PATHFINDER
A Cogema Resources Company

February 16, 1999

Mr. N. King Stablein
Acting Chief, Uranium Recovery Branch
Division of Waste Management
Office of Nuclear Mateial Safety & Safeguards Mail Stop T 7-J-8
U. S. Nuclear Regulatory Commission
11545 Rockville Pike
Rockville, MD 20852

Ref: Docket No. 40-2259
License No. SUA-672

Dear Mr. Stablein:

Enclosed please find two copies of a revised windblown tailings cleanup completion report for the Lucky Mc Mill Site. The revised report addresses the NRC staff comments dated June 23, 1998 that grew out of the original completion report submitted on March 2, 1998, and subsequently withdrawn by Pathfinder after further discussions with your staff. Please note that the original Appendix E (gamma isocontour maps - only one set was sent originally) that accompanied the March 2, 1998 submittal is applicable to this revision and should be attached to it. Because the NRC had previously received a set of these rather numerous maps, we elected not to duplicate it again with this submittal.

The submittal of this revised report was delayed until now because of the need to complete additional field work during the fall of 1998, and the subsequent wait for the completion of laboratory analytical work. Please call me if there are any questions regarding this submittal.

Sincerely,

Tom Hardgrove

T. W. Hardgrove
Manager, Environmental and Regulatory Services

Enclosure

cc: B. Spitzberg, U. S. NRC, Region IV
D. L. Wichers
R. W. Poyser w/o enclosure
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K. R. Baker, ERG w/o enclosure

Lucky Mc Mill Site Completion Report

February 1999

prepared for:

Pathfinder Mines Corporation
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1. INTRODUCTION

Pathfinder Mines Corporation (PMC), owner of the Lucky Mc Uranium Mill, has completed the off-pile cleanup and verification program in accord with the U.S. Nuclear Regulatory Commission (NRC)-approved Reclamation Plan and the Radioactive Materials License (SUA-672). The cleanup of the windblown contaminated soils occurred from May to November, 1996. Because of inclement weather, the soil verification activities were continued in May 1997 and were completed in November 1997. Some additional cleanup was done in support of the verification of the windblown area cleanup. Final laboratory data were available in January 1998. This report consolidates all data taken over the two-year reclamation period to demonstrate that the areas have been reclaimed according to 10CFR Part 40, Appendix A.

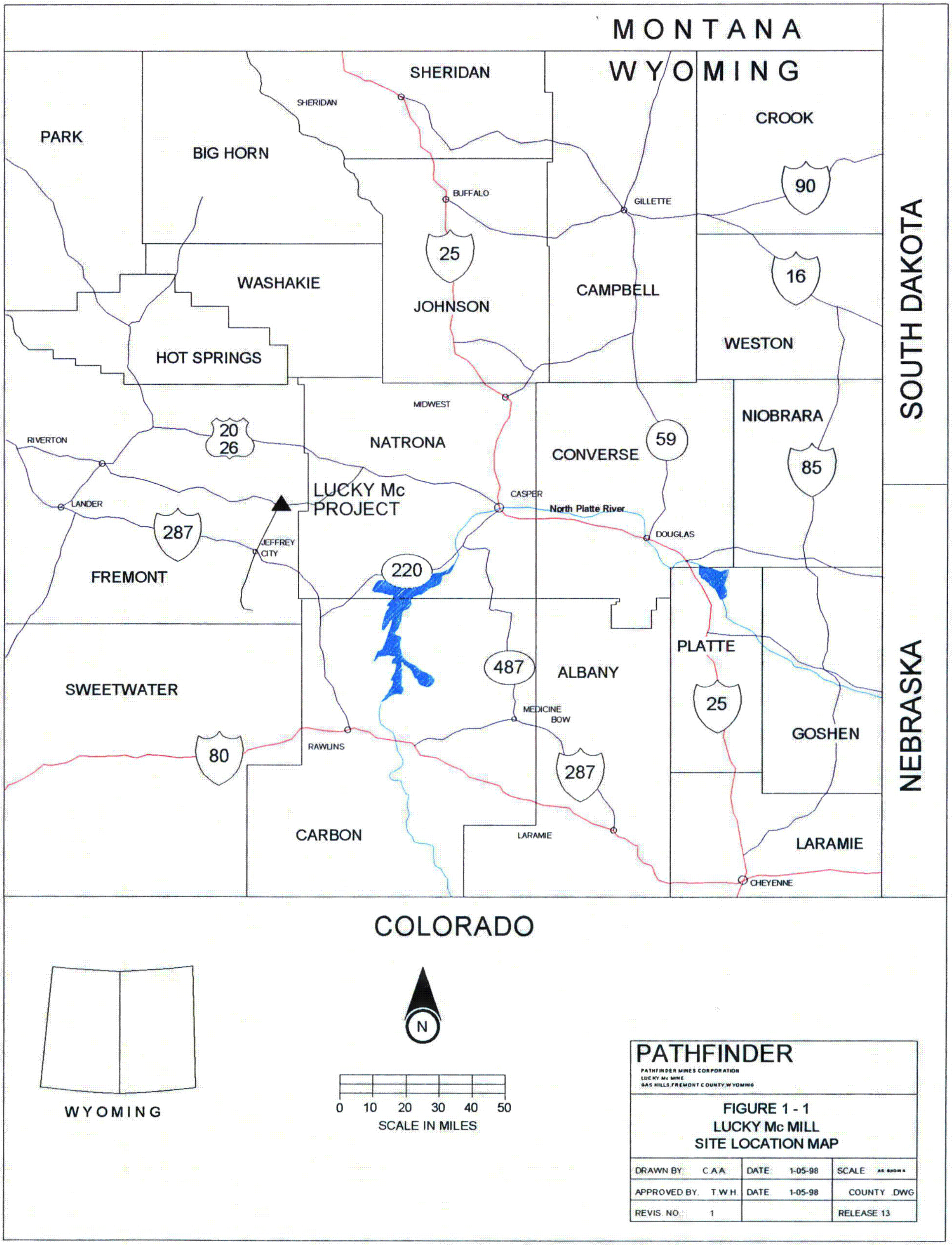
1.1 Site Description and Current Status

The mill site is located in the Gas Hills of Wyoming about 45 miles east of Riverton, WY, as shown in Figure 1-1. Structures remaining at the site are an office building, fire and rescue station, and two storage buildings used for managing the soil cleanup and groundwater restoration programs. A site groundwater restoration project is underway, and upon completion, these buildings will be razed and consolidated with the tailings, or the materials will be surveyed and demonstrated suitable for unrestricted release.

The cleanup of the off-pile areas was complicated by ore outcrops, mine drainage through the site, and an ore haul road upwind of the windblown tailings area. These complicating factors were considered during the cleanup but, in most cases, cleanup beyond what may have been required was done to assure that residual contamination that currently exists is not due to licensed byproduct material. The rationale for decision-making regarding these complications is presented in this report.

1.2 Site History Applicable to Reclamation Activities

The original discovery of surface deposits of uranium occurred in the Gas Hills in 1953. A number of companies soon were developing uranium mines in this highly mineralized area. Prior to constructing the mill, the Lucky Mc Mill site was evaluated as a potential surface mining area because of the presence of surface outcrops in the local area. The mill site was determined to be not economically viable as a mine site and therefore was selected because of its proximity to the Lucky Mc Mine that is located up-gradient to the south. Due to this proximity, mine pit water and site surface water transport of low grade ore over the last 40 years has impacted a portion of the current mill site.



PATHFINDER

PATHFINDER MINES CORPORATION
LUCKY Mc MINE
GAS HILLS,FREMONT COUNTY,WYOMING

FIGURE 1 - 1
LUCKY Mc MILL
SITE LOCATION MAP

DRAWN BY C.A.A.	DATE 1-05-98	SCALE AS SHOWN
APPROVED BY. T.W.H.	DATE 1-05-98	COUNTY .DWG
REVIS. NO. 1		RELEASE 13

The Lucky Mc Mill went into production in February 1958 and processed ore until 1988. The uranium mill facilities were decommissioned in 1993-1994 according to the Decommissioning Plan, as approved by the NRC as License Condition No. 29. The uranium mill facilities were razed and the mill debris placed in the tailings piles along with any process residues. A mill decommissioning report was submitted to the NRC upon completion of the work. The most highly contaminated surface soils within the mill yard area, Moly Pond, and ore pads were removed and placed with the tailings. Radon barrier material will be applied to these areas and the area will be stabilized.

A haul road currently exists just east of the tailings piles on which much of the ore mined prior to the startup of the Lucky Mc Mill was hauled to Riverton. The use of the haul road by some companies continued well into the 1970's. The typical ore truck carried the maximum load without any cover in place, leaving the load vulnerable to spillage, particularly in the Lucky Mc area which was near the beginning of the transport route. Frequent ore hauling on this road caused an abundance of spilled ore and ore dust along the road.

2. RADIOLOGICAL SETTING

The data presented in this report reflects the complexity of the site with regards to the origin of the naturally occurring radionuclides found in various areas. Most uranium mill sites have contaminated areas where the source of the contamination can be predicted. Areas of potential contamination include tailings contamination downwind from the tailings piles, windblown ore contamination downwind from ore storage pads, and near surface contamination in and around the former mill buildings. While the Lucky Mc Mill has these areas, delineation is complicated because the site is highly mineralized with low-grade uranium ore. The site also has been impacted by uranium ore haul roads that were used prior to and during mill operations and by mine water and surface drainage from the nearby mine site. The lack of baseline radiological data and adequate mill operations historical data has further complicated the site characterization efforts.

The basic approach to soil cleanup was to assume that all areas exhibiting elevated gamma emissions had been affected by milling operations. Surface soils were removed to depths ranging from six inches to several feet, depending on whether there was the potential for milling activities to have disturbed the area to significant depths. Layers of soil were removed until near background levels were reached or site management was convinced that the remaining surface material was not byproduct material. Naturally, when contaminated soils extended to depths far beyond those anticipated, management's frustration to explain this normally led to additional studies, sampling, and removal. While this approach was definitely not the most cost effective approach, it was considered the only approach available since there are no pre-operational data other than a general knowledge that the area is highly mineralized near the surface.

In the mill area, excavations to great depths (up to 10 feet or more) often did not significantly reduce the radionuclide content of the soils. In that case, it was decided to extend the tailings radon barrier rather than to attempt to prove that the material was not byproduct material. The radon barrier was extended to cover all of the mill site where process buildings and the heap leach facility had been placed.

To effectively interpret the sample data and gamma survey results, the remaining portion of the site was partitioned into areas which reflect the source of any residual contamination. These include two high natural background areas, the potential windblown tailings area, mine drainage area, and the tailings/solutions ponds areas. Figure 2-1 shows the boundaries and relationship of these site features. Each area is further described in subsequent sections.

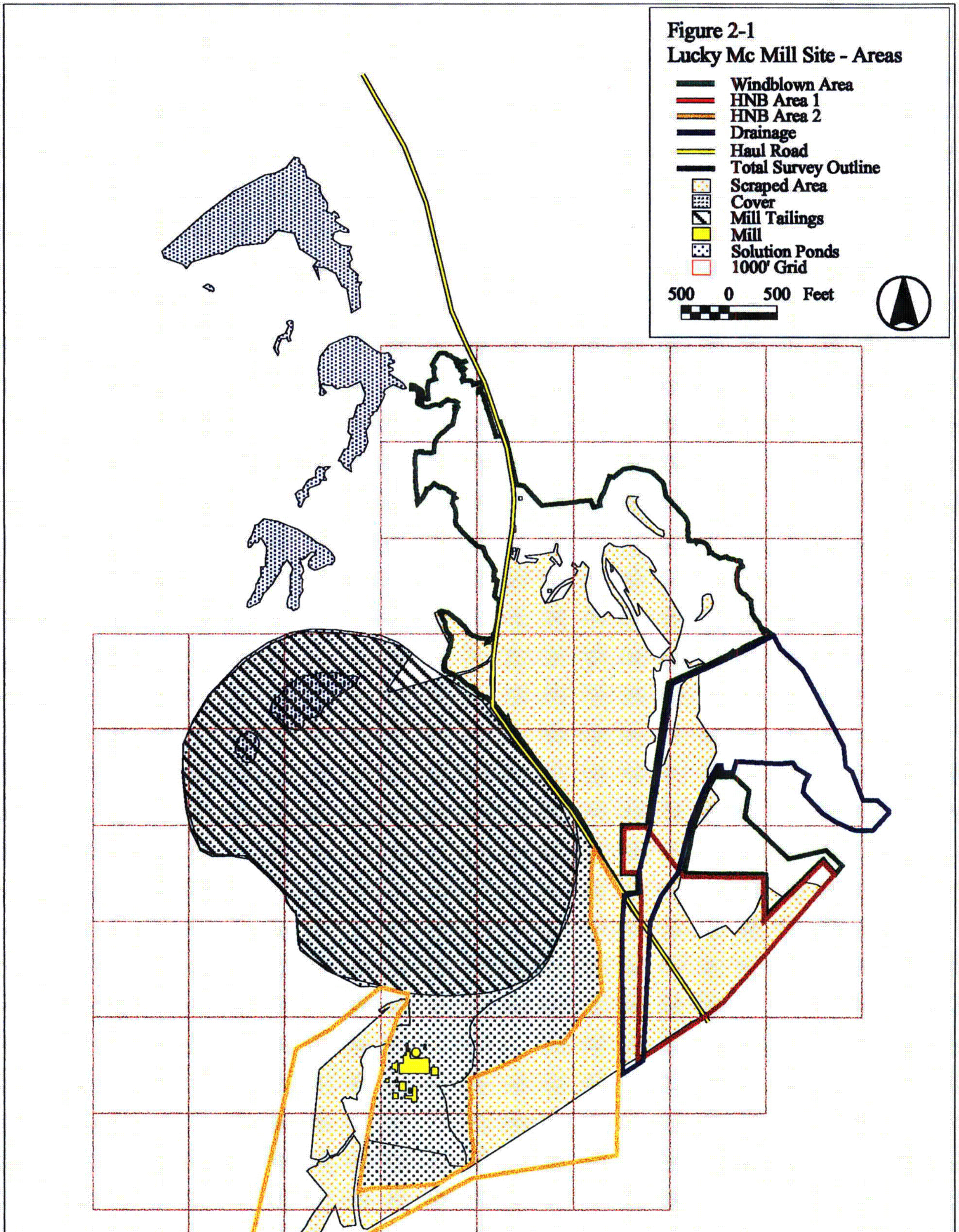


Figure 2-1
Lucky Mc Mill Site - Areas

2.1 Site-Wide Natural Background Study

No pre-operational data exist for this site other than historical records indicating that the area had been drilled for possible mining of uranium ore as discussed in Appendix A. A background study was done in 1992 and submitted as part of Volume 1 of the Lucky Mc Mine Tailings Reclamation Plan. Nineteen samples of material common to the area were collected and analyzed for Ra-226 content. The mean value of the results was 34.4 pCi/g and the median value was 7.6 pCi/g. After excluding a high value of 388 pCi/g, which was taken from mill waste, the mean value of the remaining eighteen samples was 14.8 pCi/g, with a median of 7.3 pCi/g. Unfortunately, natural uranium analyses were not performed on the samples, restricting any calculation of the Ra-226/U-nat ratio.

14.8

No attempt was made to conduct a statistically-based background sampling study. Each sample was described as to type of material and location. A few of the samples contained known overburden and low-grade ore common to the area. The NRC evaluated the data and concluded that 4.5 pCi/g was a good indicator of the local background Ra-226 concentration. The data from the cleanup suggest that the 4.5 pCi/g background value does seem appropriate for the non-mineralized portions of the windblown contaminated area northeast of the tailings pile. However, even there, a few areas exist where reasonable efforts at removing surface soils resulted in residual Ra-226 concentrations in the range of 10-15 pCi/g. It appears that natural surface outcrops of very low Ra-226 activity soils exist in the area where the thickness ranges from just a few inches to many feet.

While the background data presented by PMC for consideration was not an unbiased data set, the variability and distribution of this data is very similar to biased samples taken from the most elevated portions of the site after removing a suspected windblown layer of contamination. This relationship adds validity to the conclusion that the residual radionuclide concentrations in many areas of the site are not a result of byproduct material but arise from mineralized outcrop areas.

After all site characterization and cleanup verification data were available for evaluation, it appears that the minerialization is much more extensive and extends to great depths in and around the mill site. While mineralization exists in relatively shallow layers in the windblown area, it appears that the Ra-226 concentration is lower with the upper range of Ra-226 concentration approaching or slightly exceeding the Ra-226 cleanup criterion of 9.5 pCi/g.

2.2 Natural Ore Outcrop Areas

Historical records show that the area on which the mill site has been placed was considered part of the mineralized Gas Hills area. A review of the records revealed that in the early days of exploration, holes were drilled in the vicinity of the Lucky Mc Mill site in order to define the northern mining district boundary, based on economics of the day. Prior to establishing the current mill site, an additional drilling study was done to avoid placing the mill and tailings on an area that had mining potential. Exploration maps exist that show ore trends, drill-hole locations, and data confirming that this area had known surface ore outcrops. Maps along with a more detailed discussion of this local mineralization are included as Appendix A. The discussion in the appendix supports, from an historical perspective, the existence of significant areas within the site that are highly mineralized. The low quality ores are high in Ra-226 concentration compared to the cleanup criterion of 9.5 pCi/g even though the ore has no commercial value.

Two natural ore outcrop areas were identified during reclamation activities and are labeled high natural background (HNB) areas No.1 and 2 on Figure 2-2. As shown in Figures 2-1 and 2-2, the areas are contiguous and likely related. Detailed HNB area descriptions and sample analyses are presented in the following sections.

2.2.1 High Natural Background Area No.1

A six-inch layer of soil was removed from the triangular area bounded by the Main Road and the two mine drainages. A subsequent radiological survey revealed that there were areas where little reduction in the gamma-ray count rates occurred. After further attempts to remove additional layers of soil, it was concluded that the elevated radionuclide concentrations were due to natural outcrops. This area is referred to as High Natural Background Area No.1 (HNB-1). Orange sands were also discovered on a small portion of this area. After the surface 0.5-ft to 1-ft layer had been removed, 27 soil samples were taken from the top six-inch layer at locations shown in Figure 2-3. All but two of the samples were taken from locations representing the three grid blocks from each 500-ft by 500-ft area having the highest gamma values. The samples OS-7 and OS-8 were composite samples taken from areas made up of orange sands. The Ra-226 and natural uranium concentration values are given in Table 2-1, The data show that 22 of the 27 samples had Ra-226 concentrations above the cleanup limit of 9.5 pCi/g. The average Ra-226 concentration in HNB-1 is 18 pCi/g.

The Ra-226/U-nat ratio is highly variable, ranging from 0.6 to 5.1, with an average of 1.8 and standard deviation of 1.1. The two orange sands composite samples showed widely different Ra/uranium ratios, one being 1.8 and the other being 5.1. The ratio of 5.1 might normally suggest the presence of tailings. However, this area is cross wind of the tailings pile, has had the surface layer removed, and is located in an area that has not been disturbed by milling or mining operations. No explanation for this widely different state of equilibrium for the two samples exists. It does, however, indicate how widely the radionuclide equilibrium varies even for materials that look as if they are physically and geologically identical.

The majority of the samples in Table 2-1 with high Ra-226/U-nat ratios are grouped near the road and on the eastern side of HNB Area 1 (see OS-8, U19B10D, U20A01C,

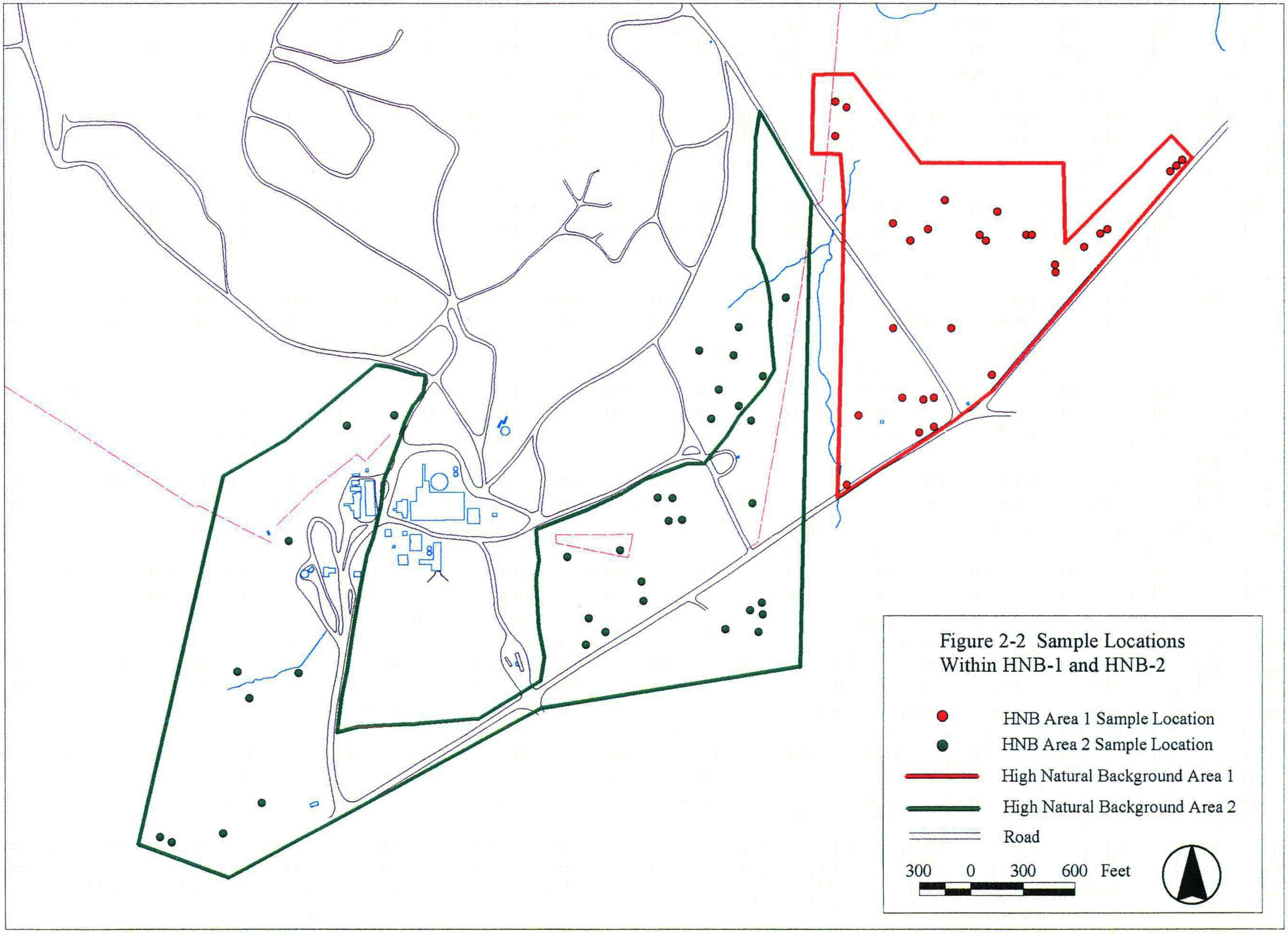


Figure 2-2 Sample Locations Within HNB-1 and HNB-2

T20C23A, and T20D01J in Figure 2-3). There appears to be a thick ore body in this area where the activity increases with depth. If these samples are excluded from Table 2-1, the Ra-226/U-nat ratio averages 1.4 with a standard deviation of 0.5. This ratio is more consistent with the other outcrops measured across the site.

Table 2-1. HNB-1 Sample Data.

Sample ID	Number of Gamma Readings	Ave. Gamma Count	ERG Ra-226 (pCi/g)	ELI Ra-226 (pCi/g)[1]	ELI Ra-226 (pCi/g)[2]	ELI U-Nat (pCi/g)	Ra-226/U_{nat} Ratio
T18D20J	14	59763	14.1			24.8	0.57
T19C21J	17	49173	11.8			6.9	1.71
T19D21G	5	48239	11.7			11.4	1.03
T20C23A	16	130938	64.9			19.1	3.40
U18B25J	25	52762	15.7			10.6	1.48
U18D23J	15	67238	22.2			16.6	1.34
U19A24G	16	61018	12.1			4.9	2.47
U19B10D	16	117383	32.5			8.8	3.69
U19C18G	31	64422	20.4			10.6	1.92
U19D11E	20	60079	20.4			16.6	1.23
U20A01C	13	76264	17.7			8.0	2.21
V18B18G	27	65096	17.6			24.2	0.73
V19A03D	18	70181	20.1			12.1	1.66
T18B13A	5	41958	3.7	4.0			
T18B07H	20	37697	8.2	8.2			
T18B17H	22	39374	16.8	15.0		20.3	0.83
T19C22C	24	46462	11.2	10.3		9.9	1.13
T19C25F	22	46009	16.0	7.6		7.5	2.13
T19C13F	15	45887	12.3	9.8		15.6	0.79
T19D23E	12	47325	11.6	17.8		10.9	1.06
T19D23F	14	46921	11.5	9.3			
T19D16C	15	46356	10.6	10.0		8.8	1.20
T20D01J	38	45223	12.8	13.1		8.7	1.47
T20D02D	38	44341	15.6	12.6		7.3	2.14
T20D02B	18	43820	11.4	9.5			
OS-7[3]	N/A	N/A	22.1		32.2	12.3	1.80
OS-8[3]	N/A	N/A	55.8		60.0	10.9	5.12

[1] Ra-226 Analyzed using wet chemistry.

[2] Ra-226 Analyzed using closed-can gamma spectrometry.

[3] Note: Results for OS samples are from composite samples for OS-7 and OS-8.

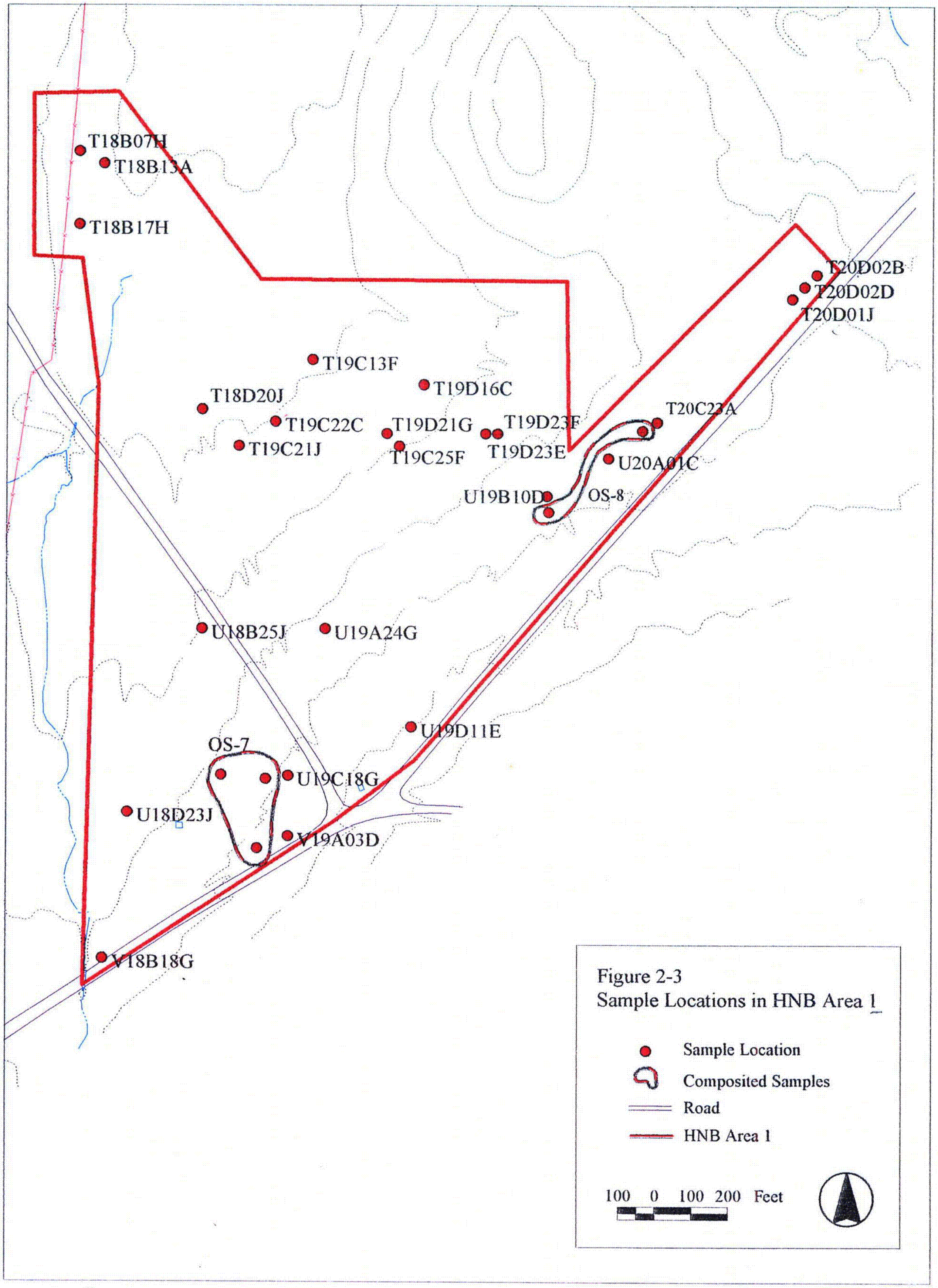


Figure 2-3
Sample Locations in HNB Area 1

A possible origin of the contamination is windblown material from the ore storage pads, mill yard, or the mine waste pile to the south of the Main Road. However, since the top six inches or more of soil had been removed prior to sampling, the area is unlikely to have been affected by windblown material. Byproduct material from the mill site as well as ore pads would have had a Ra-226 to uranium ratio of 0.5 or less. Also since the elevation of this area is above the mine drainages and top of the 004 dam elevation, it is impossible for the area to have been contaminated by water transport of material from the mine drainage. It was therefore concluded that the area must be elevated above the cleanup criterion due to high natural background radionuclides.

2.2.2 High Natural Background Area No. 2

The presence of natural ore outcrops became apparent when removing surface contamination from the area labeled "High Natural Background Area No. 2" (HNB-2) in Figure 2-2. Work first began in the mill area where it was known that mill operations and the presence of the ore pads had the potential for subsurface contamination. As the top layers of soil were removed, it was discovered that much of the area consisted of an orange sand layer of undetermined thickness that had a Ra-226 content well above the cleanup criterion of 9.5 pCi/g. At that point, it was decided to extend the radon barrier over the mill yard and heap leach facility.

Layers as thick as several feet were removed in areas contiguous to what will be the covered mill site. As an example, Figure 2-4 shows excavation depths in an area southeast of the mill yard. Difference contours were developed from the differences in aerial topography taken in 1993 and 1997. As can be seen, the depth of excavation in some areas ranged as high as 32 feet. Within the formerly fenced area, originally a yellowcake drum storage area, the average excavation depth was seven to eight feet deep. The white area represents a negative excavation depth. While fill was a possibility over time, this probably reflects the error in estimating the 2-ft contours from aerial photographic maps. Since a minimum of six inches was removed from this area, all 1997 elevations should have been less than the corresponding 1993 elevations and therefore the white areas in Figure 2-4 should represent a minimum cut depth of six inches.

Contaminated areas extended beyond the covered mill yard in all directions. A boundary was established as HNB Area 2 to include this area as shown in Figure 2-5.

Twenty-two sample locations for HNB-2 are shown in Figure 2-5. It should be noted that sample aliquot locations for five composite samples of orange sands areas are shown in Figure 2-5. The composites were considered appropriate since the areas appeared to have a geologic similarity within the immediate sampling area. Samples of mine waste piles located at the western edge of the area (Waste#1 and Waste#2) were taken. The remaining samples were unbiased samples other than the locations were selected to obtain a representative sampling of the area. The analytical results for the samples from HNB-2 are provided in Table 2-2.

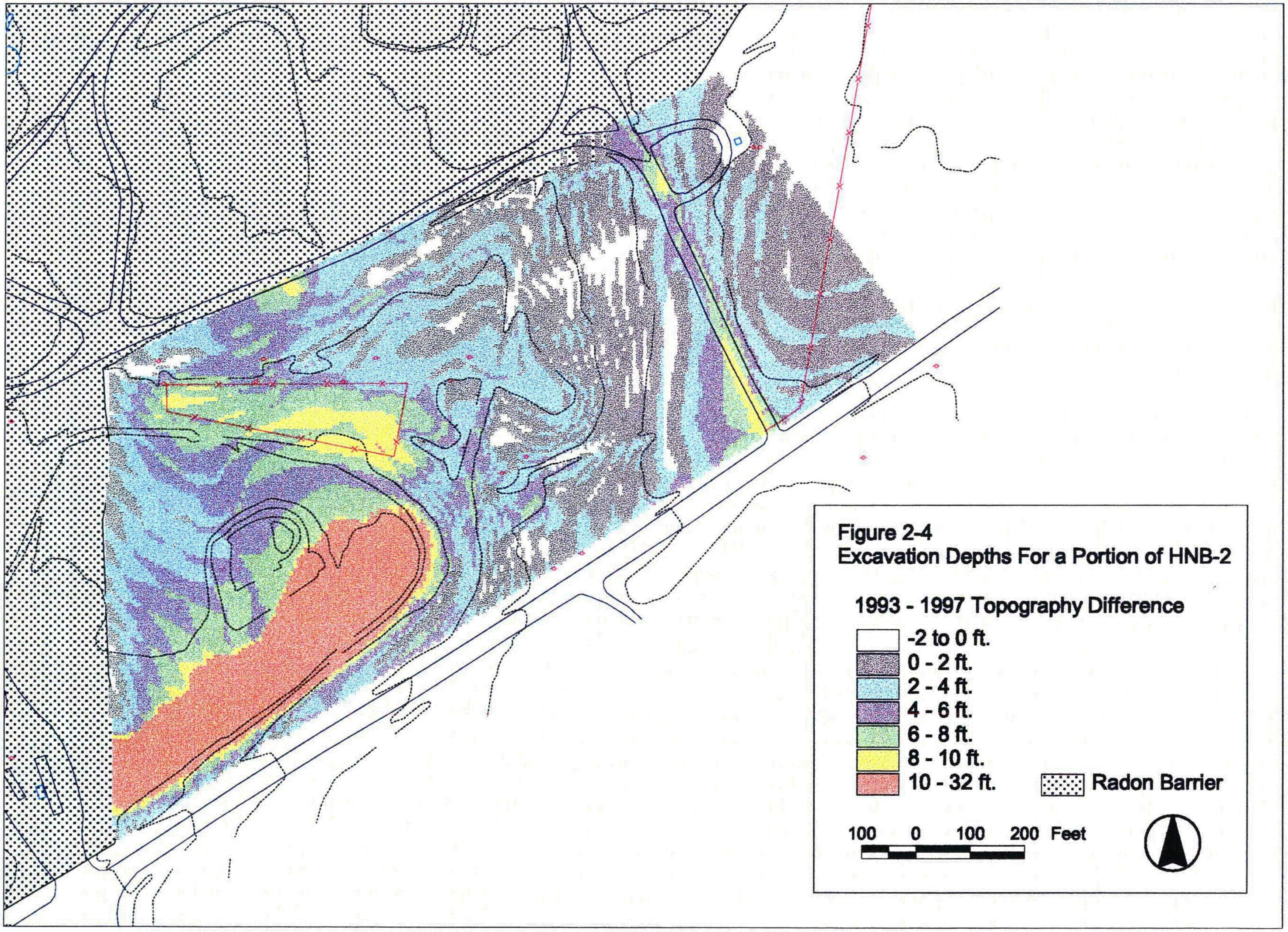


Figure 2-4
Excavation Depths For a Portion of HNB-2

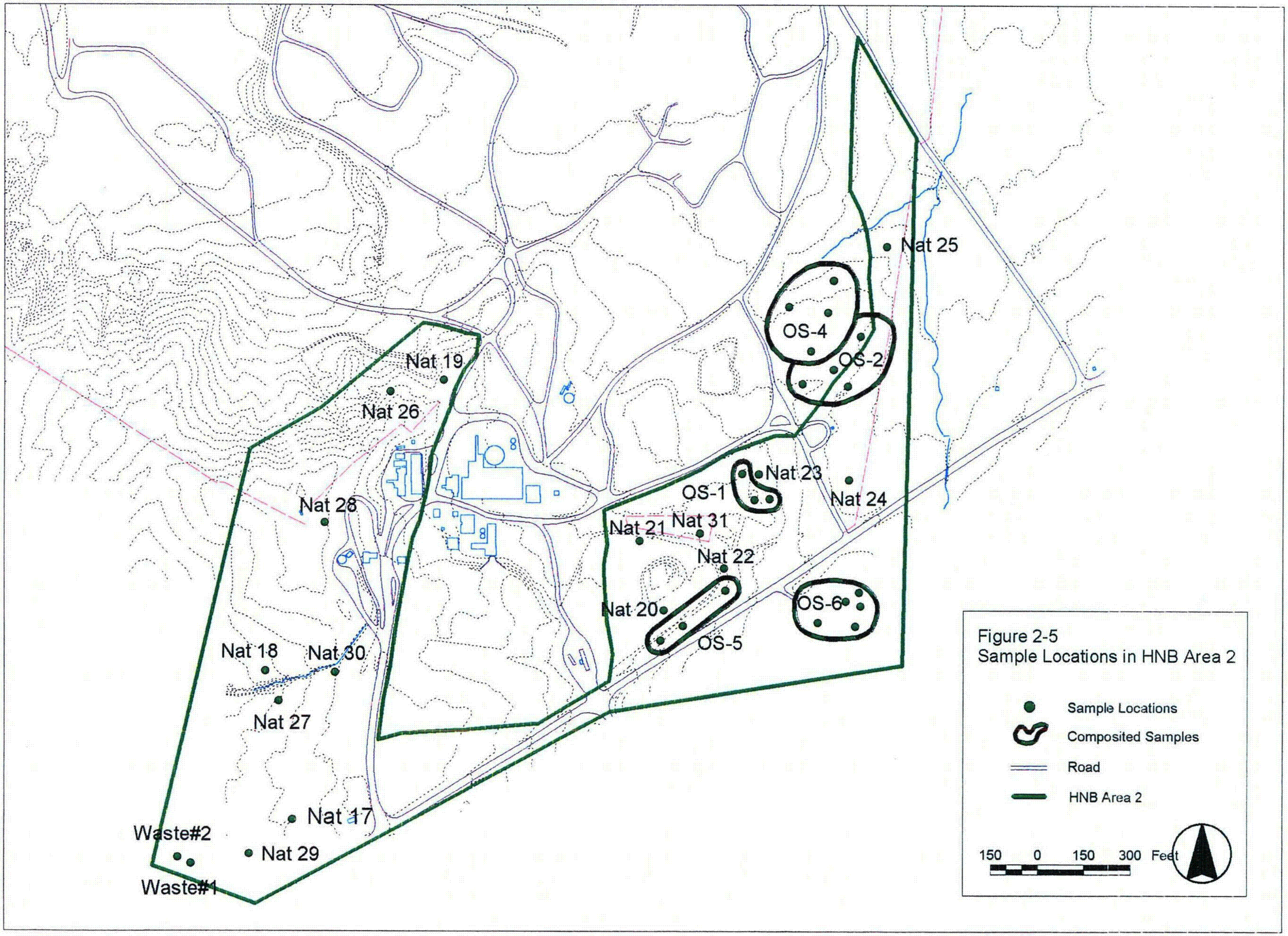


Figure 2-5
Sample Locations in HNB Area 2

Table 2-2. HNB-2 Sample Data.

Sample ID	Sample Depth (inches	Northing Coordinate	Easting Coordinate	ERG/ELI Ra-226 (pCi/g)[1]	ELI U-Nat (pCi/g)	Ra-226 /U-nat ratio
Nat 17	0-6	783,786	804,340	7.6	11.2	0.7
Nat 18	0-6	784,538	804,202	4.3	8.5	0.5
Nat 19	0-6	786,019	805,101	6.3	22.7	0.3
Nat 20	0-6	784,826	806,227	19.5	18.4	1.1
Nat 21	0-6	785,200	806,105	8.0	44.5	0.2
Nat 22	0-6	785,060	806,533	8.0	27.3	0.3
Nat 23	0-6	785,540	806,675	7.7	14.8	0.5
Nat 24	0-6	785,511	807,170	4.6	18.5	0.2
Nat 25	0-6	786,692	807,363	3.0	4.9	0.6
Nat 26	0-6	785959	804831	39.8	42.4	0.9
Nat 26	6-12			31.1	18.7	1.7
Nat 26	12-18			23.5	19.3	1.2
Nat 26	18-24			29.6	31.1	1.0
Nat 27	0-6	784385	804270	22.5	37.3	0.6
Nat 27	6-12			9.0	19.2	0.5
Nat 28	0-6	785294	804500	8.3	16.9	0.5
Nat 29	0-6	783612	804120	12.2	169	0.1
Nat 30	0-6	784531	804553	17.3	27.3	0.6
Nat 30	6-12			6.8	24.9	0.3
Nat 30	12-18			2.0	1.0	2.0
Nat 30	18-24			1.6	0.7	2.3
Nat 31	0-6	785240	806410	3.8	5.1	0.7
Nat 31	6-12			3.3	4.3	0.8
Nat 31	12-18			2.4	4.0	0.6
Nat 31	18-24			3.1	3.8	0.8
Waste#1	0-6	783560	803821	31.7	50.2	0.6
Waste#2	0-6	783591	803754	54.7	40.2	1.4
OS-1-1[2]	0-6	785,409	806,689	3.5	6.8	0.5
OS-2-1[2]	0-6	785,998	806,932	7.2	140.0	0.1
OS-4-1[2]	0-6	786,165	806,974	9.2	41.0	0.2
OS-5-3[2]	0-6	784,766	806,323	10.7	44.5	0.2
OS-6-1[2]	0-6	784,783	807,014	16.5	27.4	0.6

[1] Ra-226 values are from ELI wet chemistry analyses, when available, otherwise ERG on-site analysis values are reported

[2] Composite sample created from multiple location aliquots.

The Ra-226 and U-nat results for the mine waste samples illustrate that the Ra-226 levels are above cleanup criteria but well below mill-grade uranium concentrations. The Ra-226 to uranium concentration ratios in one case show a depletion of uranium relative to Ra-226 while the other sample shows a ratio similar to most natural ores. The Ra-226 to U-nat in the samples given in Table 2-2 show that the Ra-226 concentration for seven out of the twenty surface soil samples (0-6 in.) exceed the cleanup criterion of 9.5 pCi/g. A few samples were taken extending to 2 feet deep. In most cases, the concentrations decreased with depth while at location, Nat26, the concentrations remained elevated above the cleanup criteria down to 2 feet.

The mean Ra-226 concentration for all surface soil samples (0-6 in.) taken from HNB-2 is 12.4 pCi/g. The Ra-226/U-nat ratio is highly variable, ranging from 0.05 to 1.8, with an average of 0.9.

2.3 Affected (Man-Enhanced) Areas

Areas known to be affected by site milling or unrelated offsite uranium mining activities include the former mill and tailings area, mine waste drainage areas, a former uranium ore haul road and the windblown tailings area. As shown in Figure 2-1, the previous mill site and tailings piles are being covered with a radon barrier and stabilized. Areas contiguous to the previous mill site and tailings piles were decontaminated by removing surface soils to various depths. As discussed in prior sections, decontamination of these areas was not completed due to the natural ore outcrops. The following sections discuss the latter three areas with respect to the reclamation.

2.3.1 Mine Waste Drainage Areas

Surface water runoff and mine water from the uranium mines situated up-gradient of the mill site discharge into Fraser Draw and to the Fraser Draw tributary just to the east and contiguous to the mill yard. This tributary connects to Fraser Draw just south of the Stock Pond Dam. Runoff water and sediment were trapped behind the Stock Pond Dam from the time it was constructed in 1958 until 1963 when it was deliberately breached to avoid dam failure arising from unusually heavy precipitation events.

Records show that mine water discharges from the dewatering of the Lucky Mc Mine pits and other sources were channeled to the Fraser Draw tributary. The water flowed into Fraser draw and was stored behind the Stock Pond Dam for various uses by the mining companies. The flow from the dewatering activities alone is estimated at 1,000-2,000 gpm.

In addition, water from a "hot well" near the mill site was used for process water. The Ra-226 concentration in this water was approximately 110 pCi/l. Untreated overflow from the well was released to the Fraser Draw tributary just east of the mill site during the mill operations period.

For the 15 years prior to 1974, untreated water was released directly to the draws. While data do not exist to support a quantitative assessment of the impact of these releases, data exist to show that the Ra-226 concentration decreases downstream, probably from precipitation as radium sulfate. The Ra-226 concentration in the water as it is pumped from the pits appears to range between 100-200 pCi/l. The U-nat concentration may have reached more than 1,000 pCi/l. An assessment of the situation, based on Company correspondence and data, is presented in Appendix B.

In 1973, PMC began treating the water near the source prior to release. The water was then routed into the Fraser Draw tributary. The 004 Dam was constructed and served as the compliance monitoring point for their NPDES Permit. An Environmental Statement related to the operation of the Lucky Mc Mill (NUREG 1977) reviewed all operations, including the mine. The mine water was pumped into a holding pit where it was treated and released to the Fraser Draw tributary under an NPDES permit. Data for treated water released to the draw from July 1974 through April 1977 are provided in NUREG 1977 and indicate average constituent levels as total suspended solids-7.2 mg/l, soluble Ra-226-2.5 pCi/l, and soluble uranium-0.685 mg/l (464 pCi/l).

Contaminated mine water and silt from the releases discussed above resulted in a significant contaminated silt deposit in Fraser Draw above the old Stock Pond Dam and in the Fraser Draw tributary. Another possible source of contamination is the natural drainage from the mill site. PMC initially attempted to remove all contaminated soil from the Fraser Draw tributary. After an exhaustive effort, it was concluded that any material that remained could not possibly be byproduct material. Excavations to several feet deep in the tributary removed most of the contaminated material.

Surface samples (0-6 in.) taken along this deep excavation at 150-ft intervals show that only three out of the seventeen samples failed. While the excavation is not exactly a trench, the samples were labeled as trench samples in Table 2-3 with the locations given in Figure 2-6. PMC has removed the primary source of radioactivity from Fraser Draw tributary although it is unlikely that runoff from the mill site was a major contributor to the source.

The extensive pond sediment area above the Stock Pond Dam in Fraser Draw has existed prior to the construction of the mill. The major source of the contaminated sediments is the water and sediments from the mine dewatering program, prior to 1974. Five surface soil samples were taken north of the 004 Dam at locations shown in Figure 2-6. At one location, samples were taken to 42 inches deep. The data indicate that the depth of contamination extends beyond 42 inches.

The residual Ra-226 sample concentrations in the mine drainage areas are less than 40 pCi/g. The uranium concentrations were comparable to Ra-226 concentrations, with the exception of one sample taken at 36-42 inches that had a U-nat concentration of 207 pCi/g. Excluding the sample with the high uranium concentration, the Ra-226 to U-

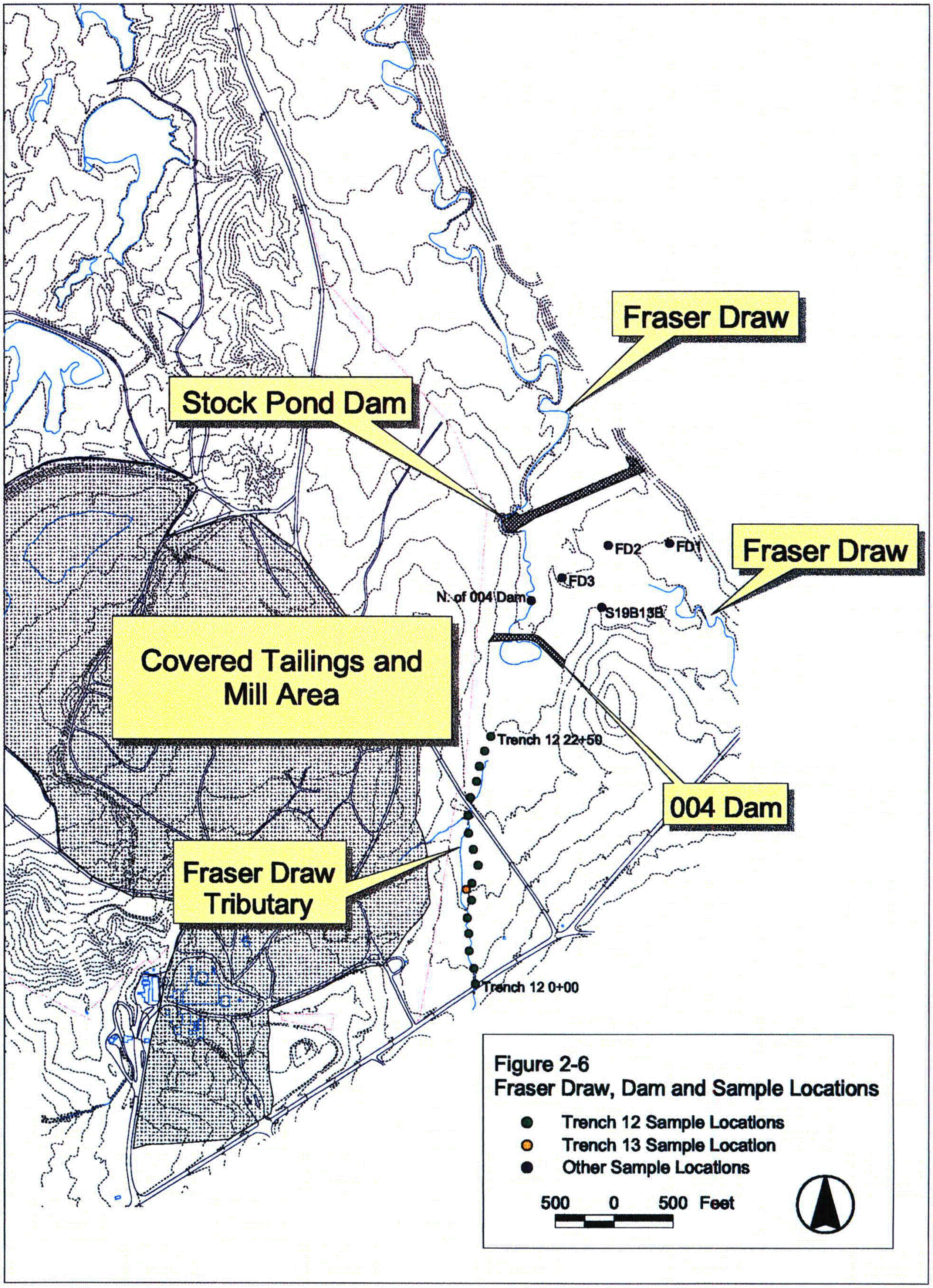


Figure 2-6
Fraser Draw, Dam and Sample Locations

Table 2-3. Soil Sample Data from Mine Drainage Area

Sample ID	Northing Coordinate	Easting Coordinate	ERG Ra-226 (pCi/g)	ELI Ra-226 (pCi/g)[1]	ELI U-Nat (pCi/g)[2]
FD 1	789,327	809,321		14.4	19.3
FD 2	789,308	808,807		11.7	15.3
FD 3	789,033	808,414		9.4	11.7
Trench 12 0+00	785,585	807,677	20.1✓		
Trench 12 1+50	785,716	807,666	9.4		
Trench 12 3+00	785,863	807,624	12.8✓		
Trench 12 4+50	786,012	807,620	7.3		
Trench 12 6+00	786,145	807,611	7.0		
Trench 12 7+50	786,296	807,645	18.3✓		
Trench 12 9+00	786,442	807,647	7.5		
Trench 12 10+50	786,593	807,702	6.2		
Trench 12 12+00	786,724	807,660	4.5		
Trench 12 13+50	786,864	807,620	7.0		
Trench 12 15+00	787,011	807,618	5.3		
Trench 12 16+50	787,165	807,637	7.7		
Trench 12 18+00	787,300	807,690	5.3		
Trench 12 19+50	787,426	807,712	7.5		
Trench 12 21+00	787,554	807,757	8.0		
Trench 12 22+50	787,678	807,810	8.6		
Trench 13 0+50	786,386	807,600	8.7		
N. of 004 Dam 0 - 6"	788,840	808,151	39.9✓	36.5	32.4
N. of 004 Dam 12 - 18"	788,840	808,151	15.2✓	14.7	9.4
N. of 004 Dam 24 - 30"	788,840	808,151	35.3✓	34.2	18.8
N. of 004 Dam 36 - 42"	788,840	808,151	21.5✓	18.6	207.0
S19B13B[3]	788,784	808,750	10.6	10.1	18.3

[1] Ra-226 Analyzed using wet chemistry.

[2] Ra-226 Analyzed using closed-can gamma spectrometry.

[3] Note: Survey of S19B13B had 11 gamma readings with an average of 43221 cpm.

nat concentration ratio is 1.1. This ratio is not reflective of uranium ore or uranium mill tailings but is consistent with the ratio found in mine overburden and other surface ore outcrops.

From the discussions above, PMC concludes that the contamination in the mine drainage areas is not byproduct material. However, because of the proximity of the Fraser Draw tributary to the Mill Operations, PMC removed a vast amount of material, hoping to clean the area to the cleanup criteria. While most of the source term was removed, they abandoned the effort when it became apparent that it may be impossible, possibly due to natural outcrops within the immediate area. However, there is no way of knowing whether the residual material arises from natural outcrop or from mine water contamination, but it is considered very unlikely to be from byproduct material.

2.3.2 Haul Road

Prior to the construction of the Lucky Mc Mill, uranium ore was transported by truck across the current mill site on the road labeled Haul Road on Figure 2-1. The historical practice was to use mine overburden waste rock as a road base. Ore trucks were not covered which allowed ore spillage along the road. Based on these observations, it would be natural to expect ore within 100 feet or more of this road.

During the cleanup, the presence of ore near the road was visually confirmed. In one location, a large piece of ore approximately one foot in diameter was found at a distance of approximately 60 feet from the Haul Road. At the time the road was used, it was built to accommodate large off-road trucks and therefore was very wide. The road runs northwest within the site and then turns and runs almost due north. The segment adjacent to the tailings pile cover will be covered by an extension of radon barrier as shown in Figure 2-7.

No attempt was made to remediate the roadway north of the tailings piles. While the area next to the road may have been scraped, any residual contamination within 100 feet of the road was ignored since it is not byproduct material.

2.3.3 Solution Ponds Reclamation Area

The solution ponds lie north of the tailings piles and west of the Haul Road. The ponds will be reclaimed under a plan approved by the NRC. As a part of the reclamation, any residual contamination west of the wind blown tailings outline (WBT) as shown in Figure 2-7 and other figures will be removed and the area verified using NRC-approved procedures.

2.3.4 Windblown Tailings Areas

The windblown tailings areas identified on Figure 2-1 were subject to extensive remediation measures that are described in Section 3 of this document. The nature and

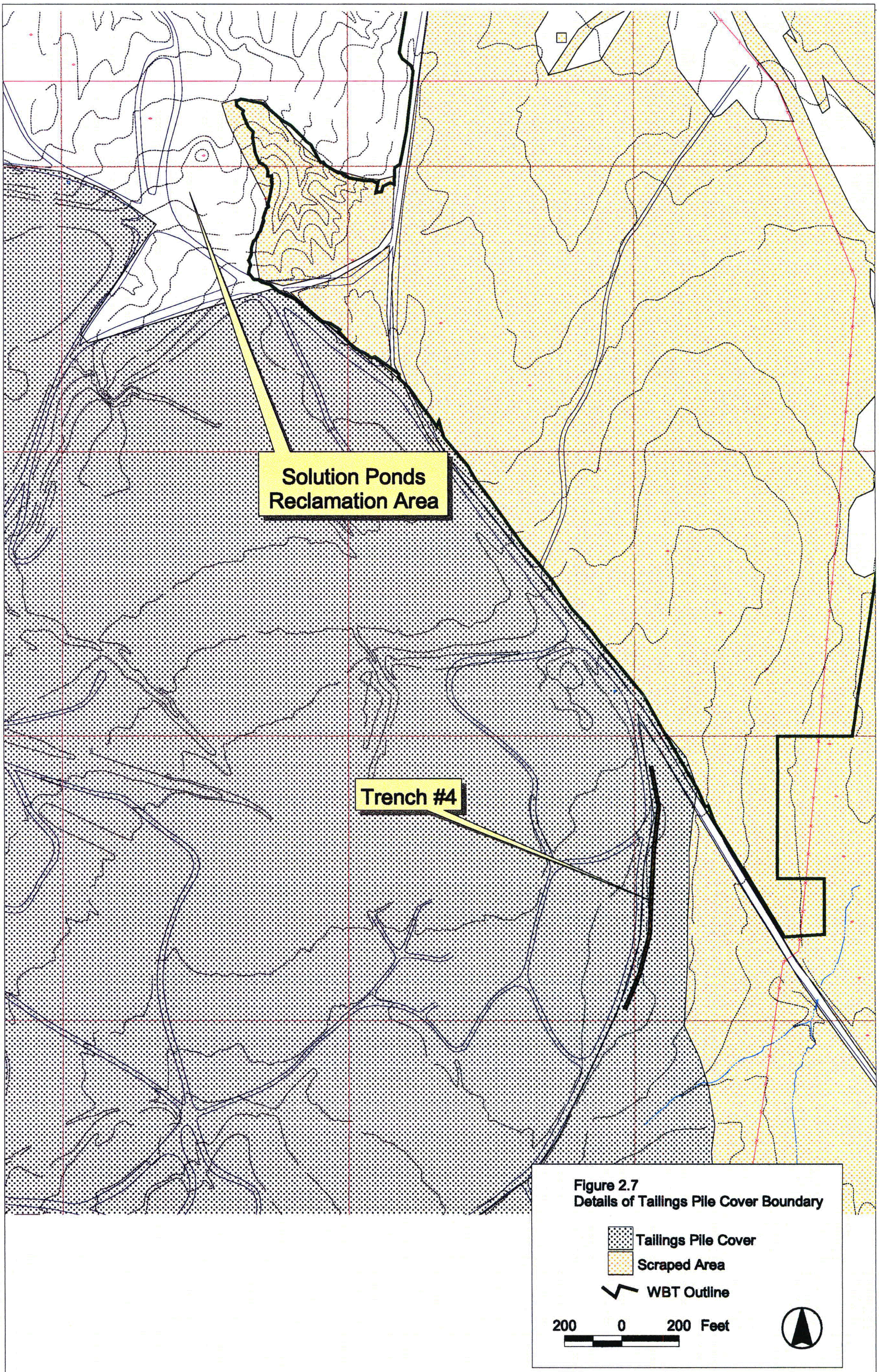


Figure 2.7
Details of Tailings Pile Cover Boundary

distribution of radionuclide concentrations with respect to the objectives of the Reclamation Plan and U.S. NRC License requirements are discussed in Sections 3 and 4 of this report.

2.4 Potential for Deep Contamination

The potential for deep contamination existed in the old mill yard, heap leach facility, and ore storage pad areas due to construction activities over the life of the plant. PMC excavated to great depths (more than 10 feet) in some areas to remove contaminated soils. In other areas, surface soils were excavated down to natural soils without a noticeable change in gamma exposure rate levels. Since it was difficult to ascertain whether the material was natural or mill related, PMC has revised the reclamation plan to apply radon barrier and erosion protection to these areas. The area to be covered is shown in Figure 2-1.

PMC is currently conducting a ground-water restoration program where contaminated ground water is pumped and evaporated. Ground water from an uncontaminated aquifer is pumped and injected at the boundary of the contaminated plume to maintain a hydraulic gradient to contain the plume. The wells and piping from these injection wells are located within trenches in the windblown tailings contaminated area. Some of the trenches containing the pipes had been back filled with contaminated soil. Remediation of these trenches is discussed in Section 4.3.

Lastly, a thick layer of contaminated silt and sediment exist above the Stock Pond Dam within Fraser Draw. As was discussed previously, this contamination resulted primarily from mine dewatering efforts. Since this is not classified as byproduct material, the area will not be remediated.

3. SOIL CLEANUP AND VERIFICATION PLAN

A revised Soil Cleanup Verification Survey and Sampling Plan was submitted to the NRC on January 12, 1996 to replace Appendix H, Volume II of the Lucky Mc Mine Tailings Reclamation Plan. The plan called for the use of Global Positioning System (GPS)-based gamma-ray surveys to be used to identify areas requiring cleanup. Gamma-ray action levels were determined by correlation studies in the windblown area. During the course of the NRC review, informal discussions led PMC to submit modifications to the plan as indicated in letters dated March 13, 1996, March 21, 1996, and May 9, 1996. The NRC requested two additional studies. These studies were completed, with the data supporting the use of a gamma-ray action level of 50,000 cpm.

The plan is based on removal of surface soils having Ra-226 concentrations that exceed 5 pCi/g above background, or 9.5 pCi/g, averaged over a layer with thickness of 15 cm and an area of 100 m^2. For subsurface layers of 100 m^2 area, the cleanup criterion is 15 pCi/g above background, or 19.5 pCi/g. Gamma-ray surveys were done to identify areas having gamma-ray count rates higher than 50,000 cpm. Heavy equipment including scrapers and motor graders was used to remove surface soils to a depth of approximately 15-30 cm. The area was then resurveyed and areas requiring additional removal were identified. This iterative procedure was used until all areas were below the action level or it was determined that the elevated readings resulted from natural background radionuclide concentrations.

3.1 Site Coordinate System

The data was managed using the ArcView GIS software program. A site coordinate system, based on state plane coordinates, was developed across the site as shown in Figure 3-1. Each 1000-ft by 1000-ft area was divided into four equal grid blocks of 500-ft by 500-ft dimensions. These "major grid blocks", each being 500-ft by 500-ft, were then further divided into 33.33-ft by 33.33-ft grid blocks. Each of these smaller grid blocks corresponds to an area approximately equal to 100 m^2, the basis of the cleanup standard.

The grid block nomenclature is best understood by looking at Figure 3-2. In the figure, the 1000-ft by 1000-ft area is subdivided into four major grid blocks. Then the grid block W19B is subdivided into 25 grid blocks, each being 100-ft by 100-ft and numbered from 1 to 25. The Grid Block No. W19B15 is then divided into nine 33.33-ft by 33.33-ft grid blocks. The names of the smallest grid blocks in this example are W19B15A, W19B15B, ...and W19B15J. For ease in managing the soil samples, the composite surface soil samples taken from these grid blocks were identified by using the corresponding grid block number as the sample number.

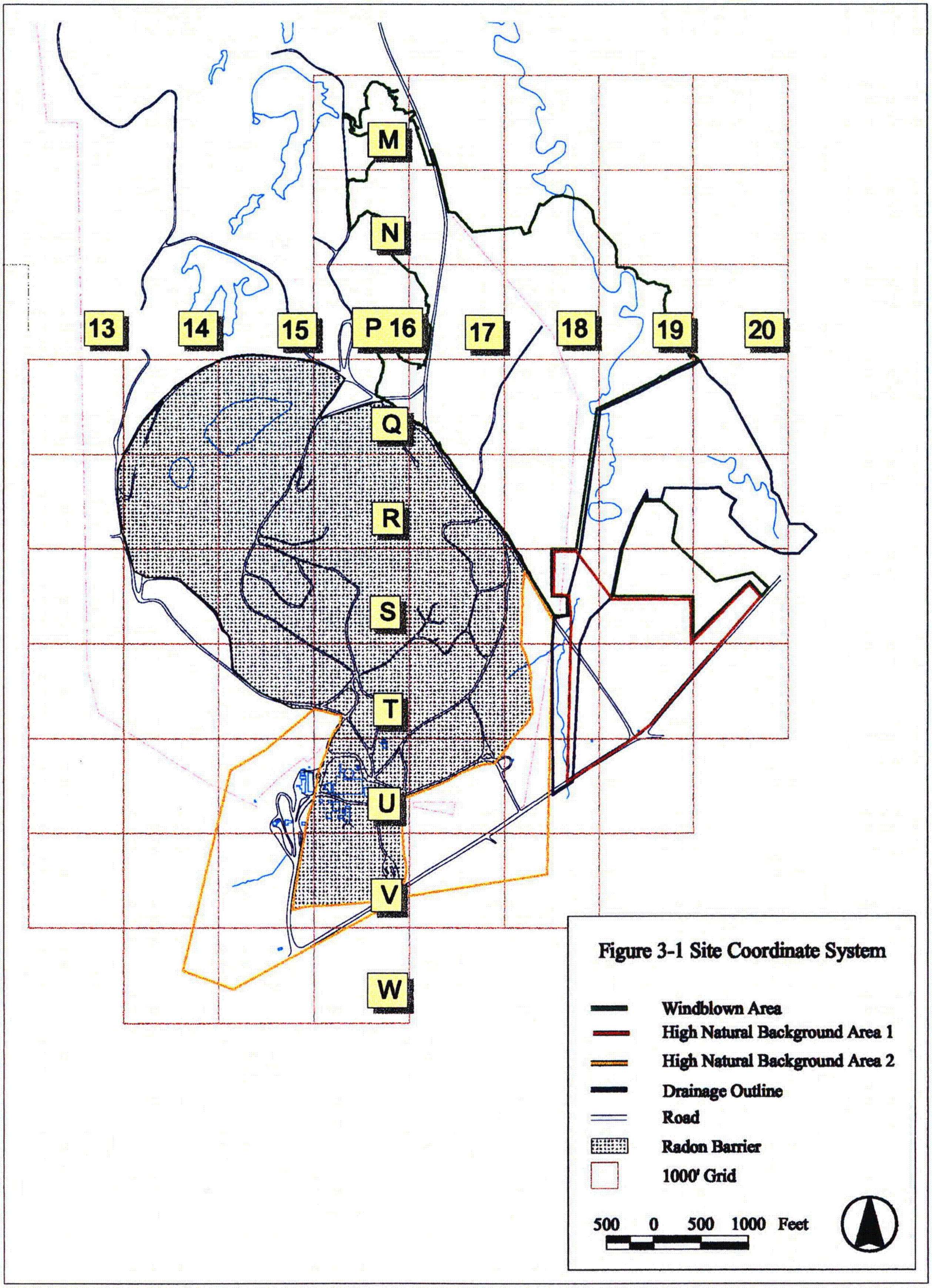
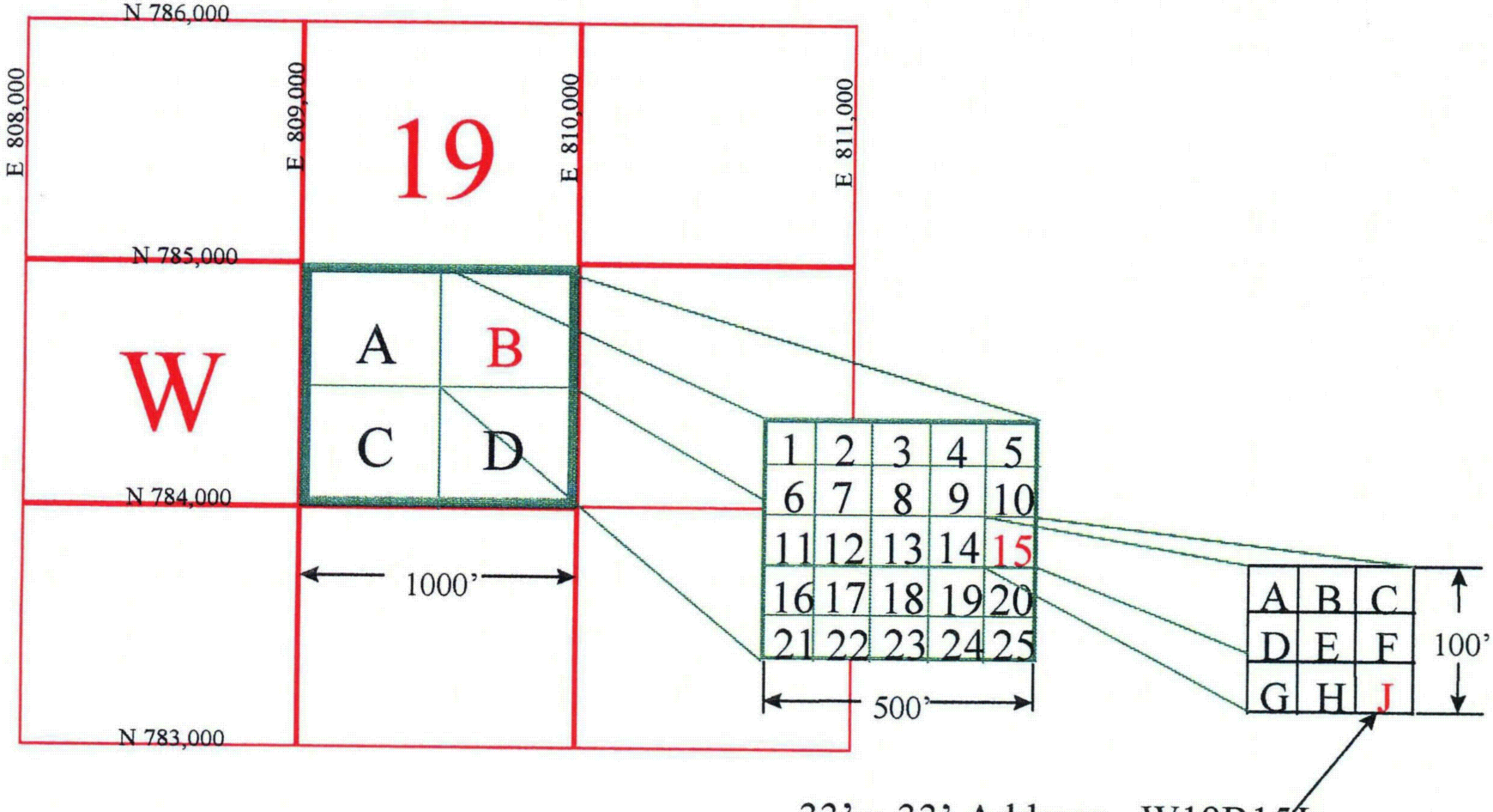


Figure 3-1 Site Coordinate System



33' x 33' Address - W19B15J

Figure 3-2 Site Coordinate and Grid Block Nomenclature

3.2 Changes to Original Plan

Reclamation activities at the Lucky Mc Mill Site are regulated through the activities and procedures contained in PMC (1992) and its subsequent amendments, as well as conditions of the NRC Radioactive Materials License SUA-672. Throughout the project it was necessary to deviate from two requirements contained in these licensing documents. A notice that deviation from the original analytical methods was submitted to the NRC in a letter (PMC 1997), while a modification to the gamma-ray action level from the "Blazer" survey was presented to NRC staff during an April 1997 conference in Rockville, MD.

3.2.1 Analytical Methods

The original analytical plans called for screening all verification samples using the on-site gamma-ray spectrometer to provide assurance that the cleanup was successful. The samples were to have been submitted to Energy Laboratories, Inc. (ELI) for analysis by gamma-ray spectroscopy. Of the total submitted, five percent of the samples were to be analyzed using radiochemical analytical procedures. Early in the cleanup, data from samples that were analyzed by these methods were compared to one another as well as to that of an NRC laboratory. The ELI gamma-ray spectroscopy results were in disagreement with the other methods. Conversely, data obtained from the ERG gamma-ray spectroscopy, ELI radiochemistry and NRC methods showed excellent agreement (PMC 1997). Additional supporting data are presented in Section 5. PMC advised the NRC on January 1, 1997 (PMC 1997) that, until ELI resolved this discrepancy, PMC would have ELI analyze all duplicate samples using radiochemical methods. PMC had all windblown cleanup verification samples analyzed using the ELI radiochemistry method. Uranium in soil samples was analyzed using fluorometric methods.

3.2.2 Gamma Surveys

The studies to support the initial Soil Cleanup Verification Survey and Sampling Plan proposed a 55,000 cpm gamma-ray action level. The initial gamma surveys for the study had been performed by personnel holding the detectors, while the Blazer-mounted detectors were used to obtain most of the data for the actual cleanup. The early results indicated an unacceptably high failure rate for the verification soil samples using the 55,000 cpm action level. PMC therefore reduced the action level to 50,000 cpm. A study was later done to determine the difference between data obtained using the Blazer-mounted detectors and hand-held detectors. The finding was that the action level should be reduced to 51,000 cpm when using the Blazer due to a shielding effect caused by the detector mount. Since an action level of 50,000 cpm was being used at the time, no changes were made as a result of the study. The data and results from this study are included in Appendix C . An additional study was done at the request of the NRC to demonstrate that the action level was appropriate for use in the mill area. The results, as reported in PMC, 1997, supported a value of 50,000 cpm as a gamma ray action level.

4. REMEDIATION AND VERIFICATION OF THE WINDBLOWN TAILINGS AREA

Remediation of windblown tailings areas at the PMC Site required a series of activities including initial gamma survey, scraping and removal of tailings with heavy equipment, collection and analysis of verification samples, and a final gamma survey. In certain windblown areas this process was repeated several times. As areas were being decontaminated by removal of surface layers of soil, subsequent gamma-ray surveys revealed that some pipe trenches had been back-filled with slightly contaminated material. The contaminated soil was removed, the trench cleanup verified, the trench back filled with uncontaminated material, and a final gamma-ray survey was conducted on the surface.

4.1 Initial and Post-Remediation Gamma Surveys of Lucky Mc Mill Site

Figure 4-1 shows the initial gamma-ray survey of the off-pile areas around the mill yard and tailings piles. All off-pile areas with a gamma-ray count rate above 50,000 cpm were considered for cleanup. After areas were decontaminated, the gamma-ray survey was extended a minimum of 250 feet beyond the areas that required decontamination. Radiological surveys were conducted in some areas well beyond where any windblown cleanup was required since the area was downwind of the tailings pile. This is particularly evident north of the tailings pile. This area beyond the boundary of the cleanup area is referred to as the "buffer zone" which has been included in the "Windblown Area" shown in the figures of this report.

An initial plot of all gamma data records for the decontaminated area was done to identify data gaps in the area surveyed. All 100-m^2 grid blocks having areas with no data on approximately 30 percent or more of the area were identified. The GPS units were taken back to the field and used to locate those particular grid blocks. Another survey was conducted where possible. This additional data was added to the data base prior to further analysis. In some cases, the area could not be safely surveyed due to the terrain. In other cases, large brushy areas could not be surveyed without removal of the vegetation. Hindrance by heavy vegetation occurred beyond the decontaminated areas where the gamma-ray levels were low. A decision was made to not remove the vegetation in these environmentally sensitive areas. A few grid blocks were inaccessible because of an existing soil pile or standing water. PMC will fill these data gaps when access is possible. All areas with data gaps were documented as to why the data were not obtained with the descriptions provided in Appendix D. The locations of the grid blocks where the data gaps exist are shown in Figure D-1 of the appendix.

A GIS data management application was used to count the number of gamma data records in each 100-m^2 grid block to assure that a minimum of five data records existed. The average of the data records was also calculated and documented to assure that the average gamma-ray count rate was below the action level of 50,000 cpm. After

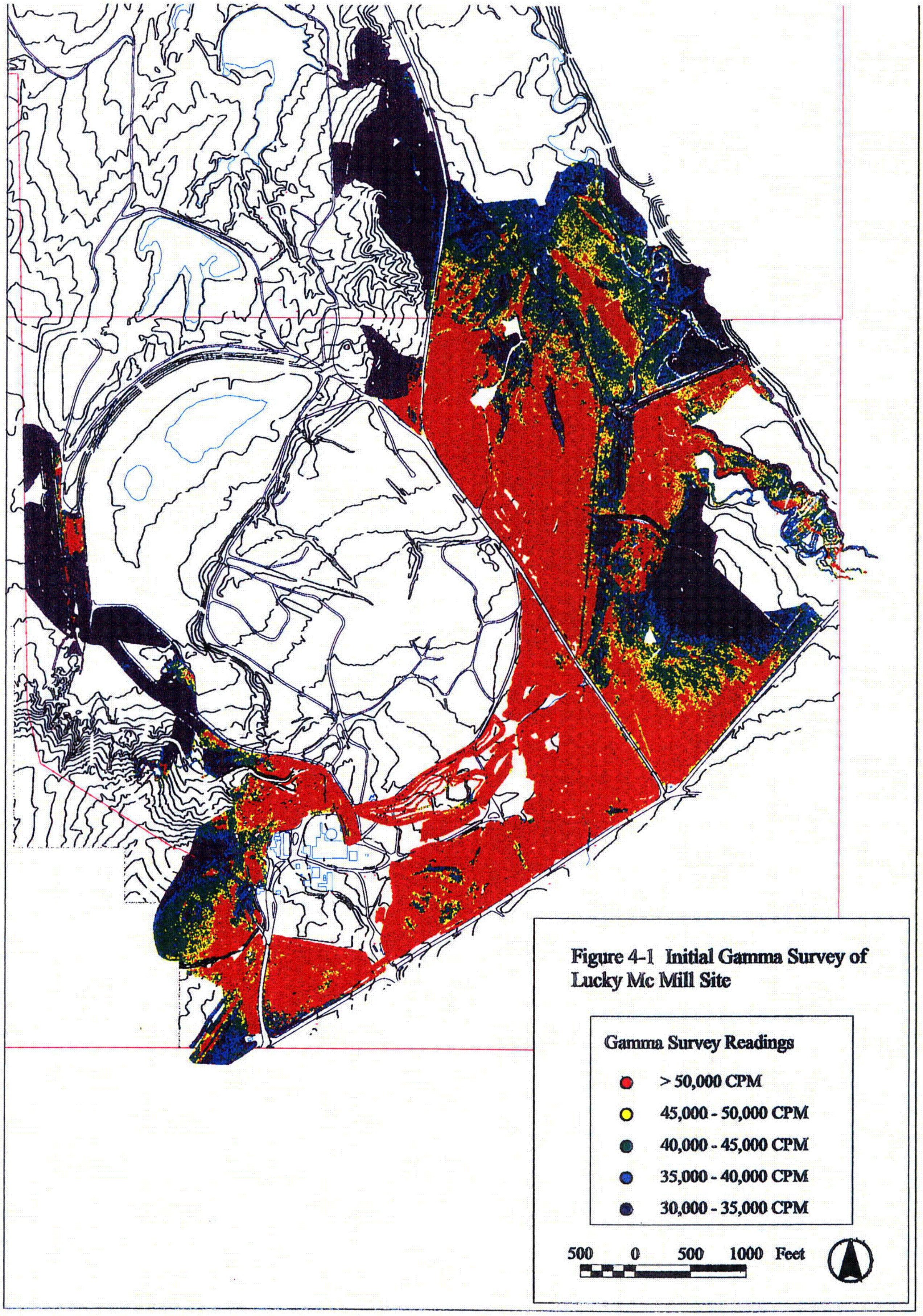


Figure 4-1 Initial Gamma Survey of Lucky Mc Mill Site

this was achieved, the software was used to identify the three 100-m^2 grid blocks within each 500-ft by 500-ft grid block that had the highest average gamma count rate. These three grid blocks were then sampled and analyzed for Ra-226, using a five-point-composite sampling procedure. All major grid blocks that had a portion or all surface soils removed were sampled using this procedure.

Additional samples were taken beyond the 500-ft by 500-ft grid blocks containing the scraped area, referred to as the buffer zone. At a minimum, the next 500-ft by 500-ft grid block beyond the grid blocks containing the scraped area will have one 100-m^2 grid block sampled, the sample being taken from the grid block with the highest average gamma-ray count rate. In many cases three samples were taken from the 500-ft by 500-ft grid blocks in the buffer zone. While this was not required by the NRC-approved verification plan, the data provide additional comfort that the boundary of the cleanup was adequately defined.

The final gamma survey of the areas decontaminated and not proposed to be covered is shown in Figure 4-2. Eliminating the areas that were discussed in Sections 2.1 and 2.2, considered as high natural background areas or mine drainage areas, results in the identification of the potential windblown area shown in Figure 4-3. Figure 4-3 highlights the area that required cleanup (scraped area) within the potential windblown area. Two very large areas were surveyed even though cleanup was not required. The first area extends north along the haul road for approximately 2,000 ft beyond the scraped area. Another area is a slight knoll bounded by HNB-1 and the Mine Drainage Area. Both of these areas had the potential for windblown contamination from the mill yard or tailings impoundments and therefore were sampled using the sampling protocol for the buffer zone. The 100-ft corridor on each side of the haul road north of the tailings ponds was not included in the survey since this area is considered to be affected by ore rather than byproduct material. Sample locations for the windblown contaminated area and buffer area are shown in Figure 4-3.

A set of 24-inch by 36-inch maps has been produced to show the final gamma-ray count rate data. A map sheet exists for each 500-ft by 500-ft grid block. Isocontour data for areas above 50,000 are highlighted. These maps sheets are included as Appendix E.

4.2 Windblown Tailings Area Verification Data

4.2.1 Sample Results and Associated Gamma-Ray Survey Data

Table 4-1 provides the results of all samples taken in the windblown area along with the average gamma-ray count rate. The 170 sample locations and sample numbers are shown in Figure 4-3. Seventy-eight of the samples were collected from areas where heavy equipment had been used to scrape surface layers of elevated-activity soil. The remaining 92 samples were taken from non-scraped areas contiguous to the scraped areas or from the extensive buffer zone. All of the grid blocks that failed the on-site

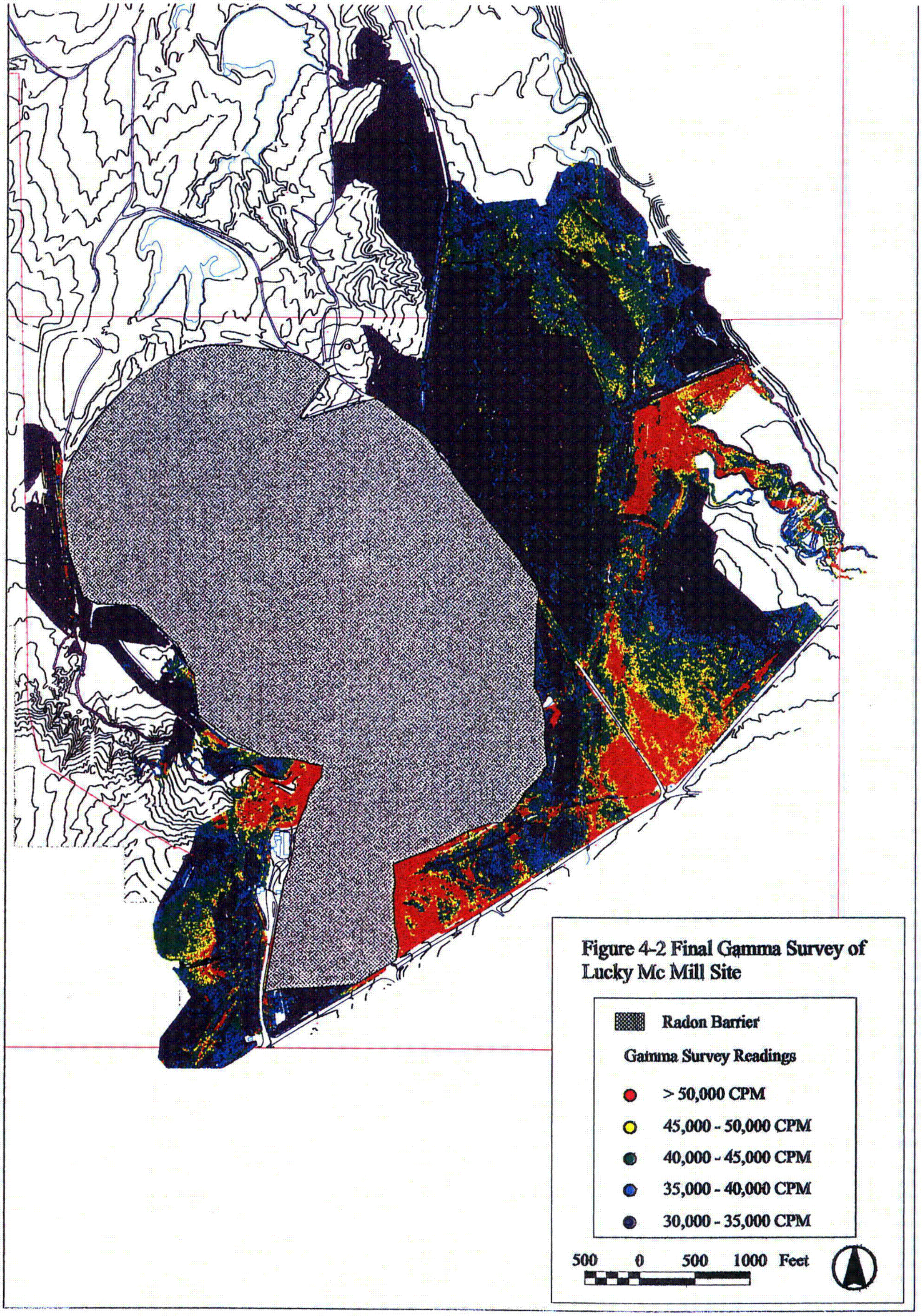


Figure 4-2 Final Gamma Survey of Lucky Mc Mill Site

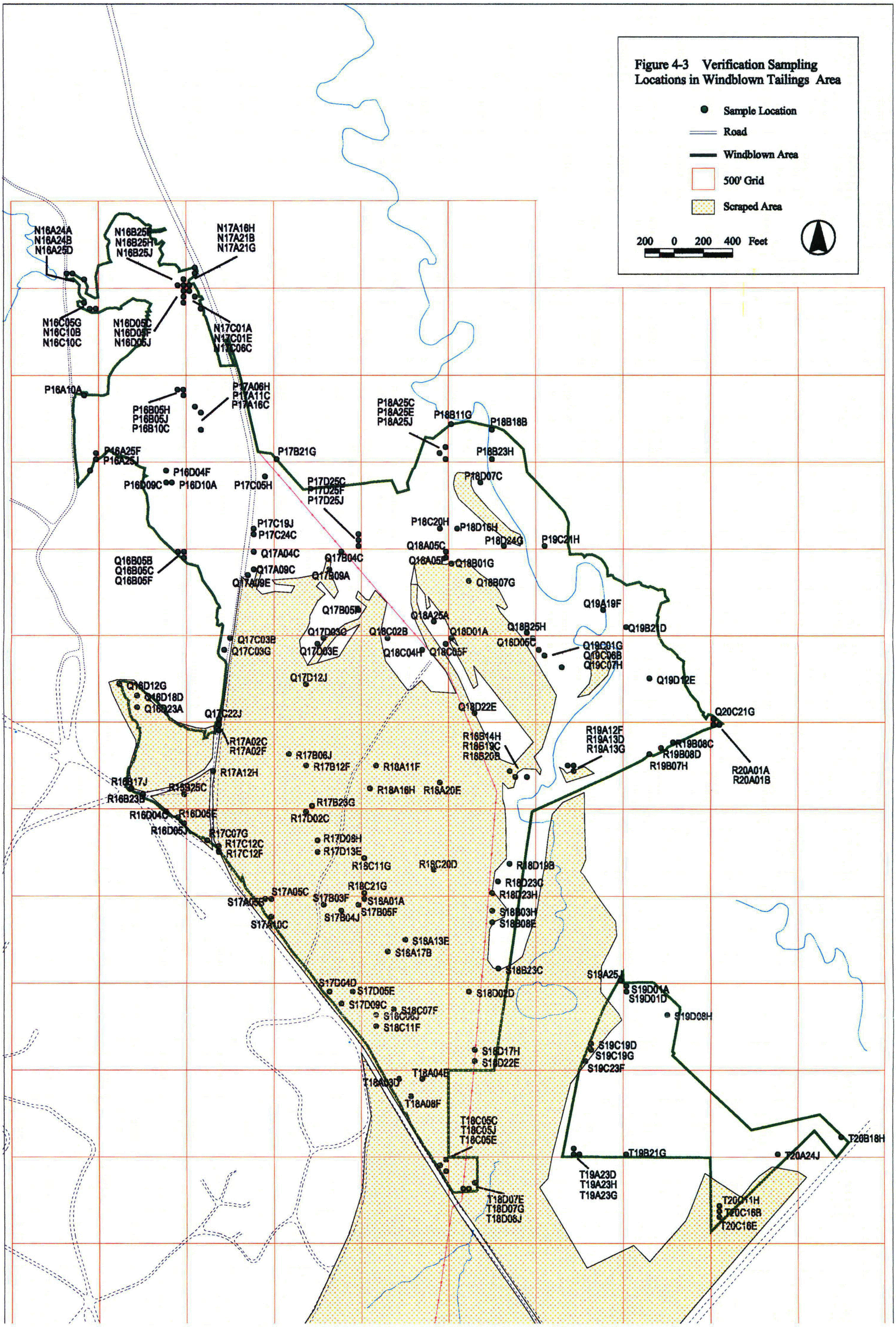


Figure 4-3 Verification Sampling Locations in Windblown Tailings Area

Table 4-1 Windblown Tailings Area Gamma Measurements and Sample Results

did Partial chemistry analysis for all samples

Sample ID	Grid Block[1] Northing	Easting	Number of Gamma Readings	Avg. Gamma Count Rate (cpm)	ELI Ra-226[2] (pCi/g)	ELI U-nat (pCi/g)
N16A24A	792,583	805,317	10	21502	1.5	N/A
N16A25D	792,550	805,417	5	21278	3.0	N/A
N16A24B	792,583	805,350	18	21243	1.5	N/A
N16B25J	792,516	805,984	23	31935	2.2	N/A
N16B25H	792,516	805,950	19	29839	2.3	N/A
N16B25F	792,550	805,984	21	29691	1.9	N/A
N16C05G	792,416	805,417	17	22716	2.7	N/A
N16C10C	792,383	805,484	23	22474	2.7	N/A
N16C10B	792,383	805,450	28	22332	3.5	N/A
N16D05F	792,450	805,984	30	35986	3.2	N/A
N16D05C	792,483	805,984	29	34553	4.8	N/A
N16D05J	792,416	805,984	24	33295	2.1	N/A
N17A21G	792,516	806,017	17	35516	7.4	N/A
N17A21B	792,583	806,050	30	33081	7.3	3.15
N17A16H	792,616	806,050	5	33019	5.2	N/A
N17C01A	792,483	806,017	35	41660	9.8	10.9
N17C06C	792,383	806,084	11	39002	7.4	N/A
N17C01E	792,450	806,050	26	37732	8.7	N/A
P16A10A	791,883	805,417	13	21389	1.4	N/A
P16A25J	791,516	805,484	11	20133	0.8	N/A
P16A25F	791,550	805,484	22	19727	1.5	N/A
P16B05H	791,916	805,950	25	34048	3.9	N/A
P16B05J	791,916	805,984	31	33337	6.6	N/A
P16B10C	791,883	805,984	38	33066	3.4	N/A
P16C05E	791,450	805,450	9	20456	1.2	N/A
P16D10A	791,383	805,917	36	33405	1.5	N/A
P16D09C	791,383	805,884	26	32763	2.4	N/A
P16D04F	791,450	805,884	29	32665	4.8	N/A
P17A11C	791,783	806,084	33	36713	10.4	9.43
P17A06H	791,816	806,050	43	36452	10.0	9.86
P17A16C	791,683	806,084	20	35570	7.9	7.9
P17B21G	791,516	806,517	8	34293	4.0	N/A
P17C24C	791,083	806,384	14	42832	5.7	5.2
P17C05H	791,416	806,450	16	42810	7.7	8.6
P17C19J	791,116	806,384	11	41528	6.1	5.8
P17D25C	791,083	806,984	23	45921	5.7	N/A
P17D25J	791,016	806,984	14	45659	6.7	N/A
P17D25F	791,050	806,984	22	44773	9.0	N/A
P18A25C	791,583	807,484	15	39677	2.9	N/A
P18A25J	791,516	807,484	26	39448	3.4	N/A
P18A25E	791,550	807,450	18	38959	2.8	N/A
P18B11G	791,716	807,517	11	46215	7.9	N/A
P18B18B	791,683	807,750	17	43912	5.2	N/A
P18B23H	791,516	807,750	21	42132	9.0	N/A

non scraped from 9.5 pci/g

12 exceedence

non scraped

non scraped beyond

Avg of 28 samples taken scraped areas 4.35pci/g Ra-226

2091

4.75 pci/g

44

NRC Bkg 4.5 pci/g

Sample ID	Grid Block[1] Northing	Easting	Number of Gamma Readings	Avg. Gamma Count Rate (cpm)	ELI Ra-226[2] (pCi/g)	ELI U-nat (pCi/g)	
P18C20H	791,116	807,450	18	46813	5.4	N/A	
P18D07C	791,383	807,684	25	47593	3.5	N/A	
P18D16H	791,116	807,550	13	46575	2.6	N/A	
P18D24G	791,016	807,817	28	46419	3.2	N/A	
P19C21H	791,016	808,050	21	44821	3.8	N/A	
Q16B05F	790,950	805,984	17	31618	5.2	N/A	
Q16B05B	790,983	805,950	16	30523	3.8	N/A	
Q16B05C	790,983	805,984	15	29909	2.1	N/A	
Q16D23A	790,083	805,717	35	26298	5.3	3.3	
Q16D12G	790,216	805,617	11	24387	2.7	N/A	
Q16D18D	790,150	805,717	19	23557	2.2	N/A	
Q17A09C	790,883	806,384	16	46088	2.6	4.5	
Q17A09E	790,850	806,350	16	45832	15.4	10.0	Non scraped
Q17A04C	790,983	806,384	17	44907	9.4	N/A	
Q17C22J	790,016	806,184	5	44706	6.4	6.83	
Q17C03G	790,416	806,217	31	39691	8.1	9.06	
Q17C03B	790,483	806,250	6	38959	8.5	6.96	
Q17B09A	790,883	806,817	19	46218	2.6	N/A	
Q17B04C	790,983	806,884	15	46001	4.5	N/A	
Q17B05F	790,650	806,984	20	44693	10.8	9.25	non scraped
Q17D12J	790,216	806,684	14	41641	8.8	N/A	
Q17D03E	790,450	806,750	21	40832	10.9	6.4	non scraped on an edge
Q17D03C	790,483	806,784	18	39830	14.4	14.0	non scraped " " "
Q18A05C	790,983	807,484	14	46588	3.3	N/A	
Q18A25A	790,583	807,417	17	46304	5.5	N/A	
Q18A05F	790,950	807,484	17	45485	6.0	N/A	
Q18B07G	790,816	807,617	32	47514	1.3	N/A	
Q18B25H	790,516	807,950	10	47059	8.6	N/A	
Q18B01G	790,916	807,517	13	46851	7.8	N/A	
Q18C04H	790,416	807,350	37	45409	7.9	N/A	
Q18C05F	790,450	807,484	12	45111	8.0	N/A	
Q18C02B	790,483	807,150	25	45091	14.7	10.5	non scraped
Q18D01A	790,483	807,517	16	45713	9.1	N/A	
Q18D22E	790,050	807,650	14	45589	3.4	N/A	
Q18D05C	790,483	807,984	8	45425	7.3	N/A	
Q19A19F	790,650	808,384	6	45757	9.5	N/A	
Q19B21D	790,550	808,517	28	38501	9.1	N/A	
Q19C01G	790,416	808,017	9	44862	5.4	N/A	
Q19C06B	790,383	808,050	9	44624	4.3	N/A	
Q19C07H	790,316	808,150	10	44522	6.8	N/A	
Q19D12E	790,250	808,650	8	38223	8.0	7.69	
Q20C21G	790,016	809,017	17	30909	3.6	N/A	
R16B23B	789,583	805,750	18	36937	1.9	N/A	
R16B25C	789,583	805,984	26	31834	7.1	N/A	
R16B17J	789,616	805,684	23	31160	2.8	N/A	
R16D05J	789,416	805,984	7	26952	2.9	N/A	

28615

6.23 pCi/g

46

Sample ID	Grid Block[1]		Number of Gamma Readings	Avg. Gamma Count Rate (cpm)	ELI Ra-226[2] (pCi/g)	ELI U-nat (pCi/g)	
	Northing	Easting					
R16D05E	789,450	805,950	8	24750	1.9	N/A	
R16D04C	789,483	805,884	6	24291	1.1	N/A	
R17A12H	789,716	806,150	11	45260	8.8	6.64	
R17A02F	789,950	806,184	10	39294	9.7	7.7	scraped
R17A02C	789,983	806,184	9	37212	7.7	7.19	
R17B06J	789,816	806,584	15	37536	1.9	N/A	
R17B12F	789,750	806,684	14	37523	6.7	4.74	
R17B23G	789,516	806,717	13	36750	12.4	8.77	scraped
R17C12F	789,250	806,184	8	40620	7.5	6.3	
R17C07G	789,316	806,117	9	39858	10.4	7.36	scraped
R17C12C	789,283	806,184	18	37676	9.6	5.48	scraped
R17D02C	789,483	806,684	18	41415	6.8	N/A	
R17D13E	789,250	806,750	9	38920	7.4	N/A	
R17D08H	789,316	806,750	21	37342	8.3	8.2	
R18A20E	789,650	807,450	15	35382	5.7	N/A	
R18A16H	789,616	807,050	10	34235	2.9	N/A	
R18A11F	789,750	807,084	20	33862	4.8	N/A	
R18B14H	789,716	807,850	25	47098	1.6	N/A	
R18B19C	789,683	807,884	17	46698	6.0	N/A	
R18B20B	789,683	807,950	15	46649	7.1	N/A	
R18C20D	789,150	807,417	13	47098	5.5	N/A	
R18C11G	789,216	807,017	12	46698	4.1	N/A	
R18C21G	789,016	807,017	13	46649	2.2	N/A	
R18D23C	789,083	807,784	17	46987	6.0	N/A	
R18D19B	789,183	807,850	13	45089	4.8	N/A	
R18D23H	789,016	807,750	14	44742	3.6	N/A	
R19A12F	789,750	808,184	16	46534	6.8	N/A	
R19A13D	789,750	808,217	27	46230	3.2	N/A	
R19A13G	789,716	808,217	22	45936	3.5	N/A	
R19B07H	789,816	808,650	6	39475	3.3	N/A	
R19B08C	789,883	808,784	10	39229	8.7	N/A	
R19B08D	789,850	808,717	9	38852	8.4	N/A	
R20A01A	789,983	809,017	8	31257	4.7	N/A	
R20A01B	789,983	809,050	12	30953	3.7	N/A	
S17A05B	788,983	806,450	19	36469	2.5	N/A	
S17A10C	788,883	806,484	16	22726	2.5	N/A	
S17A05C	788,983	806,484	17	21298	2.0	N/A	
S17B05F	788,950	806,984	18	39689	6.0	N/A	
S17B04J	788,916	806,884	14	35473	8.7	N/A	
S17B03F	788,950	806,784	14	34804	3.2	N/A	
S17D09C	788,383	806,884	19	32659	6.3	N/A	
S17D04D	788,450	806,817	15	32560	3.7	N/A	
S17D05E	788,450	806,950	11	31660	4.7	N/A	
S18A13E	788,750	807,250	13	40559	2.0	N/A	
S18A17B	788,683	807,150	12	36363	2.9	N/A	
S18A01A	788,983	807,017	12	35515	1.8	N/A	

243.1

5.28 pci/g

46

Sample ID	Grid Block[1] Northing	Grid Block[1] Easting	Number of Gamma Readings	Avg. Gamma Count Rate (cpm)	ELI Ra-226[2] (pCi/g)	ELI U-nat (pCi/g)
S18B08E	788,850	807,750	16	47186	6.2	N/A
S18B23C	788,583	807,784	17	47046	8.9	N/A
S18B03H	788,916	807,750	16	45707	7.1	N/A
S18C07F	788,350	807,184	18	39602	2.0	N/A
S18C06J	788,316	807,084	20	39104	4.8	N/A
S18C11F	788,250	807,084	16	38728	5.1	N/A
S18D02D	788,450	807,617	31	38160	7.2	N/A
S18D17H	788,116	807,650	18	36268	7.1	N/A
S18D22E	788,050	807,650	13	34779	7.3	N/A
S19A25J	788,516	808,484	7	34980	8.6	N/A
S19C19D	788,150	808,317	9	39380	5.7	N/A
S19C23F	788,050	808,284	12	38028	7.2	N/A
S19C19G	788,116	808,317	14	37900	4.2	N/A
S19D01A	788,483	808,517	24	32696	4.5	N/A
S19D01D	788,450	808,517	21	30585	6.2	N/A
S19D08H	788,316	808,750	35	30164	3.2	N/A
T18A03D	787,950	807,217	14	42613	4.4	N/A
T18A04E	787,950	807,350	13	40400	7.5	N/A
T18A08F	787,850	807,284	13	39228	3.4	N/A
T18C05E	787,450	807,450	24	32839	2.8	N/A
T18C05J	787,416	807,484	23	31160	7.0	N/A
T18C05C	787,483	807,484	19	29720	2.7	N/A
T18D06J	787,316	807,584	13	40310	7.4	N/A
T18D07G	787,316	807,617	13	39583	4.5	N/A
T18D07E	787,350	807,650	14	39108	4.9	N/A
T19A23H	787,516	808,250	12	44910	6.3	N/A
T19A23D	787,550	808,217	30	44800	6.8	N/A
T19A23G	787,516	808,217	13	44212	4.5	N/A
T19B21G	787,516	808,517	15	33901	4.1	N/A
T20A24J	787,516	809,384	11	40768	4.9	N/A
T20B18H	787,616	809,750	8	43997	9.2	N/A
T20C16B	787,183	809,050	16	42921	7.0	8.91
T20C11H	787,216	809,050	18	42715	8.0	N/A
T20C16E	787,150	809,050	14	41954	8.9	N/A

[1] Radiochemistry results

[2] Coordinates of NW corner of grid block

199.6

5.87 pCi/g

34
/170

9283

Avg 5.52 pCi/g for 170 samples

screening Ra-226 analysis were evaluated by looking for gamma-ray anomalies using hand-held radiation detectors. Second or third attempts at removing soil with elevated activity were often made prior to taking the final soil verification sample. The twelve verification samples that failed are strongly believed to arise from slight elevations of natural background radionuclides or from ore or waste rock from the haul road. Data to support this conclusion is presented in the next section. The locations of the failed samples are shown in Figure 4-4.

4.2.2. Ra-226 to U-nat Concentration Ratios

It became apparent early in the windblown cleanup that portions of the windblown area were affected by ore from the old haul road as well as natural background anomalies with Ra-226 concentrations above 4.5 pCi/g. Extensive efforts were made to remove all soils above the gamma action level. Surface deposits of various thickness were removed even though it was known that the material could not have been windblown tailings. Verification samples were taken and screened by analyzing for Ra-226 on the on-site spectrometer. If the screening Ra-226 value was significantly above background, further screening was done to determine whether the Ra-226 could have arisen from windblown tailings. If the Ra-226 concentration was 5 pCi/g or more greater than the U-nat value and the Ra-226 exceeded the cleanup limit, additional cleanup was normally done and a final verification sample was taken and reported in Table 4-1.

The rationale for limiting the Ra-226 concentration to 5 pCi/g above the uranium concentration was developed near the end of the project and is based on data obtained during cleanup of the windblown area and the high natural background areas. In previous sections, it has been shown that the Ra-226/U-nat concentration ratio is quite variable for natural ore outcrops as well as mine waste. The average concentration ratio for these selected samples is close to one. The radionuclides in the ore that was milled normally was close to secular equilibrium and thus the ratio was approximately 0.5. For tailings sands, assuming a 90 percent or greater recovery, the Ra-226/U-nat ratio should be a minimum of 5. If it is assumed that the Ra-226/U-nat concentration ratio of the background radionuclides in the windblown area is 1, then the U-nat concentration must be limited to about 4.5 pCi/g plus the contribution from the windblown contamination. If a sample contains an average background concentration of Ra-226 plus an additional 5 pCi/g of Ra-226 from windblown tailings, the sample should have a maximum of 5.5 pCi/g uranium. This would result in a minimum ratio of 9.5/5.5 or 1.7 for the average sample with windblown contamination but still passing the Ra-226 cleanup criterion of 9.5 pCi/g. Because of the variability in the natural background Ra-226/U-nat ratio, this will apply to most but not all of the samples.

The use of a ratio of 1.7 as typical of a windblown sample that barely passes the cleanup criteria, providing the average Ra-226 background concentration is 4.5 pCi/g, is supported by an analysis of the plot studies that were used to develop the gamma-ray action level. In that study, 25 plots were sampled where the Ra-226

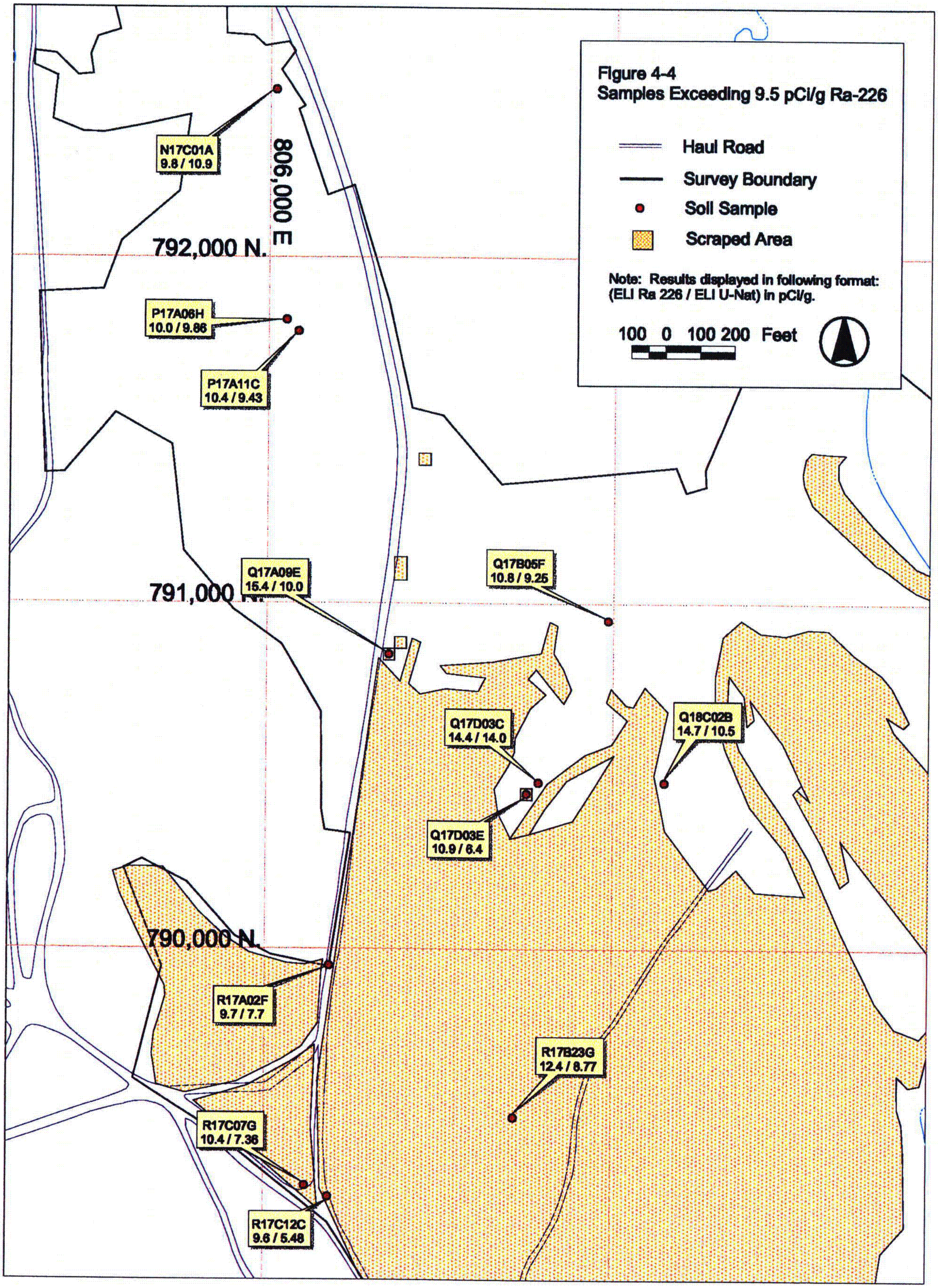


Figure 4-4
Samples Exceeding 9.5 pCi/g Ra-226

concentration ranged from 6 to 30 pCi/g and the average Ra-226 to U-nat concentration ratio was 1.9 with a standard deviation of 0.36. The Ra-226/U-nat concentration ratios ranged from 1.1 to 3.0. Ten of the 15 samples that had Ra-226/U-nat ratios greater than 1.7 had Ra-226 concentrations greater than 9.5 pCi/g. There were also four samples with Ra-226 concentrations greater than 9.5 pCi/g that had Ra-226/U-nat ratios less than 1.7. Since there was no way of determining what the natural Ra-226 concentrations were for areas chosen for the study, it must be assumed that the natural background variability for the plots chosen for the study was representative of the variablity for the entire area. This variability is probably responsible for the variability in the ratios. It is significant that the average Ra-226/U-nat ratio for the select group of samples presented in Table 4-2 averages only 1.2 while the average for the windblown study was 1.9. This confirms that on the average, the windblown component of the residual activity in the samples in Table 4-2 is low compared to that in the referenced study.

The reasonableness of this approach can be seen by looking at the data in Table 4-2, where the Ra-226/U-nat concentration ratios are provided for 29 final verification samples. As indicated earlier, any final verification sample where the Ra-226 screening value approached or exceeded 9.5 pCi/g was also analyzed for U-nat. Therefore Table 4-2 includes most samples with elevated Ra-226 concentrations, including the 12 samples that exceed the 9.5 pCi/g Ra-226 cleanup criterion. As can be seen from the table, the Ra-226/U-nat ratio is very consistent, averaging 1.2. In addition, all samples that had high Ra-226 concentrations also had elevated U-nat concentrations. This indicates that it is highly unlikely that the excess activity arises from windblown tailings.

PMC did additional cleanup in the windblown area in the fall of 1998 in a further attempt at reducing the number of grid blocks that had failed. Grid blocks that had failed and the uranium and Ra-226 values differed by 5 pCi/g or more were selected for further remediation by removing another 15-30 cm surface layer. The Ra-226 and U-nat concentrations before and after further remediation are provided in Table 4-3. As can be seen from the data, the concentrations for two of the grid blocks remained above the cleanup criterion of 9.5 pCi/g. For the other five grid blocks, removing additional material brought the Ra-226 concentrations below the 9.5 pCi/g criterion. It is interesting to note that the uranium concentration increased in five of the seven final verification samples when compared to the initial samples. While this additional work eliminated five failed grids, no conclusion can be reached as to whether tailings were involved in those five grids.

4.2.3 Gamma-Ray Action Level

The gamma-ray action level of 50,000 cpm was derived from data taken in the windblown area of the site prior to reclamation. For windblown contamination, the distribution of the radionuclides as a function of depth is significantly different from that of natural outcrops of low-grade ore or for any area where the windblown

Table 4-2 Windblown Tailings Area Radium-226/U-nat Concentration Ratios

Sample ID	Grid Block[1]		Number of Gamma Readings	Avg. Gamma Count Rate (cpm)	ELI Ra-226[2] (pCi/g)	ELI U-nat (pCi/g)	Ra-226/U-nat Ratio
	Northing	Easting					
N17A21B	792,583	806,050	30	33081	7.3	3.15	2.3
N17C01A	792,483	806,017	35	41660	9.8	10.9	0.9
P17A11C	791,783	806,084	33	36713	10.4	9.43	1.1
P17A06H	791,816	806,050	43	36452	10.0	9.86	1.0
P17A16C	791,683	806,084	20	35570	7.9	7.9	1.0
P17C24C	791,083	806,384	14	42832	5.7	5.2	1.1
P17C05H	791,416	806,450	16	42810	7.7	8.6	0.9
P17C19J	791,116	806,384	11	41528	6.1	5.8	1.1
Q16D23A	790,083	805,717	35	26298	5.3	3.3	1.6
Q17A09C	790,883	806,384	16	46088	2.6	4.5	0.6
Q17A09E	790,850	806,350	16	45832	15.4	10.0	1.5
Q17C22J	790,016	806,184	5	44706	6.4	6.83	0.9
Q17C03G	790,416	806,217	31	39691	8.1	9.06	0.9
Q17C03B	790,483	806,250	6	38959	8.5	6.96	1.2
Q17B05F	790,650	806,984	20	44693	10.8	9.25	1.2
Q17D03E	790,450	806,750	21	40832	15.8	6.17	2.6
Q17D03C	790,483	806,784	18	39830	14.4	14.0	1.0
Q18C02B	790,483	807,150	25	45091	14.7	10.5	1.4
Q19D12E	790,250	808,650	8	38223	8.0	7.69	1.0
R17A12H	789,716	806,150	11	45260	8.8	6.64	1.3
R17A02F	789,950	806,184	10	39294	9.7	7.7	1.3
R17A02C	789,983	806,184	9	37212	7.7	7.19	1.1
R17B12F	789,750	806,684	14	37523	6.7	4.74	1.4
R17B23G	789,516	806,717	13	36750	12.4	8.77	1.4
R17C12F	789,250	806,184	8	40620	7.5	6.3	1.2
R17C07G	789,316	806,117	9	39858	10.4	7.36	1.4
R17C12C	789,283	806,184	18	37676	9.6	5.48	1.8
R17D08H	789,316	806,750	21	37342	8.3	8.2	1.0
T20C16B	787,183	809,050	16	42921	7.0	8.91	0.8

Average 1.2

[1] Radiochemistry results

[2] Coordinates of NW corner of grid block

Table 4-3. Ra-226 and Uranium Concentrations Before and After Reclamation

Before Further Remediation

Sample ID	Scraped (s) or Unscraped(u)	ELI Ra226 (pCi/g)	ELI U-Nat (pCi/g)	Ratio Ra-226/Unat
P17C24C	u	10	4	2.5
P17C05H	u	11.8	4.9	2.4
P17C19J	u	9.7	1.8	5.4
Q17A09	u	14	5.4	2.6
Q17A09	u	15.3	6.22	2.5
Q17D03	s	15.8	6.17	2.6
R17D08	s	17	9.5	1.8
Mean		13.4	5.43	2.8
Std. Dev.		2.9	2.35	1.2

After Further Remediation

Sample ID	Scraped (s) or Unscraped(u)	ELI Ra226 (pCi/g)	ELI U-Nat (pCi/g)	Ratio Ra-226/Unat
P17C24C	s	5.7	5.21	1.1
P17C05H	s	7.7	8.62	0.9
P17C19J	s	6.1	5.79	1.1
Q17A09	s	2.6	4.53	0.6
Q17A09	s	15.4	10.03	1.5
Q17D03	s	10.9	6.4	1.7
R17D08	s	8.3	8.2	1
Mean		8.1	6.97	1.1
Std. Dev.		4.1	2.02	0.4

contamination has been removed. Therefore a gamma-ray action level will be significantly different for the situations. In order to illustrate this, the code RESRAD was used to calculate the dose rate from direct radiati.on for two different situations. The first assumed that a windblown tailings layer of 1 cm thickness was deposited on a 14-cm layer of natural background soil (4.5 pCi/g Ra-226). The Ra-226 concentration was adjusted so that, if averaged over the 15 cm layer, the average Ra-226 concentration would equal 9.5 pCi/g. The corresponding values for uranium were added but were naturally found to have little influence on the results. The resulting exposure rate was calculated to be 117 mrem/y. The second case assumed that the radionuclides were distributed uniformly in the top15-cm layer such that the average Ra-226 concentration was 9.5 pCi/g. In this case, the resulting exposure rate was 86 mrem/y. While ratios of exposure rates may not be exactly equivalent to the corresponding gamma-ray count rate ratios, they should be approximately equal. Therefore the 50,000 cpm gamma-ray action level for windblown would have to be reduced by a factor equal to the fraction of the calculated doses, or to 37,000 cpm if one were to apply it to outcrops of natural material at 9.5 pCi/g. Naturally, if one assumes a different vertical distribution, the ratio would change. This analysis demonstrates why there was a scatter in the correlation study data and that a conservative action level was required to compensate for the varying thickness of the windblown tailings layer and to a lesser extent, the natural background concentration at the study points.

The data in Table 4-1 show that the average count rate for all of the 170 verification samples was less than the gamma-ray action level of 50,000 cpm. One would expect that all of the Ra-226 values would be within the cleanup limit if the action level had been properly selected. For 158 samples taken from grid blocks having the highest average gamma-ray levels, the Ra-226 values show that the cleanup was successful. However, there are twelve samples that still exceed the cleanup criteria, with the average gamma count rates ranging from approximately 37,000 cpm to 45,000 cpm. Since standard procedure was to carefully scan all grid blocks that were sampled to look for "hot spots", we can assume that the radioactivity is evenly distributed over the grid blocks. In addition, since the average count rate is below the gamma-ray action level, the radionuclide distribution is expected to be rather constant within the first 15-cm layer. This evidence indicates that the radionuclides in the twelve failed grids do not arise from windblown tailings.

The concepts discussed above show why it is not possible to use verification data to check the accuracy of the gamma-ray action level developed from studies done on windblown areas at the Lucky Mc Mill site. This would have been possible for sites where the natural background concentration was small compared to the cleanup criterion. However, it appears that there are at least a few areas (e.g. grid blocks Q17A09E and Q17D03E) where the natural background concentrations exceed the cleanup criteria.

4.3 Trench Excavations and Verification Data

All known water-line and gas-line trenches on the site that contain piping are currently being used. Since the gas pipe line and on-going ground-water restoration operations could not be interrupted, contaminated soils were removed only to a depth equal to that of the top of the pipe. In most cases, this was adequate to verify that the trench was clean. In a few places within the water-line trenches, slightly contaminated soils (up to 30.5 pCi/g Ra-226) extended beyond these depths around the pipes. Since the Ra-226 concentrations are low, it is unlikely that soils will exceed the cleanup criteria if the pipes are removed in the future since these soils will be mixed with clean material during the removal. The trenches were back filled with clean soil soon after sampling to prevent the water pipes from freezing. PMC has no plans for removing the pipes and intends to include them in the area to be transferred to the Federal Government.

All trenches were sampled according to Lucky Mc Mine SOP 03.022.02. The SOP requires that a soil sample be taken of the trench bottom and walls at 150- ft intervals. Gamma-ray count rate measurements were done using a shielded Ludlum 44-10 probe. On a few occasions, the shield was not available and a bare probe was used. Gamma-ray action levels of 20,000 cpm for the shielded probe and 50,000 for the bare probe were applied. Average gamma-ray count rates were measured for each side wall and the floor for segments of the trench no longer than 150 feet. This was normally done by taking an integrated count for one minute as the surfaces were scanned.

Figure 4-5 provides the locations of trench segments that showed evidence of contaminated back fill. Trench No. 1 is a segment of the gas line that runs across the site; the remaining trenches contain pipes related to the groundwater restoration program. Expanded views of Figure 4-5 sections are presented in Appendix F for greater clarity. Trench System 1 is merely a large section of the clean water injection system that had evidently been back filled with contaminated soils. Current plans are to include Trench No. 4 under the Tailings Pile radon barrier since large quantities of tailings were later discovered to the south and east of this trench. The coordinates of all trench segments are presented in Appendix F.

Gamma-ray count rate data and the soil sample Ra-226 results for the trench segments and Trench System 1 are presented in Appendix F. The gamma-ray integrated counts were found to exceed the 20,000 cpm action level for the shielded detector at several locations even though the soil samples were within the 19.5 pCi/g cleanup criterion (subsurface layer). The action level was derived based on the correlation for surface soils. As the detector is dropped into a trench, the geometry conditions are more favorable for detection of gamma rays and thus the count rate per pCi/g of Ra-226 increases. In this case, it appears that there was up to a 50 percent increase in the count rate due to geometry conditions.

The soil samples indicate that two out of the 24 soil samples taken from Trench System 1 failed the 19.5 pCi/g cleanup criterion. The two values were 24.2 and 28 pCi/g. The

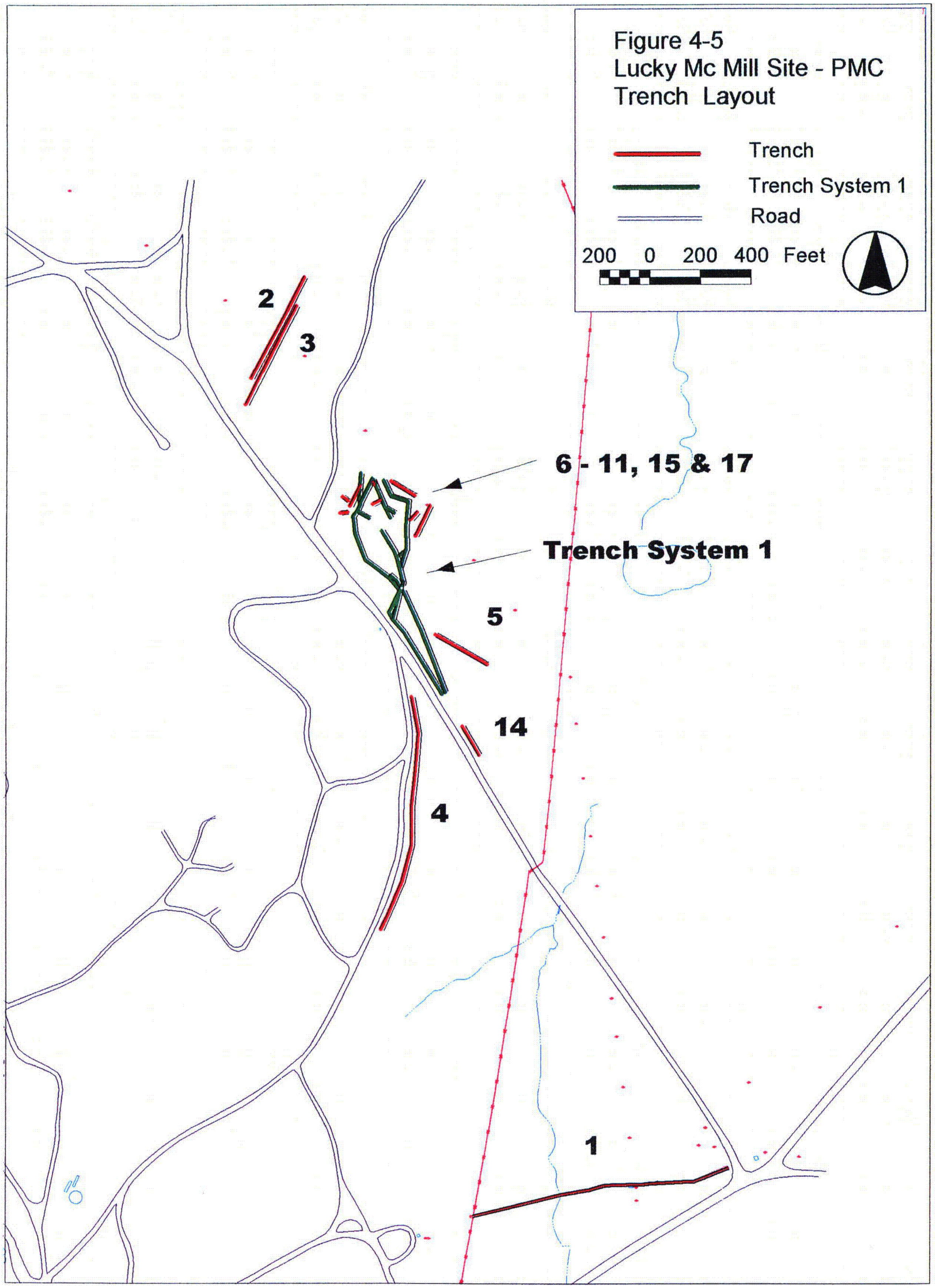


Figure 4-5
Lucky Mc Mill Site - PMC
Trench Layout

one sample in Trench 4 that failed (30.5 pCi/g) the cleanup criterion is not of concern since this trench is now proposed to be covered by radon barrier. All other soil samples were below 19.5 pCi/g. PMC does not believe that reopening the trench to remove additional material can be justified since the concentrations exceeded the cleanup limit by less than 9 pCi/g. Dilution due to mixing will have occurred to the extent that one would not expect to find the area previously sampled.

5. QUALITY CONTROL

Project quality control measures included a validation study for the collection and analysis of gamma-ray data, verification that adequate numbers of measurements were obtained from each 10-meter by 10-meter grid block, and a comparison of analytical duplicate samples analyzed by multiple laboratories. The results of these measures indicated that all data reported and analyzed in this report are of sufficient quality.

5.1 Validation Study for Gamma-Ray Data Collection and Analysis

A quality control test was performed on the data collection process associated with the logging of gamma-ray measurements with accurate location coordinates. The logging system combined Ludlum Instruments, Inc. radiological monitoring equipment, the Trimble global positioning system (GPS), and the ArcView geographic information system (GIS).

Raw radiological survey data are first obtained with a Ludlum 2221 ratemeter / Ludlum 44-10 probe combination, which may be hand held or mounted on a vehicle. The count rate obtained from this combination is displayed on the 2221 digital readout and transferred from memory to the GPS system through an RS232 serial connection. During field surveys, each discrete count rate is then logged with an X and Y coordinate as a single data point in the TDC-1 data logger. When surveying is completed the TDC-1 is disconnected from the rest of the GPS system and the data is downloaded to a computer. The data is then converted to a format used by the GIS. The data can then be displayed and analyzed by the various GIS applications. The GIS applications that may be applied to any data set include statistical calculations including the sum of the count rates, total number of count rates, statistical mean, maximum and minimum count rates, range, standard deviation, and variance.

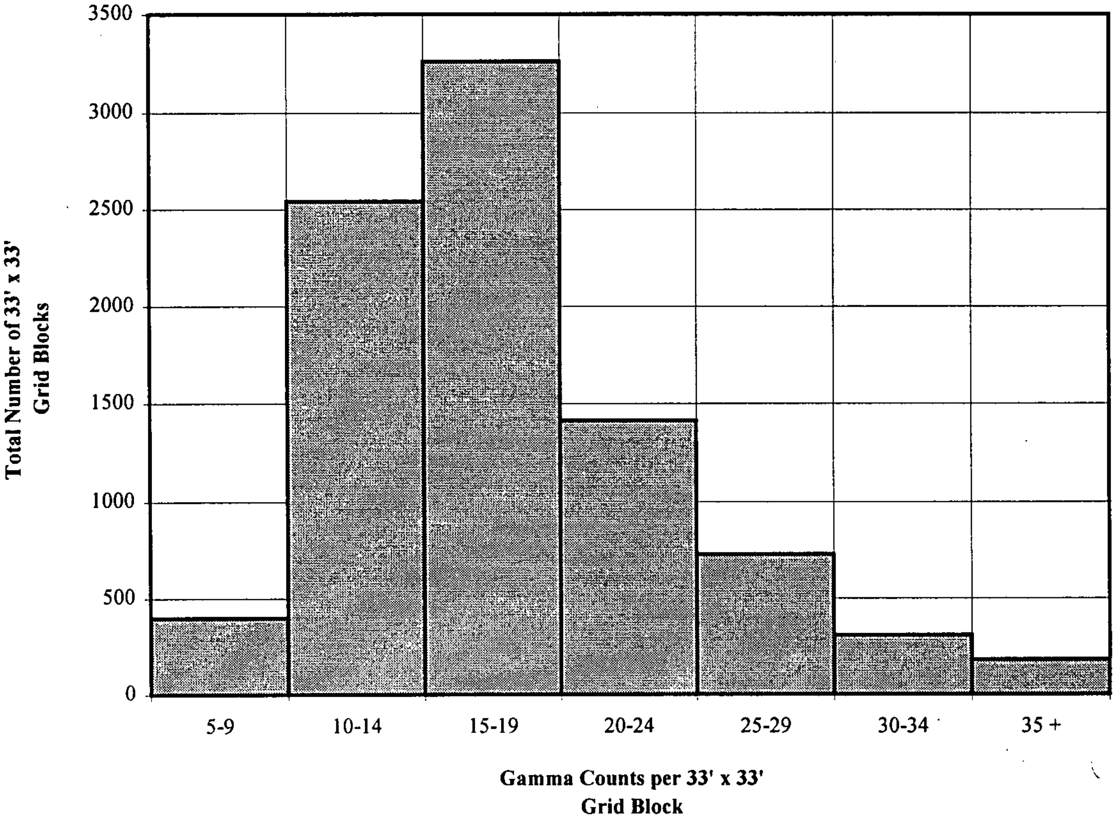
A test was developed to determine if the equipment would maintain the correct values from data acquisition through data processing. The first test step was to visually monitor count rates from a Ludlum 2221 ratemeter. These count rates were manually recorded and compared with those logged by the Trimble Data Collector (TDC-1). After 35 points had been obtained, the Trimble data file was downloaded and converted into a new format used by the ArcView GIS system. The data, now in GIS format, was checked with that originally recorded from the Ludlum 2221. All data pairs matched exactly, validating the conclusion that no error occurs during data logging, downloading or through the changing of format.

Additional quality assurance measures included manual averaging of grid block count rate data, manual counting of records, and daily checks of the GPS position accuracy. These quality assurance measures were performed to the requirements of standard operating procedures. The results of quality control checks were reviewed by NRC inspectors during an August 1997 audit.

5.2 Verification of Adequate Number of Gamma-Ray Measurements per Grid Block

A check was made to assure that the total number of gamma-ray measurements obtained per grid block is five or greater. All radiological survey points were assigned to their appropriate grid block and the total number of measurements in the block tallied using the GIS system. Partial grid blocks along roads and the periphery of the windblown tailings containing fewer than five data points were excluded from the analysis. This exclusion is justifiable since the boundary (periphery) determination was somewhat arbitrary and none of the blocks exhibited elevated gamma-ray count rates. No grid blocks surveyed at the site were found to have fewer than five gamma-ray measurements. The mean number of gamma-ray records per grid block is eighteen, with a standard deviation of six. A histogram presenting the number of records per grid block versus frequency is presented in Figure 5-1.

Figure 5-1. Histogram of Gamma-Ray Count Frequency per Grid Block



5.3 Quality Control Data

Throughout the reclamation project a total of 170 split samples (duplicates) were analyzed by both ERG, Inc. and ELI, Inc. ERG utilized the closed-can method in which sealed samples at equilibrium were counted on a gamma spectrometer to determine Ra-226 concentrations. ELI used a radiochemical separation process through which samples were counted on an alpha spectrometer. ELI did utilize the closed-can method on a group of samples (not included in the 170 total), but experienced analytical difficulties as mentioned in Section 3.2. The ELI closed-can Ra-226 results are not included in this analysis.

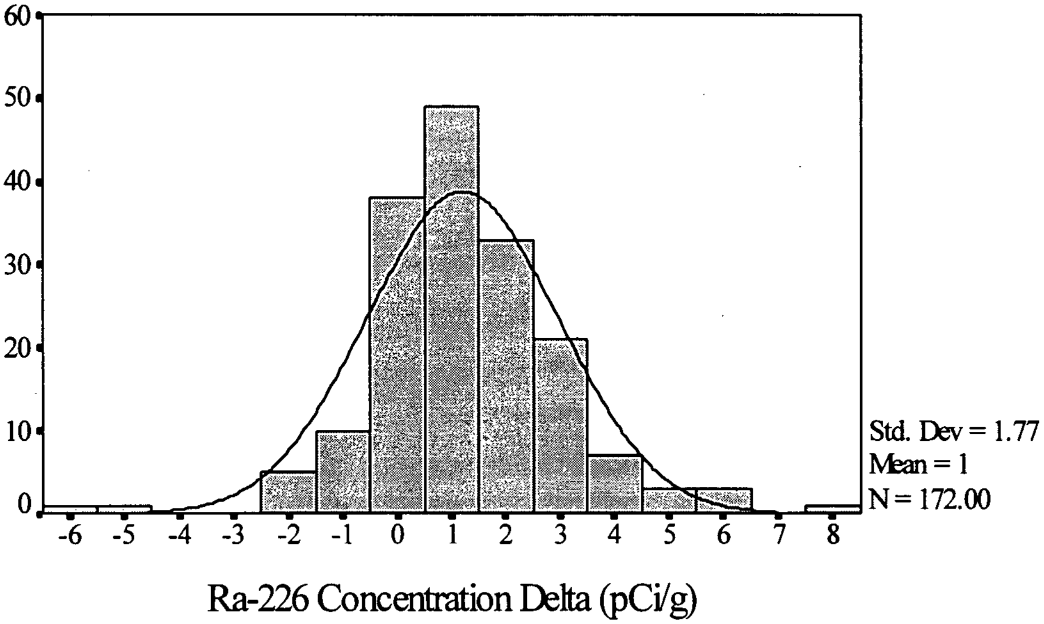
The difference (delta) between all duplicate sample pairs was calculated relative to the ELI radiochemistry results. If the analytical results were in complete agreement, the predicted mean delta would be zero. Based on the results of 170 sample pairs, the mean delta is calculated to be 1.2 pCi/g, with the ERG results being higher than the ELI results.

A number of statistical tests were applied to this data set to determine whether the mean difference in the laboratory results was zero. The results showed that the mean difference was not equal to zero and confirmed the small bias presented above. Tests were also done to confirm that the difference data set was symmetric about the mean as shown in Figure 5-2 and that normality can be assumed. These statistical tests are presented in Appendix H.

Assuming normality, Figure 5-2 shows a small but relatively consistent upward bias in the ERG sample results. However, this bias is well within the measurement error and may be considered to be in good agreement when all potential sources of error are considered, including the error in calibration standards. We should point out that the ERG results were used primarily for screening purposes. The fact that the ERG results are higher than ELI results also added a small degree of conservatism to the program.

Another interlaboratory test was conducted by choosing ten samples from Reid Draw that were known to be contaminated by Ra-226 as well as Th-230. Ten samples were first analyzed for Ra-226 by ERG at the on-site laboratory. The samples were then sent to a vendor laboratory for sample preparation and splitting into three 200 g aliquots. The samples were analyzed for Ra-226 and Th-230 by Acculabs Research, Barringer Laboratories, and Energy Laboratories using radiochemical methods. The results for Ra-226 and Th-230 were very close although statistically, there were some differences. When the reported errors were considered, there were no differences in the reported results. Further details are provided in Appendix G.

Figure 5-2. Histogram of Delta Between ERG/ELI Duplicate Ra-226 Analyses



Only duplicate analyses from split samples included.

6. REFERENCES

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Appendix A

Natural Mineralization and Ore Haul Road Related Contamination in the Immediate Vicinity of the Lucky Mc Mill Site

Appendix A

Natural Mineralization and Ore Haul Road Related Contamination in the Immediate Vicinity of the Lucky Mc Mill Site

I. Natural Mineralization

The mineralization in the Gas Hills Mining District of Wyoming is due to the movement of uranium-enriched groundwater in the Wind River formation, and the subsequent preferential deposition of the uranium due to geochemical reduction in the formation. As a result characteristic roll fronts of uranium mineralization were formed. These roll fronts are located at progressively shallower depths from south to north in the district. In the vicinity of the Lucky Mc mill site the earlier formed roll fronts have been eroded away, are partially eroded and exposed at the surface, or are identifiably intact below the surface. In all these cases the mineralization has been subject to varying degrees of oxidation which remobilized the uranium. Consequently, the uranium was at least partially re-dissolved and leached from the area, leaving behind very low grade residual deposits of uranium accompanied by less mobile daughter radionuclides. The net effect was a mixed picture of residual deposits with varying, but universally lower, uranium content, and varying ratios of Ra226 to Unat. Generally, near complete leaching of the uranium resulted in relatively high Ra/U ratio values, while partial leaching of the uranium resulted in lower Ra/U ratios. A selected bibliography is provided at the conclusion of this discussion that lists various references containing detailed discussions of the uranium mineralization of the Gas Hills Mining District.

These surface or near surface deposits typically exhibit relatively high gamma radiation levels but are not of economic value. The most obvious example lies 3500 feet to the east of the mill site as the original discovery point of mineralization in the Gas Hills. That discovery was made by Neil McNeice in 1953, and the site remains as he found it because of the relative absence of uranium. There are numerous similar but less obvious outcrops immediately adjacent to the mill site. Figure A-1 depicts the major mineralization trends in the Gas Hills as interpreted by Armstrong (1970). The figure is a reduced reproduction of a figure in the referenced paper. It demonstrates the near surface and eroded nature of the ore deposits (labeled "thin") along the northern edge of the uranium district. The Lucky Mc mill site has been located on this copy of the Armstrong figure in order to illustrate that the mill site is impacted by these "thin" zones of residual mineralization.

During the course of early exploratory drilling in the Gas Hills, a number of holes were drilled in the area of the future mill. The earliest holes were drilled while defining the northern limits of the mineralization, but later holes also were intended to confirm the selection of the mill site, avoiding placement of the mill and tailings in any area that might have mining potential. The results of some of that early drilling are presented here. All of the exploration discussed here was conducted prior to any mill construction or tailings deposition. The only exception is hole N136 E66 which was located in the vicinity of the orange sand outcrop knoll south of the main haul road. Figure A-2 presents the locations of the selected holes along with any notations from the original drill hole logs concerning mineralization in the top five feet of each hole. Figure A-3 presents greater detail on hole locations in the immediate vicinity of the mill site. The notations refer to actual sample chemical analyses conducted to ascertain the presence of uranium. In some cases, the radiometric probing of the holes did not indicate sufficient mineralization at the surface to prompt any chemical analyses of near surface samples. In such cases a "NA" notation for "not analyzed" has been used. References to uranium content are expressed in percent U3O8. A value of .01 is equivalent to about 58 pCi Unat/gm of soil. A "trace" can be considered as measureable uranium at some concentration less than 58 pCi/gm. Copies of the original drill hole records for selected holes are included at the end of this appendix.

Bearing in mind that the concentrations of uranium of interest to a miner typically are orders of magnitude higher than what would be considered significant from a site cleanup perspective, it is evident from this baseline data that there are naturally occurring radioactive "hotspots" surrounding the mill site. Since these deposits often are not in equilibrium with uranium due to the previously discussed leaching of the uranium, one would expect in many cases to see disproportionately higher levels of Ra226.

The outcrop of mineralization located on the knoll southeast of the site (see Figure A-2) is particularly noteworthy since it has elevated uranium levels and a relatively high gamma count associated with a readily observable orange colored fine to medium grained sand. That same material is present to the northwest of the knoll, in the area of the east mill ore pad. It was exposed during the removal of the overlying ore pad. This same material is also evident immediately north of the mill shop and old mine office on another knoll. Again, the gamma count is elevated where this material is exposed. See the copies of representative drill logs that provide lithologic descriptions and notations concerning chemical analyses for uranium. There is a correlation between the presence of the so-called orange sand and trace or higher levels of uranium. However, there are sedimentary layers other than the orange sand that also have elevated gamma counts and at least trace amounts of uranium, based upon the early site drilling.

The accumulated data supports the contention that "background" radiation at the Lucky Mc mill site is rather diverse, and in some areas, quite elevated.

II. Ore Haul Road Contamination

The original uranium discovery in the Gas Hills occurred in 1953. At that time the Atomic Energy Commission (AEC) was actively pursuing new uranium reserves in support of the weapons program. By 1954 there was a significant amount of mining activity already underway in the Gas Hills. The earliest mining focused on shallow deposits, and there were a number of different operators such as Levi, Vipont, Atlas, Globe, Western Nuclear, and Lucky Mc developing mines in the district. All of the early production from the Gas Hills was hauled from the district for processing since the first mill in the district (the Lucky Mc mill) did not go into production until February of 1958.

Most of the ore produced in those early years was transported to Riverton where it was loaded into hopper cars for transport by rail to the Edgemont, South Dakota mill for processing. By 1956 the AEC had established a buying station at the Riverton railhead, further encouraging the hauling of ore to Riverton from the Gas Hills. The present day haul route along the east side of the Lucky Mc tailings system was the original haul road for ore deliveries to Riverton. By 1958 The Susquehanna mill had been commissioned in Riverton. As a result, the hauling of Gas Hills ore to Riverton continued despite the startup of three mills in the district during the period 1958-60. Ore hauling to Riverton continued routinely until 1963 when the Susquehanna mill was closed. Even after 1963 the same haul road was used in part on occasion for uranium ore transport. Western Nuclear hauled ore from an underground operation on Copper Mountain (northwest of the Gas Hills) to the Split Rock mill at Jeffrey City. While the normal haul route did not encompass the east side road, when there was inclement weather the east haul road was utilized because it remained passable. Consequently there was some ore transport along the route well into the 1970's.

The hauling of uranium ore along the east side of the Lucky Mc tailings occurred to varying degrees for over twenty years. During that period the east side road was excluded from the Lucky Mc restricted area. The typical ore truck carried a maximum load without any cover in place, leaving the load vulnerable to spillage, particularly as it just started its journey to Riverton when it traversed the section of the haul road east of the Lucky Mc tailings. The end result has been a relatively abundant amount of spilled ore along the east haul road not related to any Lucky Mc milling activities. That material remains today as an additional complicating factor in the area when evaluating the cleanup of windblown tailings at the Lucky Mc mill site.

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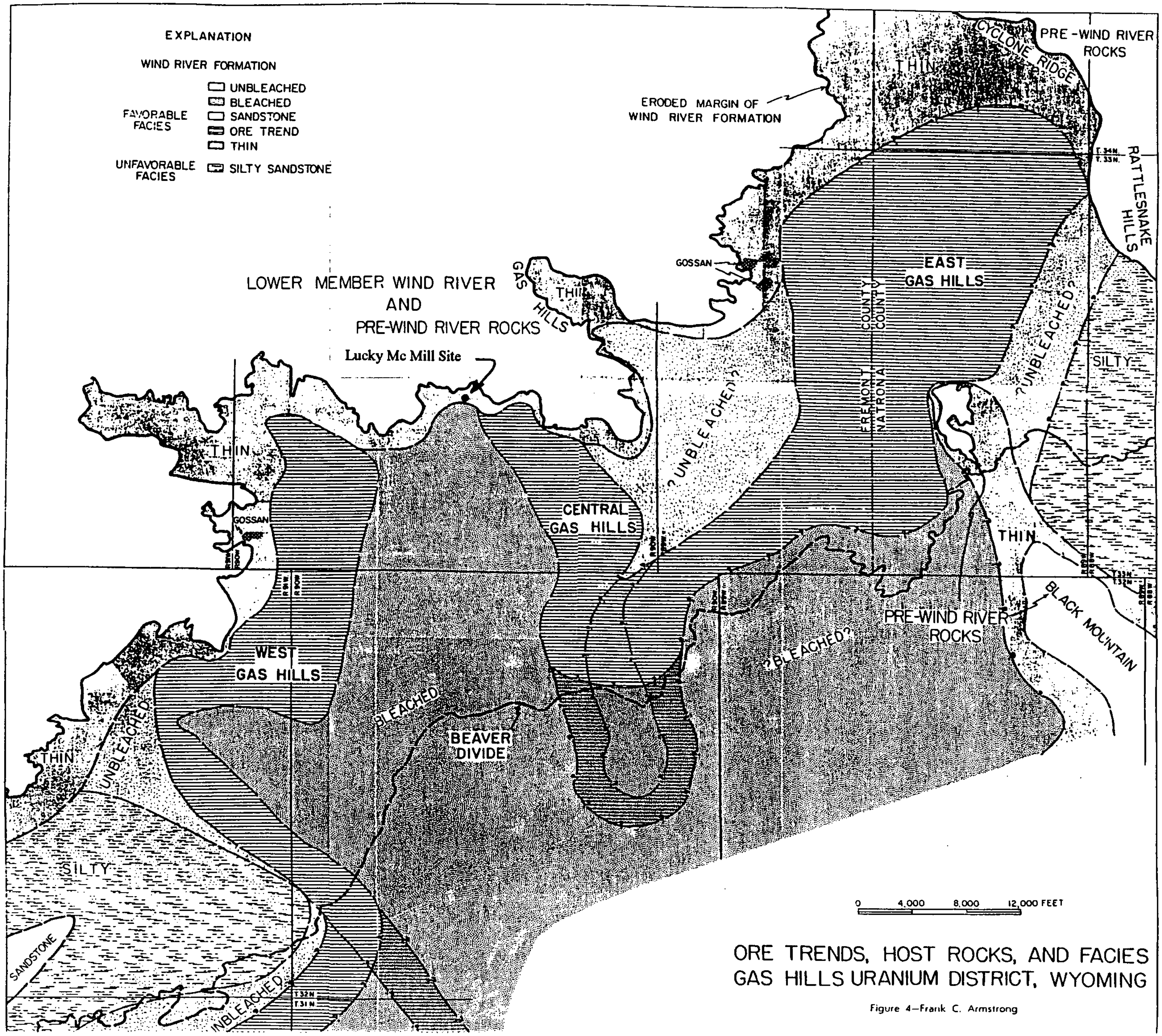
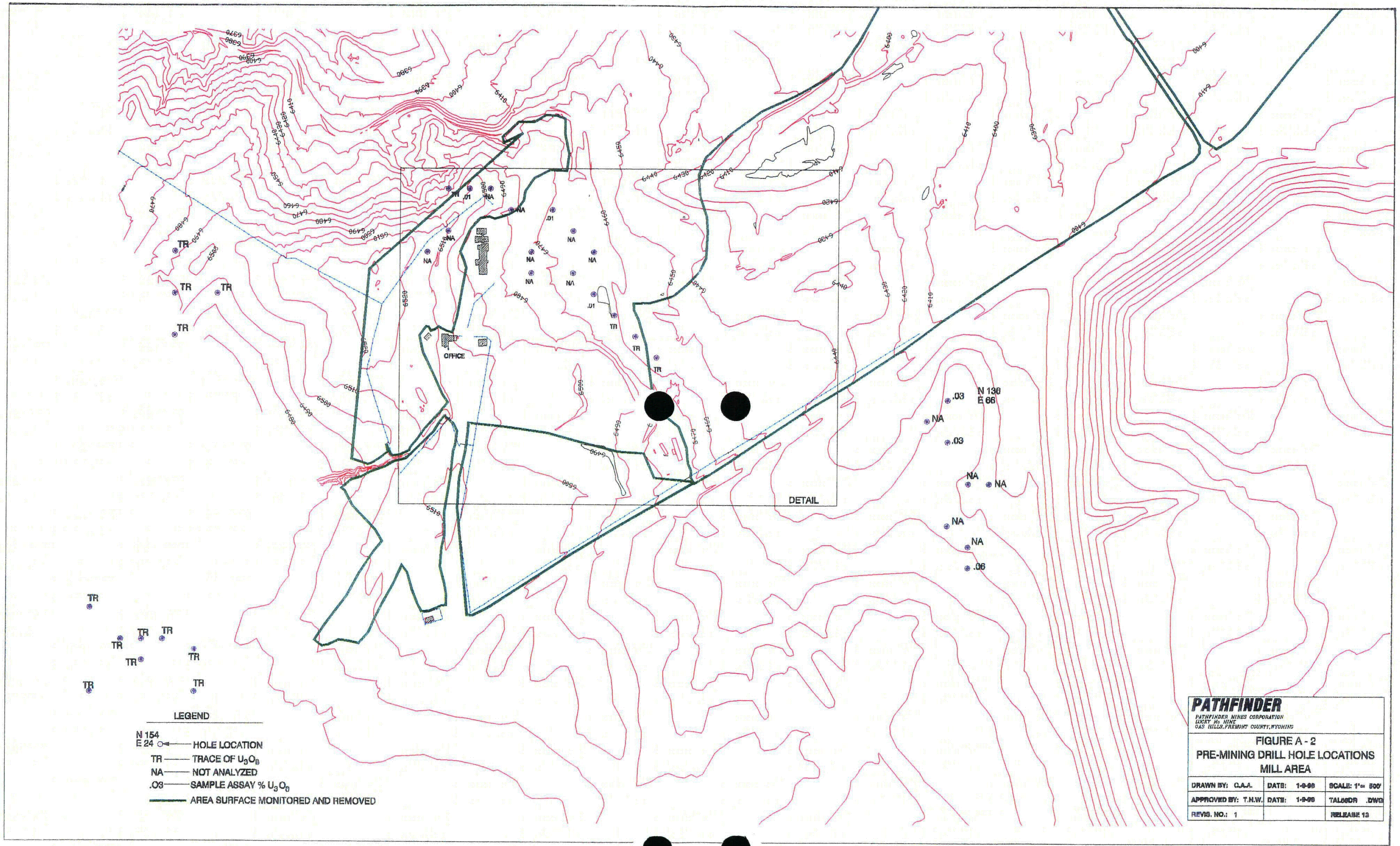
Figure A-1
Mineralization As It Relates to the Lucky Mc Mill Site. Adapted from Armstrong (1970).



ORE TRENDS, HOST ROCKS, AND FACIES
GAS HILLS URANIUM DISTRICT, WYOMING

Figure 4—Frank C. Armstrong

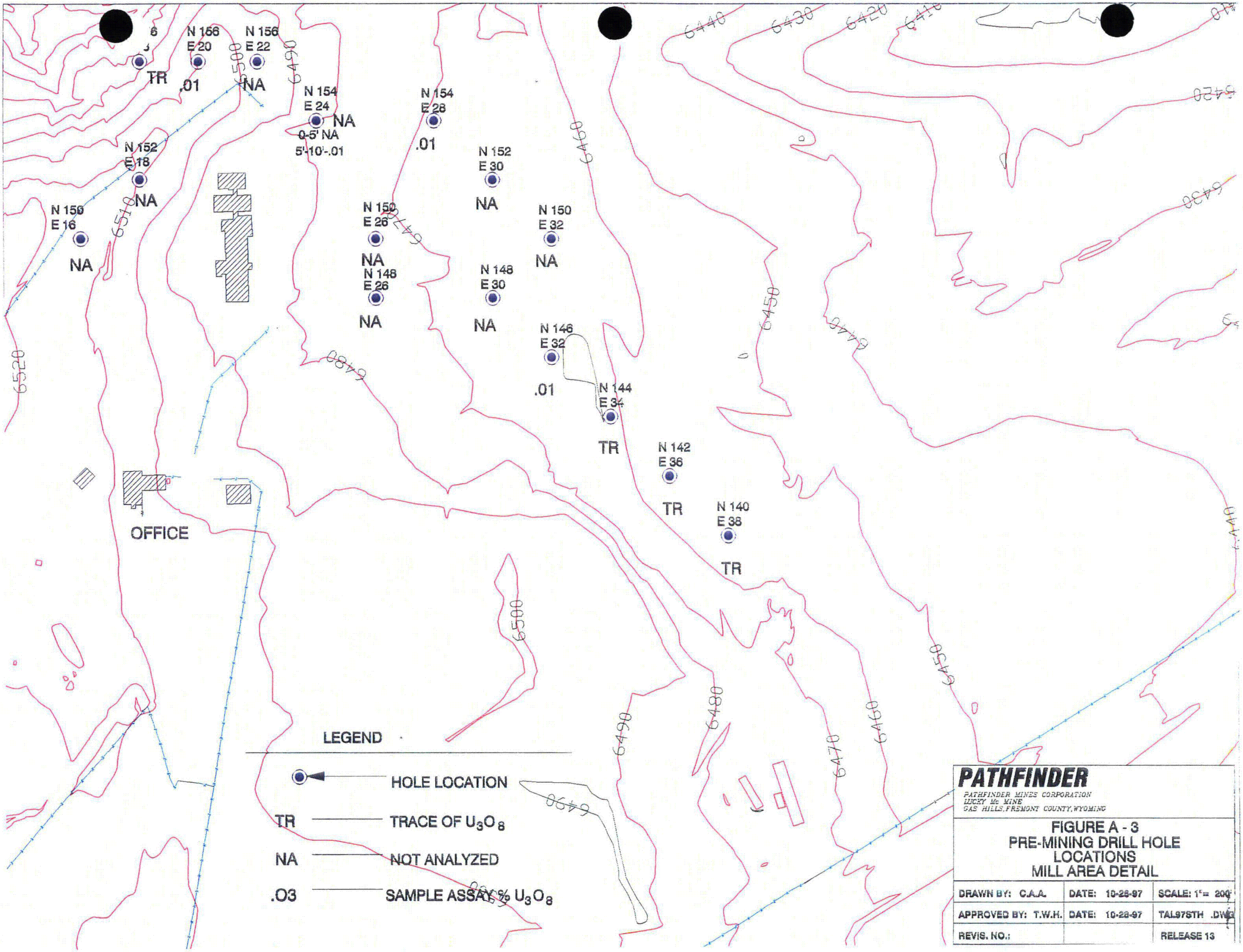


PATHFINDER

PATHFINDER MINES CORPORATION
LUCKY Mc MINE
GAS HILLS, FREMONT COUNTY, WYOMING

FIGURE A - 2
PRE-MINING DRILL HOLE LOCATIONS
MILL AREA

DRAWN BY: C.A.A.	DATE: 1-9-99	SCALE: 1"= 500'
APPROVED BY: T.H.W.	DATE: 1-9-99	TAL66DR .DWG
REVIS. NO.: 1		RELEASE 13



PATHFINDER

PATHFINDER MINES CORPORATION
LUCKY Mc MINE
GAS HILLS, FREMONT COUNTY, WYOMING

FIGURE A - 3
PRE-MINING DRILL HOLE LOCATIONS
MILL AREA DETAIL

DRAWN BY: C.A.A.	DATE: 10-28-97	SCALE: 1"= 200'
APPROVED BY: T.W.H.	DATE: 10-28-97	TAL97STH .DWG
REVIS. NO.:		RELEASE 13

UTAH CONSTRUCTION COMPANY

DRILL HOLE RECORD

E HOLE 4¼" TYPE Air DEPTH OF HOLE 180 FT. ELEV. COL. 6400± END 6280± DIP.

ARING COORDINATES COLLAR N E., END N E

BY [illegible]

STARTED [illegible] FINISHED [illegible] LOCALITY [illegible] PROJECT Lucky Mc HOLE K-1313

			SAMPLES								REMARKS	
ed	Feet Rec.	% Rec.	Feet Drilled	Thick	No. Samp.	UTAH % U_3O_8			HOLE PROBE H-443		Feet Drilled	
80			0 - 5	5	11706	TR			0	↑ no count ↓	0 - 5	SS tan M-C
			5 - 10	5	11707	TR					5 - 10	SS tan M-F
			10 - 15	5	11708	TR					10 - 15	SS Lt. Brn. M-F
			15 - 20	5	11709	.01					15 - 20	SS Orange M
			20 - 25	5	11710	.01					20 - 25	Shale - Carbonaceous - Brn. M
			25 - 30	5	11711	TR					25 - 30	SS + Clay Lt. Brn. M
			30 - 35	5	11712	TR					30 - 35	SS Dk. Grn M Arkosic
			35 - 40	5	11713	TR					35 - 40	Silt - SS Grn M
			40 - 45	5	11714	TR					40 - 45	Clay Silt Gn M
			45 - 50	5	11715	TR					45 - 50	SS Lt. Brn. M
			50 - 55	5	11716	.01					50 - 65	SS - Clay Grn (SS - Lt. Brn.) M
			55 - 60	5	11717	TR			57.3		55 - 60	Clay Blu M
			60 - 65	5	11718	TR			(Caved not probed		60 - 65	Clay Red M
			65 - 70	5	11719	TR			below this)		65 - 70	SS Blu Fine
			70 - 75	5	11720	TR					70 - 75	SS Blu - Grn Fine
			75 - 80	5	11721	TR					75 - 80	SS - (Clayey) Red - Brn. M
			80 - 85	5	11722	TR					80 - 85	SS (Clayey) Grn Fine
			85 - 90	5	11723	TR					85 - 90	Clay Red Brn Fine
			90-180	90	NS						90-180	Loss of circulation - made sampling impossible

UTAH CONSTRUCTION COMPANY

DRILL HOLE RECORD

SIZE HOLE 4¼ TYPE Air DEPTH OF HOLE 100 FT. ELEV. COL. 6457° END 6357° DIP.

BEARING COORDINATES COLLAR N E., END N E

BY Mayhew [illegible] M.D.T.

Project 3 PROJECT Lucky Mc

STARTED ~~June~~ MAY 15, 1956 FINISHED ~~June~~ MAY 15, 1956 LOCALITY N142 E 36 HOLE X4312

Feet Drilled	Feet Rec.	% Rec.	SAMPLES Feet Drilled	Thick	No. Samp.	Utah % U_3O_8			Hole Probe Highs	
100			0-5	5	11686	TR				← NO COUNT →
			5-10	5	11687	TR				
			10-15	5	11688	TR				
			15-20	6	11689	TR				
			20-25	5	11690	TR				
			25-30	6	11691	TR				
			30-35	6	11692	TR				
			35-40	5	11693	TR				
			40-45	6	11694	TR				
			45-50	6	11695	TR				
			50-55	5	11696	TR				
			55-60	5	11697	TR				
			60-65	6	11698	TR				
			65-70	6	11699	TR				
			70-75	5	11700	TR				
			75-80	5	11701	TR				
			80-85	5	11702	TR				
			85-90	5	11703	TR				
			90-95	5	11704	TR				
			95-100	5	11705	TR				

REMARKS

Feet Drilled				
0-5	SS	tan	Fine grained	
5-10	SS	tan	Fine grain	
10-15	SS	L. tan	Fine grain	
15-20	SS	brindle brn.	Fine grain	
20-25	sandy clay	Dk. Blue	more sand than adjac- SS ~~M~~	
25-30	Sandy Clay	Dk. Blu	Mg - Fg	
30-35	clayey Sand	Dk. blu ~~Gy~~ Gn	Fine	
35-40	Clayey Sand	Dk. Blu. Grn	Fine	
40-45	Sand	Gn.	Med. grained	Some clay
45-50	Clayey Sand	Gn.	M - F	
50-55	Clay	Gn-Blu.	M - F	
55-60	Silt	L. Gn.	F	
60-65	SS	Gn	F	
65-70	SS	Gn	F	
70-75	Clay	Red	F	
75-80	Clay	Gy	F	
80-85	Clayey SS	Gn-Gy	M	Arkosic
85-90	SS	Gn	M	Some clay
90-95	Clay	Gy	M	
95-100	Clay	Gy	M	

UTAH CONSTRUCTION COMPANY

DRILL HOLE RECORD

IZE HOLE 4¼" TYPE Air DEPTH OF HOLE 100 FT. ELEV. COL. 6460± END 6360± DIP.

EARING COORDINATES COLLAR N E., END N E

BY Mayhew Rig #6 STARTED ~~[illegible]~~ May 16, 1956 FINISHED ~~[illegible]~~ May 16, 1956 LOCALITY [illegible] PROJECT Lucky Mc HOLE X-1314

eet Drilled	Feet Rec.	% Rec.	SAMPLES Feet Drilled	Thick	No. Samp.	% U₃O₈			[illegible]		REMARKS Feet Drilled				
-100			0-5	5	N724	TR				Air Cont	0-5	SS	L. Brn.	Fine	
			5-10	5	N725	TR					5-10	SS	L. Brn.	Fine	
			10-15	5	N726	TR					10-15	SS	Tan	Med.	
			15-20	5	N727	TR					15-20	SS	L. Tan	med.	
			20-25	5	N728	.01					20-25	SS + Silt	Brn	Fine-med.	
			25-30	5	N729	.01					25-30	SS	Gy	med.	
			30-35	5	N730	TR					30-35	SS	Gn	med.	Arkosic
			35-40	5	N731	TR					35-40	Silt	Gn	med.	
			40-45	5	N732	TR					40-45	SS	Gy Gn	Fine	
			45-50	5	N733	TR					45-50	SS	Gy-Gn	Fine	
			50-55	5	N734	.01					50-55	SS	L. Gy	Med.	
			55-60	5	N735	TR					55-60	SS	L. Gy	Med.-Fine	
			60-65	5	N736	TR					60-65	SS + Clay	Gn	Fine	
			65-70	5	N737	TR					65-70	SS + Silt	Gy	Fine	
			70-75	5	N738	TR					70-75	SS + Silt	Gy-Gn	Fine	
			75-80	5	N739	TR					75-80	Clay Silt	Brn.	Fine	
			80-85	5	N740	TR					80-85	Clay	Gy	Fine	Bentonite
			85-90	5	N741	TR					85-90	Clay	Brn.	Fine	Bentonite
			90-95	5	N742	TR					90-95	SS + Clay	L. Gy	Fine	
			95-100	5	N743	TR					95-100	SS + Clay	Red Gy	Fine	

UTAH CONSTRUCTION COMPANY

DRILL HOLE RECORD

E HOLE 4¼" TYPE Air DEPTH OF HOLE 100 FT. ELEV. COL. 6461° END 6361° DIP.

ARING COORDINATES COLLAR N E., END N E

BY Whitney Fife N.G.T.

STARTED May 16 1956 FINISHED May 16 1956 LOCALITY N 196 E 32 Pickers 3 PROJECT Lucky Mc HOLE X-1315

t ed	Feet Rec.	% Rec.	SAMPLES Feet Drilled	Thick	No. Samp.	Utah % U3O8			Hole Probe Highs		REMARKS Feet Drilled	
00			0 - 5	5	H744	.01				NO COUNT	0 - 5	Silt Brn. Fine
			5 - 10	5	H745	TR					5 - 10	SS Wh. Med.
			10 - 15	5	H746	TR					10 - 15	SS TAN Med.
			15 - 20	5	H747	TR					15 - 20	SS + Silt Brn-Tan FINE
			20 - 25	5	H748	.01					20 - 25	SS + Silt Brn.-TAN FINE
			25 - 30	5	H749	TR					25 - 30	Clay Gn Fine
			30 - 35	5	H750	TR					30 - 35	SS Gn Med ARKOSIC
			35 - 40	5	H751	TR					35 - 40	SS Gn Med.
			40 - 45	5	H752	TR					40 - 45	SS Gn Fine
			45 - 50	5	H753	TR					45 - 50	SS L. Gn Fine
			50 - 55	5	H754	.00					50 - 55	SS Gn Med.
			55 - 60	5	H755	TR					55 - 60	SS + Clay Gn Fine
			60 - 65	5	H756	.00					60 - 65	SS Gn Fine
			65 - 70	5	H757	TR					65 - 70	SS Gn Gy Fine
			70 - 75	5	H758	TR					70 - 75	SS Gn Fine
			75 - 80	5	H759	TR					75 - 80	Clay Brn. Fine
			80 - 85	5	H760	TR					80 - 85	Clay Gn FINE
			85 - 90	5	H761	TR					85 - 90	Clay RED FINE
			90 - 95	5	H762	TR					90 - 95	Clay RED-Gy FINE
			95 - 100	5	H763	TR					95 - 100	Clay Gy Fine

UTAH CONSTRUCTION COMPANY

DRILL HOLE RECORD

E HOLE 4¼ TYPE Air DEPTH OF HOLE 70 FT. ELEV. COL. 6517.9 END ___ DIP ___

ARING ___ COORDINATES COLLAR ___ N ___ E., END ___ N ___ E

BY Snow Mayhew

STARTED 12-30-55 FINISHED 12-30-55

LOCALITY N 150 Elk PROJ J

PROJECT Lucky Mc

HOLE X 1027

et led	Feet Rec.	% Rec.	SAMPLES								REMARKS	
			Feet Drilled	Thick	No. Samp.	% U_3O_8		UTAH	AMANO		Feet Drilled	
70			0-5		6618	NA					0-5	Sand, Br, M-VF
			5-8		6619	NA					5-8	SS, Br, C-F
			8-10		6620			TR			8-10	SS, Or, M-F
			10-13		6621			TR			10-13	SS, Or-Br, C-F
			13-15		6622	NA					13-15	SS, Br C-VF, Sh Stringers
			15-18		6623			TR			15-20	SS, Br-Or C-F
			18-20		6624			TR			20-25	SS, Br - C-F
			20-25		6625				.012		25-30	SS, Gy Gn M-UF
			25-30		6626			TR			30-33	SS, Gy M-VF
			30-33		6627			.01			33-35	Slts, Gy
			33-35		6628	NA					35-38	SS, Gy, M-UF
			35-38		6629	NA					38-40	SS, Br M-VF
			38-40		6630			TR			40-43	SS, Br-Bl Gn, M-VF
			40-43		6631	NA					43-70	SS, Bl Gn, ~~M-UF~~, Arkosic
			43-45		6632	NA						
			45-48		6633	NA						
			48-50		6634	NA						
			50-55		6635	NA						
			55-60		6636	NA						
			60-65		6637	NA						
			65-70		6638	NA						
						OK						

Note Plugged 70' w 4¼ bit w Air - Open hole

UTAH CONSTRUCTION COMPANY

DRILL HOLE RECORD

E HOLE 4¼ TYPE Air DEPTH OF HOLE 80 FT. ELEV. COL. 6489^{8} END ____ DIP ____

ARING ____ COORDINATES COLLAR ____ N ____ E., END ____ N ____ E

BY Snow Wayne

STARTED 12-28-55 FINISHED 12-28-55 LOCALITY N154 E24 HOLE X1023

PROJECT Lucky Mc

ed	Feet Rec.	% Rec.	SAMPLES Feet Drilled	Thick	No. Samp.	% U_3O_8	MIN	UT		
80			0-5		6506	NA				
			5-10		6507		.01			
			10-15		6508	NA				
			15-20		6509	NA				
			21-25		6510		.01			
			25-30		6511		NIL			
			30-33		6512	NA				
			33-35		6513	NA				
			35-38		6514			TR		
			38-40		6515			.01		
			40-43		6516			TR		
			43-45		6517			NIL		
			45-48		6518	NA				
			48-50		6519	NA				
			50-55		6520	NA				
			55-60		6521	NA				
			60-65		6522	NA				
			65-70		6523	NA				
			70-75		6524	NA				
			75-80		6525	NA				

REMARKS Feet Drilled	
0-5	Sand, Br C-F
5-20	SS, Br-Or M-F Sh stringers
20-30	SS, Br-Or-Gy, M-VF
30-35	SS, Br M-VF
35-38	SS, LBr-Or, M-VF
38-40	SS, -Br-Or, C-F
40-43	SS, Br-Or-Gy, M-VF
43-45	SS-Sh; Br-BK, SS M-VF
45-48	Sh-SS, Bl Gn, Arkosic, Bentonitic
48-75	SS, Bl Gn, M-VF, Arkosic
75-80	SS-Sh, Bl Gn-R, SS M-VF, Arkosic

Plugged 80' w 4¼" bit
W Air - open hole

UTAH CONSTRUCTION COMPANY

DRILL HOLE RECORD

E HOLE 4 1/4 TYPE Air DEPTH OF HOLE 80 FT. ELEV. COL. 6474.5 END DIP

ARING COORDINATES COLLAR N E., END N E

BY Snow Mayhew
STARTED 12/27/55
FINISHED 12/27/55
LOCALITY NW 34 F 26
PROJECT Lucky Mc.
HOLE X-1020

d	Feet Rec.	% Rec.	SAMPLES Feet Drilled	Thick	No. Samp.	% U_3O_8 [illegible]
80			0-5		6233	↑
			5-10		6234	
			10-15		6235	
			15-20		6236*	.01
			20-23		6237*	.02
			23-25		6238*	Nil
			25-28		6239*	Nil
			28-30		6240*	Nil
			30-35		6241	
			35-40		6242	
			40-45		6243	
			45-50		6244	
			50-55		6245	
			55-60		6246	
			60-65		6247	
			65-70		6248	
			70-75		6249	
			75-80		6250	↓

dR

REMARKS Feet Drilled	
0-5	Sand, Br., C-F.
5-10	S.S., Br., M-F.
10-15	S.S., Br., M-F.
15-20	S.S., Br-Yl., M-F.
20-23	S.S., Br-Yl., M-F.
23-25	S.S., Br., M-F.
25-28	S.S.-sh., Br., M-V.F. Gypsum xls in sh
28-30	Sh. Br-Bl.Gn. Bentonitic, " " Br. Sh.
30-35	S.S., Bl.Gn. M-V.F., Arkosic
35-40	S.S., Bl.Gn. M-V.F., "
40-45	S.S., Bl.Gn. M-V.F., "
45-50	S.S., Bl.Gn. M-V.F., " lime cement
50-55	S.S., Bl.Gn M-V.F., "
55-60	S.S.-Sh., Bl.Gn.-R, M-V.F., S.S. Arkosic
60-65	Sh.-S.S., R.-Bl.Gn., SS M-V.F., "
65-70	S.S., Bl.Gn., M-V.F., "
70-75	S.S., Bl.Gn., M-V.F. "
75-80	S.S.-Sh., Bl.Gn.-R., S.S. M-V.F. "

Plugged 80' W 4 1/4" bit w. air. - Open hole.

* Samples run.

UTAH CONSTRUCTION COMPANY

DRILL HOLE RECORD

E HOLE 4 1/4 TYPE Air DEPTH OF HOLE 80 FT. ELEV. COL. 6471.4' END DIP.

RING COORDINATES COLLAR N E., END N E

BY Snow Mayhew PROJECT Lucky Mc

STARTED 12-29-55 FINISHED 12-29-55 LOCALITY N156 E18 HOLE X1026

d	Feet Rec.	% Rec.	SAMPLES								REMARKS	
			Feet Drilled	Thick	No. Samp,	% U_3O_8		UTAH	AMANO		Feet Drilled	
0			0-5		6567			TR			0-5	SS, Br-Or M-F 5
			5-10		6568			.07			5-10	SS-SltS, Br, M-VF 14
			10-13		6569			TR			10-13	SS, Br-Gy, M-VF 1
			13-15		6570			TR			13-18	SS, Bl Gn, M-VF, Arkosic 9 153
			15+18		6571			.00			18-20	SS, Gy-Br, M-F 54
			18-20		6572			TR			20-30	SS, Br, M-F 14
			20-25		6573	NA					30-33	SS, Br-Bl Gn, M-VF, Sh Gv, Bentonitic 134
			25-30		6574	NA					33-40	SS, Bl Gn, M-VF, Arkosic 153
			30-33		6575			.01			40-45	SS, Bl Gn-Br, M-VF, Arkosic 75
			33-35		6576	NA					45-60	SS, Bl Gn, M-VF, Arkosic 9 153
			35-40		6577	NA					60-70	SS-Sh, Bl Gn-R, SS M-F, Arkosic 30
			40-45		6578				.006		70-80	SS, Bl Gn, M-VF, Arkosic 9 153
			45-50		6579	NA						
			50-55		6580	NA						
			55-60		6581	NA						
			60-65		6582	NA						
			65-70		6583	NA						
			70-75		6584				.006			
			75-80		6585	NA						
							ok					Note Plugged 80' W 4¼" bit W Air- open hole

UTAH CONSTRUC..JN COMPANY

DRILL HOLE RECORD

BY Snow Mayhew

PROJECT Lucky Mc

STARTED 12-29-55 FINISHED 12-29-55 LOCALITY N156E20 HOLE X1025

E HOLE 4¼ TYPE Air DEPTH OF HOLE 80 FT. ELEV. COL. 6494.0 END ___ DIP. ___

ARING ___ COORDINATES COLLAR ___ N. ___ E., END ___ N. ___ E

t ed	Feet Rec.	% Rec.	SAMPLES							
			Feet Drilled	Thick	No. Samp.	% U3O8		UTAH	AMANO	
80			0-5		6549			.01		
			5-10		6550			.01		
			10-15		6551			.01		
			15-20		6552			.01		
			20-23		6553			.02		
			23-25		6554			.01		
			25-28		6555	NA				
			28-30		6556	NA				
			30-35		6557	NA				
			35-40		6558				.012	
			40-45		6559				.015	
			45-50		6560	NA				
			50-55		6561				.009	
			55-60		6562	NA				
			60-65		6563	NA				
			65-70		6564	NA				
			70-75		6565	NA				
			75-80		6566	NA				
						OK				

REMARKS

Feet Drilled	
0-5	SS, Or, C-F
5-15	SS, Or-Br, M-VF, Sh stringers
15-23	SS, Br-BlGn, M-VF
23-28	SS-Sh, Gy Gn
28-35	SS, Bl Gn, M-VF
35-45	SS, Gy, M-VF
45-55	SS-Sh, Gy Gn, Bentonitic
55-80	SS, Bl Gn, M-VF, Arkosic

Note - Plugged 80' W 7¼" bit
W Air - Open hole

P

Page 16
under
1 Area

UTAH INTERNATIONAL INC.

LUCKY Mc MINE

LOG INTERPRETATION

GEARHART-OWEN UNIT NO. 250-11

COL. ELEV. 6433 8
TOTAL DEPTH 60
PROBE DEPTH 13
P.D. ELEV. 6420 8

LOGGED BY RAY NANTT
DATE 6-29-78
INTERP. BY LONNIE WOODARD
DATE 6-30-78 √ C.A.

AREA 2 LMC
NORTH 136 (AIR SAMPLE
EAST 66
HOLE SIZE

Np							
$\frac{N_p}{2}$							
E_1							
E_2		NO	COUNT	! IN AIR	SAMPLE		
$E_1 + E_2$							
$(E_1 + E_2)(1.38)$		AIR	SAMPLES	FROM 0'	TO 50'		
N		Depth	Elevation	Thickness	PROBE GAMMA	SCALER ASSAY	
N		15' to 16'	6418.8 -	1.0 -	? -	.02	
N		22' to 23'	6411.8 -	1.0 -	? -	.02	
N		23' to 24'	6410.8 -	1.0 -	? -	.02	
N		25' to 26'	6408.8 -	1.0 -	? -	.06	
N		27' to 28'	6406.8 -	1.0 -	? -	.02	
N		28' to 29'	6405.8 -	1.0 -	? -	.11	
N		29' to 30'	6404.8 -	1.0 -	? -	.04	
N		30' to 31'	6403.8 -	1.0 -	? -	.17	
N		31' to 32'	6402.8 -	1.0 -	? -	.03	
N		32' to 33'	6401.8 -	1.0 -	? -	.03	
N		36' to 37'	6397.8 -	1.0 -	? -	.03	
total CPS		40' to 41'	6393.8 -	1.0 -	? -	.02	
× water factor (1.1)		43' to 44'	6390.8 -	1.0 -	? -	.02	
× .000022 = GT		47' to 48'	6386.8 -	1.0 -	? -	.02	
bottom depth							
t[illegible] depth	IN ORE						
[illegible] ELEVATION	Couldn't Probe Deep ENOUGH						
THICKNESS (T)							
$\frac{GT}{T}$ = GRADE	Probably .03						

.000044 Np = GRADE WHEN Np <1500 CPS

Appendix B

Mine Water Discharge Impacts to Fraser Draw

Appendix B

Mine Water Discharge Impacts To Fraser Draw

A review of historical Lucky Mc Mine internal reports and data files revealed strong evidence that there were various exclusively mine-related activities that collectively impacted the radionuclide picture in Fraser Draw. These impacts involved non-11e2 materials that nevertheless resulted in significant contributions to the radionuclide "load" seen today in Fraser Draw, particularly in the area immediately below the 004 dam and in the flood plain upgradient of the large breached dam structure across Fraser Draw (see Figure 2-6 in the main body of the report for the locations of these structures).

The large dam across Fraser Draw was constructed by Lucky Mc Mine by 1958. The structure did not exist in 1956 as evidenced by aerial photographs taken in May of that year, but discussions with former mine personnel who were present in the late 50's indicated that the dam was built within a couple of years after the aerial photographs were taken. Apparently, the dam served multiple purposes: as a recreational body of water for mine personnel living in the mine camp, and as a convenient source of water to fill water trucks servicing the numerous exploratory drill rigs working in the mine district at the time. It appears that the dam was intentionally breached to avoid a catastrophic failure of the structure due to excessive precipitation events that occurred most likely in mid-1963. Thus there was a period of approximately five years during which the large dam across Fraser Draw impounded a significant volume of water.

The water stored behind the Fraser Draw dam came from runoff in the draw and from various mine-related discharges. Those discharges consisted of routine and more or less continuous releases of water pumped from the Lucky Mc mine pits. All pumped water resulting from the dewatering of mine pits at Lucky Mc was released to a tributary draw to Fraser Draw that emerged from the northern extent of the mine, crossed the main Gas Hills haul road, and angled north-northeast to finally merge with Fraser Draw just upgradient of the dam discussed above. The tributary draw is the same one which is currently blocked by the 004 discharge settling pond, a pond which did not exist until about 1974, coincident with the commencement of regulated mine water discharge through the NPDES program. The dewatering of Lucky Mc pits began at a relatively early stage in the life of the mine, and continued until the early 1980's when most mining ceased. Discharged water for at least fifteen years was not subject to any treatment to remove Ra226. During the five year life span of the Fraser Draw dam, untreated mine water was stored in the impoundment with ample opportunity for radium to settle out in the basin.

Unfortunately, there is a lack of hard data regarding the radionuclide content of the earlier mine discharges. The earliest significant data relate to an evaluation of the nature of mine discharges which was initiated in early 1973, preparatory to the start of mine water treatment for Ra226 removal and the regulation of discharge by mid-1974. Table B-1 is a summary of the data collected over a 16 month span. Three distinct mine-related discharges were sampled on a monthly basis in addition to the flow in Fraser Draw some distance downstream from the mine (see location "1" on Figure B-1). Figure B-1 is based on the original map associated with the sampling program, illustrating the various sample locations. Two of the mine discharges related to pit dewatering, as discussed above. These discharge and sampling points are designated "3" and "4" on Figure B-1. The third was a routine overflow from a "hot water" well that provided mill process water (location "2" on Figure B-1). The pipeline from the hot water well fed a booster tank where the water was then pumped the last leg to the mill. At the booster tank excess water (beyond the needs for mill processing) was routinely discharged into the previously noted tributary draw, joining the flow of pit water discharge. The hot water overflow was about 28 to 30 gpm, while the collective mine water discharge rate was around 1,000 gpm. See the attached memorandum dated October 11, 1973, D. F. Wright to C. D. Snow, for a discussion of the discharges. Only the first two pages of the memorandum (and two of the attached graphs) are included here since the balance of the memorandum is devoted to various mine water treatment options which are not important to this discussion.

It is clear from Table B-1 that these mine discharges carried significant concentrations of uranium and particularly Ra226. It can be safely assumed that the radionuclide concentrations of the mine discharges pre-dating 1973 were comparable to those presented in Table B-1. Bearing in mind that there was a period of approximately five years when this water was stored by the Fraser Draw dam, the evidence is compelling that these discharges were the main source of the uranium and Ra226 concentrations currently seen in the basin sediments upgradient of the old Fraser Draw dam. The fact that a major portion of the Ra226 probably settled out in the impoundment is supported by the 1973-74 Fraser Draw downgradient data, which demonstrate a significant decline in Ra226 concentrations by the time the water flows a mile or so downstream.

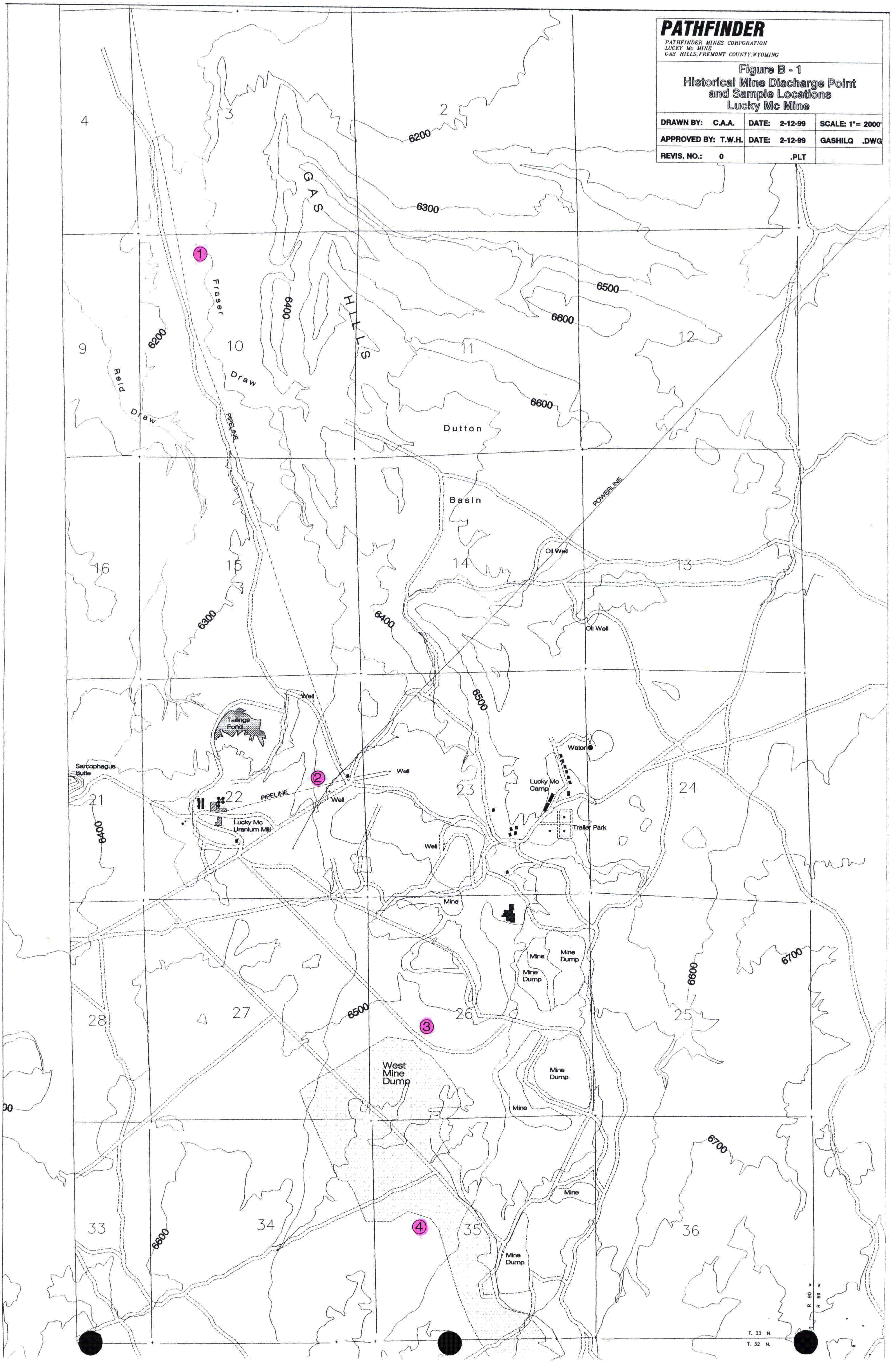
TABLE B-1 SUMMARY OF DISCHARGE DATA FOR WATER FLOWING TO FRASER DRAW DURING 1973 - 1974

16-Feb-99

SAMPLE SITES

DATE (Mo/Yr)	FRASER DR., DOWNGRADIENT (#1)		HOT WATER WELL OVERFLOW (#2)		4R MINE SUMP DISCHARGE (#3)		4L MINE SUMP DISCHARGE (#4)	
	U (pCi/L)	Ra226 (pCi/L)	U (pCi/L)*	Ra226 (pCi/L)	U (pCi/L)	Ra226 (pCi/L)	U (pCi/L)	Ra226 (pCi/L)
Feb-73	635	2	4	78.6	735	110	502	147
Mar-73	785	9	3	112	460	189	650	171
Apr-73	650	9	3	83.6	487	114	785	144
May-73	785	31	5	361	569	51.8	704	390
Jun-73	474	19	3	82.6	961	90.7	812	168
Jul-73	663	31	3	116	812	135	663	129
Aug-73	555	23	3	119	1083	91.9	691	118
Sep-73	440	17	3	65	948	112	643	108
Oct-73	501	26	3	107	677	128	582	139
Nov-73	372	18	3	97.5	1313	87.3	487	107
Dec-73	542	13	5	112	677	125	623	146
Jan-74	311	6	3	111	812	114	298	155
Feb-74	179	10	3	73.7	487	111	162	118
Mar-74	609	43	4	99.8	636	124	406	108
Apr-74	235	24	0	124	348	124	535	124
May-74	529	15	0	81.3	499	147	1009	685
AVERAGE	517	19	3	114	719	116	597	185

*Reported values of 3 are below the detection limit and should be read as "less than 3".



PATHFINDER

PATHFINDER MINES CORPORATION
LUCKY Mc MINE
GAS HILLS, FREMONT COUNTY, WYOMING

Figure B - 1
Historical Mine Discharge Point and Sample Locations
Lucky Mc Mine

DRAWN BY: C.A.A.	DATE: 2-12-99	SCALE: 1"= 2000'
APPROVED BY: T.W.H.	DATE: 2-12-99	GASHILQ .DWG
REVIS. NO.: 0	.PLT	

D-1.1 6-62

INTER-OFFICE CORRESPONDENCE

Date: October 11, 1973

To: C. D. SNOW
Lucky Mc Mine

From: D. F. WRIGHT
Lucky Mc Mine

Sub: WATER DISCHARGE TREATMENT SYSTEM DESIGN AND COST ESTIMATE FOR COMPLIANCE WITH PENDING DISCHARGE PERMIT

Ref:

Copies to:
~~D. C~~. Anderson (2)
J. J. Russell
H. W. Cosner
L. G. Dooley
J. L. Balzer - SFO
Engineering File

Attachments:

A) Lucky Mc parameters and standards for discharge
B) Proposed water discharge plan
C) Discharge water analysis graphs
D) Semi-annual, July 1973, analysis for metals
E) 4L discharge Ba-Ra SO_4 precipitate settling basin map
F) 4R discharge Ba-Ra SO_4 precipitate settling basin map

Enclosures:

1) Water discharge map
2) Composite settling basin map

Discussion:

The enactment of the Federal Water Pollution Control Act Amendments of 1972 on October 18, 1972, established a national permit program for water discharge to be administered by the EPA. All applications for discharge permits under the no-longer operational Refuse Act of 1899 were transferred to the EPA for processing. Lucky Mc submitted an application for discharge under the Refuse Act on September 14, 1971. The EPA has subsequently reviewed our application and set parameters, standards, and sampling requirements. Attached hereto, Attachment A. The target date for Lucky Mc Mine to meet these discharge water standards is January 1974. At the present time, Lucky Mc Mine has five (5) sources discharging into the local drainage: 1) The Pit 4L sump discharge. SW¼NW¼, Sec. 35, T33N R90W. 2) The Pit 4R sump discharge. NW¼SW¼, Sec. 26, T33N R90W. 3) The hot water booster pump feed tank overflow. SE¼NE¼, Sec. 22, T33N R90W. 4) The hot water mill head tank overflow. NW¼SW¼, Sec. 22, T33N R90W. 5) The mill and office potable water head tank overflow. NW¼SW¼, Sec. 22, T33N R90W. The Pit 4L and 4R sump discharges and the hot water booster pump feed tank overflow discharge into the same drainage -- a tributary draw of Frazier Draw. The hot water mill head tank overflow discharges into Willow Springs Draw. The potable water head tank overflow discharges into Reid Draw. (See enclosed Water Discharge Map.)

The original permit application listed only three (3) discharge sources: the Pit 4L discharge, the hot water booster tank overflow, and the potable water head tank overflow. The hot water head tank overflow and the 4R sump discharge did not exist at that time.

A revised discharge and water treatment plan was submitted to the EPA Region 8 administrator in March 1973. (Copy attached hereto - Attachment B).

In summary, the plan requires all discharges to be confined to one drainage -- the west tributary of Frazier Draw. The water would be treated at the pump intakes with $BaCl_2$ to reduce the Ra_{226} concentrations. Settling ponds located immediately adjacent to the discharge points to settle out the barium - radium sulfate precipitate and confine it to one location. The settling basins will have a 24 to 48 hour flow-through capacity and will be fenced to prohibit access. Water flowing from the settling basins should be of sufficient quality to be utilized by livestock and wildlife. A final settling reservoir and sampling station would be constructed at the northern most property boundary of Lucky Mc Mine along the discharge flow course.

A voluntary sampling program was started by Lucky Mc Mine in February 1973 to varify the concentration of Radium 226 and uranium in the 4L and 4R sump discharges, the hot water well water, and at a point in Frazier Draw where the three sources are joined. Sulfate and total dissolved solids were added to the monthly analysis/daily composite program in April 1973. Weekly grab samples and analysis for pH and total suspended solids were commenced in June 1973 to complete the monthly and weekly samples which will be required by the EPA. (Graphs of analysis results are attached hereto. Attachment C). Semi-annual samples and analysis requirements will be taken in July and January. (July 1973 analysis results attached hereto - Attachment D). Review of analysis results shows concentrations of Ra226 and SO_4 above the maximum permissible concentrations set by the EPA. Total suspended solids surpassed maximum permissible limits at the Frazier Draw sampling station due to high silt load in rain storm run-off. Analysis results also indicate that radium 226 is precipitating out along the drainage as the three sources, 4L and 4R sump discharge and hot water well overflow, are higher in radium 226 than the station down drainage in Frazier Draw. The discharge water is also picking up sulfate ion along its course as indicated by the concentration of sulfate at the 4L sump discharge, the major discharge source, as compared to the Frazier Draw sample station analysis results.

Construction and Material Requirements

Mine Water Treatment System:

Each pit dewatering system will consist of the following:

1) A $BaCl_2$ solution mixing and feed tank of approximately 5,000 gallons capacity.

2) A solution agitator/mixer.

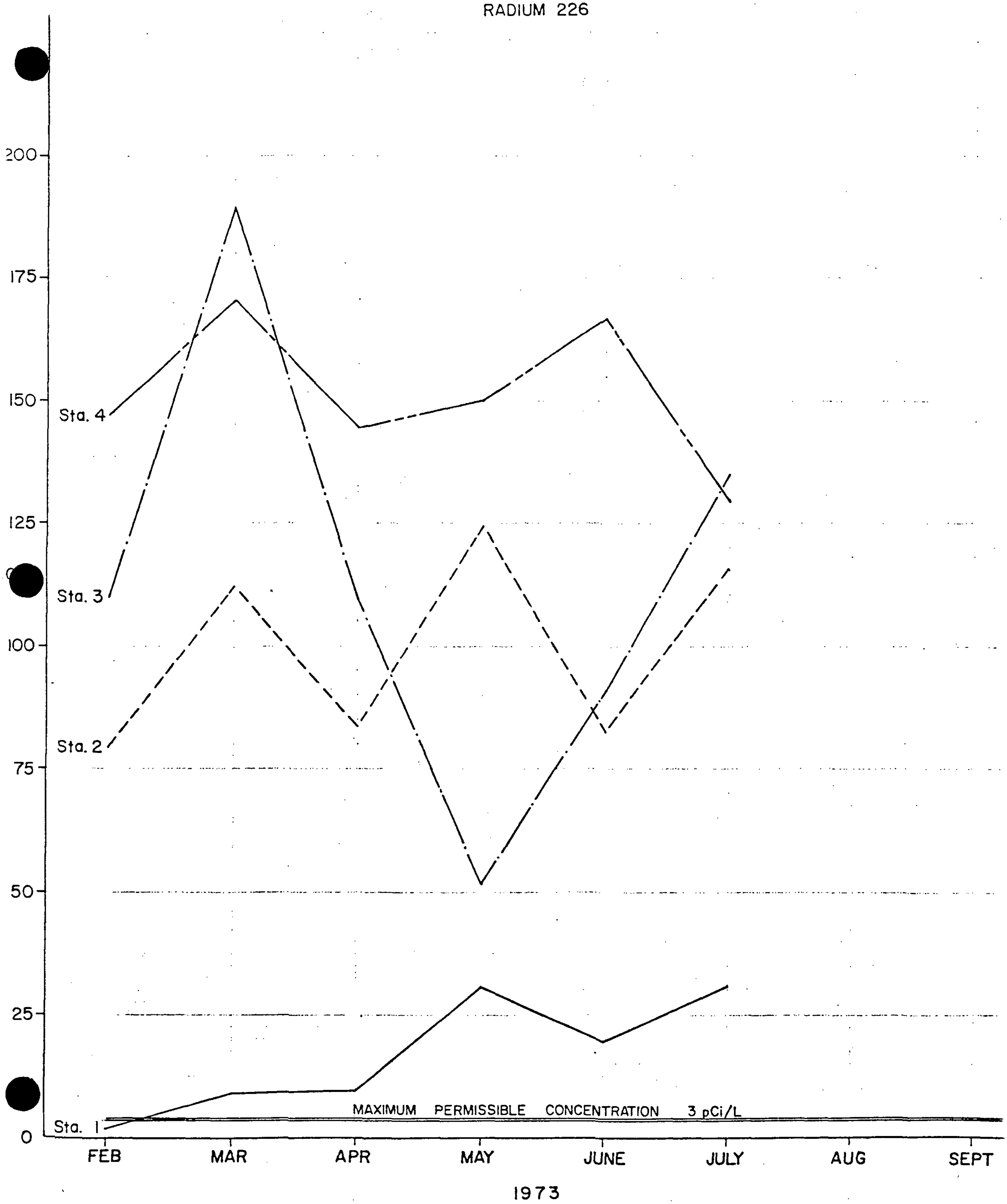
3) A solution metering pump.

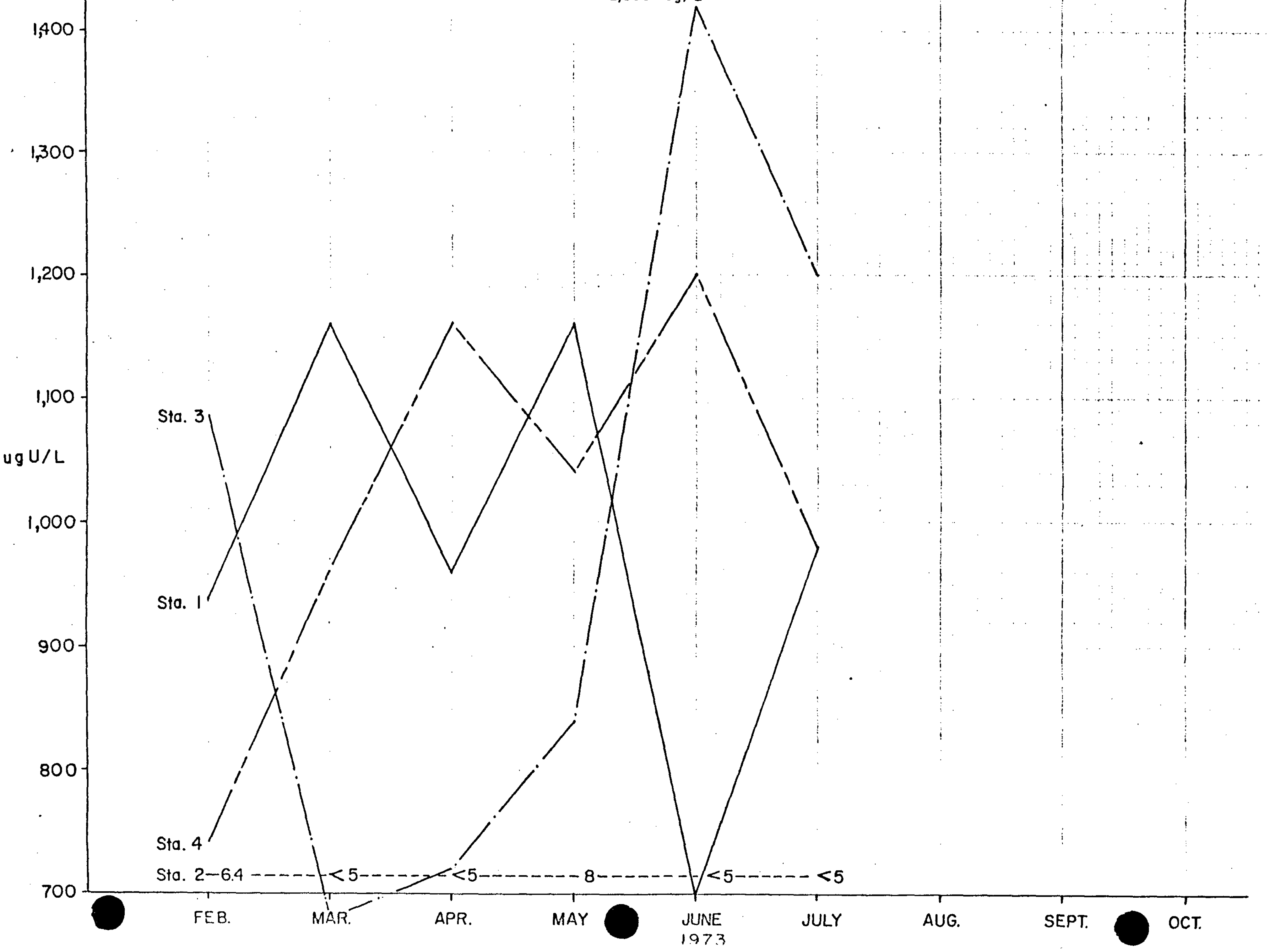
4) Feed lines to pump.

Attachment C

MONTHLY DISCHARGE WATER ANALYSIS
DAILY COMPOSITE

RADIUM 226





ANALYSIS of Total URANIUM

MAXIMUM PERMISSIBLE CONCENTRATION
2,000 ug/L

Appendix C

Gamma-Ray Action Level for Vehicle-Mounted Detectors

Appendix C

Gamma-Ray Action Level for Vehicle-Mounted Detectors

This study was done in response to a concern by the NRC that the correlation studies were done using hand-held instrumentation while the radiological surveys were done using the detectors mounted on a Chevrolet Blazer. In order to assess whether there is a difference between these two configurations, the gamma-ray count rate was measured for an unshielded Ludlum 44-10 NaI detector, held by a person at a height of 18 inches above the ground, and compared to that of a detector mounted on the Blazer detector suspension assembly at a similar height and at the same location. Eighty points were chosen in the windblown portion of the site. A 30-second integrated count was taken with the Blazer positioned at a point; the Blazer was then driven forward and a 30-second integrated count taken by a person holding the detector at the same 18-inch height above the point.

The data are provided in the Table C-1 and plotted in Figure C-1 along with the least-square-fit linear regression line. As one can see from the data and the chart, the attenuation of the Blazer and holder assembly is significant enough to consider in determining the action level.

In determining the 55,000 cpm action level as initially proposed, the hand-held detector data was used. Substituting this into the linear regression equation, this corresponds to a count rate of 51,000 cpm when using the Blazer.

In the early stages of cleanup and prior to performing this study, PMC noticed that the use of 55,000 cpm as an action level resulted in too many failures in meeting the cleanup standard. An administrative limit of 50,000 cpm was established to prevent these failures. Upon receipt of the results of this study, PMC proposed to the NRC a new action level of 50,000 cpm.

Table C-1 Comparison of Gamma Count Rates from Blazer and Hand-Held Detectors

Reading	Blazer Mount (cpm/2)	Hand-held (no vehicle (cpm/2)	Blazer Mount (cpm)	Hand-held (no vehicle) (cpm)	Difference
1	28462	30670	56924	61340	4416
2	22182	24323	44364	48646	4282
3	23582	25930	47164	51860	4696
4	19504	21692	39008	43384	4376
5	19356	21397	38712	42794	4082
6	18985	21574	37970	43148	5178
7	18176	21003	36352	42006	5654
8	19181	21769	38362	43538	5176
9	19539	22090	39078	44180	5102
10	22370	24396	44740	48792	4052
11	24146	26919	48292	53838	5546
12	21865	25012	43730	50024	6294
13	21278	23924	42556	47848	5292
14	23426	26013	46852	52026	5174
15	25423	28194	50846	56388	5542
16	27892	31312	55784	62624	6840
17	24880	27691	49760	55382	5622
18	25780	28628	51560	57256	5696
19	25462	28271	50924	56542	5618
20	25146	28065	50292	56130	5838
21	26605	29455	53210	58910	5700
22	23338	26197	46676	52394	5718
23	26945	29045	53890	58090	4200
24	21270	23792	42540	47584	5044
25	20852	23628	41704	47256	5552
26	20752	23329	41504	46658	5154
27	18984	21603	37968	43206	5238
28	35368	38510	70736	77020	6284
29	20890	24167	41780	48334	6554
30	28794	30951	57588	61902	4314
31	38964	40574	77928	81148	3220
32	21163	24078	42326	48156	5830
33	68125	68528	136250	137056	806
34	44813	46147	89626	92294	2668
35	28066	30124	56132	60248	4116
36	40685	42153	81370	84306	2936
37	75736	76168	151472	152336	864

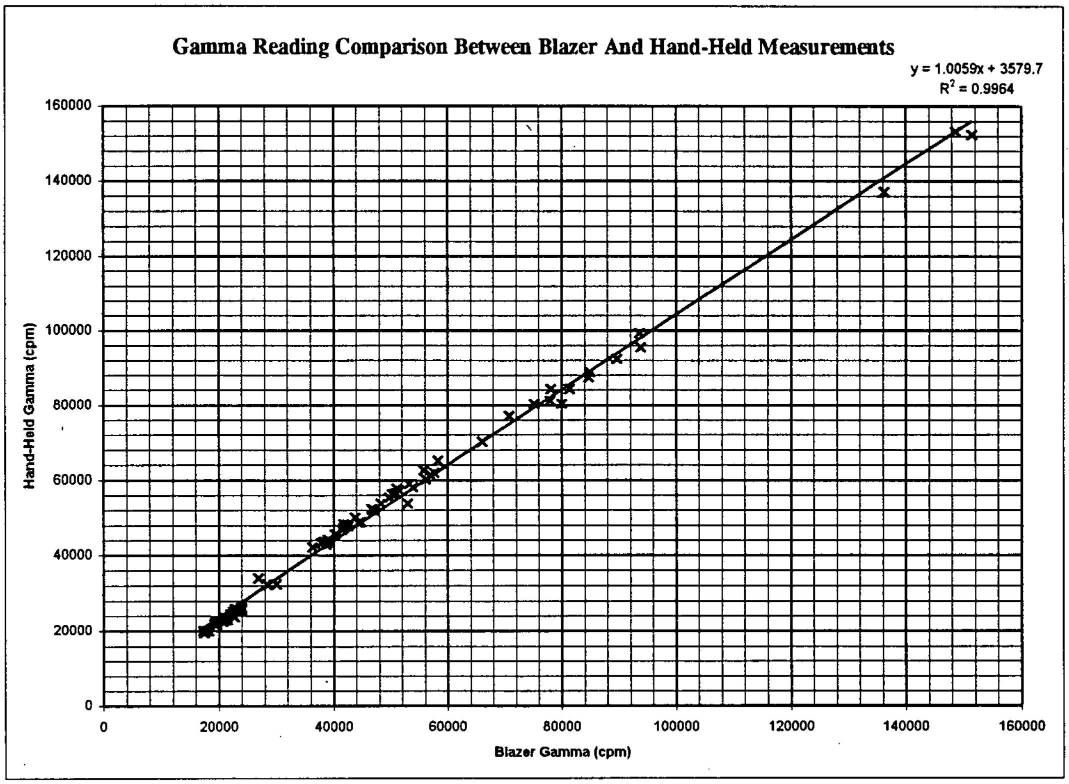
Table C-1 Comparison of Gamma Count Rates from Blazer and Hand-Held Detectors

Reading	Blazer Mount (cpm/2)	Hand-held (no vehicle (cpm/2)	Blazer Mount (cpm)	Hand-held (no vehicle) (cpm)	Difference
38	40002	40102	80004	80204	200
39	42340	43662	84680	87324	2644
40	33051	35044	66102	70088	3986
41	29132	32543	58264	65086	6822
42	42486	44403	84972	88806	3834
43	37567	40091	75134	80182	5048
44	74341	76636	148682	153272	4590
45	39046	42082	78092	84164	6072
46	12002	13173	24004	26346	2342
47	10338	11230	20676	22460	1784
48	10394	11568	20788	23136	2348
49	11640	12828	23280	25656	2376
50	11968	12831	23936	25662	1726
51	10757	11476	21514	22952	1438
52	11045	12267	22090	24534	2444
53	11258	12660	22516	25320	2804
54	11554	12649	23108	25298	2190
55	11709	12743	23418	25486	2068
56	10576	11488	21152	22976	1824
57	10433	11742	20866	23484	2618
58	11422	12995	22844	25990	3146
59	9890	11364	19780	22728	2948
60	9650	11106	19300	22212	2912
61	9814	11297	19628	22594	2966
62	9847	10916	19694	21832	2138
63	9766	10850	19532	21700	2168
64	9646	10900	19292	21800	2508
65	15038	16142	30076	32284	2208
66	8892	10032	17784	20064	2280
67	10576	11784	21152	23568	2416
68	8646	10015	17292	20030	2738
69	8697	9672	17394	19344	1950
70	11362	11839	22724	23678	954
71	9130	9949	18260	19898	1638
72	14195	16203	28390	32406	4016
73	9688	10872	19376	21744	2368
74	14254	16081	28508	32162	3654

Table C-1 Comparison of Gamma Count Rates from Blazer and Hand-Held Detectors

Reading	Blazer Mount (cpm/2)	Hand-held (no vehicle (cpm/2)	Blazer Mount (cpm)	Hand-held (no vehicle) (cpm)	Difference
75	26476	26914	52952	53828	876
76	25515	28858	51030	57716	6686
77	13426	16931	26852	33862	7010
78	46792	49626	93584	99252	5668
79	46904	47761	93808	95522	1714
80	20164	22779	40328	45558	5230

Figure C-1 Linear Regression of Hand-Held and Blazer-Mounted Detector Data



Appendix D

Gamma Survey Data Gaps

Appendix D

Gamma Survey Data Gaps

D-1. Introduction

The gamma surveys were conducted primarily by mounting the detectors on a vehicle. When access was not possible using a vehicle, the detectors were carried by technicians with the GPS equipment placed in backpacks.

After all data were plotted on 24-in by 36-in maps, a thorough review was done to look for data gaps. The maps were divided into 100 m^2 grid blocks. Grid blocks where data were missing on 30 percent or more of the area were identified for further investigation. The GPS units were used to locate the grid blocks and the area evaluated as to why the data were missing. Where possible, additional data were obtained and the new data added to the data base. Otherwise, an explanation as to why the data are missing was documented. A listing of all grid blocks with data gaps is provided in Table D-1.

Most of the voids fall within two groups, obstructions or unsafe terrain. Obstructions included heavy brush, temporary buildings, and standing water. Unsafe conditions were almost always due to very steep terrain. Since the area has an abundance of rattle snakes, it was imperative that technicians be able to walk under control at all times and therefore technicians were encouraged to consider safety first. Most of the obstructions and unsafe terrain occurred at the edge of the potential windblown area, far beyond where scraping was required. Since the area was unlikely to be above the cleanup criteria, very little information was lost by not having the data. This is apparent by comparing the locations of the data voids shown in Figure D-1 to the Verification Soil Sampling locations shown in Figure 4-3. It should be noted that if these grid blocks contained a minimum of 5 data records, they were considered in the analysis to determine the grid blocks with the highest average gamma count rates.

PMC will fill the data voids caused by standing water and soil pile as soon as these areas are accessible. An addendum will be prepared to this report.

Table D-1. Voids in Gamma Survey Data (cont).

Sample ID	Reason	Note
Q19A18D	unsafe	steep sidewall; thick underbrush
Q19A24H	unsafe	thick underbrush; steep sidewall
Q19C03J	unsafe	thick underbrush; steep sidewall
Q19C12J	underbrush	thick
Q19C15C	unsafe	steep sidewall
Q19C20A	unsafe	steep sidewall
Q19C22J	unsafe	steep sidewall; thick underbrush
Q19D12E	unsafe	steep sidewall; thick underbrush
Q19D12G	unsafe	metal culvert in middle
Q19D12H	unsafe	steep sidewall; thick underbrush
Q19D12J	unsafe	steep sidewall; thick underbrush
Q19D17B	unsafe	steep sidewall; thick underbrush
Q19D17C	unsafe	steep sidewall; thick underbrush
Q19D17F	unsafe	steep sidewall; thick underbrush
Q19D18A	unsafe	steep sidewall; thick underbrush
Q19D18B	unsafe	steep sidewall; thick underbrush
Q19D18D	unsafe	steep sidewall; thick underbrush
Q19D18E	unsafe	steep sidewall; thick underbrush
Q19D18H	unsafe	steep sidewall; thick underbrush
Q19D18J	unsafe	steep sidewall; thick underbrush
Q19D19G	unsafe	steep sidewall; thick underbrush
Q19D24A	unsafe	steep sidewall; thick underbrush
R16B03F	unsafe	steep sidewall
R16B03J	unsafe	steep sidewall
R16B08C	unsafe	steep sidewall
R16B08F	unsafe	steep sidewall
R16B08J	unsafe	steep sidewall
R16B13G	unsafe	steep sidewall
R17B17H	obstruction	pump house
R17B22B	obstruction	pump house
R17C04A	standing water	long term ponding
R17C04E	standing water	long term ponding
R17C04J	standing water	long term ponding
R18B09A	unsafe	25’ sidewalls
R18B24E	unsafe	25’ sidewalls
R18B24F	unsafe	25’ sidewalls
R18B25A	unsafe	25’ sidewalls
R18B25D	unsafe	25’ sidewalls
R18D04C	unsafe	25’ sidewalls
R18D05G	unsafe	25’ sidewalls

Table D-1. Voids in Gamma Survey Data (cont).

Sample ID	Reason	Note
Q19A18D	unsafe	steep sidewall; thick underbrush
Q19A24H	unsafe	thick underbrush; steep sidewall
Q19C03J	unsafe	thick underbrush; steep sidewall
Q19C12J	underbrush	thick
Q19C15C	unsafe	steep sidewall
Q19C20A	unsafe	steep sidewall
Q19C22J	unsafe	steep sidewall; thick underbrush
Q19D12E	unsafe	steep sidewall; thick underbrush
Q19D12G	unsafe	metal culvert in middle
Q19D12H	unsafe	steep sidewall; thick underbrush
Q19D12J	unsafe	steep sidewall; thick underbrush
Q19D17B	unsafe	steep sidewall; thick underbrush
Q19D17C	unsafe	steep sidewall; thick underbrush
Q19D17F	unsafe	steep sidewall; thick underbrush
Q19D18A	unsafe	steep sidewall; thick underbrush
Q19D18B	unsafe	steep sidewall; thick underbrush
Q19D18D	unsafe	steep sidewall; thick underbrush
Q19D18E	unsafe	steep sidewall; thick underbrush
Q19D18H	unsafe	steep sidewall; thick underbrush
Q19D18J	unsafe	steep sidewall; thick underbrush
Q19D19G	unsafe	steep sidewall; thick underbrush
Q19D24A	unsafe	steep sidewall; thick underbrush
R16B03F	unsafe	steep sidewall
R16B03J	unsafe	steep sidewall
R16B08C	unsafe	steep sidewall
R16B08F	unsafe	steep sidewall
R16B08J	unsafe	steep sidewall
R16B13G	unsafe	steep sidewall
R17B17H	obstruction	pump house
R17B22B	obstruction	pump house
R17C04A	standing water	long term ponding
R17C04E	standing water	long term ponding
R17C04J	standing water	long term ponding
R18B09A	unsafe	25' sidewalls
R18B24E	unsafe	25' sidewalls
R18B24F	unsafe	25' sidewalls
R18B25A	unsafe	25' sidewalls
R18B25D	unsafe	25' sidewalls
R18D04C	unsafe	25' sidewalls
R18D05G	unsafe	25' sidewalls

Table D-1. Voids in Gamma Survey Data (cont).

Sample I. D.	Reason	Note
R19A02G	unsafe	25' sidewalls
R19A05E	unsafe / underbrush	too steep / side of dam
R19A06F	unsafe	25' sidewalls
R19A06J	unsafe	25' sidewalls
R19A07A	unsafe	25' sidewalls
R19A08C	unsafe / underbrush	too steep / side of dam
R19A08D	unsafe / underbrush	too steep / side of dam
R19A08H	underbrush	thick
R19A11C	unsafe	25' sidewalls
R19A11F	unsafe	25' sidewalls
R19A11J	unsafe	25' sidewalls
R19A12H	unsafe	25' sidewalls
R19A13B	underbrush	thick
R19A13E	underbrush	thick
R19A18F	unsafe / underbrush	too steep / side of dam
R19A18G	unsafe / underbrush	too steep / side of dam
R19A18H	unsafe / underbrush	too steep / side of dam
R19A18J	unsafe / underbrush	too steep / side of dam
R19A19D	unsafe / underbrush	too steep / side of dam
R19B07G	underbrush	very tall; very thick
R19B07H	underbrush	very tall; very thick
R19B11B	underbrush	very tall; very thick
R19B11C	underbrush	very tall; very thick
S17A04C	standing water	long term ponding
S17A05A	standing water	long term ponding
S17B18C	standing water	long term ponding
S19D12C	unsafe	too steep
T19B06A	obstruction	large sandstone outcrop 10x20x5
T19B06B	obstruction	large sandstone outcrop 10x20x5

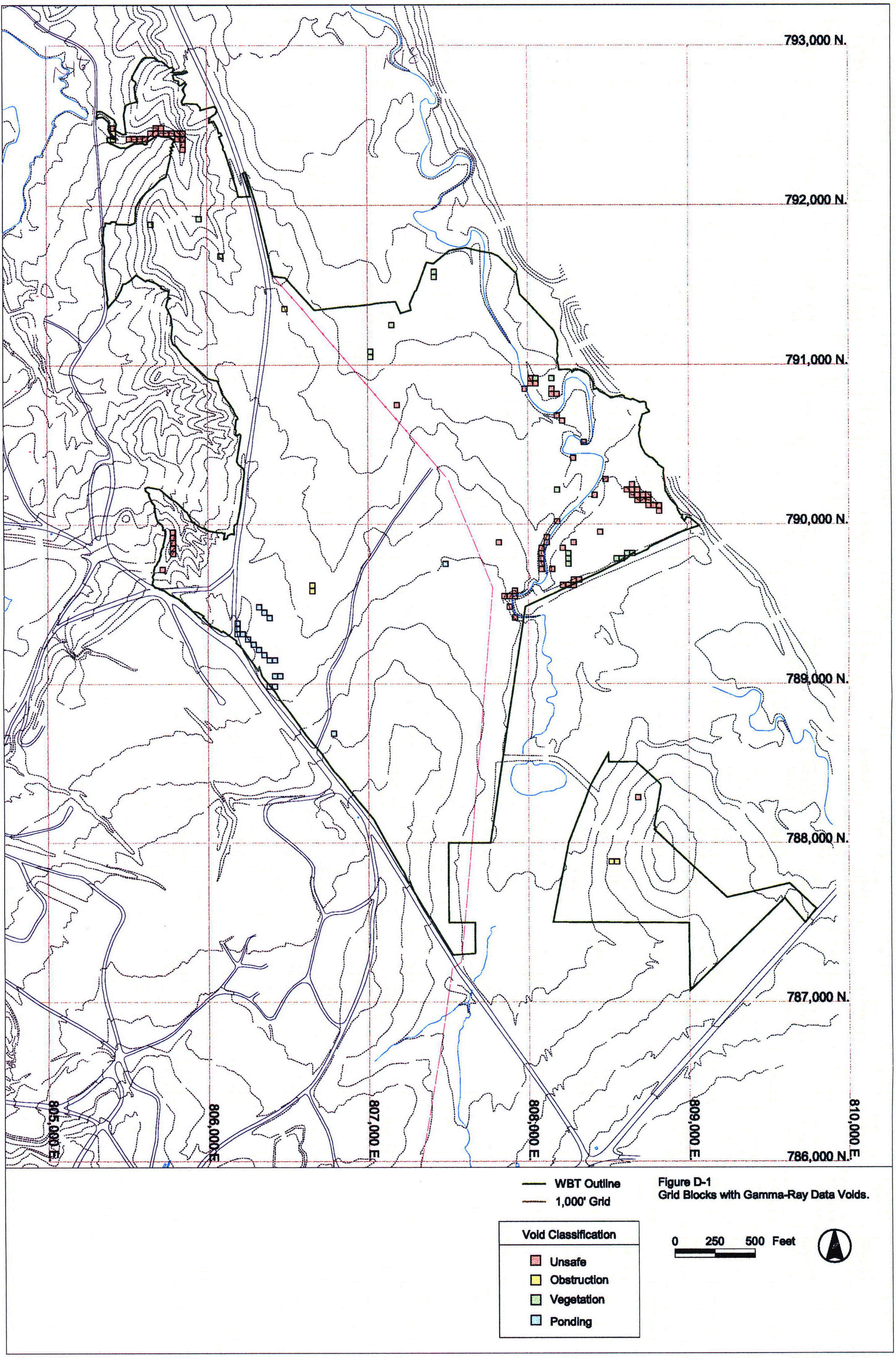


Figure D-1
Grid Blocks with Gamma-Ray Data Voids.

Appendix E

Gamma Isocontour Maps

APPENDIX E

GAMMA ISOCONTOUR MAPS
(INCUDED IN SEPARATE BINDER)

Appendix F

Trench Survey Information

APPENDIX F
TRENCH SURVEY INFORMATION

Table F-1 Pipe Trench Results

Pipe Trench 1 Data

Sampled On : 8/30/96 & 9/30/96

Surveyed By: Dario Rocha and David Hunter

Station	Gamma Count (1 min. integrated count)			Depth of Trench	ERG Ra-226 Conc. (pCi/g)		ELI Ra-226 Conc. (pCi/g)	
	FLOOR	NORTH WALL	SOUTH WALL	(feet)	FLOOR	WALL (Comp.)	FLOOR	WALL (Comp.)
0+00	8360	12220	11422	6	4.0	3.8	9.0	1.4
0+50	8282	-	-	8				
1+00	9181	-	-	8				
1+50	10341	13119	10988	9	5.5	3.5		
2+00	10240	-	-	8				
2+50	14896	-	-	10				
3+00 (A)	14896	15339	14101	10	18.7	10.5		
3+50	14896	-	-	10				
4+00	19295	-	-	10				
4+00 (B)	19295	18286	16869	10	18.2	12.5		
5+00	19295	-	-	10				
5+50	16494	-	-	9				
6+00	13102	29903	21694	6	10.0	16.4	7.1	13.5
6+50	18980	-	-	7				
7+00	15590	-	-	7				
7+50	13696	29766	22952	6	6.4	11.8		
8+00	16086	-	-	6				
8+50	24274	-	-	6				
9+00 (C)	24274	25902	21860	8	18.3	16.3		
9+50	24274	-	-	8				
10+00	19385			8				

NOTE: Gamma count rates on walls are 1 minute integrated counts from station to station at a maximum of 150 feet.

Shielded probe used for survey.

(A) Signifies resurvey was 1 minute integrated count from station 2+50 to 3+50.

(B) Signifies resurvey was 1 minute integrated count from station 3+50 to 4+50.

(C) Signifies resurvey was 1 minute integrated count from station 8+50 to 9+50.

Table F-1 Pipe Trench Results

Pipe Trench 2 Data

Sampled On : 9/26/96

Surveyed By: Dario Rocha and John Gorman

Station	Gamma Count			Depth of Trench	ERG Ra-226 Conc.	ELI Ra-226 Conc.
	(1 min. integrated count)				(pCi/g)	(pCi/g)
	FLOOR	NORTH WALL	SOUTH WALL	(feet)	FLOOR & WALL (Comp.)	FLOOR & WALL (Comp.)
0+00				3	6.6	
	27184	19468	23454			
1+50				3	4.3	5.8
	17998	15370	16350			
3+00				3	7.6	
	17692	19240	15422			
4+50				3	4.5	
	17668	15290	21358			
5+00						

NOTE: Gamma count rates are one minute integrated counts from station to station at maximum of 150 feet.

Shielded probe used for survey.

Pipe Trench 3 Data

Sampled On : 9/26/96

Surveyed By: Dario Rocha and John Gorman

Station	Gamma Count			Depth of Trench	ERG Ra-226 Conc.	ELI Ra-226 Conc.
	(1 min. integrated count)				(pCi/g)	(pCi/g)
	FLOOR	NORTH WALL	SOUTH WALL	(feet)	FLOOR & WALL Composite	FLOOR & WALL (Comp.)
0+00				3	2.4	
	12876	12104	13748			
1+50				3	1.9	
	14700	14034	14256			
3+00				3	1.9	1.5
	15504	13766	15076			
4+50				3	7.6	
	17776	14142	15534			
5+50						

NOTE: Gamma count rates are one minute integrated counts from station to station at maximum of 150 feet.

Shielded probe used for survey.

Table F-1 Pipe Trench Results

Pipe Trench 4 Data

Sampled On : 9/25/96

Surveyed By: Dario Rocha, John Gorman, and Chuck Farr

Station	Gamma Count	Depth of Trench	ERG Ra-226 Conc.	ELI Ra-226 Conc.
	(1 min. integrated count)		(pCi/g)	(pCi/g)
	FLOOR	(feet)	FLOOR	FLOOR
0+00		0 - 1	5.7	
	24909			
1+50		0 - 1	14.8	17.7
	26630			
3+00		0 - 1	7.7	
	21572			
4+50		0 - 1	9.2	
	14488			
6+00		0 - 1	4.1	
	19719			
7+50		0 - 1	30.5	27.6
	20054			
9+00		0 - 1	11.7	
	18733			
9+75		0 - 1		

NOTE: Gamma count rates are 1 minute integrated counts from station to station at maximum of 150 feet.

Shielded probe used for survey.

Table F-1 Pipe Trench Results

Pipe Trench 5 - 11 Data

Sampled On: 10/15/96
Surveyed By: Dario Rocha

Trench	Station	Gamma Count Rate (1 min. integrated count)			Depth of Trench	ERG Ra-226 Conc. (pCi/g)	ELI Ra-226 Conc. (pCi/g)
		FLOOR	RIGHT WALL	LEFT WALL	(feet)	FLOOR	FLOOR
5	0+00				0 - 1	5.3	
		8079	7747	7848			
5	1+50				0 - 1	2.1	
		8628	7603	8313			
5	2+25						
6	0+00						
		12155	14496	10856	0 - 1	7.6	3.0
6	1+15						
7	0+00						
		9173	9394	9049	0 - 1	3.0	
7	0+75						
8	0+00						
		11219	9348	8602	0 - 1	4.7	
8	0+35						
9	0+00						
		8866	8265	9177	0 - 1	2.0	
9	0+25						
10	0+00						
		11811	10477	10580	0 - 1	4.1	3.0
10	0+25						
11	0+00						
		18563	16535	20528	0 - 1	15.9	
11	0+10						

NOTE: Gamma count rates are 1 minute integrated counts from station to station at maximum of 150 feet.
Shielded probe used for survey.

Table F-1 Pipe Trench Results

Pipe Trench 14, 15 &17

Sampled On: 8/8/97, 8/22/97& 10/3/97

Surveyed By: Kim Weikum & Chuck Farr

Trench	Gamma Count Rate			Depth of Trench	ERG Ra-226 Conc.	ELI Ra-226 Conc.
	(1 min. integrated count)				(pCi/g)	(pCi/g)
	FLOOR	RIGHT WALL	LEFT WALL	(feet)	WALL & FLOOR	WALL & FLOOR
14	34545	34253	-	0 - 1	9.2	
15	40000	30000	30000	0 - 3	3.7	
17	43220	-	-	0 - 3.5	7.7	6.1
NOTE:	Gamma count rates are 1 minute integrated counts from station to station at maximum of 150 feet.					
	Unshielded probe used for survey.					

Table F-2 Pipe Trench System 1 Results

Trench System 1 Data

Sampled On : 9/14/96

Surveyed By: Dario Rocha

Section	Gamma Count			ERG Ra-226 Conc.	ELI Ra-226 Conc.
	(1 min. integrated count)			(pCi/g)	(pCi/g)
	FLOOR	RIGHT WALL	LEFT WALL	FLOOR & WALL Comp.	FLOOR & WALL Comp.
A					
0+00				7.7	
	20660	22618	21364		
0+50					
	28720	20064	31950		
1+00					
1+50 (A)	22315	20935	28720	28.0	
2+00					
	19356	13498	14156		
2+50					
	16838	12210	12364		
3+00				8.5	
	18388	15874	16972		
3+50					
4+00 (B)	15295	11862	15093		
4+50				3.8	
B					
0+00				10.4	
	22910	30110	20881		
0+50					
	25858	17748	14552		
1+00					
C					
0+00				3.6	
	18416	21740	15594		
0+50					
	25592	37838	18672		
1+00					

NOTE: Soil sample A 4+50 results initially found to be 17.8 pCi/g (ERG) and 14.3 pCi/g(ELI). The value of 3.8 pCi/g (ERG) was a resample of A 4+50 (A 4+50 R) taken after further decontamination efforts.

(A) Signifies resurvey was 1 minute integrated count from station A 1+00 to 2+00.

(B) Signifies resurvey was 1 minute integrated count from station A 3+50 to 4+50.

Shielded probe used for survey.

Table F-2 Pipe Trench System 1 Results

Trench System 1 Data

Sampled On : 9/14/96

Surveyed By: Dario Rocha

Section	Gamma Count			ERG Ra-226 Conc.	ELI Ra-226 Conc.
	(1 min. integrated count)			(pCi/g)	(pCi/g)
	FLOOR	RIGHT WALL	LEFT WALL	FLOOR & WALL (Comp.)	FLOOR & WALL (Comp.)
D					
0+00				9.8	
	19530	15074	15146		
0+50					
	43752	31028	17270		
1+00					
	40712	17762	23880		
1+50				11.1	
	27008	18434	16040		
2+00					
	24084	16102	14902		
2+50					
	17714	13878	12762		
3+00				2.9	6.4
	16002	12842	11422		
3+50					
	14170	12586	14890		
4+00					
E					
0+00				5.1	
	12200	11320	13682		
0+50					
	15012	18942	17268		
1+00					
1+50 (A)	16405	22239	21829	5.8	
2+00					
F					
0+00					
	14426	23516	13474		
0+50					
	17194	22932	13216		
1+00				11.0	6.9
	24190	14480	19216		
1+50					
	21312	17038	12928		
2+00					
	17000	16348	13236		
2+50					

NOTE: (A) Signifies resurvey was 1 minute integrated count from station A 1+00 to 2+00.
Shielded probe used for survey.

Table F-2 Pipe Trench System 1 Results

Trench System 1 Data

Sampled On : 9/14/96
Surveyed By: Dario Rocha

Section	Gamma Count (1 min. integrated count)			ERG Ra-226 Conc. (pCi/g)	ELI Ra-226 Conc. (pCi/g)	Special Notes
	FLOOR	RIGHT WALL	LEFT WALL	FLOOR & WALL (Comp.)	FLOOR & WALL Comp.	
G						
0+00						
	20598	22016	13586			
0+50						
	15858	20216	11786	6.7		Soil sample taken AT 80'.
1+00						
	15212	14968	16598			
1+50						
H						
0+00						
	15632	16022	14870	5.8		Soil sample taken AT 40'.
0+50						
I						
0+00						
	16974	18354	16328	7.9		Soil sample taken at 20'.
0+50						
	12202	13332	13912			
1+00						
	9046	N/A	9376			
1+50						
J						
0+00						
	13908	14102	11888	7.0	4.1	Soil sample taken at 25'.
0+50						
	15492	N/A	14126			
0+75						
NOTE:	Shielded probe used for survey.					

Table F-2 Pipe Trench System 1 Results

Trench System 1 Data

Sampled On : 9/14/96

Surveyed By: Dario Rocha

Section	Gamma Count			ERG Ra-226 Conc.	ELI Ra-226 Conc.	Special
	(1 min. integrated count)			(pCi/g)	(pCi/g)	Notes
	FLOOR	RIGHT WALL	LEFT WALL	FLOOR & WALL (Comp.)	FLOOR & WALL (Comp.)	
K						
0+00						
	12800	10768	13802			
0+50						
	18100	16660	12720			
1+00						
	20888	17254	20096			
1+50				24.2		
	27868	15200	29012			
2+00						
	15234	14962	11552			
2+50						
	16650	16864	12298			
2+75						
L						
0+00						
	26184	21522	14308	4.4		Soil sample taken at 25'.
0+50						
	20422	15314	N/A			
0+75						
M						
0+00						
	14654	11378	13788	7.1		Soil sample taken at 25'.
0+50						
N						
0+00						
	15058	14816	20062			
0+50						
	18534	19176	12054			
1+00				7.4	5.1	
	26188	10820	18688			
1+50						
	15772	10954	16778			
2+00						
	15074	9774	13590			
2+50				4.2		
	13114	N/A	11446			
3+00						
NOTE:	Shielded probe used for survey.					

Table F-2 Pipe Trench System 1 Results

Trench System 1 Data

Sampled On : 9/14/96

Surveyed By: Dario Rocha

Section	Gamma Count (1 min. integrated count)			ERG Ra-226 Conc. (pCi/g)	ELI Ra-226 Conc. (pCi/g)	Special Notes
	FLOOR	RIGHT WALL	LEFT WALL	FLOOR & WALL (Comp.)	FLOOR & WALL (Comp.)	
O						
0+00				13.8		
	25466	19964	24162			
0+50						
	22284	28182	14472			
1+00						
	18024	15640	21062			
1+50				9.0		
	17178	20570	14326			
1+60						
P						
0+00						
	16319	24204	23717			
0+25				8.1		Soil sample taken at 25'.

NOTE: Soil sample P 0+25 results initially found to be 27.7 pCi/g (ERG) and 23.7 pCi/g(ELI). The value of 8.1 pCi/g (ERG) was a resample of P 0+25 (P 0+25 R) taken after further decontamination efforts.

Shielded probe used for survey.

Table F-3 Pipe Trench Sample Coordinates

Trench Sample ID	Coordinates of Sample Northing	Easting
TREN 1 SAMP 0+00	785,859	807,316
TREN 1 SAMP 1+50	785,896	807,463
TREN 1 SAMP 3+00	785,932	807,606
TREN 1 SAMP 4+50	785,963	807,764
TREN 1 SAMP 6+00	785,977	807,900
TREN 1 SAMP 7+50	785,987	808,081
TREN 1 SAMP 9+00	786,015	808,226
TREN 2 SAMP 0+00	789,045	806,407
TREN 2 SAMP 1+50	789,170	806,471
TREN 2 SAMP 3+00	789,301	806,537
TREN 2 SAMP 4+50	789,431	806,605
TREN 3 SAMP 0+00	789,148	806,427
TREN 3 SAMP 1+50	789,278	806,496
TREN 3 SAMP 3+00	789,411	806,568
TREN 3 SAMP 4+50	789,546	806,635
TREN 4 SAMP 0+00	787,890	807,057
TREN 4 SAMP 1+50	787,745	807,085
TREN 4 SAMP 3+00	787,599	807,070
TREN 4 SAMP 4+50	787,455	807,059
TREN 4 SAMP 6+00	787,307	807,056
TREN 4 SAMP 7+50	787,167	807,019
TREN 4 SAMP 9+00	787,039	806,967
TREN 5 SAMP 0+00	788,138	807,150
TREN 5 SAMP 1+50	788,067	807,286
TREN 6 SAMP 0+58	788,588	807,099
TREN 7 SAMP 0+38	788,609	807,064
TREN 8 SAMP 0+18	788,665	806,922
TREN 9 SAMP 0+13	788,623	806,793
TREN 10 SAMP 0+13	788,677	806,794
TREN 11 SAMP 0+05	788,735	806,906
TREN 14 SAMP	787,722	807,287
TREN 15 SAMP	788,716	807,017
TREN 17 SAMP	788,690	806,832

Table F-4 Pipe Trench System 1 Sample Coordinates

Trench Sample ID	Coordinates of Sample	
	Easting	Northing
A0	807,028	788,301
A150	807,083	788,182
A300	807,136	788,048
A450	807,183	787,923
B0	807,002	788,277
C0	806,987	788,270
D150	807,026	788,147
D300	807,101	788,028
D450	807,172	787,911
E0	807,002	788,323
E150	806,897	788,419
F100	806,835	788,535
G80	806,860	788,669
H40	806,871	788,607
I20	806,850	788,674
J25	806,997	788,352
K150	806,990	788,469
L25	807,017	788,458
M25	807,025	788,439
N100	807,035	788,567
N250	806,974	788,689
O0	806,908	788,740
O150	806,968	788,610
P25	806,977	788,628

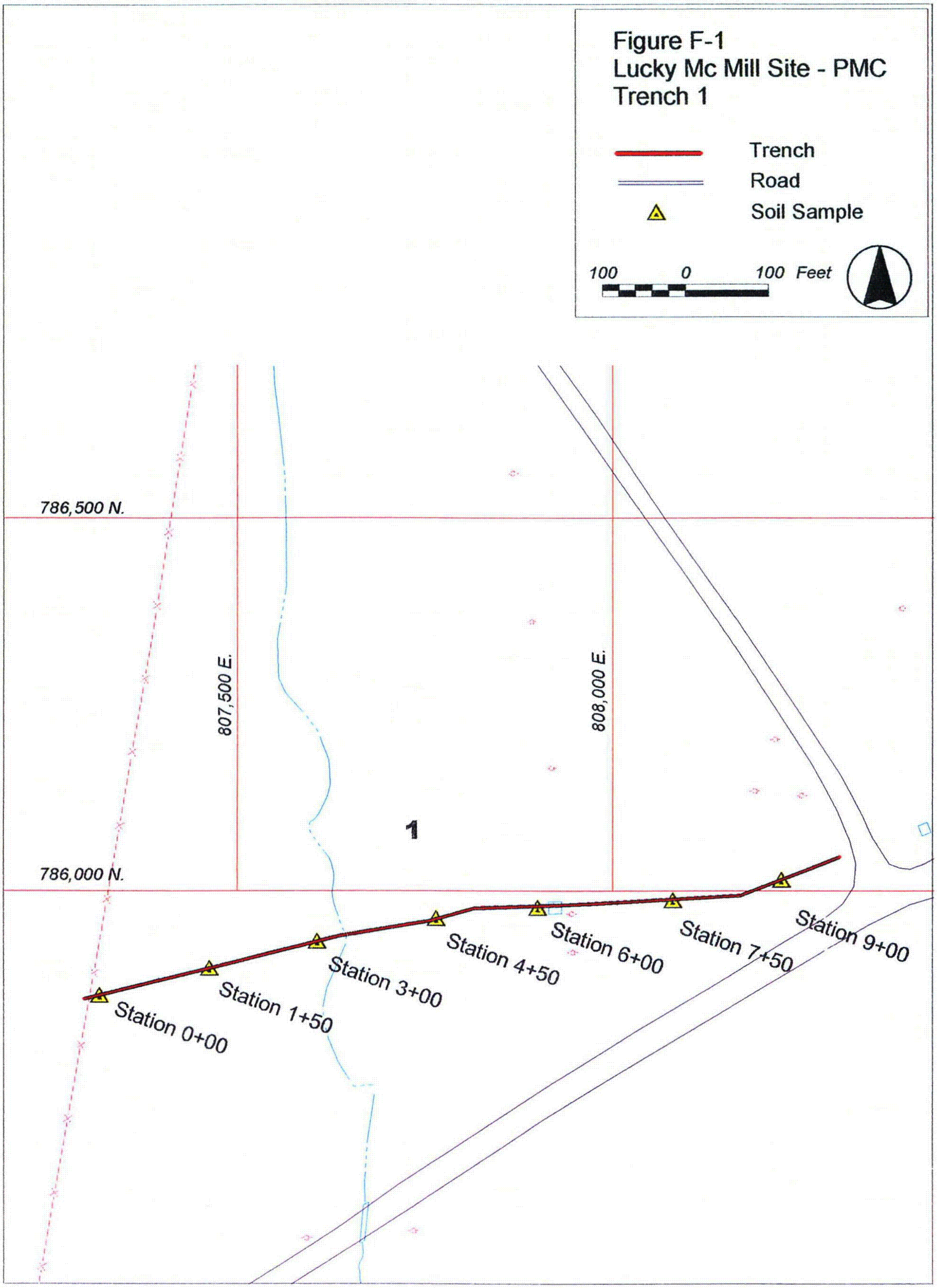


Figure F-1
Lucky Mc Mill Site - PMC
Trench 1

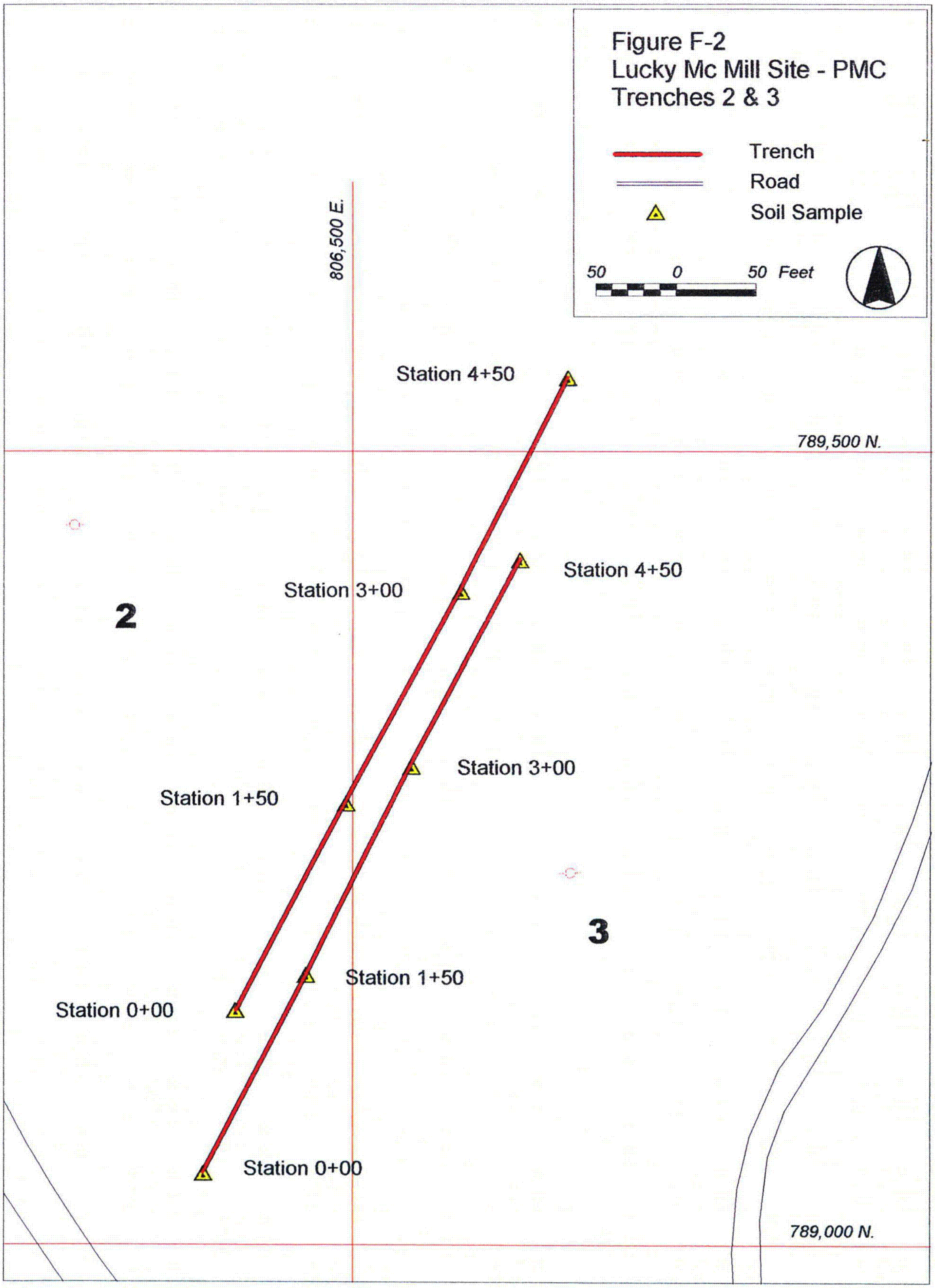


Figure F-2
Lucky Mc Mill Site - PMC
Trenches 2 & 3

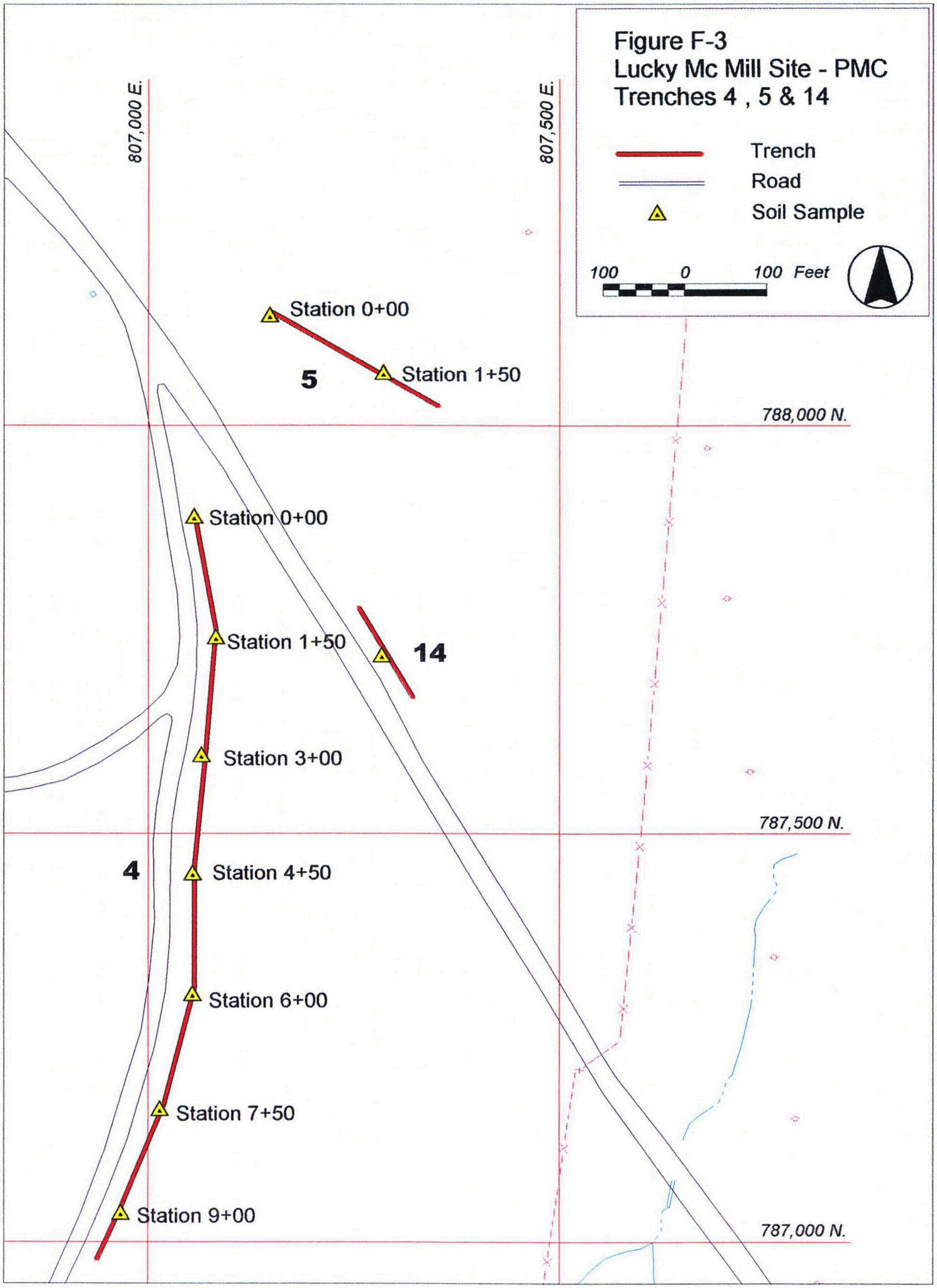


Figure F-3
Lucky Mc Mill Site - PMC
Trenches 4 , 5 & 14

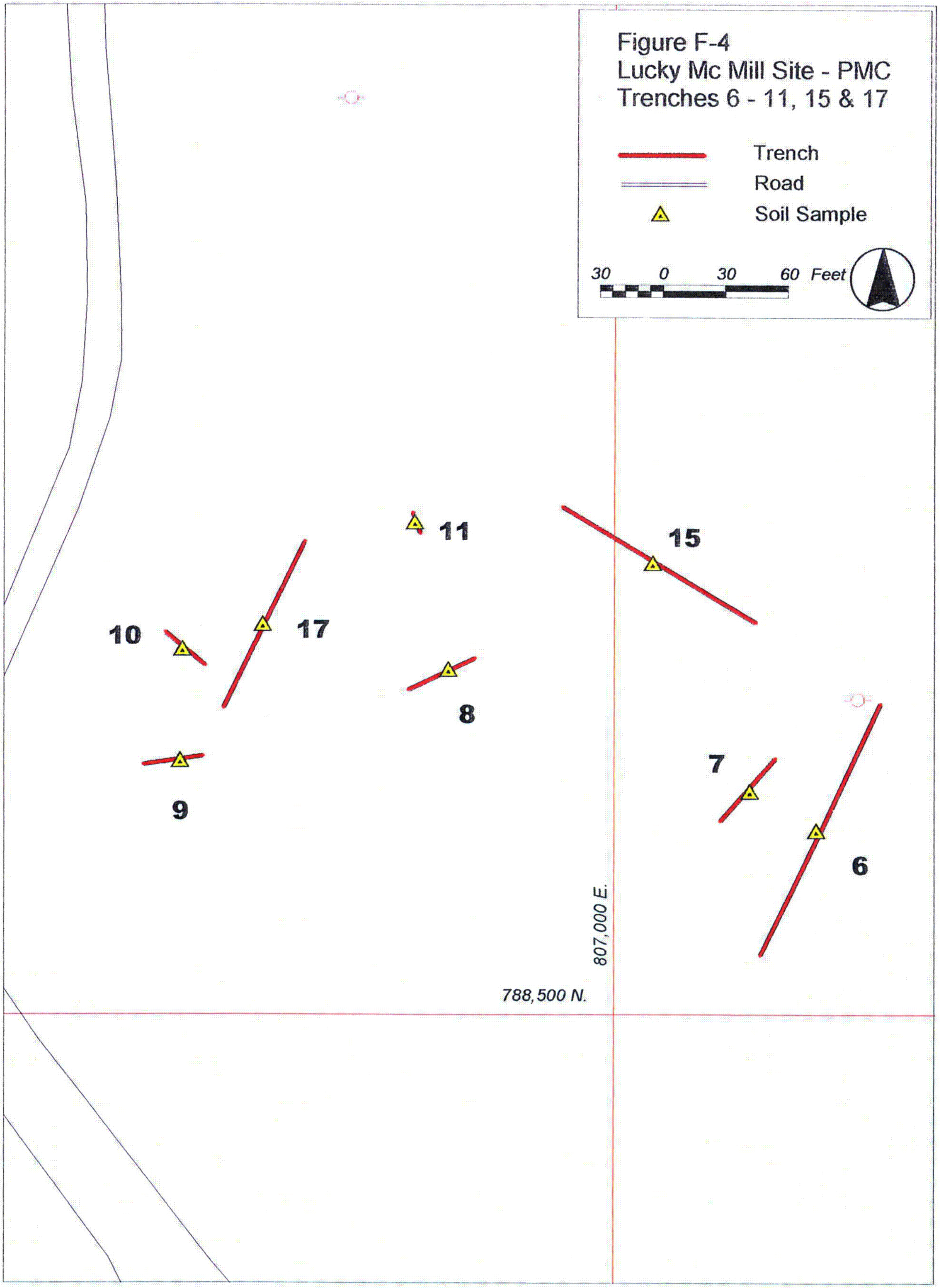


Figure F-4
Lucky Mc Mill Site - PMC
Trenches 6 - 11, 15 & 17

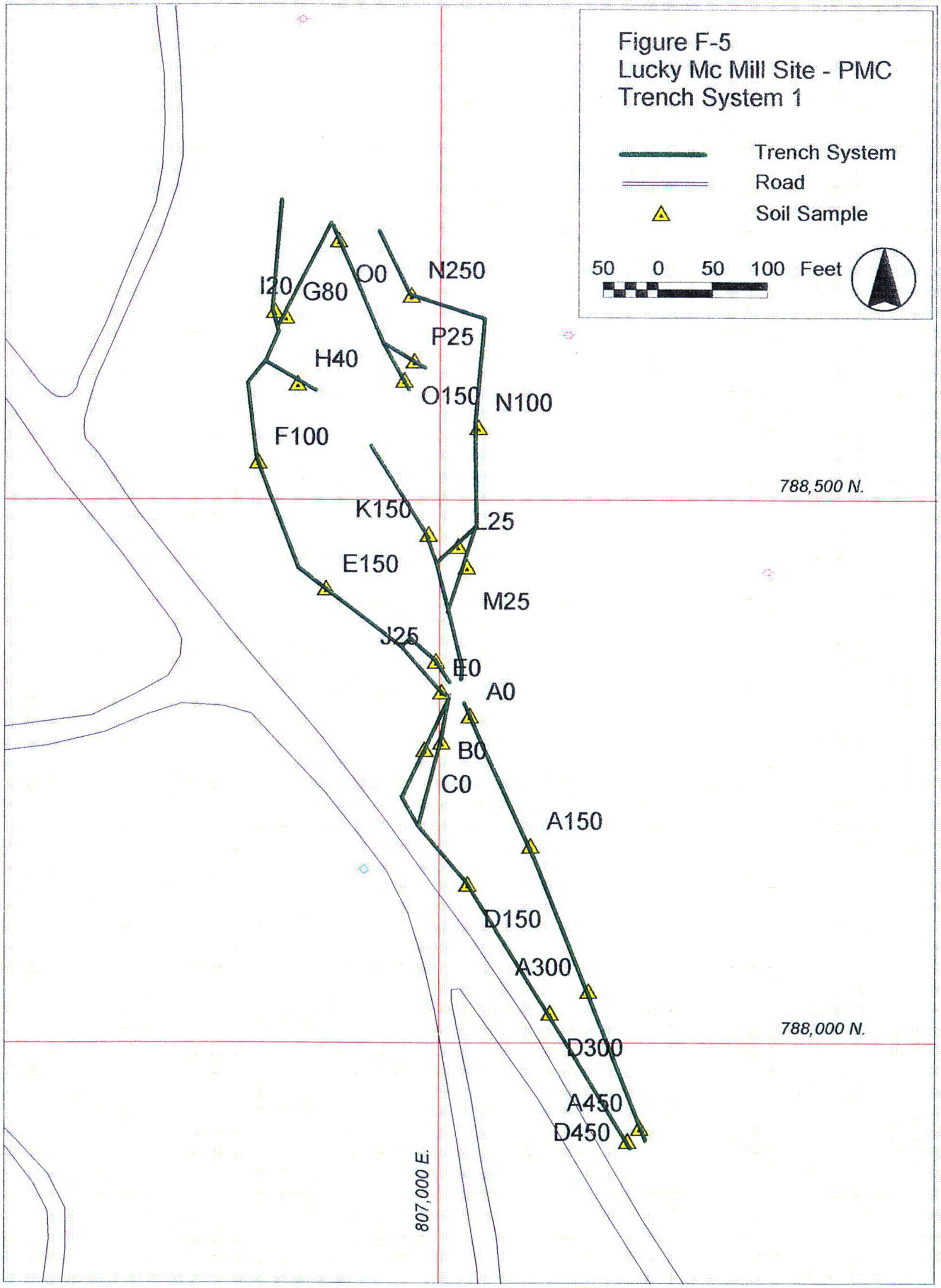


Figure F-5
Lucky Mc Mill Site - PMC
Trench System 1

Appendix G

Interlaboratory Comparison of Ra-226 and Th-230 Sample Results

Appendix G

INTERLABORATORY COMPARISON OF Ra-226 AND Th-230 SAMPLE RESULTS

G-1. Introduction

This report presents a comparison of Ra-226 and Th-230 results for 10 samples that were analyzed by different analytical laboratories. The Ra-226 samples were analyzed by four different laboratories; the Th-230 samples were analyzed by three different laboratories (Table 1). The samples were selected from soil samples collected from the Lucky Mc Mill Site (Pathfinder Mines Corporation - PMC) during field investigations.

Environmental Restoration Group, Inc.(ERG), using a portable NaI gamma spectroscopy system, initially analyzed all 10 Ra-226 samples at a field laboratory. These samples are included in the Ra-226 inter-laboratory comparison analysis. The archived samples were sent to Acculabs Research, Inc. of Golden, Colorado in the spring of 1998 for preparation and splitting. Of the 200 g splits prepared, one was analyzed in-house at Acculabs, another sent to Barringer Laboratories, Inc. in Denver, Colorado and the final split went to Energy Laboratories, Inc. (ELI) in Casper, Wyoming. All samples were analyzed using radiochemical chemical methods. Laboratory reports were received by PMC in June 1998.

While the ERG results were included for comparison of Ra-226 analyses, the reported errors reflect the field laboratory conditions, including non-ideal sample preparation equipment and laboratory climate controls, and changing ambient radon concentrations in the laboratory. These errors were added to the normal counting errors that occur in all radiometric systems.

G-2. Methodology

Several different statistical methods were utilized to determine comparability between laboratories for Ra-226 and Th-230 analytical results. The first was a simple ranking procedure. The next statistical test was Friedman's test. Friedman's test compares all the laboratories simultaneously for a particular radionuclide to determine if at least one of the sets of laboratory concentrations is statistically different than the other laboratories. Failures (differences) occurred during Friedman's test, so the Sign Test was applied. The Sign Test compares two labs at a time to determine statistically significant differences in reported concentrations. Finally, comparison of analytical results was performed by calculating overlap of the associated analytical results when considering the 2-sigma error.

The following sections provide a brief summary of the statistical tests performed on the data.

Simple Ranking Procedure

Concentrations for each sample for a particular radionuclide and location were ranked in descending order from n to 1. For identical concentrations, the ranks were averaged. The average of the ranks for a particular laboratory should be the summation of n to 1 divided by n. Large deviance from the expected average rank could indicate high or low bias (depending whether the average rank was higher or lower than the expected rank) in reported concentrations from that particular laboratory.

Friedman's Test

Friedman's test is an extension of the Sign Test from two paired populations to k related populations. Friedman's test can be performed unconstrained by the underlying distribution and can also accommodate a few not detected concentrations. However, no missing values are allowed (Gilbert, 1987).

The null hypothesis is:

H_O: There is no tendency for one population to have larger or smaller values than any other of the k populations.

The alternative hypothesis is:

H_A: At least one population tends to have larger values than one or more of the other populations.

The Friedman test statistic is calculated as follows

$$F_r = \frac{12\sum_{j=1}^{k}\left[R_j - \frac{n(k+1)}{2}\right]^2}{nk(k+1) - \frac{1}{k-1}\sum_{i=1}^{n}\left\{\left(\sum_{j=1}^{g_i} t_{i,j}^3\right) - k\right\}}$$

where

n = number of samples
k = number of populations
R_j = the sum of the ranks for the jth population
g_i = the number of tied groups in block i
$t_{i,j}$ = the number of tied data in the jth tied group in block i

Note: each untied value within block i is considered to be a "group" of ties of size 1.

For an α level test, reject H_O and accept H_A if $Fr > X_{1-\alpha, k-1}$, where $X_{1-\alpha, k-1}$ is the 1-α quantile of the chi-square distribution with k-1 degrees of freedom, where k is the number of populations. The chi-square distribution is appropriate only if n is reasonably large.

Sign Test

The Sign Test is easy to use and can be performed unconstrained by the underlying distribution (Gilbert, 1987). The Sign Test can also accommodate a few not detected concentrations. The sign test statistic, B, is the number of data pairs (x_{1i}, x_{2i}) for which $x_{1i} < x_{2i}$,. In other words, it is the number of positive differences D_i. The magnitudes of the positive differences are not considered; only their signs. If any D_i is zero so that a + or - sign cannot be assigned, the data pair is removed from the data set and n is reduced by 1. The statistic B is used to test the null hypothesis:

H_O: The median of the population of all possible differences is zero. That is, x_{1i} is as likely to be larger than x_{2i} as x_{2i} is likely to be larger than x_{1i}.

The alternative hypothesis is:

H_A: The median difference does not equal zero. That is, x_{1i} is more likely to exceed x_{2i} as x_{2i} is likely to be larger than x_{1i} or vice versa.

Then, reject H_O and accept H_A at the specified significance level if:

$$B \leq l\text{-}1 \text{ or } B \geq u$$

The critical values of l and u are confidence limits for the median of any continuous distribution (Geigy, 1982).

Intuitively, if the number of + and - signs are approximately equal, there is little reason to reject H_O.

Comparison of Laboratory Results Considering 2-Sigma Error

Radionuclide data results are associated with counting error. Therefore, a final analysis was to determine the correlation of the data considering the expected range of the concentration (adding and subtracting the 2-sigma error from the reported concentration). This analysis was performed in both a tabular manner and also graphically.

G-3. Results for Ra-226

Simple Ranking Procedure

The results from each set of split samples were ranked in descending order from 4 to 1, based on the Ra-226 concentration reported by each laboratory (Tables 2a and 2b). The ranks were averaged for identical concentrations. The average of the ranks (for the 10 samples) should approximately equal 2.5 if the analytical results are statistically similar. ERG, Berringer, and ELI had average ranks of 2.2, 2.2, and 2.1 respectively. The average rank for Acculabs was considerably higher at 3.5, indicating that concentrations reported from this laboratory could be consistently higher than the other three labs.

The variance from ERG is at least twice as high as any other lab possibly indicating less consistent or uniform sample preparation or laboratory instrumentation.

Friedman's Test

Friedman's test was then applied to the data sets. This test was performed to determine if the hypothesis that Acculabs measurements were consistently higher than the other labs had any merit. The test was performed at the $\alpha = 0.05$ significance level. Because the Friedman's test statistic was greater than the critical value for the appropriate significance level and degrees of freedom, it can be concluded that, statistically, at least one of the laboratories tends to report concentrations consistently different than the other labs (Table 3).

Sign Test

The Sign Test was performed on two laboratories at a time to determine if reported concentrations were statistically similar or different (Tables 4a to 4g). The Sign Test revealed that results from Acculabs versus Barringer and Acculabs versus ELI were not statistically similar (Tables 4e and 4f).

Comparison of Laboratory Results considering 2-Sigma Error

The reported concentrations from the four laboratories compared significantly better when the 2-sigma error was considered (Tables 5a and 5b, Figure 1). The average error was 32%, 31%, 26% and 5% for ERG, Acculabs, Barringer, and ELI respectively. These average errors were used to construct the error bars in Figure 1. Though some concentration ranges from the laboratories do not overlap, the statistical tests performed earlier would not fail considering the possible values provided in Table 5b and Figure 1. That is to say, the results from all 4 labs could be considered to be statistically equivalent.

G-4. Results for Th-230

Simple Ranking Procedure

The results from each set of split samples were ranked in descending order from 3 to 1, based on the Th-230 concentration reported by each laboratory (Tables 6a and 6b). The ranks were averaged for identical concentrations. The average of the ranks (for the 10 samples) should approximately equal 2 if the analytical results are statistically similar. ELI had an average rank of 1.5, Acculabs had and average rank of 1.85 and Barringer had an average rank of 2.65. These results indicate that ELI concentrations may be consistently low and Barringer concentrations may be consistently high compared to the other labs.

Friedman's Test

Friedman's test was then applied to the data sets. This test was performed to determine if the hypothesis that ELI concentrations are consistently low while Barringer measurements are consistently higher than the other labs had any merit . The test was performed at the $\alpha = 0.05$ significance level. Because the Friedman's test statistic was greater than the critical value for the appropriate significance level and degrees of freedom, it can be concluded that statistically at least one of the laboratories tends to report concentrations consistently different than the other labs (Table 7).

Sign Test

The Sign Test was performed on two laboratories at a time to determine if reported concentrations were statistically similar or different (Tables 8a to 8d). The Sign Test revealed that results from Acculabs versus Barringer were not statistically similar (Table 8b). Interestingly, the concentrations between Acculabs and ELI were determined to be statistically similar though the average ranks between the two provided the greatest difference. It must be noted that the sign test does not measure the magnitude of the difference but the consistency of one laboratory concentration being greater or less than another laboratory concentration.

Comparison of Laboratory Results considering 2-Sigma Error

The reported concentrations from the three laboratories compared generally well when the 2-sigma error was considered (Tables 9a and 9b, Figure 2). The average error was 27%, 15%, and 5% for Acculabs, Barringer, and ELI respectively. These average errors were used to construct the error bars in Figure 2. It can be seen that on four occasions the concentration range for Barringer is greater than ELI which was also demonstrated in the results of the simple ranking procedure and possibly Friedman's test. Though some concentration ranges from the laboratories do not overlap, the statistically tests performed earlier would not fail considering the possible values provided in Table 9b and Figure 2. . Which is to say, the results from all 4 labs could be considered to be statistically equivalent.

G-5. Summary

The statistical tests used to compare Ra-226 and Th-230 concentrations between laboratories indicate statistically significant differences. The statistical tests included a simple ranking procedure, Friedman's test, and the Sign Test. However, when the 2-sigma error was considered, the possible concentration range for each sample was similar. By manipulating the data within the 2-sigma data range, all of the statistical tests that previously failed could pass. Therefore, the data from the laboratories are statistically similar when the 2-sigma error is considered though "stand-alone" concentrations (no consideration of the 2-sigma error) have statistically significant differences.

It should be noted that no minimum sample number or power calculations have been performed in this analysis. It should also be noted that the statistical tests used (simple ranking, Friedman's, and the Sign Test) do not measure the magnitude of the difference, only the consistency of one laboratory reporting higher or lower concentrations than the other laboratories. A final note is that splitting soil samples is always a difficult task and some of the perceived error or inconsistencies can be a product of the heterogeneity of the soils or the contamination which exists within the soil which is impossible to replicate in split samples.

G-6. References

Geigy, 1982, Geigy Scientific tables, in Vol. 2, Introduction to Statistics, Statistical Tables and Mathematical Formulae, 8th ed., C. Lentner, ed. Ciby-Geigy Corporation, West Caldwell, N.J.

Gilbert, R.O., 1987, Statistical Methods for Environmental Pollution Monitoring, Van Nostrand Reinhold, NY, 320p.

Table 1. Laboratory Comparison for Reid Draw Samples

Sample ID	Ra-226 (pCi/g)				Th-230 (pCi/g)		
	ERG	Acculabs	Barringer	ELI	Acculabs	Barringer	ELI
RDTP2 (12-18")	3.1	2.4	2.2	2.1	16	16	13.4
RDTP3 (0-6")	25.5	37	27	36	1200	1210	1620
RDTP3 (24-30")	3	2	1.5	1.3	2.2	2.8	1.5
RDTP4 (24-30")	2.2	3.5	1.7	2.7	28	29	32.2
RDTP4 (60-66")	1.5	1.7	1.6	1.7	2.7	4	1.4
RDTP11 (12-18")	16.1	27	20	19	1000	943	792
RDTP14 (36-42")	27.3	30	28	28	2100	2240	1640
RDTP16 (36-42")	51	63	63	58.5	3800	4870	3720
RDTP17 (72-78")	2.3	1.9	2	1.3	2.3	4.4	3.4
RDTP19 (48-54")	15.9	20	12	13.2	61	65	59.4

Table 2. Ra-226 Simple Ranking Procedure

Table 2a. Ra-226 Concentrations (pCi/g)

	Ra-226 (pCi/g)			
Sample ID	ERG	Acculabs	Barringer	ELI
RDTP2 (12-18")	3.1	2.4	2.2	2.1
RDTP3 (0-6")	25.5	37	27	36
RDTP3 (24-30")	3	2	1.5	1.3
RDTP4 (24-30")	2.2	3.5	1.7	2.7
RDTP4 (60-66")	1.5	1.7	1.6	1.7
RDTP11 (12-18")	16.1	27	20	19
RDTP14 (36-42")	27.3	30	28	28
RDTP16 (36-42")	51	63	63	58.5
RDTP17 (72-78")	2.3	1.9	2	1.3
RDTP19 (48-54")	15.9	20	12	13.2

Table 2b. Ra-226 Ranking Results

	Ra-226 (pCi/g)			
Sample ID	ERG	Acculabs	Barringer	ELI
RDTP2 (12-18")	4	3	2	1
RDTP3 (0-6")	1	4	2	3
RDTP3 (24-30")	4	3	2	1
RDTP4 (24-30")	2	4	1	3
RDTP4 (60-66")	1	3.5	2	3.5
RDTP11 (12-18")	1	4	3	2
RDTP14 (36-42")	1	4	2.5	2.5
RDTP16 (36-42")	1	3.5	3.5	2
RDTP17 (72-78")	4	2	3	1
RDTP19 (48-54")	3	4	1	2
Average	2.2	3.5	2.2	2.1
Variance	1.96	0.44	0.68	0.82
Standard Deviation	1.40	0.67	0.82	0.91
Count	10	10	10	10

Table 3. Friedman's Test for Comparing k Populations for Ra-226 (pCi/g)

Sample ID	RDTP2 (12-18")		RDTP3 (0-6")		RDTP3 (24-30")		RDTP4 (24-30")		RDTP4 (60-66")		RDTP11 (12-18")		RDTP14 (36-42")		RDTP16 (36-42")		RDTP17 (72-78")		RDTP19 (48-54")		Sum of Ranks (Rj)
	Block 1		Block 2		Block 3		Block 4		Block 5		Block 6		Block 7		Block 8		Block 9		Block 10		
Lab Name	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	
ERG	3.1	4	25.5	1	3	4	2.2	2	1.5	1	16.1	1	27.3	1	51	1	2.3	4	15.9	3	22
Acculabs	2.4	3	37	4	2	3	3.5	4	1.7	3.5	27	4	30	4	63	3.5	1.9	2	20	4	35
Barringer	2.2	2	27	2	1.5	2	1.7	1	1.6	2	20	3	28	2.5	63	3.5	2	3	12	1	22
ELI	2.1	1	36	3	1.3	1	2.7	3	1.7	3.5	19	2	28	2.5	58.5	2	1.3	1	13.2	2	21

k = 4 (number of populations, in this case the number of laboratories)
n = 10 (number of related field samples)

Friedman's Test Correction for Ties

Block	g_i	$t_{i,j}$	$\Sigma t_{i,j}$^3 -k
5	3	$t_{5,1}=2,\ t_{5,2}=t_{5,3}=1$	6
7	3	$t_{7,1}=2,\ t_{7,2}=t_{7,3}=1$	6
8	3	$t_{8,1}=2,\ t_{8,2}=t_{8,3}=1$	6
		sum =	18

n(k+1)/2 = 25

F_r = 8.29

For $\alpha = 0.05$, the $\chi^2_{0.95,3} = 7.81$

Since $F_r > 7.81$, we reject H_o and accept H_a that at least 1 laboratory has consistently different concentrations than the other laboratories.

Table 4. The Sign Test for Comparing 2 Paired Observations for Ra-226

Table 4a. Ra-226 Concentrations (pCi/g)

	Ra-226 (pCi/g)			
Sample ID	ERG	Acculabs	Barringer	ELI
RDTP2 (12-18")	3.1	2.4	2.2	2.1
RDTP3 (0-6")	25.5	37	27	36
RDTP3 (24-30")	3	2	1.5	1.3
RDTP4 (24-30")	2.2	3.5	1.7	2.7
RDTP4 (60-66")	1.5	1.7	1.6	1.7
RDTP11 (12-18")	16.1	27	20	19
RDTP14 (36-42")	27.3	30	28	28
RDTP16 (36-42")	51	63	63	58.5
RDTP17 (72-78")	2.3	1.9	2	1.3
RDTP19 (48-54")	15.9	20	12	13.2

Table 4b. Comparison Between ERG and Acculabs Ra-226 Results

	Ra-226 (pCi/g)		
Sample ID	ERG	Acculabs	Sign of Difference
RDTP2 (12-18")	3.1	2.4	-
RDTP3 (0-6")	25.5	37	+
RDTP3 (24-30")	3	2	-
RDTP4 (24-30")	2.2	3.5	+
RDTP4 (60-66")	1.5	1.7	+
RDTP11 (12-18")	16.1	27	+
RDTP14 (36-42")	27.3	30	+
RDTP16 (36-42")	51	63	+
RDTP17 (72-78")	2.3	1.9	-
RDTP19 (48-54")	15.9	20	+

n = 10
B = 7 (number of "+" signs)
a = 0.05
l = 2 (for n = 10)
u = 9

Accept Ho since B is greater than l - 1 and less than u

Thus results from ERG and Acculabs are statistically similar.

Table 4c. Comparison Between ERG and Barringer Ra-226 Results

	Ra-226 (pCi/g)		
Sample ID	ERG	Barringer	Sign of Difference
RDTP2 (12-18")	3.1	2.2	-
RDTP3 (0-6")	25.5	27	+
RDTP3 (24-30")	3	1.5	-
RDTP4 (24-30")	2.2	1.7	-
RDTP4 (60-66")	1.5	1.6	+
RDTP11 (12-18")	16.1	20	+
RDTP14 (36-42")	27.3	28	+
RDTP16 (36-42")	51	63	+
RDTP17 (72-78")	2.3	2	-
RDTP19 (48-54")	15.9	12	-

n = 10
B = 5 (number of "+" signs)
a = 0.05
l = 2 (for n = 10)
u = 9

Accept Ho since B is greater than l - 1 and less than u
Thus results from ERG and Barringer are statistically similar.

Table 4d. Comparison Between ERG and ELI Ra-226 Results

	Ra-226 (pCi/g)		
Sample ID	ERG	ELI	Sign of Difference
RDTP2 (12-18")	3.1	2.1	-
RDTP3 (0-6")	25.5	36	+
RDTP3 (24-30")	3	1.3	-
RDTP4 (24-30")	2.2	2.7	+
RDTP4 (60-66")	1.5	1.7	+
RDTP11 (12-18")	16.1	19	+
RDTP14 (36-42")	27.3	28	+
RDTP16 (36-42")	51	58.5	+
RDTP17 (72-78")	2.3	1.3	-
RDTP19 (48-54")	15.9	13.2	-

n = 10
B = 6 (number of "+" signs)
a = 0.05
l = 2 (for n = 10)
u = 9

Accept Ho since B is greater than l - 1 and less than u
Thus results from ERG and ELI are statistically similar.

Table 4e. Comparison Between Acculabs and Barringer Ra-226 Results

	Ra-226 (pCi/g)		
Sample ID	Acculabs	Barringer	Sign of Difference
RDTP2 (12-18")	2.4	2.2	-
RDTP3 (0-6")	37	27	-
RDTP3 (24-30")	2	1.5	-
RDTP4 (24-30")	3.5	1.7	-
RDTP4 (60-66")	1.7	1.6	-
RDTP11 (12-18")	27	20	-
RDTP14 (36-42")	30	28	-
RDTP16 (36-42")	63	63	--[a]
RDTP17 (72-78")	1.9	2	+
RDTP19 (48-54")	20	12	-

--[a] = tied concentrations
n = 9
B = 1 (number of "+" signs)
a = 0.05
l = 2 (for n = 9)
u = 8

Reject H_o and accept H_a since B is equal to l-1

Thus results from Acculabs and Barringer are not statistically similar.

Table 4f. Comparison between Acculabs and ELI Ra-226 Results

	Ra-226 (pCi/g)		
Sample ID	Acculabs	ELI	Sign of Difference
RDTP2 (12-18")	2.4	2.1	-
RDTP3 (0-6")	37	36	-
RDTP3 (24-30")	2	1.3	-
RDTP4 (24-30")	3.5	2.7	-
RDTP4 (60-66")	1.7	1.7	--[a]
RDTP11 (12-18")	27	19	-
RDTP14 (36-42")	30	28	-
RDTP16 (36-42")	63	58.5	-
RDTP17 (72-78")	1.9	1.3	-
RDTP19 (48-54")	20	13.2	-

--[a] = tied concentrations
n = 9
B = 0 (number of "+" signs)
a = 0.05
l = 2 (for n = 9)
u = 8

Reject H_o and accept H_a since B is less than l-1

Thus results from Acculabs and ELI are not statistically similar.

Table 4g.' Comparison Between Barringer and EL I Ra-226 Results

	Ra-226 (pCi/g)		
Sample ID	Barringer	ELI	Sign of Difference
RDTP2 (12-18")	2.2	2.1	-
RDTP3 (0-6")	27	36	+
RDTP3 (24-30")	1.5	1.3	-
RDTP4 (24-30")	1.7	2.7	+
RDTP4 (60-66")	1.6	1.7	+
RDTP11 (12-18")	20	19	-
RDTP14 (36-42")	28	28	--[a]
RDTP16 (36-42")	63	58.5	-
RDTP17 (72-78")	2	1.3	-
RDTP19 (48-54")	12	13.2	+

--[a] = tied concentrations

n = 9
B = 4 (number of "+" signs)
a = 0.05
l = 2 (for n = 9)
u = 8

Accept Ho since B is greater than l - 1 and less than u

Thus results from Barringer and ELI are statistically similar.

Table 5. Analysis of Concentation Overlap Considering 2-Sigma Analytical Error Between Laboratories for Ra-226

Table 5a. Laboratory Concentrations and 2-Sigma Error

	ERG		Acculabs		Barringer		ELI	
Sample ID	Conc	2-Sigma Error	Conc.	2-Sigma Error	Conc.	2-Sigma Error	Conc.	2-Sigma Err
RDTP2 (12-18")	3.1	1	2.4	0.8	2.2	0.8	2.1	0.2
RDTP3 (0-6")	25.5	5	37	11	27	3	36	0.6
RDTP3 (24-30")	3	1	2	0.6	1.5	0.7	1.3	0.1
RDTP4 (24-30")	2.2	1	3.5	1.1	1.7	0.7	2.7	0.2
RDTP4 (60-66")	1.5	1	1.7	0.6	1.6	0.7	1.7	0.1
DTP11 (12-18"	16.1	3	27	8	20	2	19	0.5
DTP14 (36-42"	27.3	5	30	8.8	28	3	28	0.6
DTP16 (36-42"	51	10	63	19	63	4	58.5	0.8
DTP17 (72-78"	2.3	1	1.9	0.6	2	0.8	1.3	0.1
DTP19 (48-54"	15.9	3	20	5.9	12	2	13.2	0.4

Table 5b. Determination of Concentration Overlap Considering 2-Sigma Error

	ERG			Acculabs			Barringer			ELI			
Sample I. D.	Conc	Conc. Minus 2-Sigma Error	Conc. Plus 2-Sigma Error	Conc.	Conc. Minus 2-Sigma Error	Conc. Plus 2-Sigma Error	Conc.	Conc. Minus 2-Sigma Err	Conc. Plus 2-Sigma Error	Conc.	Conc. Minus 2-Sigma Error	Conc. Plus 2-Sigma Err	Do laboratory concentrations overlap considering positive and negative error?
RDTP2 (12-18")	3.1	2.1	4.1	2.4	1.6	3.2	2.2	1.4	3.0	2.1	1.9	2.3	Yes
RDTP3 (0-6")	25.5	20.5	30.5	37	26.0	48.0	27	24.0	30.0	36	35.4	36.6	No, ERG and Barringer<ELI
RDTP3 (24-30")	3	2.0	4.0	2	1.4	2.6	1.5	0.8	2.2	1.3	1.2	1.4	No, ELI<ERG
RDTP4 (24-30")	2.2	1.2	3.2	3.5	2.4	4.6	1.7	1.0	2.4	2.7	2.5	2.9	No, Barringer<ELI
RDTP4 (60-66")	1.5	0.5	2.5	1.7	1.1	2.3	1.6	0.9	2.3	1.7	1.6	1.8	Yes
DTP11 (12-18"	16.1	13.1	19.1	27	19.0	35.0	20	18.0	22.0	19	18.5	19.5	Yes
DTP14 (36-42"	27.3	22.3	32.3	30	21.2	38.8	28	25.0	31.0	28	27.4	28.6	Yes
DTP16 (36-42"	51	41.0	61.0	63	44.0	82.0	63	59.0	67.0	58.5	57.7	59.3	Yes
DTP17 (72-78"	2.3	1.3	3.3	1.9	1.3	2.5	2	1.2	2.8	1.3	1.2	1.4	Yes
DTP19 (48-54"	15.9	12.9	18.9	20	14.1	25.9	12	10.0	14.0	13.2	12.8	13.6	No, Barringer and ELI<Acculabs

Table 6. Th-230 Simple Ranking Procedure

Table 6a. Th-230 Concentrations (pCi/g)

	Th-230 (pCi/g)		
Sample ID	Acculabs	Barringer	ELI
RDTP2 (12-18")	16	16	13.4
RDTP3 (0-6")	1200	1210	1620
RDTP3 (24-30")	2.2	2.8	1.5
RDTP4 (24-30")	28	29	32.2
RDTP4 (60-66")	2.7	4	1.4
RDTP11 (12-18")	1000	943	792
RDTP14 (36-42")	2100	2240	1640
RDTP16 (36-42")	3800	4870	3720
RDTP17 (72-78")	2.3	4.4	3.4
RDTP19 (48-54")	61	65	59.4

Table 6b. Th-230 Ranking Results

	Th-230 (pCi/g)		
Sample ID	Acculabs	Barringer	ELI
RDTP2 (12-18")	2.5	2.5	1
RDTP3 (0-6")	1	2	3
RDTP3 (24-30")	2	3	1
RDTP4 (24-30")	1	2	3
RDTP4 (60-66")	2	3	1
RDTP11 (12-18")	3	2	1
RDTP14 (36-42")	2	3	1
RDTP16 (36-42")	2	3	1
RDTP17 (72-78")	1	3	2
RDTP19 (48-54")	2	3	1
Average	1.85	2.65	1.5
Variance	0.45	0.23	0.72
Standard Deviation	0.67	0.47	0.85
Count	10	10	10

Table 7. Friedman's Test for Comparing k Populations for Th-230 (pCi/g)

Sample ID	RDTP2 (12 18")		RDTP3 (0-6")		RDTP3 (24-30")		RDTP4 (24-30")		RDTP4 (60-66")		RDTP11 (12-18")		RDTP14 (36 42")		RDTP16 (36-42")		RDTP17 (72-78")		RDTP19 (48-54")		Sum of Ranks (Rj)
	Block 1		Block 2		Block 3		Block 4		Block 5		Block 6		Block 7		Block 8		Block 9		Block 10		
Lab Name	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	Conc.	Rank	
Acculabs	16	2.5	1200	1	2.2	2	28	1	2.7	2	1000	3	2100	2	3800	2	2.3	1	61	2	18.5
Barringer	16	2.5	1210	2	2.8	3	29	2	4	3	943	2	2240	3	4870	3	4.4	3	65	3	26.5
ELI	13.4	1	1620	3	1.5	1	32.2	3	1.4	1	792	1	1640	1	3720	1	3.4	2	59.4	1	15

k = 3 (number of populations, in this case the number of laboratories)
n = 10 (number of related field samples)

Friedman's Test Correction for Ties

Block	g_i	$t_{i,,j}$	$St_{i,j}$^3 -k
1	2	$t_{1,1}=2$, $t_{1,2}=1$	6

sum 6

n(k+1)/2 = 20

F_r = 7.13

For a = 0.05, the $c^2_{0.95,2}$ = 5.99

Since $F_r > 5.99$, we reject H_o and accept H_a that at least 1 laboratory has consistently different concentrations than the other laboratories.

Table 8. The Sign Test for Comparing 2 Paired Observations for Th-230 (pCi/g)

Table 8a. Th-230 Concentrations (pCi/g)

	Th-230 (pCi/g)		
Sample ID	Acculabs	Barringer	ELI
RDTP2 (12-18")	16	16	13.4
RDTP3 (0-6")	1200	1210	1620
RDTP3 (24-30")	2.2	2.8	1.5
RDTP4 (24-30")	28	29	32.2
RDTP4 (60-66")	2.7	4	1.4
RDTP11 (12-18")	1000	943	792
RDTP14 (36-42")	2100	2240	1640
RDTP16 (36-42")	3800	4870	3720
RDTP17 (72-78")	2.3	4.4	3.4
RDTP19 (48-54")	61	65	59.4

Table 8b. Comparison Between Acculabs and Barringer Th-230 Results

	Th-230 (pCi/g)		
Sample ID	Acculabs	Barringer	Sign of Difference
RDTP2 (12-18")	16	16	--[a]
RDTP3 (0-6")	1200	1210	+
RDTP3 (24-30")	2.2	2.8	+
RDTP4 (24-30")	28	29	+
RDTP4 (60-66")	2.7	4	+
RDTP11 (12-18")	1000	943	-
RDTP14 (36-42")	2100	2240	+
RDTP16 (36-42")	3800	4870	+
RDTP17 (72-78")	2.3	4.4	+
RDTP19 (48-54")	61	65	+

[a] = tied concentrations

n = 9 (one data pair is tied and is therefore eliminated)
B = 8 (number of "+" signs)
a = 0.05
l = 2 (for n = 9)
u = 8

Reject Ho and accept Ha since B is greater than or equal to u
Thus results from Acculabs and Barringer are not statistically similar.

Table 8c. Comparison Between Barringer and ELI Th-230 Results

	Th-230 (pCi/g)		
Sample ID	Barringer	ELI	Sign of Difference
RDTP2 (12-18")	16	13.4	-
RDTP3 (0-6")	1210	1620	+
RDTP3 (24-30")	2.8	1.5	-
RDTP4 (24-30")	29	32.2	+
RDTP4 (60-66")	4	1.4	-
RDTP11 (12-18")	943	792	-
RDTP14 (36-42")	2240	1640	-
RDTP16 (36-42")	4870	3720	-
RDTP17 (72-78")	4.4	3.4	-
RDTP19 (48-54")	65	59.4	-

n = 10
B = 2 (number of "+" signs)
a = 0.05
l = 2 (for n = 10)
u = 9

Accept Ho since B is greater than l - 1 and less than u
Thus results from Barringer and ELI are statistically similar.

Table 8d. Comparison Between Acculabs and ELI Th-230 Results

	Th-230 (pCi/g)		
Sample ID	Acculabs	ELI	Sign of Difference
RDTP2 (12-18")	16	13.4	-
RDTP3 (0-6")	1200	1620	+
RDTP3 (24-30")	2.2	1.5	-
RDTP4 (24-30")	28	32.2	+
RDTP4 (60-66")	2.7	1.4	-
RDTP11 (12-18")	1000	792	-
RDTP14 (36-42")	2100	1640	-
RDTP16 (36-42")	3800	3720	-
RDTP17 (72-78")	2.3	3.4	+
RDTP19 (48-54")	61	59.4	-

n = 10
B = 3 (number of "+" signs)
a = 0.05
l = 2 (for n = 10)
u = 9

Accept Ho since B > I-1 and < u
Thus results from Acculabs and ELI are statistically similar.

Table 9. Analysis of Concentation Overlap Considering 2-Sigma Analytical Error Between Laboratories for Th-230

Table 9a. Laboratory Concentrations and 2-Sigma Error

	Acculabs		Barringer		ELI	
Sample ID	Conc.	2-Sigma Error	Conc.	2-Sigma Error	Conc.	2-Sigma Error
RDTP2 (12-18")	16	5.2	16	3	13.4	0.6
RDTP3 (0-6")	1200	310	1210	20	1620	17
RDTP3 (24-30")	2.2	0.8	2.8	1.1	1.5	0.2
RDTP4 (24-30")	28	8	29	3	32.2	1.6
RDTP4 (60-66")	2.7	1.2	4	1.4	1.4	0.2
RDTP11 (12-18"	1000	230	943	19	792	8.4
RDTP14 (36-42"	2100	450	2240	30	1640	12
RDTP16 (36-42"	3800	810	4870	90	3720	18.1
RDTP17 (72-78"	2.3	0.1	4.4	1.4	3.4	0.3
RDTP19 (48-54"	61	18	65	5	59.4	1.8

Table 9b. Determination of Concentration Overlap Considering 2-Sigma Error

	Acculabs			Barringer			ELI			
Sample ID	Conc.	Conc. Minus 2-Sigma Error	Conc. Plus 2-Sigma Error	Conc.	Conc. Minus 2-Sigma Error	Conc. Plus 2-Sigma Error	Conc.	Conc. Minus 2-Sigma Error	Conc. Plus 2-Sigma Error	Do laboratory concentrations overlap considering positive and negative error?
RDTP2 (12-18")	16	10.8	21.2	16	13.0	19.0	13.4	12.8	14.0	Yes
RDTP3 (0-6")	1200	890.0	1510.0	1210	1190.0	1230.0	1620	1603.0	1637.0	No, Acculabs and Barringer < ELI
RDTP3 (24-30")	2.2	1.4	3.0	2.8	1.7	3.9	1.5	1.3	1.7	Yes
RDTP4 (24-30")	28	20.0	36.0	29	26.0	32.0	32.2	30.6	33.8	Yes
RDTP4 (60-66")	2.7	1.5	3.9	4	2.6	5.4	1.4	1.2	1.6	No, ELI < Barringer
RDTP11 (12-18"	1000	770.0	1230.0	943	924.0	962.0	792	783.6	800.4	No, ELI < Barringer
RDTP14 (36-42"	2100	1650.0	2550.0	2240	2210.0	2270.0	1640	1628.0	1652.0	No, ELI < Barringer
RDTP16 (36-42"	3800	2990.0	4610.0	4870	4780.0	4960.0	3720	3701.9	3738.1	No, Acculabs and ELI < Barringer
RDTP17 (72-78"	2.3	2.2	2.4	4.4	3.0	5.8	3.4	3.1	3.7	No, Acculabs < ELI and Barringer
RDTP19 (48-54"	61	43.0	79.0	65	60.0	70.0	59.4	57.6	61.2	Yes

Figure 1. Comparison of Ra-226 Laboratory Data Considering Analytical Error

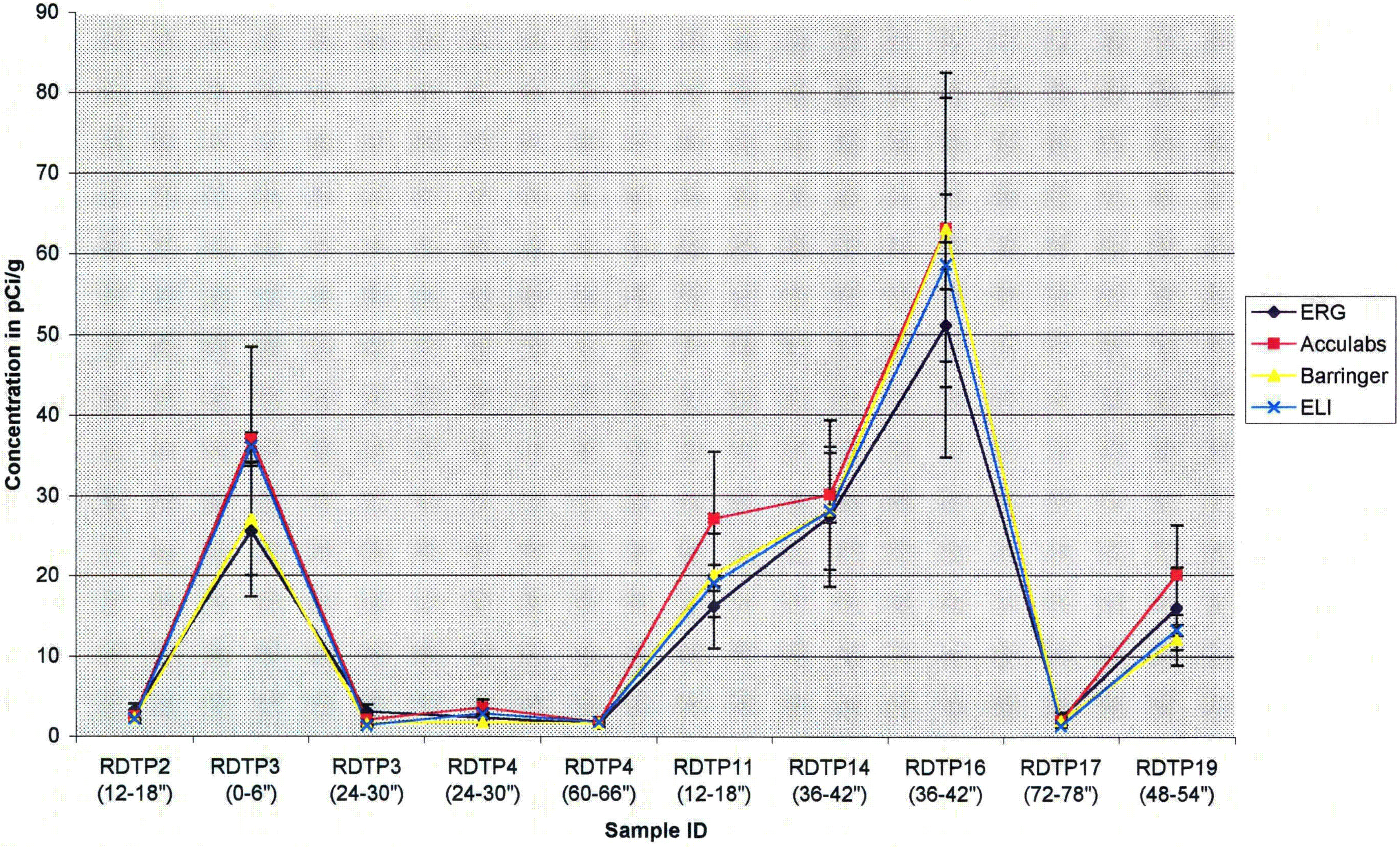
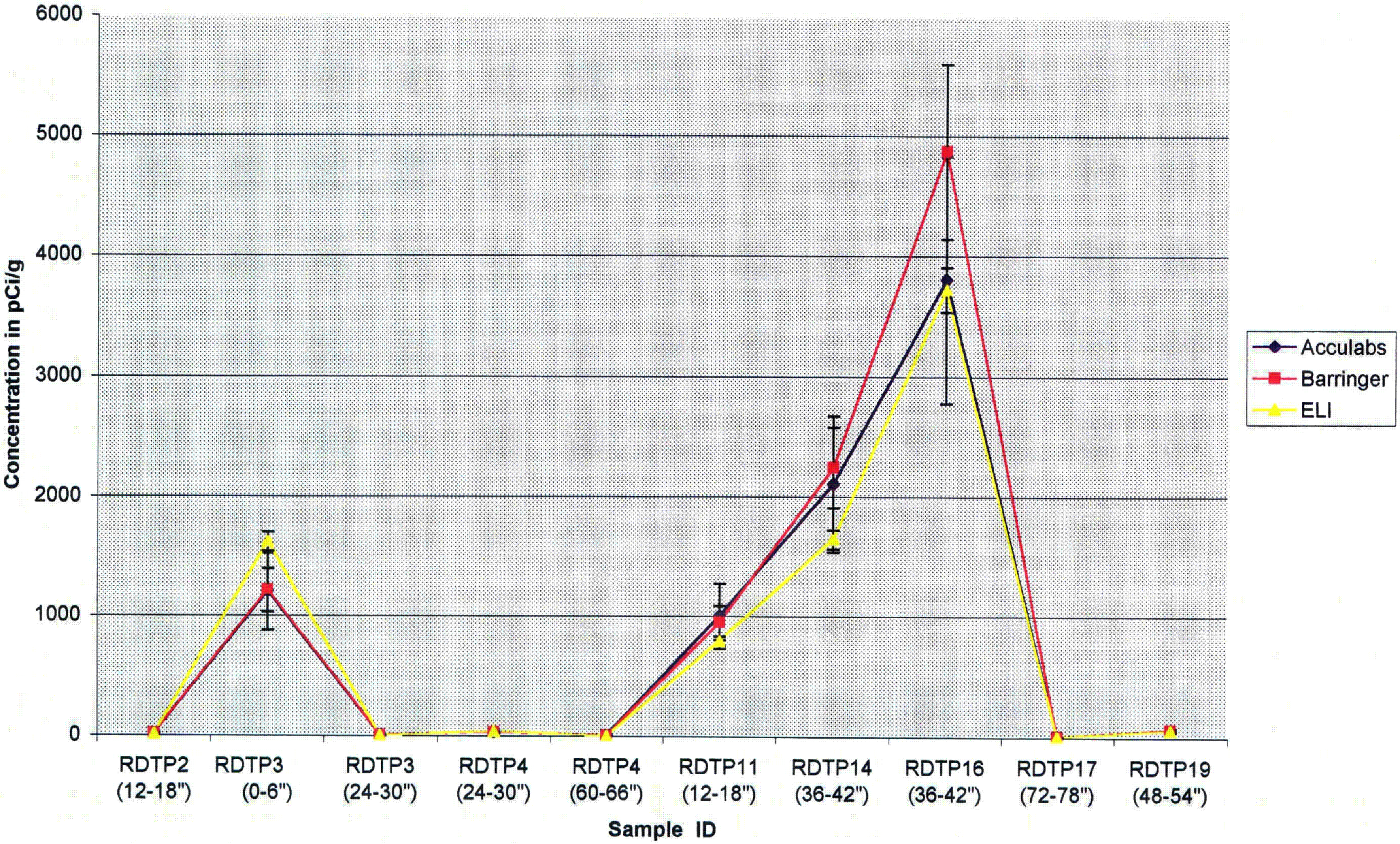


Figure 2. Comparison of Th-230 Laboratory Data Considering Analytical Error



Appendix H

Interlaboratory Comparison of Ra-226 Sample Results

Appendix H

INTERLABORATORY COMPARISON OF Ra-226 SAMPLE RESULTS

H-1. Introduction

This report presents a comparison of Ra-226 results for 170 samples that were analyzed by two different analytical laboratories, ELI and ERG (Table 1).

H-2. Methodology

Wilcoxon's signed rank test was used to determine if the two dependent analytical results obtained from ELI and ERG laboratories represented two similar populations. Wilcoxon's signed rank test is a nonparametric test. The null hypothesis is:

> H_O: The median of the population of all possible differences is zero. That is, x_{1i} is as likely to be larger than x_{2i} as x_{2i} is likely to be larger than x_{1i}.

The alternative hypothesis is:

> H_A: The median difference does not equal zero. That is, x_{1i} is more likely to exceed x_{2i} as x_{2i} is likely to be larger than x_{1i} or vice versa.

This test is based on the following assumptions:

1. The sample of n subjects has been randomly selected from the population it represents
2. The distribution of the difference scores in the populations represented by the two samples is symmetric about the median of the population of difference scores.

The steps in the procedure are:

1. Rank the differences between paired values from smallest to largest without regard to sign.
2. Assign to the ranks the signs of the original differences
3. Compute the sum of the positive ranks T_+ and the sum of the negative ranks T_-. These are related by the equation $T_+ + T_- = n(n+1)/2$. Choose the numerically smaller of T_+ and T_- and call it T.
4. Compare the sum obtained at step 3 with the critical value

For n > 50 data pairs, Z is used to test significance.

$$Z = \frac{(T - \mu_T)}{\sigma_T}$$

where,

$$\mu_T = \frac{n(n+1)}{4}$$

$$\sigma_T = \sqrt{\frac{n(n+1)(2n+1)}{24}}$$

Thus, for a two-tailed test and $\alpha = 0.05$, the null hypothesis is rejected when $|Z| \geq 1.96$.

The assumption of symmetry for the paired differences was verified by calculating the coefficient of skewness and performing the Studentized Range Test. Symmetry is a less stringent assumption than normality since all normal distributions are symmetric, but some symmetric distributions are not normal. The symmetry analysis tests if the data is symmetrical around the mean. Since the median and mean are equal if symmetry exists, the symmetry tests were considered applicable.

The degree of symmetry displayed by a data set is measured by the coefficient of skewness. This test is considered useful by the USEPA (1998) for large sample sizes. The coefficient of skewness indicates to what degree a data set is skewed or asymmetric with respect to the mean. Data from a perfectly shaped normal distribution have a coefficient of skewness of zero, while asymmetric data have either positive or negative skewness depending on whether the right- or left-hand tail of the distribution is longer and "skinnier" than the opposite tail. A small degree of skewness (between -1 and +1) is not likely to affect the results of statistical tests based on an assumption of normality. The formula for the coefficient of skewness (γ_i) is shown below, where n is the number of data points, x_i is an individual sample observation, $\bar{x}$ is the mean of the data set, and σ is the standard deviation.

$$\gamma_i = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^3}{\left(\frac{n-1}{n}\right)^{\frac{3}{2}} (\sigma)^3}$$

The Studentized range test (or w/s test) compares the range of the sample to the sample standard deviation. This test is highly recommended by the EPA (1998). Tables of critical values are used to determine whether the absolute value of this ratio is significantly large. The Studentized range test does not perform well if the data are asymmetric and if the tails of the data are heavier than the normal distribution. In addition, this test may be sensitive to extreme values. The formula for the Studentized range test is shown below, where w equals the range of values (X_n-X_1) and σ is the standard deviation.

$$\frac{w}{s} = \frac{X_n - X_1}{s}$$

If w/s falls outside the two critical values then the data do not follow a normal curve.

As stated earlier, all normal distributions are symmetric, but some symmetric distributions are not normal. Therefore failure of this test would not necessarily indicate non-symmetry for the paired differences. However, passage of the test would indicate that the data was indeed symmetrical.

H-3. Results

The sum of the negative ranks was 12,495 (Table 1). The sum of the positive ranks was 1200.5. Thus the sum of the positive ranks was used as T. The calculated Z considering 165 paired differences (5 paired differences were zero and therefore eliminated from the calculation) was -9.1878. For $\alpha = 0.05$, the critical value is 1.96. Since the absolute value of Z was greater than 1.96, the null hypothesis is rejected and the alternative hypothesis that the median difference does not equal zero is accepted.

As stated previously Wilcoxon's Signed Rank Test is a nonparametic test. However, an underlying assumption is that the paired differences are symmetric. The coefficient of skewness was calculated and the Studentized Range test was performed to determine if indeed the data were symmetric.

The coefficient of skewness calculation is provided in Table 2. The coefficient of skewness was calculated to be -0.8628 compared to the critical range of -1 to +1.

The results of the Studentized Range test are provided in Table 3. The w/s value for n = 170 was calculated to be 6.09. This value is within the critical range for $\alpha = 0.05$ and n = 150 to n = 200.

H-4. Conclusions

The paired differences data from ERG and ELI failed Wilcoxon's Signed Rank Test (Table 1). Thus, the null hypothesis is rejected and the alternative hypothesis that the median difference does not equal zero is accepted. From Table 1 it can be seen that the top 37 ranked differences were from ERG results being greater than ELI results. Thus it can be stated that ERG results tend to be greater than ELI results. It should be noted that no explicit trend was seen in the ERG data vs. ELI data. In other words, ERG appears to have consistently larger values over the entire reported concentration range.

An underlying assumption for the applicability of Wilcoxon's Signed Rank test is that the paired differences are symmetric. The paired differences passed both applied tests for symmetry (the coefficient of skewness and the Studentized Range test), therefore it was concluded that the paired differences were symmetric about the median.

H-5. References

United States Environmental Protection Agency (USEPA), 1998, Guidance for Data Quality Assessment, Office of Research and Development, Washington D.C., EPA/600/R-96/084.

Table 1. Wilcoxon's Signed Rank Test Applied to ELI and ERG Data

	Laboratory			Rank	
Sample ID	ELI[1] Ra 226 (pCi/g)	ERG Ra-226 (pCi/g)	Paired Difference	T_-	T_+
N16A24A	1.5	2.2	-0.7	-52	
N16A25D	3.0	2.9	0.1		6
N16A24B	1.5	1.9	-0.4	-32	
N16B25J	2.2	2.4	-0.2	-15.5	
N16B25H	2.3	3.7	-1.4	-91.5	
N16B25F	1.9	3.0	-1.1	-77	
N16C05G	2.7	2.6	0.1		6
N16C10C	2.7	2.4	0.3		24
N16C10B	3.5	3.5	0		
N16D05F	3.2	5.1	-1.9	-110	
N16D05C	4.8	5.4	-0.6	-46	
N16D05J	2.1	3.5	-1.4	-91.5	
N17A21G	7.4	7.0	0.4		32
N17A21B	7.3	10.8	-3.5	-152.5	
N17A16H	5.2	6.0	-0.8	-56.5	
N17C01A	9.8	10.4	-0.6	-46	
N17C06C	7.4	5.5	1.9		110
N17C01E	8.7	10.6	-1.9	-110	
P16A10A	1.4	0.9	0.5		38.5
P16A25J	0.8	2.3	-1.5	-96.5	
P16A25F	1.5	2.0	-0.5	-38.5	
P16B05H	3.9	4.2	-0.3	-24	
P16B05J	6.6	5.7	0.9		65
P16B10C	3.4	5.8	-2.4	-129.5	
P16C05E	1.2	2.0	-0.8	-56.5	
P16D10A	1.5	5.4	-3.9	-155.5	
P16D09C	2.4	5.9	-3.5	-152.5	
P16D04F	4.8	5.3	-0.5	-38.5	
P17A11C	10.4	8.4	2		116.5
P17A06H	10.0	9.6	0.4		32
P17A16C	7.9	8.2	-0.3	-24	
P17B21G	4.0	4.6	-0.6	-46	
P17C24C	10.0	14.3	-4.3	-158.5	
P17C05H	11.8	14.5	-2.7	-139	
P17C19J	9.7	13.1	-3.4	-150	

Table 1. Wilcoxon's Signed Rank Test Applied to ELI and ERG Data (cont.)

	Laboratory			Rank	
Sample ID	ELI [1] Ra 226 (pCi/g)	ERG Ra-226 (pCi/g)	Paired Difference	T_-	T_+
P17D25C	5.7	6.7	-1	-72.5	
P17D25J	6.7	7.4	-0.7	-52	
P17D25F	9.0	9.6	-0.6	-46	
P18A25C	2.9	4.2	-1.3	-85.5	
P18A25J	3.4	4.9	-1.5	-96.5	
P18A25E	2.8	4.7	-1.9	-110	
P18B11G	7.9	11.8	-3.9	-155.5	
P18B18B	5.2	7.8	-2.6	-135	
P18B23H	9.0	8.1	0.9		65
P18C20H	5.4	8.1	-2.7	-139	
P18D07C	3.5	6.1	-2.6	-135	
P18D16H	2.6	4.6	-2	-116.5	
P18D24G	3.2	3.8	-0.6	-46	
P19C21H	3.8	4.8	-1	-72.5	
Q16B05F	5.2	6.3	-1.1	-77	
Q16B05B	3.8	4.7	-0.9	-65	
Q16B05C	2.1	3.8	-1.7	-102.5	
Q16D23A	5.3	4.4	0.9		65
Q16D12G	2.7	3.8	-1.1	-77	
Q16D18D	2.2	3.5	-1.3	-85.5	
Q17A09C	14.0	13.4	0.6		46
Q17A09E	15.3	15.2	0.1		6
Q17A04C	9.4	12.0	-2.6	-135	
Q17C22J	6.4	10.0	-3.6	-154	
Q17C03G	8.1	10.7	-2.6	-135	
Q17C03B	8.5	10.5	-2	-116.5	
Q17B09A	2.6	3.8	-1.2	-81	
Q17B04C	4.5	7.9	-3.4	-150	
Q17B05F	10.8	13.8	-3	-145	
Q17D12J	8.8	9.0	-0.2	-15.5	
Q17D03E	10.9	18.1	-7.2	-165	
Q17D03C	14.4	13.1	1.3		85.5
Q18A05C	3.3	6.3	-3	-145	
Q18A25A	5.5	6.6	-1.1	-77	
Q18A05F	6.0	6.1	-0.1	-6	

Table 1. Wilcoxon's Signed Rank Test Applied to ELI and ERG Data (cont.)

	Laboratory			Rank	
Sample ID	ELI[1] Ra 226 (pCi/g)	ERG Ra-226 (pCi/g)	Paired Difference	T_-	T_+
Q18B07G	1.3	1.6	-0.3	-24	
Q18B25H	8.6	10.4	-1.8	-105	
Q18B01G	7.8	13.4	-5.6	-162	
Q18C04H	7.9	7.7	0.2		15.5
Q18C05F	8.0	6.1	1.9		110
Q18C02B	14.7	14.8	-0.1	-6	
Q18D01A	9.1	12.2	-3.1	-147	
Q18D22E	3.4	5.1	-1.7	-102.5	
Q18D05C	7.3	7.8	-0.5	-38.5	
Q19A19F	9.5	9.4	0.1		6
Q19B21D	9.1	9.4	-0.3	-24	
Q19C01G	5.4	6.0	-0.6	-46	
Q19C06B	4.3	4.3	0		
Q19C07H	6.8	8.7	-1.9	-110	
Q19D12E	8.0	9.6	-1.6	-99.5	
Q20C21G	3.6	5.5	-1.9	-110	
R16B23B	1.9	3.3	-1.4	-91.5	
R16B25C	7.1	8.6	-1.5	-96.5	
R16B17J	2.8	4.4	-1.6	-99.5	
R16D05J	2.9	4.2	-1.3	-85.5	
R16D05E	1.9	3.0	-1.1	-77	
R16D04C	1.1	1.9	-0.8	-56.5	
R17A12H	8.8	11.4	-2.6	-135	
R17A02F	9.7	13.1	-3.4	-150	
R17A02C	7.7	9.8	-2.1	-120	
R17B06J	1.9	3.6	-1.7	-102.5	
R17B12F	6.7	11.4	-4.7	-160	
R17B23G	12.4	10.1	2.3		126
R17C12F	7.5	12.3	-4.8	-161	
R17C07G	10.4	16.2	-5.8	-163	
R17C12C	9.6	9.5	0.1		6
R17D02C	6.8	6.9	-0.1	-6	
R17D13E	7.4	6.5	0.9		65
R17D08H	8.3	15.3	-7	-164	
R18A20E	5.7	5.7	0		

Table 1. Wilcoxon's Signed Rank Test Applied to ELI and ERG Data (cont.)

	Laboratory			Rank	
Sample ID	ELI [1] Ra 226 (pCi/g)	ERG Ra-226 (pCi/g)	Paired Difference	T_-	T_+
R18A16H	2.9	6.2	-3.3	-148	
R18A11F	4.8	5.1	-0.3	-24	
R18B14H	1.6	2.2	-0.6	-46	
R18B19C	6.0	6.3	-0.3	-24	
R18B20B	7.1	6.9	0.2		15.5
R18C20D	5.5	7.7	-2.2	-122.5	
R18C11G	4.1	6.2	-2.1	-120	
R18C21G	2.2	3.6	-1.4	-91.5	
R18D23C	6.0	8.5	-2.5	-131.5	
R18D19B	4.8	5.6	-0.8	-56.5	
R18D23H	3.6	4.5	-0.9	-65	
R19A12F	6.8	6.7	0.1		6
R19A13D	3.2	3.6	-0.4	-32	
R19A13G	3.5	4.0	-0.5	-38.5	
R19B07H	3.3	3.0	0.3		24
R19B08C	8.7	7.8	0.9		65
R19B08D	8.4	8.0	0.4		32
R20A01A	4.7	4.9	-0.2	-15.5	
R20A01B	3.7	4.7	-1	-72.5	
S17A05B	2.5	3.3	-0.8	-56.5	
S17A10C	2.5	3.3	-0.8	-56.5	
S17A05C	2.0	3.4	-1.4	-91.5	
S17B05F	6.0	6.9	-0.9	-65	
S17B04J	8.7	10.0	-1.3	-85.5	
S17B03F	3.2	4.1	-0.9	-65	
S17D09C	6.3	9.1	-2.8	-142	
S17D04D	3.7	6.5	-2.8	-142	
S17D05E	4.7	4.8	-0.1	-6	
S18A13E	2.0	4.0	-2	-116.5	
S18A17B	2.9	5.4	-2.5	-131.5	
S18A01A	1.8	4.1	-2.3	-126	
S18B08E	6.2	6.5	-0.3	-24	
S18B23C	8.9	9.0	-0.1	-6	
S18B03H	7.1	9.0	-1.9	-110	

Table 1. Wilcoxon's Signed Rank Test Applied to ELI and ERG Data (cont.)

	Laboratory			Rank	
Sample ID	ELI[1] Ra 226 (pCi/g)	ERG Ra-226 (pCi/g)	Paired Difference	T_-	T_+
S18C07F	2.0	4.4	-2.4	-129.5	
S18C06J	4.8	6.9	-2.1	-120	
S18C11F	5.1	6.6	-1.5	-96.5	
S18D02D	7.2	7.2	0		
S18D17H	7.1	7.3	-0.2	-15.5	
S18D22E	7.3	8.7	-1.4	-91.5	
S19A25J	8.6	8.2	0.4		32
S19C19D	5.7	8.0	-2.3	-126	
S19C23F	7.2	7.9	-0.7	-52	
S19C19G	4.2	6.1	-1.9	-110	
S19D01A	4.5	5.4	-0.9	-65	
S19D01D	6.2	7.1	-0.9	-65	
S19D08H	3.2	4.4	-1.2	-81	
T18A03D	4.4	6.6	-2.2	-122.5	
T18A04E	7.5	7.7	-0.2	-15.5	
T18A08F	3.4	4.7	-1.3	-85.5	
T18C05E	2.8	3.2	-0.4	-32	
T18C05J	7.0	7.0	0		
T18C05C	2.7	3.7	-1	-72.5	
T18D06J	7.4	7.6	-0.2	-15.5	
T18D07G	4.5	6.8	-2.3	-126	
T18D07E	4.9	5.5	-0.6	-46	
T19A23H	6.3	6.8	-0.5	-38.5	
T19A23D	6.8	8.0	-1.2	-81	
T19A23G	4.5	7.2	-2.7	-139	
T19B21G	4.1	6.9	-2.8	-142	
T20A24J	4.9	7.2	-2.3	-126	
T20B18H	9.2	12.2	-3	-145	
T20C16B	7.0	11.0	-4	-157	
T20C11H	8.0	12.3	-4.3	-158.5	
T20C16E	8.9	10.6	-1.7	-102.5	

[1] Radiochemistry results

Table 1. Wilcoxon's Signed Rank Test Applied to ELI and ERG Data (cont.)

Summary of Wilcoxon's Signed Rank Test

	T-	T+
sum of ranks:	-12494.5	1200.5

T = 1200.5

m = 6847.5

s = 614.616751

Z = -9.1878394

For a two-tailed test and a = 0.05, we reject the hypothesis of "identical population distributions" when [z] is greater than or equal to 1.96

Thus reject the null and accept the alternative hypothesis that the median difference does not equal zero.

Table 2. Coefficient of Skewness Calculation

Paired Differences	**(X_i-avg)^3**
2.3	46.97692
2	36.20672
1.9	33.02164
1.9	33.02164
1.3	17.74354
0.9	10.76802
0.9	10.76802
0.9	10.76802
0.9	10.76802
0.9	10.76802
0.6	6.948575
0.5	5.912414
0.4	4.984746
0.4	4.984746
0.4	4.984746
0.4	4.984746
0.3	4.159573
0.3	4.159573
0.2	3.430894
0.2	3.430894
0.1	2.792709
0.1	2.792709
0.1	2.792709
0.1	2.792709
0.1	2.792709
0.1	2.792709
0	2.239018
0	2.239018
0	2.239018
0	2.239018
0	2.239018
-0.1	1.763821
-0.1	1.763821
-0.1	1.763821
-0.1	1.763821
-0.1	1.763821
-0.2	1.361118
-0.2	1.361118

standard deviation = 1.55877
mean = -1.30824
count = 170
sum of (xi-avg)^3 = -550.629
1/n = 0.00588
standard deviation cubed 3.78742
((n-1)/n)^(3/2) = 0.99119

coef. of skewness = -0.8628

acceptable range -1 to 1 PASS

Table 2. Coefficient of Skewness Calculation (cont.)

-0.2	1.361118
-0.2	1.361118
-0.2	1.361118
-0.2	1.361118
-0.3	1.02491
-0.3	1.02491
-0.3	1.02491
-0.3	1.02491
-0.3	1.02491
-0.3	1.02491
-0.3	1.02491
-0.4	0.749195
-0.4	0.749195
-0.4	0.749195
-0.5	0.527975
-0.5	0.527975
-0.5	0.527975
-0.5	0.527975
-0.5	0.527975
-0.6	0.355249
-0.6	0.355249
-0.6	0.355249
-0.6	0.355249
-0.6	0.355249
-0.6	0.355249
-0.6	0.355249
-0.6	0.355249
-0.7	0.225017
-0.7	0.225017
-0.7	0.225017
-0.8	0.131279
-0.8	0.131279
-0.8	0.131279
-0.8	0.131279
-0.8	0.131279
-0.8	0.131279
-0.9	0.068035
-0.9	0.068035
-0.9	0.068035
-0.9	0.068035
-0.9	0.068035

Table 2. Coefficient of Skewness Calculation (cont.)

-0.9	0.068035
-1	0.029285
-1	0.029285
-1	0.029285
-1	0.029285
-1.1	0.009029
-1.1	0.009029
-1.1	0.009029
-1.1	0.009029
-1.1	0.009029
-1.2	0.001268
-1.2	0.001268
-1.2	0.001268
-1.3	5.59E-07
-1.3	5.59E-07
-1.3	5.59E-07
-1.3	5.59E-07
-1.3	5.59E-07
-1.4	-0.000773
-1.4	-0.000773
-1.4	-0.000773
-1.4	-0.000773
-1.4	-0.000773
-1.4	-0.000773
-1.5	-0.007052
-1.5	-0.007052
-1.5	-0.007052
-1.5	-0.007052
-1.6	-0.024837
-1.6	-0.024837
-1.7	-0.060128
-1.7	-0.060128
-1.7	-0.060128
-1.7	-0.060128
-1.8	-0.118925
-1.9	-0.207227
-1.9	-0.207227
-1.9	-0.207227
-1.9	-0.207227
-1.9	-0.207227
-1.9	-0.207227

Table 2. Coefficient of Skewness Calculation (cont.)

-1.9	-0.207227
-2	-0.331036
-2	-0.331036
-2	-0.331036
-2.1	-0.49635
-2.1	-0.49635
-2.1	-0.49635
-2.2	-0.709171
-2.2	-0.709171
-2.3	-0.975497
-2.3	-0.975497
-2.3	-0.975497
-2.3	-0.975497
-2.4	-1.301329
-2.4	-1.301329
-2.5	-1.692667
-2.5	-1.692667
-2.6	-2.155511
-2.6	-2.155511
-2.6	-2.155511
-2.6	-2.155511
-2.6	-2.155511
-2.7	-2.695861
-2.7	-2.695861
-2.7	-2.695861
-2.8	-3.319716
-2.8	-3.319716
-2.8	-3.319716
-3	-4.841945
-3	-4.841945
-3	-4.841945
-3.1	-5.752319
-3.3	-7.901583
-3.4	-9.152474
-3.4	-9.152474
-3.4	-9.152474
-3.5	-10.52887
-3.5	-10.52887
-3.6	-12.03677
-3.9	-17.40952
-3.9	-17.40952

Table 2. Coefficient of Skewness Calculation (cont.)

-4	-19.50344
-4.3	-26.77826
-4.3	-26.77826
-4.7	-39.01909
-4.8	-42.57306
-5.6	-79.05106
-5.8	-90.62562
-7	-184.3915
-7.2	-204.5202

Table 3. Studentized Range Test Considering the Paired Differences of ELI and ERG Data

2.3 = maximum value (X_{170})
-7.2 = minimum value (X_1)
1.56 = standard deviation (s)
170 = number of paired differences (n)

$6.09 = w/s = (X_{170} - X_1)/s$

Critical value for a = 0.05 and n = 150 is 4.59 to 6.18
Critical value for a = 0.05 and n = 200 is 4.78 to 6.39

Calculated w/s of 6.09 falls within both critical value ranges, thus data follows a normal curve.