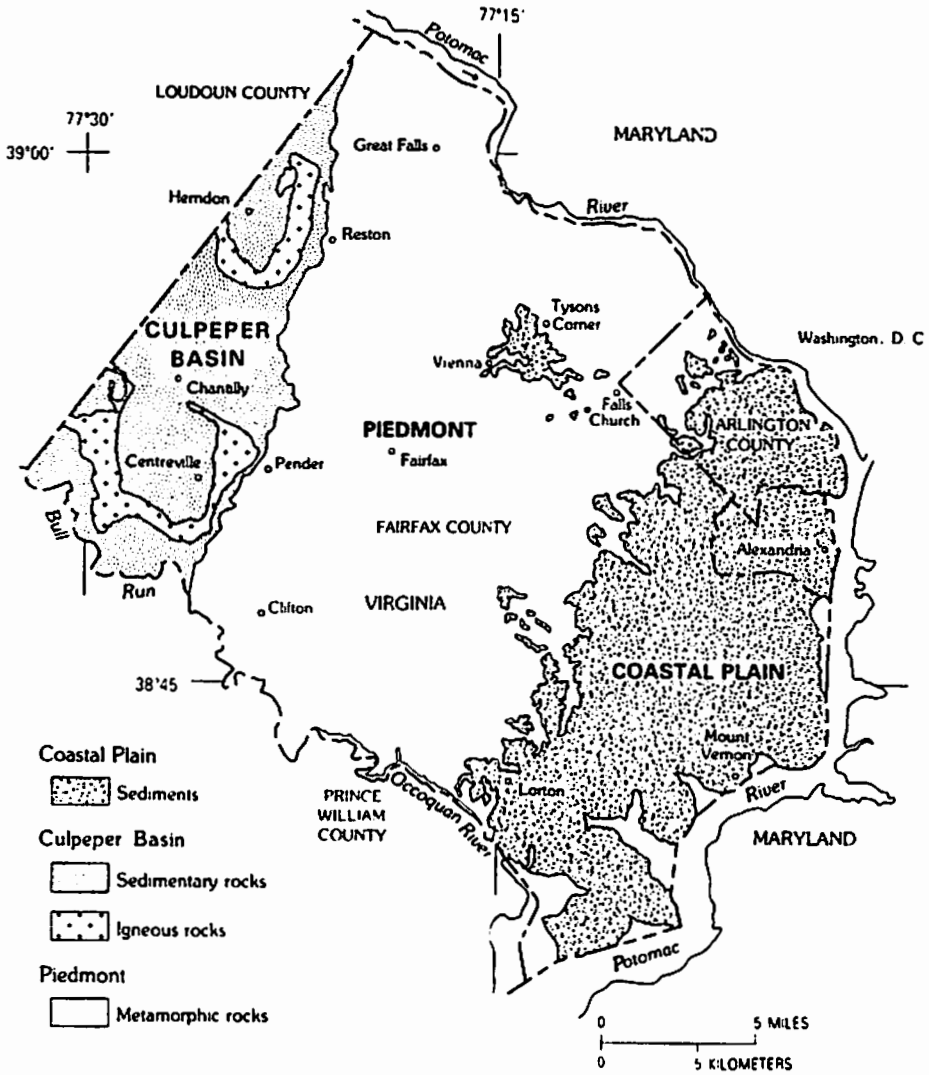
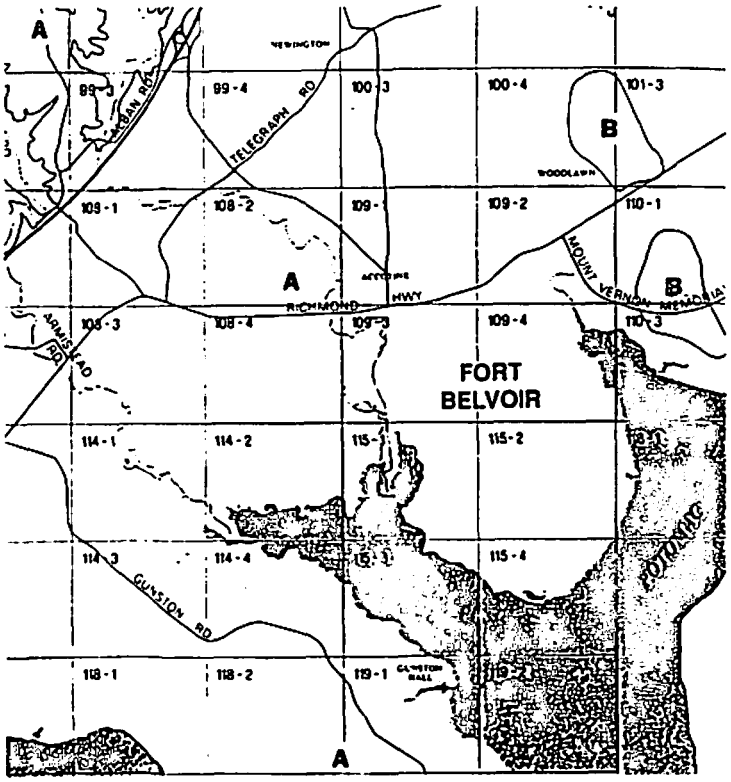


Figure 1. Geologic sketch map of Fairfax County and vicinity showing physiographic provinces (source: Otton et al., 1988)



Radon Potential	Physiographic Province	Comments
A Low	Coastal Plain: undifferentiated sediments (low aeroradioactivity, low to moderate permeability)	These areas occur mostly in the southeastern third of the county, and are scattered elsewhere. Soils have low aeroradioactivity and low to moderate permeability. In the Fairfax County study, 9% of 180 homes situated in areas within this radon-potential category had indoor radon levels greater than or equal to 4 pCi^{-1}. The median reading was 1.2 pCi^{-1} and the mean was 2.1 pCi^{-1}.
B Moderate to low	Coastal Plain: undifferentiated sediments (moderate aero-radioactivity, low to moderate permeability)	These areas are scattered across the entire county. Soils show moderate to low aeroradioactivity and moderate to low permeability. Soils over the diabase have low aeroradioactivity and low permeability, but diabase contains abundant inclusions of sedimentary rock having higher radon potential. In the Fairfax County study, 19% of 122 homes situated in areas within this radon-potential category had indoor radon levels greater than or equal to 4 pCi^{-1}. the median reading was 1.9 pCi^{-1} and the mean was 2.7 pCi^{-1}.

Figure 2. Radon potential of rocks and soils in Fairfax County (source: Otton et al., 1988)

CHARCOAL CANISTER SURVEY

Sampling Methodology

Based on the findings of the geologic survey, the second phase of the initial assessment--charcoal canister testing--was initiated. The low potential for radon production indicated that extensive testing of all facilities was not required nor could be supported by the low degree of health risks for radon levels in the vicinity. Therefore, testing was limited to sampling representative structures of varying geographic locations, construction, and use. Fort Belvoir has 12 residential neighborhoods, each having a distinct building construction, material, and use which provides housing for 2,099 families. Table 1 lists the characteristics of each neighborhood. The Post also has one hospital, three day care centers, three elementary schools, three fire stations, 73 buildings used for temporate housing of soldiers, and various other nonresidential structures.

TABLE 1. PRIMARY RESIDENCES ON FORT BELVOIR

Neighborhood	# of Bldgs	Use	Material	Construction
1 - 100	61	single family	brick	3 fl with bsmt
101 - 199 Gerber Village	67	single family	brick	3 fl with bsmt
400	35	duplex	wood	1 fl/slab on grade
400T	34	single family	wood	1 fl/vented crawl
500 Fairfax Village	78	duplex	brick	2 fl/vented crawl
800-846 Colyer Village	37	apartments	brick	2 fl/vented crawl
847-896 G. W. Village	50	duplex	brick	2 fl/vented crawl
900 Dogue Creek Village	45	apartments	brick	2 fl/vented crawl
1500 G. W. Village	72	duplex	brick	2 fl/vented crawl
1600 River Village	94	duplex	brick	4 fl with bsmt/stg
1700 Lewis Heights	40	apartments	brick	1 fl/vented crawl
2600/2700 Woodlawn Village	143	apartments	brick	2 fl/no bsmt/crawl
1400	2	apartments	brick	2 fl/slab on grade

Table 2 lists the characteristics of nonresidential structures tested excluding administrative buildings. Any minor geologic or building construction variation that may have created isolated areas of higher radon concentrations was tested by surveying at least one unit in each neighborhood and sampling a variety of nonresidential structures. Figure 3 shows the geographical locations of tested facilities on Post.

TABLE 2. SUMMARY OF NON-RESIDENTIAL FACILITIES TESTED WITH CHARCOAL CANISTERS

Description	Material	Construction
DeWitt Army Hospital	Brick	8 fl/occupied basement; 248,601 sf
Barden Elementary School	Brick	1 fl/slab on grade; 43,918 sf
T-1201 Post Nursery	Wood	1 fl/vented crawl space; 8,459 sf
T-1831 Dep. Kindergarten School	Wood	1 fl/vented crawl space; 2,808 sf
191A Fire Station	Brick	2 fl/boiler room; 9,529 sf
Markham Elementary School	Brick	1 fl/slab on grade; 22,880 sf
Cheney Elementary School	Brick	1 fl/slab on grade; 35,100 sf
T-1802 Fire Station	Brick	1 fl/vented crawl space; 3,170 sf

Figure 3. Fort Belvoir testing locations (source: Special Map, Edition 1-TPC, Fort Belvoir)

Analysis

All phases of the charcoal canister program were performed in-house. Three and one half inch open-face activated charcoal canisters were utilized and exposed for 48 hours plus or minus 6 hours. Canisters were counted on a GeLi detector no less than 3 hours and no more than 120 hours after exposure. Placement, exposure, and analysis procedures followed Environmental Protection Agency (EPA) protocol and are part of the quality assurance program for radon monitoring using charcoal canisters that has been successfully reviewed by the EPA Radon Measurement Proficiency (RMP) Program.

Calibration and Quality Assurance Procedures

1. Analyzing radium-spiked charcoal canisters and determining the known activity by the detection of radon progeny lead-214 (295, 352 keV), bismuth-214 (609 KeV), and by radium 226 (186 keV) (see Table 3).

TABLE 3. QUALITY ASSURANCE/CALIBRATION TESTING
(Ra-226 SPIKED CANISTER)

Known activity: Ra-226 (pCi^{-1})	2394.8
% Error of Determination:	
– from 185 keV	0.0
– from 295, 362, 609 keV	0.9

2. Weekly analysis of a charcoal canister spiked with known concentrations of National Institute of Standards and Technology (NIST) traceable mixed gamma standard (see Table 4).

TABLE 4. QUALITY ASSURANCE/CHARCOAL CANISTER TESTING
(NIST TRACEABLE SPIKED MIXED GAMMA)

		% Error			
Nuclide	Standard uCi	2/29	3/7	3/14	3/23
Cd-109	0.09730	6.1	1.1	7.9	4.7
Co-57	0.00395	2.2	1.2	6.3	7.3
Ce-139	0.00491	4.5	4.4	5.9	0.0
Cs-137	0.01160	1.6	0.0	0.6	6.6

3. Creating calibration curves for humidity correction utilizing the Energy Measurement Laboratory (EML) of the Department of Energy (DOE) and EPA radon chambers, and using these curves to participate in the RMP Program of analyzing radon-spiked canisters (see Table 5).

TABLE 5. QUALITY ASSURANCE/CALIBRATION TEST
(EPA CROSS CHECK PROGRAM)

Spiked Activity Rn-222 pCi^{-1}	% Error Using EML DOE Generated Curve	% Error Using EPA Generated Curve
35.9	18	4.3
35.9	10	2.5
35.9	10	2.3

4. Periodic placement of two canisters (duplicates) in the same structure to determine precision in radon detection (see Table 6).

TABLE 6. QUALITY ASSURANCE/CHARCOAL CANISTER TESTING
(DUPLICATE SAMPLES)

Sample Activity (pCi^{-1})	Duplicate Activity (pCi^{-1})	% Difference
<0.1	0.1	0
0.4	0.4	0
4.0	3.4	15
1.8	1.9	5
1.4	1.4	0
0.9	0.8	0
<0.1	0.1	0
0.7	0.7	0

5. Periodic placement of a sealed (blank) canister, at a sampling location with analysis of the blank canisters to insure no contamination occurred by handling procedures (see Table 7).

TABLE 7. QUALITY ASSURANCE/CALIBRATION TESTING
(BLANK SAMPLES)

Sample Activity (pCi^{-1})	Blank Activity (pCi^{-1})
<0.1	no peaks
0.1	no peaks
0.1	no peaks
<0.5	no peaks

Results

Testing began in February 1988 and was completed by March 1988. The EPA calibration curve for humidity correction was used to determine radon levels in Post facilities. Average concentrations in tested facilities (see Table 8) were found to range between less than .1 pCi^{-1} to 2.8 pCi^{-1}.

However, two out of a total of 78 tested (or 2.6%) were found to be at 4.5 pCi^{-1}. This correlates well with a Fairfax County study (Otton et al. 1988) which found 9% of 180 homes situated in areas other than Fort Belvoir with similar radon potentials as Fort Belvoir, to have indoor radon levels greater than or equal to 4 pCi^{-1} with the mean being 2.1 pCi^{-1}. Charcoal canister testing confirmed the geologic survey prediction of low probability for radon levels above the EPA action levels in Post facilities.

TABLE 8. FORT BELVOIR CHARCOAL CANISTER SURVEY RESULTS

Building Type	# of Samples	Range (pCi^{-1})	Average (pCi^{-1})
Primary Residences:			
1 - 100	5	0.5 - 1.6	1.1
101 - 199	4	0.8 - 1.4	1.1
400	7	0.2 - 1.4	0.6
T400	2	<0.1 - 0.6	0.4
Fairfax Village	4	<0.1 - 0.8	0.5
Colyer Village	3	<0.1 - 4.5	1.6
G. Washington Village	4	<0.1 - 0.5	0.2
Dogue Creek	4	<0.1 - 0.8	0.5
River Village	4	<0.1 - 0.9	0.5
Lewis Heights	2	<0.1 - 0.4	0.2
Woodlawn	3	0.4 - 0.6	0.5
Woodbridge	1	2.8	2.8
Hospital	2	0.1	0.1
Day Care Center	1	0.1	0.1
Elementary School	7	<0.1 - 0.5	0.3
Fire Station	3	0.1	0.1
Administration Building	24	<0.1 - 4.0	0.8

ALPHA TRACK DETECTOR SURVEY

Sampling Methodology

The Army Radon Program's objective is to have all structures on Army installations surveyed for radon levels using alpha track detectors (ATDs) (Heard 1988).

No other survey techniques are sanctioned by the Program for initial surveying. The Program established the following hierarchy of priority testing:

1. Priority one structures include all residences, child care facilities, schools, and hospitals.

2. Priority two structures include all nonpriority one structures that are occupied 24 hours a day.

3. Priority three structures include all other structures that are routinely occupied.

Test results of higher priority testing determine the extent of testing required for lower priority testing.

Analysis

Placement protocols follow EPA guidelines and require testing in the lowest livable area, closed house conditions and placement for a period of 90 to 365 days. The contract for supplying and testing ATDs was awarded to the Terradex Division of Tech/Ops Landauer, Inc, Glenwood, Illinois.

Calibration and Quality Assurance Procedures

Vail Research and Technology (VRT) Corporation, located in Alexandria, VA, was awarded the contract for establishing and monitoring the quality assurance program. Quality assurance procedures for the ARP include:

1. Spiked or blind samples in which ATDs are exposed to known levels of radon by VRT in an EPA radiation laboratory, and mixed with shipments of normally exposed detectors to check on Terradex's accuracy in reading radon levels. At least 3% of all purchased ATDs must be used as spikes.

2. Field blanks are required to identify background levels of radon to which the ATDs have been exposed during shipping and handling. Blanks are opened, immediately sealed, without actual placement, and then mixed with normally exposed detectors for analysis (see Table 9). Two field blanks are to be selected from each shipment box of ATDs.

TABLE 9. QUALITY ASSURANCE ATD SURVEYS (BLANKS)

# of Blanks	Range Activity (pCi^{-1})	Average Activity (pCi^{-1})
27	0.1 - 0.5	0.2

3. Placement of duplicate detectors in which an additional detector is placed with every tenth detector and exposed under the same conditions for the same duration to check on Terradex's precision in reading radon levels (see Table 10).

TABLE 10. QUALITY ASSURANCE/ATD
(DUPLICATE SAMPLES)

# of Samples	Sample Activity (pCi^{-1})	Duplicate Range Activity (pCi^{-1})	Average Duplicate Activity (pCi^{-1})
23	0.2	0.2 - 0.3	0.23
14	0.3	0.1 - 0.5	0.28
10	0.4	0.3 - 0.6	0.41
4	0.6	0.4 - 0.7	0.52
6	0.7	0.5 - 0.9	0.73
4	0.8	0.6 - 0.9	0.75
1	0.9	0.6	0.60
4	1.0	0.9 - 1.6	1.08
1	1.1	0.8	0.80
3	1.2	0.9 - 1.4	1.13
2	1.3	1.2 - 1.3	1.25
1	1.4	0.9	0.90
3	1.6	1.4 - 1.9	1.73
1	1.8	1.8	1.80
1	1.9	1.9	1.90
1	2.3	2.2	2.20
1	2.9	3.0	3.00
1	3.5	3.4	3.40

Results

ATD testing began in April of 1989 and as of May 1991, 98% of first and second priority structures have been completed (see Table 11). Average radon concentrations in tested facilities were found to range between 0.3 to 2.2 pCi^{-1}. Of the 693 buildings surveyed, three buildings (or .4%) have been found to be between 4.5 to 6 pCi^{-1}. All three buildings with elevated radon concentrations are primary residences. According to the ARP guidelines for structures with these concentrations, the buildings must be tested for 1 year to confirm the radon levels and, if confirmed at above 4 pCi^{-1} but below 8 pCi^{-1}, be mitigated within the next 5 years to bring levels below 4 pCi^{-1}.

TABLE 11. FORT BELVOIR ATD SURVEY RESULTS

Building Type	# of Bldgs Tested	# of Samples	Range (pCi^{-1})	Average (pCi^{-1})
Primary Residences:				
1 - 100	54	59	0.2 - 2.6	1.3
101 - 199	57	62	0.2 - 6.0	1.2
400	32	37	0.4 - 3.5	1.1
T400	23	24	0.3 - 2.9	1.0
Fairfax Village	64	75	0.2 - 1.7	0.5
Colyer Village	35	37	0.2 - 6.0	0.7
G. Washington Village	117	127	0.1 - 1.1	0.3
Dogue Creek	46	51	0.2 - 1.7	1.0
River Village	81	89	0.1 - 0.8	0.4
Lewis Heights	14	17	0.2 - 2.3	0.7
Woodlawn	113	123	0.1 - 0.9	0.4
Woodbridge	2	3	0.6 - 3.0	2.2
Barracks	42	69	0.2 - 0.7	0.3
Basic Officer's Qtrs	5	20	0.2 - 1.9	2.2
Day Care Centers	3	3	0.1 - 0.6	0.3
Elementary Schools	3	12	0.1 - 0.6	0.3
Hospital	1	21	0.1 - 2.4	0.4
Fire Station	1	3	0.5 - 1.0	0.8

CONCLUSION

The results of the geologic survey, charcoal canister survey, and ATD survey are highly consistent in their findings of low risk of elevated radon levels in Fort Belvoir Post facilities (see Table 12). The cost and time of achieving this finding, however, varied greatly. The geologic survey cost approximately 2% of the total cost to complete the charcoal canister survey; 0.1% of the total cost to complete the ATD survey, and involved 8 hours of work to be concluded. The charcoal canister survey cost approximately 5% of the total cost to complete the ATD survey, and involved three personnel for a period of 3 months. Due to the high turnover of occupancy in military housing, long term ATDs have been difficult to retrieve and 100% testing has yet to be achieved after 3 years of work involving ten temporary employees. A cost analysis shows that prudent radon assessment should be based on the geologic potential for radon production. A geologic survey of a region can be completed quickly and with low cost in that the United States Geologic Service and the Soil Conservation Service have maps showing the aeroradioactivity and geologic variability for the majority of regions throughout the United States. The geologic survey will enable the development of realistic sampling methodologies which will accurately measure radon concentrations of the region. The results of the random charcoal canister testing and extensive ATD testing correlate well, as previously shown in Table 12. Results of residential structures tested with both charcoal canisters and ATDs also correlate well (see Table 13). Structures detected above EPA action levels with charcoal canisters were also found to be above EPA action levels with ATDs. This shows that extensive, long term ATD assessment yielded no greater results than random charcoal canister

testing in regions with low radon potential and low geologic variability. This study shows that areas with a low geologic potential for radon production and low geologic variability are most economically and efficiently surveyed using random charcoal canister testing. It also suggests that blanket testing programs mandating a particular survey technique are neither cost effective nor scientifically prudent. All radon testing programs should be based on the geologic potential for radon production and the degree of geologic variability.

TABLE 12. COMPARISON BETWEEN CHARCOAL CANISTER AND ATD

Building Type	CC Range	ATD Range	CC Average (pCi^{-1})	ATD Average (pCi^{-1})
Primary Residences:				
1 - 100	0.5 - 1.6	0.2 - 2.6	1.1	1.3
101 - 199	0.8 - 1.4	0.2 - 6.0	1.1	1.2
400	0.2 - 1.4	0.4 - 3.5	0.6	1.1
T400	<0.1 - 0.6	0.3 - 2.9	0.4	1.0
Fairfax Village	<0.1 - 0.8	0.2 - 1.7	0.5	0.5
Colyer Village	<0.1 - 4.5	0.2 - 6.0	1.6	0.7
G. W. Village	<0.1 - 0.5	0.1 - 1.1	0.2	0.3
Dogue Creek	<0.1 - 0.78	0.2 - 1.7	0.5	1.0
River Village	<0.1 - 0.9	0.1 - 0.8	0.5	0.4
Lewis Heights	<0.1 - 0.4	0.2 - 2.3	0.2	0.7
Woodlawn Village	<0.1 - 0.4	0.1 - 0.9	0.5	0.4
Woodbridge	2.8	0.6 - 3.0	2.8	2.2
Day Care Centers	<0.1	0.1 - 0.6	0.3	0.3
Elementary Schools	<0.1 - 0.5	0.1 - 0.6	0.1	0.3
Fire Station	<0.1	0.5 - 1.0	0.1	0.8
Hospital	<0.1	0.1 - 2.4	0.1	0.4

TABLE 13. SAME RESIDENT COMPARISON BETWEEN CHARCOAL CANISTER AND ATD

Charcoal Canister (pCi^{-1})	# of Comparisons	Average ATD Activity (pCi^{-1})
0.1	10	0.7
0.2	2	1.5
0.4	5	0.5
0.5	4	0.6
0.6	4	1.5
0.7	1	1.3
0.8	6	0.6
0.9	1	0.2
1.0	1	1.0
1.2	3	1.1
1.4	3	4.1
1.6	1	1.6
2.8	2	3.0
4.5	2	6.0

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