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Gamma Radiation and Airborne Radionuclide Surveillance at Los Alamos National Laboratory, New Mexico, During 1996

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FOREWORD

The mission of the New Mexico Environment Department DOE Oversight Bureau is to assure that activities at DOE facilities are protective of the public health and safety and the environment. The Bureau's activities are funded through a grant from the U.S. Department of Energy in accordance with the provisions set forth in the *Agreement-in-Principle between the State of New Mexico and the U.S. Department of Energy*. One of the primary objectives of the agreement is the development and implementation of a program of independent monitoring and oversight.

This report presents the Bureau's air-quality and gamma-radiation data for 1996, along with statistical comparisons to data collected by LANL's air quality group (ESH-17) during the same period. More recent Bureau and LANL data can be found on the Internet on the LANL ESH-17 web page (http://www.air-quality.lanl.gov/).

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ABSTRACT

In 1996, the DOE Oversight Bureau of the New Mexico Environment Department measured gamma radiation, airborne radionuclides and tritium in the Los Alamos area. The data were compared to measurements made by the Los Alamos National Laboratory (LANL) at the same locations.

Gamma radiation was measured using 12 thermoluminescent dosimeters located at 11 stations near LANL and at one station in Santa Fe. The Bureau's data averaged 10.7 mrem per quarter lower than LANL's data. The variation between the Bureau's and LANL's results was attributed to differences between dosimeters used by the two groups. All radiation measurements were near background levels and below applicable regulatory standards.

Airborne radionuclides were monitored at five stations. Particulate matter was collected on filters which were analyzed for americium-241, isotopic plutonium and isotopic uranium. Americium-241 and plutonium-239 results were not statistically different from LANL's results, while plutonium-238 and the uranium isotopes were statistically different. Even though there was a statistical difference in the plutonium-238 results, the uncertainties associated with the individual values overlapped on all measurements, except for two. The difference in uranium values was attributed to differences in filter media. All measurements were at background levels and below EPA's regulatory limit.

Tritium, in the water vapor state, was measured for one quarter at four stations. For the Bureau's stations, the mean concentration was 1.67 pCi/m^3. LANL reported 1.55 pCi/m^3. The difference between each agency's data set was statistically insignificant. Tritium levels were slightly above background, but far below EPA guidelines.

INTRODUCTION

In accordance with the provisions of the Agreement in Principle (AIP), the DOE Oversight Bureau of the New Mexico Environment Department (NMED) monitors the environment at or near DOE facilities within New Mexico. In 1993, the Bureau started an air-quality monitoring program at the Los Alamos National Laboratory (LANL). Four of LANL's ambient-air monitoring stations were chosen for co-location of NMED monitoring equipment. In 1996, an additional co-located station was put in place, and there was an upgrade in equipment, which allowed for the monitoring of airborne tritium at four stations. The gamma radiation monitoring program, which started in 1993 at 12 co-located stations, underwent a transition to a different radiation measuring media in 1996. Both media were used during 1996 to allow a direct comparison.

The purpose of this report is to present the Bureau's air-quality and gamma-radiation findings for 1996, along with statistical comparisons, if applicable, to data collected by LANL's air quality group (ESH-17).

Statistical Methods

There are several statistical tests which are useful for interpreting the air monitoring results. First, it is useful to know whether or not the data set is normally distributed, i.e. has a classical Guassian distribution. A Shapiro-Wilk normality test was used for this purpose.

Statistical tests were used to determine whether or not the means of two sets of data are distinguishable from each other. If the two data sets are normally distributed, then the Student's paired *t* test, with a null hypothesis stating that the means of the two sets are equal, is the preferred statistical test. If the data sets are not normal, a non-parametric test must be used (Ott, 1988; Davis, 1986). A matched pairs Wilcoxon test is the non-parametric equivalent of the *t* test. Although this is a slightly less powerful test than the Student's *t* test, it is very useful for small data sets where normality cannot be demonstrated (StatSoft, 1995). The level of significance used in these tests was 95 percent, meaning that there is no more than a 5 percent chance that the differences are due to random variation. When a probability value (p) is calculated at less than 0.05, then the null hypothesis can be rejected, indicating that the means of the two data sets are not equal.

Besides comparing the means of the data sets, a Pearson correlation was used to determine whether two data sets tracked each other. A higher number (near 1.0) indicates good tracking while a lower number (near 0) indicates no relationship between the sets. A negative number indicates inverse tracking (when one goes up, the other goes down).

Analytical uncertainties (also called counting uncertainties) are shown in the data tables. Due to the random nature of radioactive decay, if the same sample is counted several times, each count will be slightly different. If the sample is counted enough times, a distribution can be plotted and

a mean and standard deviation established. However, time constraints usually allow for only one counting of a sample. The square root of the number of counts is then used as an estimate of the uncertainty associated with the single count (Knoll, 1979). The true mean then has a 68 percent probability of being within one standard deviation and a 95 percent probability of being within two standard deviations. As a usual practice, the counting uncertainty (or analytical uncertainty) is defined as two standard deviations.

GAMMA RADIATION

Methods

In 1993, the Bureau established a monitoring program for measuring levels of gamma radiation in the environment. It was decided that side-by-side monitoring at a selected set of LANL's stations should be undertaken, and if the data sets were comparable it would lead to more confidence in the rest of LANL's published data. The Bureau allocated resources for 12 thermoluminescent dosimeters (TLDs), to be exchanged on a quarterly basis. To monitor off-site gamma radiation and any possible impacts from LANL activities, eleven perimeter stations and one regional background station were chosen. These stations are listed below and are shown in Figure 1.

- Barranca Mesa Elementary School
- 48th Street (at the water tank near the start of the Quemazon trail)
- Shell gas station on Trinity Ave.
- McDonald's (behind the storage sheds that are behind McDonald's on Trinity Ave.)
- Los Alamos Airport (near the terminal)
- East Gate (near the old tower at the Front Gate)
- Well PM-1 (across State Road 4 from Tsankawi)
- White Rock Fire Station
- Nazarene Church in White Rock
- Pajarito Acres (on Estante loop)
- Royal Crest Trailer Park (southeast corner)
- Santa Fe (Siringo Road)

There are certain materials that exhibit the property of thermoluminescence. When the material is exposed to ionizing radiation, some of its electrons are raised to elevated energy levels within the crystalline structure. These electrons will stay in the elevated state until the crystal is heated. Then the energy will be released in the form of light. Hence, the word thermoluminescence is used (heat and light). Though the principle is the same, different materials will have different characteristics, such as the temperature needed to release the light and fading (spontaneous loss of elevated electrons without heating).

LANL uses lithium fluoride (LiF) TLDs to measure the levels of gamma radiation in the environment. This is a proven technology and has been used for years, although its primary use is for personnel dosimetry. However, the limit of detection is considered by some to be too high for measuring at environmental levels. Therefore, the Bureau originally decided to use a newer and supposedly more sensitive TLD, aluminum oxide (Al_2O_3). Twelve of these were obtained every quarter from a contractor (Landauer, Inc.) for the period of 1993 through 1996.

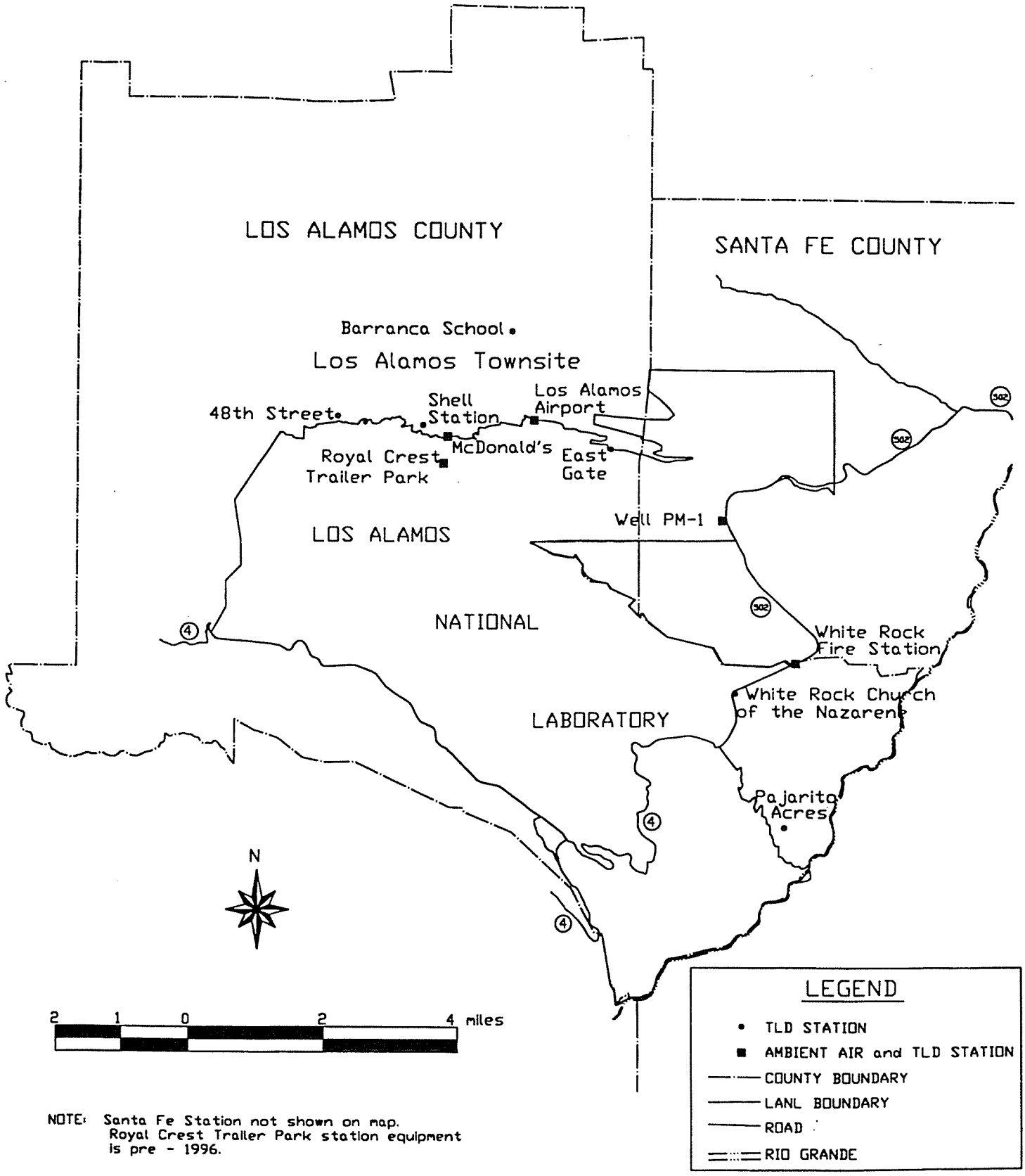

FIGURE 1. Perimeter Ambient Air Monitoring and Thermoluminescent Dosimeter (TLD) Stations

The results from the aluminum-oxide dosimeters were consistently lower than the values reported by LANL, averaging about 12 mrem per quarter less in 1996. Most of the values were too low to be consistent with other technologies as well, such as micro-R meters or pressurized ionization chambers. Although the data provided confidence that LANL was not under-reporting their results, the Bureau decided to return to a more conventional technology in order to obtain more realistic values. For the last three quarters of 1996, calcium-sulfate (CaS_2O_4) TLDs from another contractor (Teledyne Brown Engineering, Inc.) were placed alongside the aluminum-oxide TLDs. The aluminum-oxide TLDs were then discontinued at the end of 1996.

Results

All data are tabulated in the Appendix. Table 1 shows the Bureau's 1996 TLD data (both calcium sulfate and aluminum oxide chip media), and LANL's 1996 data (lithium fluoride chip media), along with descriptive statistics by station. Table 2 shows descriptive statistics by quarter. Table 3 shows the differences between the Bureau's calcium sulfate data and LANL's data. Table 4 shows the results of a two-tailed paired *t* test comparing 1996 Bureau and LANL data. Of the three quarters of available data, all show a p value of less than 0.05, indicating that the two data sets are not from the same population, i.e. that the means of the two populations are different. Although a *t* test is appropriate for normally distributed data, and the Shapiro-Wilk test shows the data to generally be normal, a Wilcoxon matched-pairs test was also performed, with a result of $p<0.05$, which confirms that the means of the two populations are different.

A statistical comparison of the calcium-sulfate versus the aluminum-oxide TLD results is presented in Table 5. For two of the three quarters in which there is side-by-side data, a Student's paired *t* test shows that the means of the two populations are different (i.e. $p<0.05$). However, the results during one quarter were very similar. The Pearson correlation shows that the data did track well, indicating that the two methods agreed on which stations showed higher or lower levels, but not on the magnitude.

Conclusions

The new calcium-sulfate TLDs are resulting in slightly higher values than the discontinued aluminum-oxide TLDs, but consistently show values lower than reported by LANL. Although closer to LANL's results, they are still below what the Bureau expected, based on pressurized ionization chamber and micro-R meter readings. The differences may be due to the shielding surrounding the TLDs that Teledyne uses to distinguish between skin dose and deep dose, or differences in how the two media measure radiation. However, the correlation between the data indicates that both the Bureau's and LANL's dosimeters are responding consistently to environmental variations.

AIRBORNE RADIONUCLIDES

Methods

With the same reasoning as for the TLD stations, the Bureau chose five of LANL's ambient-air-particulate stations for co-locating air-monitoring instruments. These stations are listed below.

- White Rock Fire Station
- Royal Crest Trailer Park (southeast corner)
- McDonald's (behind the storage sheds that are behind McDonald's on Trinity Ave.)
- Los Alamos Airport
- Well PM-1 (intersection of State Road 4 and East Jemez Road) (Started in 1996)

In 1993, the Bureau already owned four air-particulate-monitoring instruments (Eberline RAS-1) and a mass-flow meter (Teledyne Hastings-Raydist model NAHL-5) for calibration. The filters used were 47 mm glass-fiber filters from Gelman. The air pump pulled air through the filter at a rate of approximately 1.5 cubic feet per minute (CFM). This equipment was not comparable to that at LANL's stations, which had a more powerful motor (3/4 HP vs. 1/3 HP), capable of moving 4 CFM through a slightly larger filter.

The Bureau purchased four new air sampling units in 1996, with the goal of reducing the difference in sampling methodology of the two programs. These units are very similar to LANL's equipment. The new units provide an increased total sample volume, resulting in more sensitivity in detecting radionuclides. The sample volume is now comparable to LANL's. The old monitors were replaced in the second quarter of 1996. However, at one of the stations (Royal Crest) there was not enough room within the security fencing for the new-style monitor. It was decided to keep the old monitor at this location and find a new location for the new monitor. The location chosen was Well PM-1, which is at the intersection of State Road 4 and East Jemez Road, across from Tsankawi ruins. It is located in a predominately downwind direction from TA-54 and, although there is no population living at this site, it is between this potential source of airborne radionuclides and San Ildefonso.

LANL has historically used Microsorban filter paper, although that company has stopped manufacturing that particular product. When LANL's supply ran out, they switched to Dynaweb (Web Dynamics). The Bureau has always used glass-fiber filters. A LANL study has shown that both Microsorban and Dynaweb filters contain less uranium than glass-fiber filters. Analysis of a blank glass-fiber filter by the Bureau also showed detectable amounts of uranium.

The filters are collected twice per month, and are counted for gross beta radiation. They are then combined quarterly into a composite sample and sent to an independent analytical laboratory for americium-241, isotopic-plutonium, and isotopic-uranium analysis. A gamma-spectroscopy analysis is also done.

Results

Initially, the Bureau reported significantly higher values than LANL. Also, the uncertainty associated with the Bureau's data was greater than the uncertainty reported for LANL's data Therefore, an analysis of possible reasons for this discrepancy was undertaken, with a focus on differences in sampling methodology of the two programs. Since both the Bureau and LANL used the same contract analytical laboratory, we asked why LANL was getting a lower limit of detection than we were. The first and most obvious reason is that since LANL's pumps are more powerful, they could obtain a larger sample during the same time period. With less material on the filter to analyze, the laboratory could not detect levels of contaminants as low as it could with a larger amount of material. We also found out that our already small sample was being further split by requesting analysis for gross alpha/beta and strontium-90. So in late 1995, the Bureau quit requesting those analyses, in order to maximize the amount of sample left for americium, plutonium and uranium analysis. As expected, the last quarter in 1995 showed a decrease in the reported values. In order to further alleviate the problem, the Bureau purchased four new air monitors, very comparable to LANL's, to increase the volume of the sample taken. Thus, starting in 1996, the range of uncertainty for the Bureau's data was comparable to that of LANL.

In 1996, at the four stations with new equipment and procedures in place, the reported levels of plutonium and americium dropped significantly to about the same level as LANL's. Uranium levels dropped slightly, but are still above what LANL reports. This is likely due to the natural uranium present in the glass-fiber filters used by the Bureau. LANL uses a different filter medium which has a lower uranium content. The values for plutonium, americium and uranium are all approximately two or three orders-of-magnitude below EPA regulatory limits. All data are tabulated in the appendix. The data are shown in Table 6 and descriptive statistics are shown in Table 7. The data is also shown graphically in Figures 2 through 7.

All gamma spectroscopy analyses of the composited filter samples were reported to be below the detection limit, with the exception of beryllium-7 and potassium-40, which are naturally occurring radionuclides.

Statistical analyses of the air monitoring data are shown in Table 8. The Shapiro-Wilk test shows that none of the Bureau's data sets are normally distributed, while LANL had mixed results in that their americium and uranium data sets are normally distributed but their plutonium data sets are not. Based on this finding, a non-parametric test (Wilcoxon matched pairs test) was performed. The Wilcoxon test shows that the Bureau's americium-241 and plutonium-239 data sets are not statistically different from LANL's data. However, the rest of the isotopes are statistically different. The data were also compared using a Student's *t* test, which is usually best suited for comparisons of normally distributed data. The *t* test shows all of the isotopes to be statistically different. The Bureau's uranium data appears to show higher levels of uranium than LANL's data. The difference is probably due to natural uranium in the glass-fiber filters used by the Bureau.

The Pearson correlation showed that the Bureau's data did not track LANL's data, with the exception of uranium-238. This is not surprising, due to the exceedingly small values being measured and to the random nature of analytical uncertainty.

Conclusions

Based on statistical comparisons made in this report, airborne particulate data collected by the Bureau is in agreement with data reported by LANL. For both the Bureau and LANL, most measurements are barely distinguishable from zero, and are limited by uncertainties associated with measurement at low levels. Although the statistical tests show that the Bureau's data ~~often~~ differ from LANL's data, the differences are inconsequential considering the minute quantities being measured. The greatest difference is in the uranium values, but the difference is probably due to natural uranium in the glass-fiber filters used by the Bureau. The levels of radionuclides measured in this study are all two to three orders of magnitude below EPA regulatory limits.

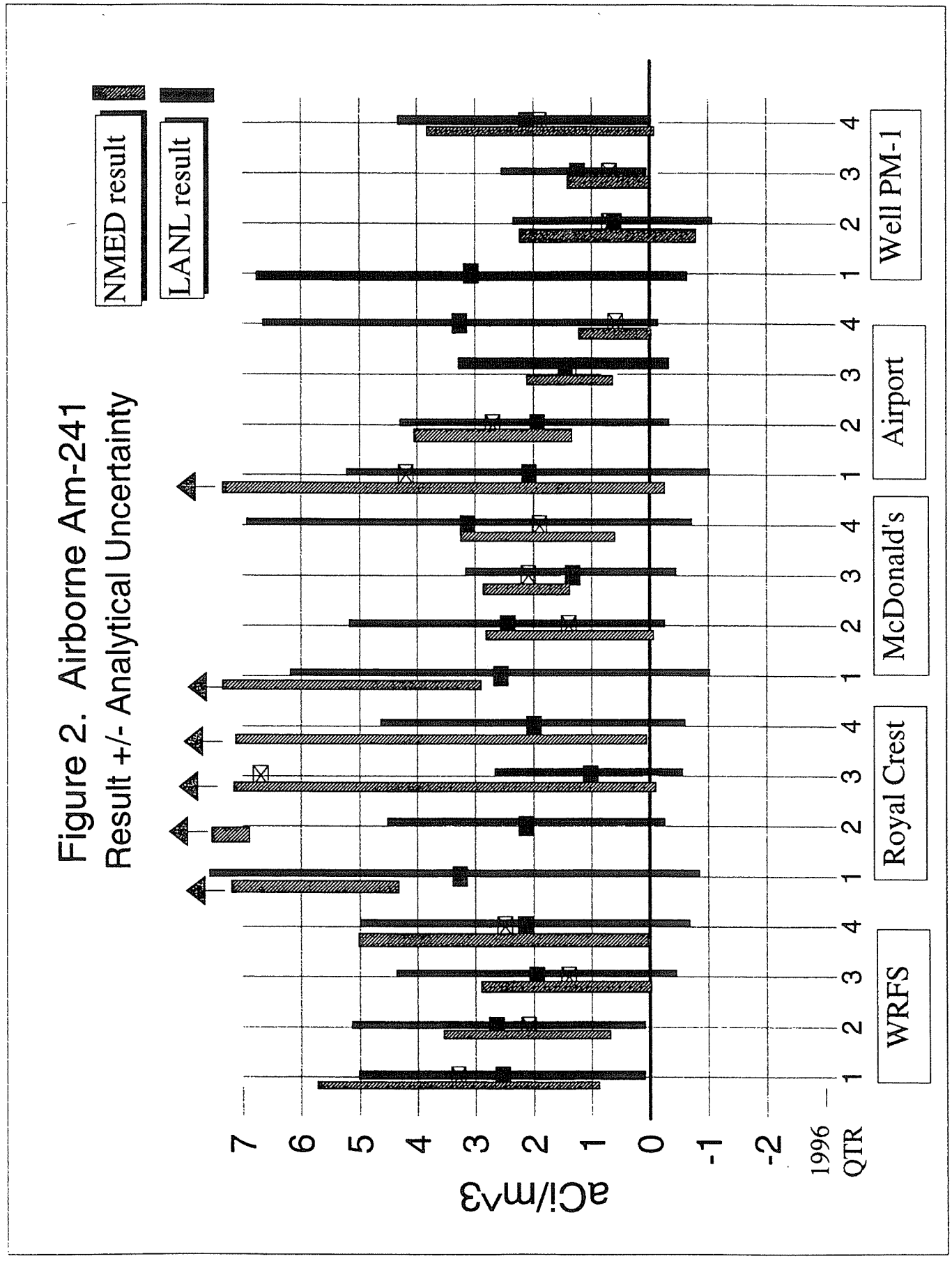
Figure 2. Airborne Am-241
Result +/- Analytical Uncertainty
NMED result
LANL result
aCi/m^3
7
6
5
4
3
2
1
0
-1
-2
1996 —
QTR
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4
WRFS
Royal Crest
McDonald's
Airport
Well PM-1

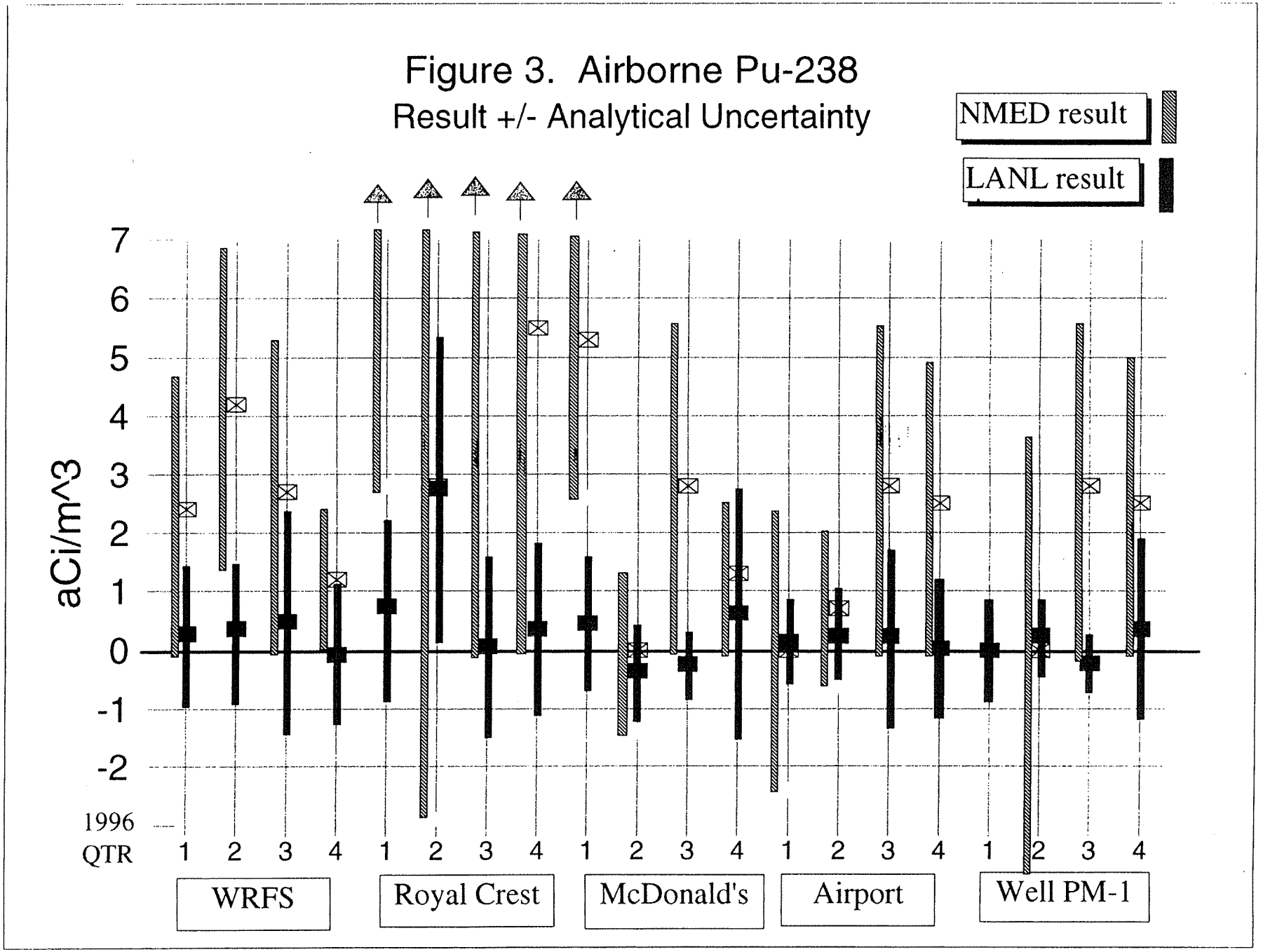
Figure 3. Airborne Pu-238
Result +/- Analytical Uncertainty
NMED result
LANL result
aCi/m^3
7
6
5
4
3
2
1
0
-1
-2
1996
QTR
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4
WRFS
Royal Crest
McDonald's
Airport
Well PM-1

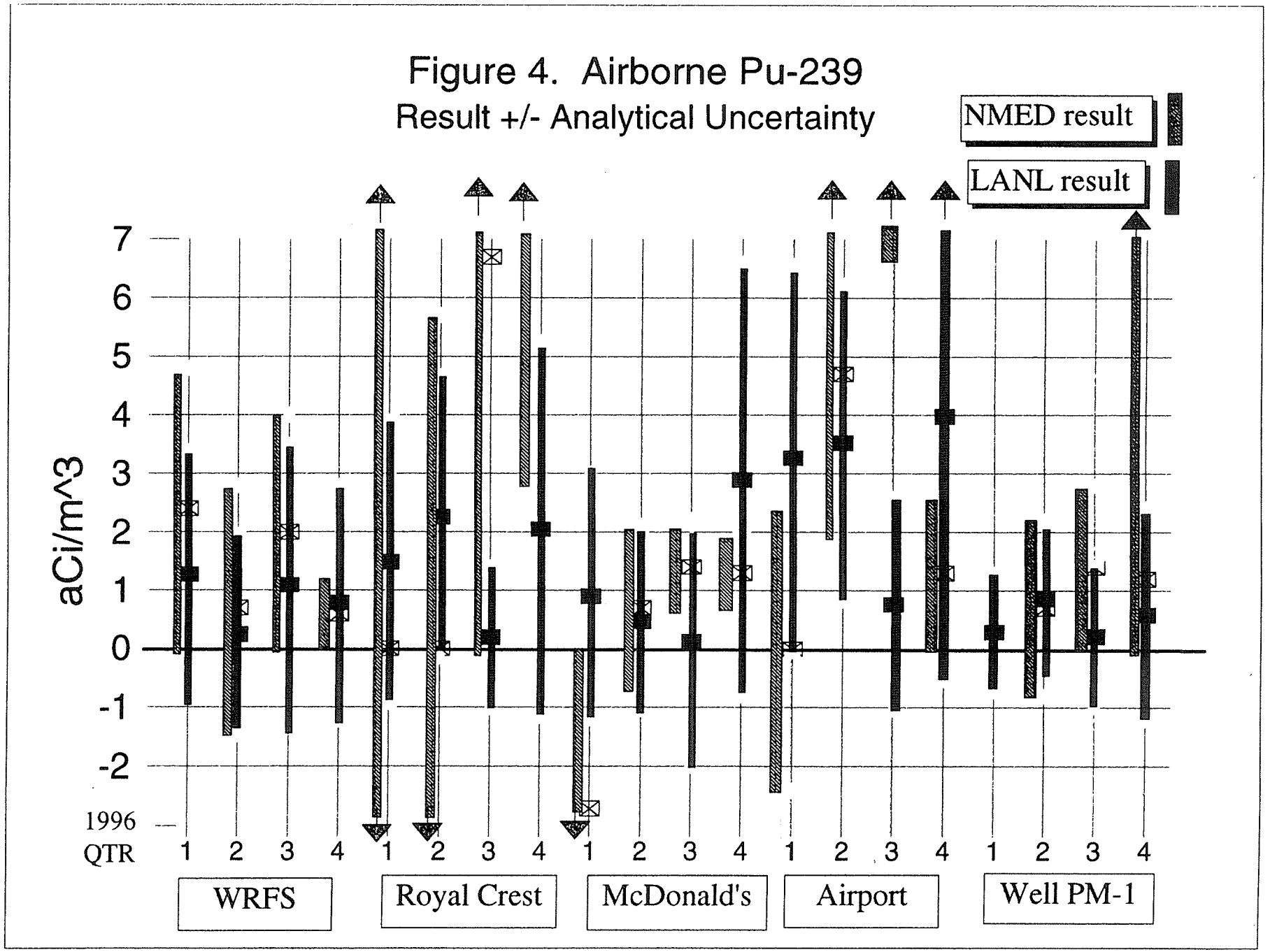
Figure 4. Airborne Pu-239
Result +/- Analytical Uncertainty
NMED result
LANL result
aCi/m^3
7
6
5
4
3
2
1
0
-1
-2
1996
QTR
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4
WRFS
Royal Crest
McDonald's
Airport
Well PM-1

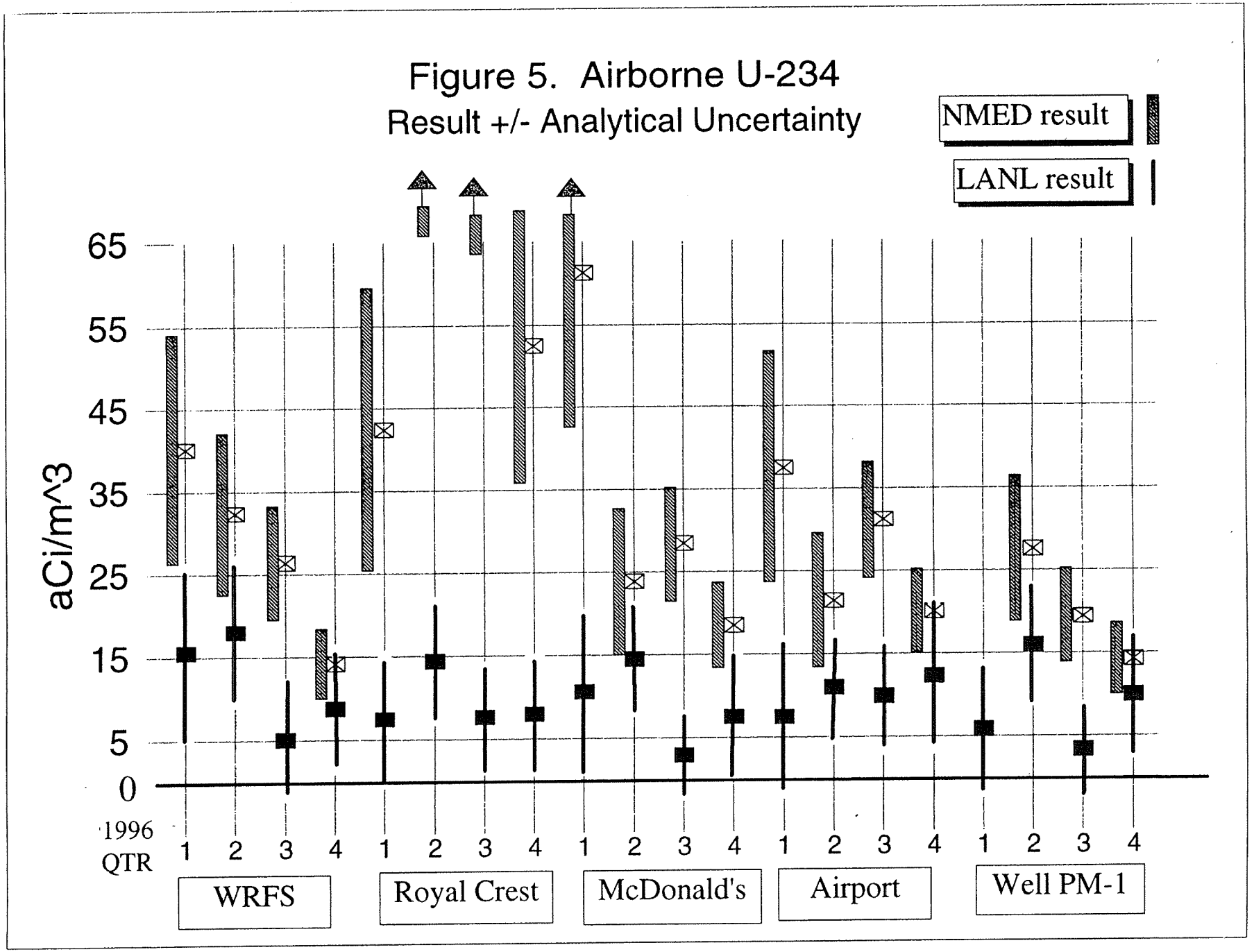
Figure 5. Airborne U-234
Result +/- Analytical Uncertainty
NMED result
LANL result
aCi/m^3
65
55
45
35
25
15
5
0
1996
QTR
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4
WRFS
Royal Crest
McDonald's
Airport
Well PM-1

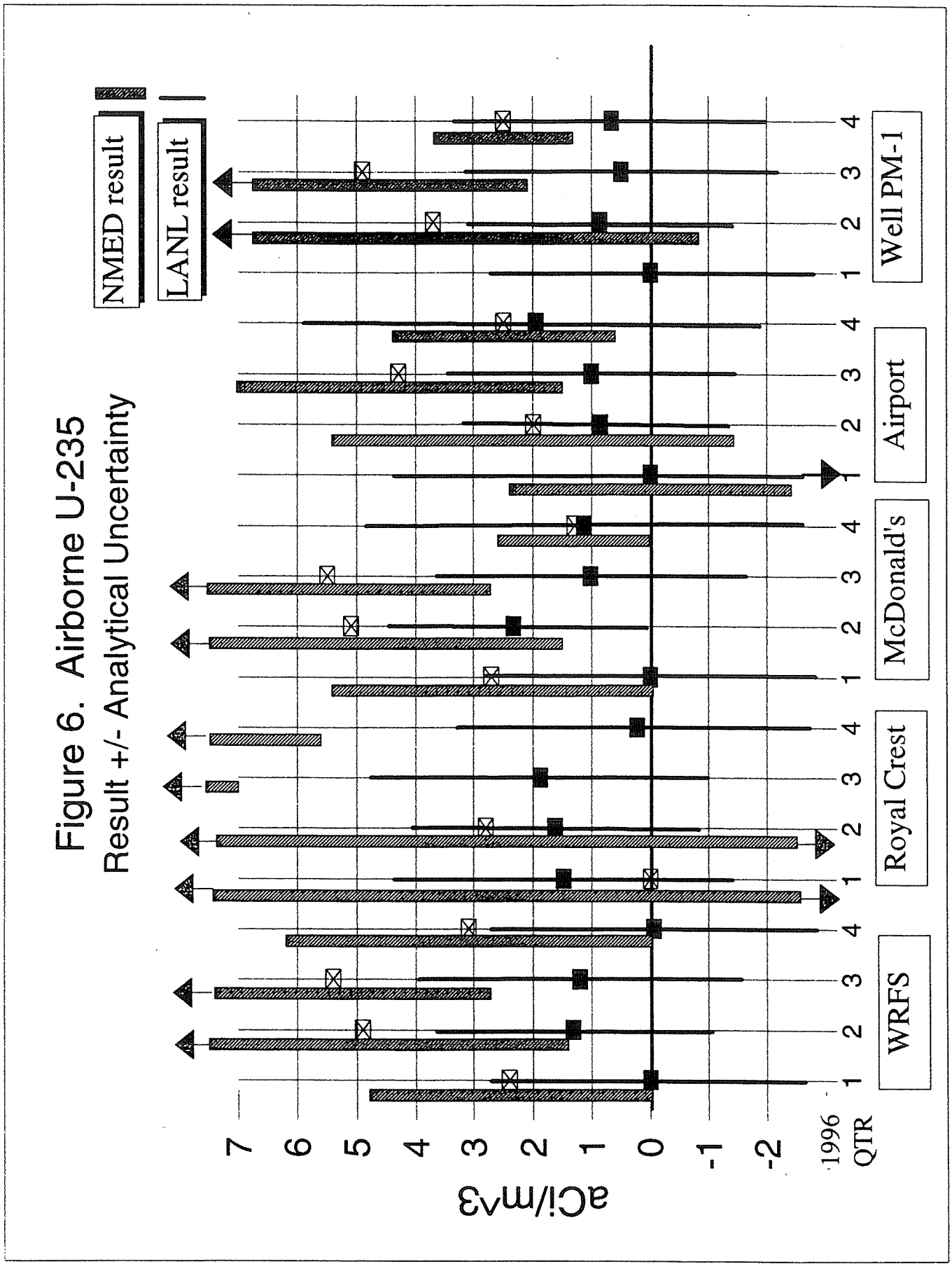
Figure 6. Airborne U-235
Result +/- Analytical Uncertainty
NMED result
LANL result
aCi/m^3
7
6
5
4
3
2
1
0
-1
-2
1996 QTR
1 2 3 4
WRFS
Royal Crest
McDonald's
Airport
Well PM-1

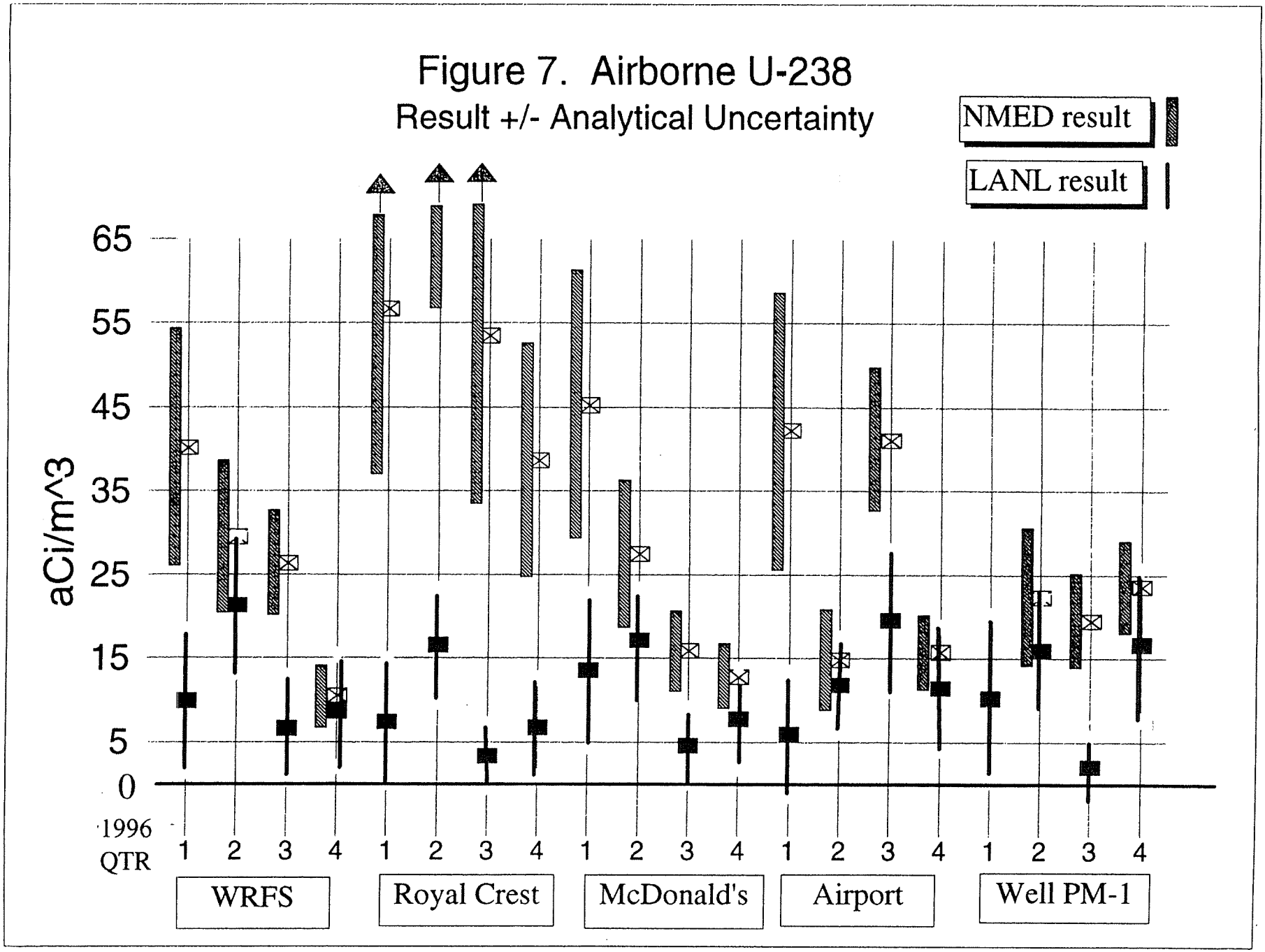
Figure 7. Airborne U-238
Result +/- Analytical Uncertainty
NMED result
LANL result
aCi/m^3
65
55
45
35
25
15
5
0
1996
QTR
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4
WRFS
Royal Crest
McDonald's
Airport
Well PM-1

TRITIUM

Methods

The radioactive isotope of hydrogen (H-3) commonly called tritium, can be released to the environment in both a gaseous form (HT or T_2) or in water form (HTO or T_2O). The gaseous form is much less hazardous to health because it will stay in the body for a much shorter period of time and hence the chance that it will decay while in the body is smaller than for the water form. Because tritium has only a weak beta decay (average energy of approximately 6 KeV) with no associated gamma radiation, it is not an external hazard and can only cause harm if ingested or inhaled.

When the four new air-monitoring stations were purchased, compatible equipment for measuring airborne tritium in its water-vapor state was also purchased. A small portion of the airflow (100 mL/min) is pulled through a tube containing silica gel to capture moisture in the air. The silica gel is then sent to a contract laboratory for analysis, by means of liquid scintillation.

Conclusions

NMED has only one quarter of data for 1996 to compare with LANL's results. The data are shown in Table 9, and appear to be consistent with LANL's data, according to a paired *t* test. The results are approximately 3 orders-of-magnitude less than the EPA concentration limit.

ACKNOWLEDGMENTS

Cooperation of LANL and DOE personnel during this investigation is greatly appreciated. The author would like to thank Dr. William Stone, Dr. David Beach, Steve Yanicak and Michael Dale for their technical review of this document, as well as Tim Michael and John Parker for their editorial review. Alice Mayer deserves special credit for her computer generated graphics.

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APPENDIX A

Data Tables

Table 1. TLD data and descriptive statistics by station for 1996.

NMED Aluminum Oxide Data[1] (mrem)	96Q1		96Q2		96Q3		96Q4	
Station	Result	2s	Result	2s	Result	2s	Result	2s
Barranca	NA	NA	20.7	NA	24.3	NA	28.8	NA
48th Street	19.1	NA	22.7	NA	22.3	NA	27.5	NA
Shell Station	NA	NA	18.9	NA	23.3	NA	29.5	NA
McDonald's	15.6	NA	NA	NA	19.6	NA	28.6	NA
Airport	15.4	NA	22.8	NA	18.1	NA	27.0	NA
East Gate	21.0	NA	24.7	NA	25.9	NA	31.1	NA
Well PM-1	28.7	NA	30.0	NA	30.1	NA	30.1	NA
WR Fire Station	24.6	NA	22.2	NA	20.5	NA	22.4	NA
Nazarene Church	16.0	NA	9.7	NA	12.3	NA	17.5	NA
Pajarito Acres	20.9	NA	21.0	NA	20.5	NA	29.3	NA
Royal Crest	18.6	NA	15.2	NA	20.5	NA	25.7	NA
Santa Fe	19.3	NA	20.2	NA	NA	NA	21.9	NA

Descriptive Statistics

Annual dose	Mean	Std Dev	Median	Min.	Max.
74[2]	24.6	4.1	24.3	20.7	28.8
92	22.9	3.4	22.5	19.1	27.5
72[2]	23.9	5.3	23.3	18.9	29.5
64[2]	21.2	6.6	19.6	15.6	28.6
83	20.8	5.2	20.5	15.4	27.0
103	25.7	4.2	25.3	21.0	31.1
119	29.7	0.7	30.0	28.7	30.1
90	22.4	1.7	22.3	20.5	24.6
55	13.9	3.5	14.1	9.7	17.5
92	22.9	4.3	21.0	20.5	29.3
80	20.0	4.4	19.5	15.2	25.7
61[2]	20.5	1.3	20.2	19.3	21.9

NMED Calcium Sulfate Data (mrem)	96Q1		96Q2		96Q3		96Q4	
Station	Result	2s	Result	2s	Result	2s	Result	2s
Barranca	NA	NA	21.2	3.4	25.2	1.5	25.5	0.6
48th Street	NA	NA	25.0	2.4	26.2	0.6	27.6	1.5
Shell Station	NA	NA	27.4	1.8	27.0	1.0	28.2	1.8
McDonald's	NA	NA	NA	NA	27.3	1.7	27.0	0.9
Airport	NA	NA	23.6	1.1	23.6	0.7	24.9	2.4
East Gate	NA	NA	27.2	0.9	27.8	1.2	30.0	1.2
Well PM-1	NA	NA	29.0	7.9	33.3	2.0	30.6	1.2
WR Fire Station	NA	NA	25.3	1.2	24.9	1.3	26.4	1.5
Nazarene Church	NA	NA	17.4	2.1	17.5	0.7	18.3	1.5
Pajarito Acres	NA	NA	25.1	1.3	24.1	1.5	24.0	1.8
Royal Crest	NA	NA	25.5	1.2	25.6	0.7	26.4	1.2
Santa Fe	NA	NA	24.2	4.4	NA	NA	24.6	0.9

Annual dose	Mean	Std Dev	Median	Min.	Max.
72[2]	24.0	2.4	25.2	25.2	25.5
79[2]	26.3	1.3	26.2	26.2	27.6
83[2]	27.5	0.6	27.4	27.4	28.2
54[3]	27.2	0.2	27.2	27.2	27.3
72[2]	24.0	0.8	23.6	23.6	24.9
85[2]	28.3	1.5	27.8	27.8	30.0
93[2]	31.0	2.2	30.6	30.6	33.3
77[2]	25.5	0.8	25.3	25.3	26.4
53[2]	17.7	0.5	17.5	17.5	18.3
73[2]	24.4	0.6	24.1	24.1	25.1
78[2]	25.8	0.5	25.6	25.6	26.4
49[3]	24.4	0.3	24.4	24.4	24.6

LANL data (mrem)	96Q1		96Q2		96Q3		96Q4	
Station	Result	2s	Result	2s	Result	2s	Result	2s
Barranca	NA	NA	30.4	5.2	32.8	5.6	40.9	6.5
48th St.	27.3	5.1	39.7	5.4	35.4	6.2	41.3	5.9
Shell Station	24.7	5.1	39.8	5.2	37.1	5.9	40.4	5.8
McDonald's	NA	NA	NA	NA	37.0	6.1	40.8	5.9
Airport	28.0	5.1	36.4	6.3	30.9	5.3	35.3	6.0
East Gate	38.7	5.2	35.5	5.2	31.6	5.9	38.9	5.9
Well PM-1	33.2	5.1	45.6	5.4	42.9	6.5	45.5	6.5
WR Fire Station	26.7	5.1	35.4	5.1	31.4	5.8	40.9	6.0
Nazarene Church	19.1	5.1	25.8	4.8	23.2	5.1	26.8	5.4
Pajarito Acres	28.3	5.1	34.0	5.0	30.7	5.6	36.7	6.2
Royal Crest	30.6	5.1	36.4	5.1	34.4	5.5	38.5	6.0
Santa Fe	29.5	5.1	35.0	5.0	NA	NA	40.0	6.0

Annual dose	Mean	Std Dev	Median	Min.	Max.
104[2]	34.7	5.5	32.8	30.4	40.9
144	35.9	6.3	37.6	27.3	41.3
142	35.5	7.4	38.5	24.7	40.4
78[3]	38.9	2.7	38.9	37.0	40.8
131	32.6	3.9	33.1	28.0	36.4
145	36.2	3.4	37.1	31.6	38.9
167	41.8	5.9	44.2	33.2	45.6
134	33.6	6.1	33.4	26.7	40.9
95	23.7	3.4	24.5	19.1	26.8
130	32.4	3.7	32.3	28.3	36.7
140	35.0	3.4	35.4	30.6	38.5
105[2]	34.8	5.2	35.0	29.5	40.0

Notes:

[1] Contractor did not report uncertainty (2s) values.

[2] Dose is sum of only 3 quarters.

[3] Dose is sum of only 2 quarters.

NA = Not Analyzed

Table 2. Descriptive statistics for TLD data by quarter for 1996 (mrem).

NMED (Aluminum Oxide)	96Q1	96Q2	96Q3	96Q4	1996
Mean	19.9	20.7	21.6	27.0	22.4
Std Deviation	4.2	5.2	4.6	4.1	5.1
Median	19.2	21.0	20.5	28.6	22.1
Minimum	15.4	9.7	12.3	17.5	9.7
Maximum	28.7	30.0	30.1	31.1	31.1

NMED (Calcium Sulfate)	96Q1	96Q2	96Q3	96Q4	1996
Mean	NA	24.6	25.7	26.1	25.5
Std Deviation	NA	3.2	3.8	3.2	3.3
Median	NA	25.1	25.6	26.4	25.5
Minimum	NA	17.4	17.5	18.3	17.4
Maximum	NA	29.0	33.3	30.6	33.3

LANL	96Q1	96Q2	96Q3	96Q4	1996
Mean	28.6	35.8	33.4	38.8	34.4
Std Deviation	5.2	5.1	5.0	4.6	6.1
Median	28.1	35.5	32.8	40.2	35.4
Minimum	19.1	25.8	23.2	26.8	19.1
Maximum	38.7	45.6	42.9	45.5	45.6

Note: NA = Not Analyzed

Table 3. Difference (mrem) between LANL and NMED calcium-sulfate TLD data for 1996 (LANL minus NMED).

	Quarter				Average
Station	1st	2nd	3rd	4th	Difference
Barranca	NA	9.2	7.6	15.4	10.7
48th Street	NA	14.7	9.2	13.7	12.5
Shell Station	NA	12.4	10.1	12.2	11.6
McDonald's	NA	NA	9.7	13.8	11.8
Airport	NA	12.8	7.3	10.4	10.2
East Gate	NA	8.3	3.8	8.9	7.0
Well PM-1	NA	16.6	9.6	14.9	13.7
WR Fire Station	NA	10.1	6.5	14.5	10.4
Nazarene Church	NA	8.4	5.7	8.5	7.5
Pajarito Acres	NA	8.9	6.6	12.7	9.4
Royal Crest	NA	10.9	8.8	12.1	10.6
Santa Fe	NA	10.8	NA	15.4	13.1
Average Difference	-	11.2	7.7	12.7	10.7

Note: NA = Not Analyzed

Table 4. Statistical test results of comparitive TLD data by quarter for 1996.

	Quarter							
	2nd		3rd		4th		1996	
	NMED[a]	LANL	NMED[a]	LANL	NMED[a]	LANL	NMED[a]	LANL
Mean (mrem)	24.6	35.8	25.7	33.4	26.1	38.8	25.5	36.1
Standard Deviation	8.1	12	8.2	10.7	8.2	12.1	3.3	5.2
Observations	11	11	11	11	12	12	34	34
Shapiro-Wilk Normality Test[1]								
p value	0.2445	0.5896	0.1772	0.5569	0.2165	0.0159	0.0282	0.5427
Pearson Correlation[2]								
Critical value	0.5760		0.5760		0.5529		0.3430	
Pearson Correlation	0.8932		0.9345		0.8680		0.8244	
Student's paired t-test[3]								
test statistic (t)	-13.82		-12.96		-18.44		-19.78	
critical two-tailed t-value	2.23		2.23		2.20		2.03	
p value	0.0000		0.0000		0.0000		0.0000	
Wilcoxon Matched Pairs Test[3]								
p value	0.0033		0.0033		0.0022		0.0000	

Notes:
[a] - NMED data are calcium sulfate TLDs.
[1] - If the Shapiro-Wilk normality test p value is less than 0.05, the data are not normally distributed.
[2] - If the Pearson correlation is less than the critical value, the data sets do not track one another at the 95% confidence level.
[3] - If the p value (for either the t test or the Wilcoxon test) is less than 0.05, the means of the data sets are different.

Table 5. Statistical comparison of results[a] for different TLD types used by NMED for 1996.

	Quarter							
	2nd		3rd		4th		1996	
	Aluminum Oxide	*Calcium Sulfate*	*Aluminum Oxide*	*Calcium Sulfate*	*Aluminum Oxide*	*Calcium Sulfate*	*Aluminum Oxide*	*Calcium Sulfate*
Mean	20.7	24.6	21.6	25.7	26.6	26.1	23.1	25.5
Standard Deviation	26.6	8.1	21.0	8.2	16.6	8.2	5.2	3.3
Observations	11	11	11	11	12	12	34	34
Shapiro-Wilk Normality Test[1]								
p value	0.4403	0.2445	0.7411	0.1772	0.0760	0.2165	0.1877	0.0282
Pearson Correlation[2]								
Critical value	0.5760		0.5760		0.5529		0.3430	
Pearson Correlation	0.7346		0.9201		0.7795		0.7613	
Student's paired t-test[3]								
test statistic (t)	-3.62		-7.38		0.64		-4.12	
critical two-tailed t-value	2.23		2.23		2.20		2.03	
p value	0.0047		0.0000		0.5358		0.0002	
Wilcoxon Matched Pairs Test[3]								
p value	0.0077		0.0033		0.4802		0.0007	

Notes:
[a] - Data are from NMED TLDs.
[1] - If the Shapiro-Wilk normality test p value is less than 0.05, the data are not normally distributed.
[2] - If the Pearson correlation is less than the critical value, the data sets do not track one another at the 95% confidence level.
[3] - If the p value (for either the t test or the Wilcoxon test) is less than 0.05, the means of the data sets are different.

Table 6. Airborne radionuclide data for 1996 (aCi/m³)

		Am-241				Pu-238				Pu-239			
		NMED		LANL		NMED		LANL		NMED		LANL	
STATION	QTR	Result	Unc.[1]	Result	Unc.[1]	Result	Unc.[1]	Result	Unc.[1]	Result	Unc.[1]	Result	Unc.[1]
WR Fire Station	1	3.3	2.4	2.5	2.5	2.4	2.4	0.3	1.3	2.4	2.4	1.3	2.1
WR Fire Station	2	2.1	1.4	2.6	2.5	4.2	2.8	0.4	1.2	0.7	2.1	0.2	1.7
WR Fire Station	3	1.4	1.4	1.9	2.4	2.7	2.7	0.5	1.9	2.0	2.0	1.1	2.4
WR Fire Station	4	2.5	2.5	2.1	2.8	1.2	1.2	-0.1	1.2	0.6	0.6	0.8	2.0
Royal Crest	1	10.2	5.9	3.3	4.2	8.5	5.7	0.7	1.6	0.0	11.3	1.5	2.4
Royal Crest	2	14.2	5.7	2.1	2.4	2.8	5.7	2.8	2.6	0.0	5.7	2.3	2.4
Royal Crest	3	6.7	6.7	1.0	1.6	13.4	13.4	0.1	1.6	6.7	6.7	0.2	1.2
Royal Crest	4	8.3	8.3	2.0	2.6	5.5	5.5	0.4	1.5	8.3	5.5	2.0	3.2
McDonald's	1	8.5	5.6	2.6	3.6	5.3	2.7	0.5	1.2	-2.7	2.7	0.9	2.1
McDonald's	2	1.4	1.4	2.4	2.7	0.0	1.4	-0.3	0.9	0.7	1.4	0.5	1.5
McDonald's	3	2.1	0.7	1.3	1.8	2.8	2.8	-0.2	0.6	1.4	0.7	0.1	2.1
McDonald's	4	1.9	1.3	3.1	3.8	1.3	1.3	0.6	2.2	1.3	0.6	2.9	3.7
Airport	1	4.2	4.5	2.1	3.1	0.0	2.4	0.1	0.7	0.0	2.4	3.3	3.3
Airport	2	2.7	1.3	1.9	2.3	0.7	1.3	0.2	0.9	4.7	2.7	3.5	2.7
Airport	3	1.4	0.7	1.5	1.8	2.8	2.8	0.2	1.5	10.6	2.8	0.8	1.8
Airport	4	0.6	0.6	3.3	3.4	2.5	2.5	0.0	1.2	1.3	1.3	4.0	4.5
Well PM-1	1	NA[2]	NA[2]	3.1	3.7	NA[2]	NA[2]	0.0	0.9	NA[2]	NA[2]	0.3	1.0
Well PM-1	2	0.7	1.5	0.6	1.7	0.0	3.7	0.2	0.7	0.7	1.5	0.9	1.2
Well PM-1	3	0.7	0.7	1.3	1.3	2.8	2.8	-0.2	0.5	1.4	1.4	0.2	1.2
Well PM-1	4	1.9	1.9	2.1	2.2	2.5	2.5	0.4	1.5	1.2	1.2	0.6	1.8

		U-234				U-235				U-238			
		NMED		LANL		NMED		LANL		NMED		LANL	
STATION	QTR	Result	Unc.[1]	Result	Unc.[1]	Result	Unc.[1]	Result	Unc.[1]	Result	Unc.[1]	Result	Unc.[1]
WR Fire Station	1	40.2	14.2	15.5	9.9	2.4	2.4	0.0	2.8	40.2	14.2	9.9	8.5
WR Fire Station	2	32.3	9.8	18.1	8.2	4.9	3.5	1.3	2.5	29.5	9.1	21.3	8.0
WR Fire Station	3	26.4	6.8	5.1	6.5	5.4	2.7	1.2	2.9	26.4	6.1	6.6	6.2
WR Fire Station	4	14.2	4.3	8.7	6.8	3.1	3.1	-0.1	2.9	10.5	3.7	8.7	6.7
Royal Crest	1	42.5	17.0	7.4	7.4	0.0	11.3	1.5	3.0	56.7	19.8	7.4	7.4
Royal Crest	2	105.1	34.1	14.4	6.9	2.8	8.5	1.6	2.6	90.9	34.1	16.6	6.8
Royal Crest	3	86.9	23.4	7.6	5.9	13.4	13.4	1.9	3.0	53.5	20.0	3.3	3.8
Royal Crest	4	52.5	16.6	7.9	6.4	11.1	5.5	0.2	3.3	38.7	13.8	6.7	5.9
McDonald's	1	61.3	18.7	10.6	9.1	2.7	2.7	0.0	3.0	45.3	16.0	13.6	9.1
McDonald's	2	23.9	8.7	14.5	6.1	5.1	3.6	2.3	2.3	27.5	8.7	17.1	6.2
McDonald's	3	28.4	6.9	2.9	4.5	5.5	2.8	1.0	2.8	15.9	4.8	4.6	4.5
McDonald's	4	18.6	5.1	7.5	6.9	1.3	1.3	1.1	3.9	12.8	3.8	7.7	6.0
Airport	1	37.6	14.1	7.4	8.9	0.0	2.4	0.0	4.5	42.3	16.5	5.9	7.4
Airport	2	21.5	8.1	11.0	6.0	2.0	3.4	0.9	2.4	14.8	6.0	11.8	5.6
Airport	3	31.2	7.1	9.9	6.2	4.3	2.8	1.0	2.6	41.1	8.5	19.6	8.4
Airport	4	20.2	5.0	12.3	8.6	2.5	1.9	2.0	4.1	15.8	4.4	11.4	7.4
Well PM-1	1	NA[2]	NA[2]	5.8	7.3	NA[2]	NA[2]	0.0	2.9	NA[2]	NA[2]	10.2	10.0
Well PM-1	2	27.6	9.0	16.1	6.6	3.7	4.5	0.9	2.4	22.4	8.2	16.0	6.1
Well PM-1	3	19.5	5.6	3.4	4.9	4.9	2.8	0.5	2.8	19.5	5.6	2.0	3.4
Well PM-1	4	14.3	4.4	10.0	6.8	2.5	1.2	0.7	2.8	23.6	5.6	16.7	9.0

Notes:

[1] - Counting uncertainty

[2] - Not analyzed

Table 7. Descriptive statistics for airborne radionuclides in 1996 (aCi/m³)

WR Fire Station	Am-241		Pu-238		Pu-239		U-234		U-235		U-238	
	NMED	LANL	NMED	LANL	NMED	LANL	NMED	LANL	NMED	LANL	NMED	LANL
Mean	2.3	2.3	2.6	0.3	1.4	0.8	28	12	3.9	0.6	27	12
Standard Deviation	0.8	0.3	1.2	0.2	0.9	0.5	11	6.0	1.5	0.7	12	6.6
Minimum	1.4	1.9	1.2	-0.1	0.6	0.2	14	5.1	2.4	-0.1	11	6.6
Maximum	3.3	2.6	4.2	0.5	2.4	1.3	40	18	5.4	1.3	40	21

Royal Crest	Am-241		Pu-238		Pu-239		U-234		U-235		U-238	
	NMED	LANL	NMED	LANL	NMED	LANL	NMED	LANL	NMED	LANL	NMED	LANL
Mean	9.8	2.1	7.6	1.0	3.7	1.5	72	9.3	6.8	1.3	60	8.5
Standard Deviation	3.2	0.9	4.5	1.2	4.4	0.9	29	3.4	6.4	0.7	22	5.7
Minimum	6.7	1.0	2.8	0.1	0.0	0.2	43	7.4	0.0	0.2	39	3.3
Maximum	14	3.3	13	2.8	8.3	2.3	105	14	13	1.9	91	17

McDonald's (LA)	Am-241		Pu-238		Pu-239		U-234		U-235		U-238	
	NMED	LANL	NMED	LANL	NMED	LANL	NMED	LANL	NMED	LANL	NMED	LANL
Mean	3.5	2.4	2.3	0.1	0.2	1.1	33	8.9	3.6	1.1	25	11
Standard Deviation	3.4	0.8	2.3	0.5	1.9	1.2	19	4.9	2.0	1.0	15	5.6
Minimum	1.4	1.3	0.0	-0.3	-2.7	0.1	19	2.9	1.3	0.0	13	4.6
Maximum	8.5	3.1	5.3	0.6	1.4	2.9	61	15	5.5	2.3	45	17

Airport	Am-241		Pu-238		Pu-239		U-234		U-235		U-238	
	NMED	LANL	NMED	LANL	NMED	LANL	NMED	LANL	NMED	LANL	NMED	LANL
Mean	2.2	2.2	1.5	0.2	4.1	2.9	28	10	2.2	1.0	29	12
Standard Deviation	1.6	0.8	1.4	0.1	4.8	1.4	8.3	2.1	1.8	0.8	15	5.6
Minimum	0.6	1.5	0.0	0.0	0.0	0.8	20	7.4	0.0	0.0	15	5.9
Maximum	4.2	3.3	2.8	0.2	11	4.0	38	12	4.3	2.0	42	20

Well PM-1	Am-241		Pu-238		Pu-239		U-234		U-235		U-238	
	NMED	LANL	NMED	LANL	NMED	LANL	NMED	LANL	NMED	LANL	NMED	LANL
Mean	1.1	1.8	1.8	0.1	1.1	0.5	21	8.8	3.7	0.5	22	11
Standard Deviation	0.7	1.1	1.5	0.3	0.3	0.3	6.7	5.6	1.2	0.4	2.1	6.8
Minimum	0.7	0.6	0.0	-0.2	0.7	0.2	14	3.4	2.5	0.0	20	2.0
Maximum	1.9	3.1	2.8	0.4	1.4	0.9	28	16	4.9	0.9	24	17

40 CFR 61 Limit	1900	2100	2000	7700	7100	8300

Table 8. Statistical test results for 1996 NMED and LANL air particulate data.

	Am-241	Pu-238	Pu-239	U-234	U-235	U-238
Pearson Correlation[1]						
Critical value	0.4438	0.4438	0.4438	0.4438	0.4438	0.4438
Pearson Correlation	0.0801	0.4011	-0.3031	0.1131	0.3766	0.6385
Student's paired t-test[2]						
Degrees of freedom	18	18	18	18	18	18
test statistic (t)	2.185	2.945	3.318	5.372	3.651	3.965
critical two-tailed t-value	2.101	2.101	2.101	2.101	2.101	2.101
p value	0.0424	0.0087	0.0038	4E-05	0.0018	0.0009
Wilcoxon Matched Pairs test[2]						
p value	0.1474	0.0003	0.658	0.0001	0.0005	0.0001
Shapiro-Wilk normality test[3]						
NMED data p-value	0.0006	0.0007	0.0014	0.0008	0.0029	0.0201
LANL data p-value	0.5343	0.0000	0.0072	0.5895	0.2263	0.5644

Notes:

[1] - If the Pearson correlation is less than the critical value, the data sets do not track one another at the 95% confidence level.

[2] - If the p value is less than 0.05, the means of the data sets are different.

[3] - If the p value is less than 0.05, the data set is not normally distributed.

Table 9. Airborne tritium concentrations for 4th quarter of 1996 (pCi/m³).

Station	NMED Result	NMED Uncertainty	LANL Result	LANL Uncertainty
White Rock Fire Station	0.97	0.72	1.91	0.23
McDonald's (Los Alamos)	2.31	0.72	2.21	0.27
Los Alamos Airport	1.67	0.53	0.48	0.25
Well PM-1	1.74	0.99	1.59	0.22
Descriptive Statistics				
Mean	1.67		1.55	
Standard Deviation	0.55		0.76	
Median	1.71		1.75	
Minimum	0.97		0.48	
Maximum	2.31		2.21	
Statistical Tests				
Shapiro-Wilk Normality Test[1]				
p value	0.7512		0.4316	
Pearson Correlation[2]				
Critical value		0.8783		
Pearson Correlation		0.1417		
Student's paired t test[3]				
Test statistic (t)		0.29		
Critical two-tailed t value		3.18		
p value		0.7900		
Wilcoxon Matched Pairs Test[3]				
p value		0.4652		
40 CFR 61 limit	1500			

Notes:

[1] - If Shapiro-Wilk normality test p value is less than 0.05, data are not normally distributed.

[2] - If Pearson correlation is less than the critical value, the data do not track each other at the 95% confidence leve

[3] - If the p value (for either the t test or the Wilcoxon test) is less than 0.05, the means of the data sets are differen