Technical Note
ORP/LV-75-5

GAMMA RADIATION SURVEYS AT INACTIVE URANIUM MILL SITES

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OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
U.S. ENVIRONMENTAL PROTECTION AGENCY
LAS VEGAS, NEVADA 89114

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PREFACE

Uranium mills, a part of the nuclear fuel cycle, are designed to extract uranium from ore which contains radioactive isotopes of the naturally-occurring uranium series decay chain. These isotopes, some of which are extremely long lived, are discarded as mill wastes into large ponds and piles. Wind and water erosion have scattered the mill wastes over large parts of the mill site's local environs, resulting in land contamination and increased population radiation exposure.

This study was made in cooperation with the Energy Research and Development Administration to evaluate existing conditions at inactive uranium mill sites in order that appropriate remedial actions can be taken to decontaminate the site environs, minimize erosion, and reduce population exposures.

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TABLE OF CONTENTS

	Page
LIST OF FIGURES	vi
LIST OF TABLES	vii
ACKNOWLEDGMENT	viii
SUMMARY AND CONCLUSIONS	1
INTRODUCTION	2
Nature of the Problem	2
Historical Background	2
Sites Surveyed	4
SURVEY METHODS	7
Radiological Measurements	7
Interpretation of Measurements	8
Physical Location of Radiological Measurement Points	9
SUMMARY OF SURVEY RESULTS AT INDIVIDUAL SITES	11
Monument Valley, Arizona	13
Tuba City, Arizona	14
Grand Junction, Colorado	15
Gunnison, Colorado	17
Slick Rock-North Continent, Colorado	18
Slick Rock-Union Carbide, Colorado	20
Rifle (Old), Colorado	21
Rifle (New), Colorado	22
Durango, Colorado	23
Maybell, Colorado	25
Naturita, Colorado	26
Lowman, Idaho	27
Ambrosia Lake (United Nuclear), New Mexico	28
Shiprock, New Mexico	29
Falls City, Texas	30
Ray Point, Texas	31
Salt Lake City, Utah	32
Green River, Utah	35
Mexican Hat, Utah	36
Converse County, Wyoming	37

APPENDICES

	Page
A - Calibration of Scintillometer	79
B - Technical Basis of Interpretation of Field Measurements	82
C - EPA Radiological Criteria for Decontamination of Inactive Uranium Mill Sites	85

LIST OF FIGURES

Figure	Page
1. Inactive Uranium Mill Sites Included in Phase I Evaluation	5
2. Gamma Radiation Survey - Monument Valley, Arizona	39
3. Gamma Radiation Survey - Tuba City, Arizona	41
4. Gamma Radiation Survey - Grand Junction, Colorado	43
5. Gamma Radiation Survey - Gunnison, Colorado	45
6. Gamma Radiation Survey - Slick Rock - North Continent, Colorado	47
7. Gamma Radiation Survey - Slick Rock - Union Carbide, Colorado	49
8. Gamma Radiation Survey - Rifle (Old), Colorado	51
9. Gamma Radiation Survey - Rifle (New), Colorado	53
10. Gamma Radiation Survey - Durango, Colorado	55
11. Gamma Radiation Survey - Maybell, Colorado	57
12. Gamma Radiation Survey - Naturita, Colorado	59
13. Gamma Radiation Survey - Lowman, Idaho	61
14. Gamma Radiation Survey - Ambrosia Lake (United Nuclear), New Mexico	63

Figure	Page
15. Gamma Radiation Survey - Shiprock, New Mexico	65
16. Gamma Radiation Survey - Falls City, Texas	67
17. Gamma Radiation Survey - Ray Point, Texas	69
18. Gamma Radiation Survey - Salt Lake City, Utah	71
19. Gamma Radiation Survey - Green River, Utah	73
20. Gamma Radiation Survey - Mexican Hat, Utah	75
21. Gamma Radiation Survey - Converse County, Wyoming	77
A-1 Differential Gamma Reading (Δ) vs. Surface Contamination Level (ω)	81
A-2 Absorbed Dose Rate (3 Feet Above Disc) vs. Radius of Disc for a Surface Contamination Level (ω) of 1 pCi/cm^2 of ^{226}Ra	81

LIST OF TABLES

Table	Page
1. Inactive Uranium Mill Sites Included in Phase 1 Evaluation	6
2. Approximate Areas Enclosed by the Iso-Exposure Rate Lines at Inactive Mill Sites	12

ACKNOWLEDGMENT

Funding for this study was provided in part by the Office of Energy, Minerals, and Industry, U.S. Environmental Protection Agency, Office of Research and Development.

SUMMARY AND CONCLUSIONS

This report presents the results of gamma radiation surveys conducted by the Office of Radiation Programs--Las Vegas Facility (ORP-LVF) of the U. S. Environmental Protection Agency (EPA) at twenty inactive uranium mill sites in the Western United States. The purpose of these surveys was to measure the extent to which radioactive material had been spread into the environment from the sites by the action of wind and/or water erosion, and by milling activities. The results indicate that hundreds of acres of land exclusive of the tailings piles have been contaminated to above-background levels. Some of the contaminated land is private, off-site property.

Survey techniques were developed to locate the spread radioactive materials and to estimate the gamma exposure rates resulting from them. These measurements were complicated by the presence of direct gamma radiation from the tailings piles. Iso-exposure rate lines were located around each site and plotted on site maps to facilitate site decontamination decisions. These lines, corresponding to post-cleanup exposure rates of background, 10 microroentgens per hour and 40 microroentgens per hour, were selected to correspond to current ORP criteria for decontamination of inactive uranium mill sites.

INTRODUCTION

NATURE OF THE PROBLEM

The uranium-bearing ore, as delivered to the mill or upgrader, contains both uranium-238 and uranium-235. Both of these isotopes are radioactive parents of long chains of radioactive daughter products. These radioactive daughter products are discharged from the mill as waste or tailings.

The principal environmental implications and associated health hazards appear to be related to radionuclides of the uranium-238 decay chain, primarily thorium-230, radium-226, radon-222 (a noble gas), and radon-222 progeny. Although these radionuclides appear in nature, their concentrations in tailings material are several orders of magnitude greater than their average terrestrial concentrations.

Since large quantities of the mill wastes have been piled at mill site locations in a relatively mobile physical form, they pose potential sources of exposure to man.

These potential sources are:

1. Inhalation of wind-blown particulate tailings material from the piles.

2. Inhalation of the progeny of radon-222 which diffuses from the tailings piles.

3. External whole body gamma exposure from the tailings piles and the tailings scattered into the local environment.

4. Internal exposure from ground and surface water contaminated by materials leached or eroded from the tailings piles.

HISTORICAL BACKGROUND

Following hearings conducted in Washington, D. C., on March 12, 1974, by the Subcommittee on Raw Materials of the Joint Committee on Atomic Energy (JCAE), the Environmental

Protection Agency (EPA) and the Atomic Energy Commission* (AEC) agreed to conduct a joint study of inactive uranium mill tailings piles in the Western United States.

The purpose of this joint effort is to perform a comprehensive study of all inactive mill sites rather than to to continue to treat the problem on a case-by-case basis as evidenced by the remedial action program in Grand Junction, Colorado, and proposed legislation relating to the Vitro site in Salt Lake City, Utah. The study will be conducted as a cooperative, two-phase undertaking by the AEC, EPA, and concerned states.

Phase I of the study, which was conducted during the period April - October 1974, was intended to provide a summary of conditions at each of the inactive sites and recommendations for further studies which were considered necessary to fully evaluate the need for remedial actions.

Twenty-one inactive mill sites, located in eight states, were selected for study. Three study teams were selected and each was assigned a list of sites. The team for each site was composed of representatives from the following organizations:

-EPA, Office of Radiation Programs, Las Vegas Facility

-EPA Regional radiation representative for the region in which the site was located.

-Lucius Pitkin, Inc. (contractor to the AEC)

-Radiation Program representative from the state involved.

The available records for each site were reviewed by the study team in order to assemble all pertinent information regarding the history and operation of that site. Each site was then visited to determine the physical condition of the site, the need for corrective action, proximity to populated areas and prospect for increased population, approximate area of tailings, and availability of suitable cover for stabilization. An interpretation of hydrological conditions at most sites was provided by ORP-LVF, and meteorological data were provided by the Las Vegas Air Resources

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* Now the Energy Research and Development Administration (ERDA)

Laboratory of the National Oceanic and Atmospheric Administration. Specific area population data were obtained by ORP-LVF and ORP-Hq.

A detailed Phase I report was then prepared for each site. A draft report was prepared by the Lucius Pitkin, Inc. (LPI) representative of the site evaluation team, and the draft was reviewed by the other team members and by other ORP-LVF staff. Comments were sent back to the AEC's Grand Junction office and a final report prepared by Atomic Energy Commission staff. These final reports, comprising all together three large loose-leaf binders, were issued and given limited distribution in September 1974. In October, a 17-page Summary Report was issued by the AEC.

The second phase of the study will include evaluation of the problem, detailed examination of alternative solutions, and the preparation of cost estimates and detailed plans and specifications for appropriate remedial action. This part of the study will require gamma radiation surveys to determine the extent of spread of wind-eroded and/or water-eroded tailings materials from the tailings pile. Estimated remedial action costs for all sites will be prepared for presentation to the JCAE during Phase II.

The ORP-LVF agreed to conduct the gamma radiation surveys at each site. In order to obtain optimum weather conditions for the field work, the surveys were started in the spring of 1974.

SITES SURVEYED

Twenty-one inactive uranium mill sites were selected for Phase I study. Their locations are listed in Table 1 and shown in Figure 1.

The four sites located on the Navajo Reservation (Shiprock, Mexican Hat, Tuba City, and Monument Valley) were handled somewhat differently from the other sites. In the fall of 1973, the Indian Health Service (IHS) approached both the EPA and the AEC for technical assistance and advice regarding these sites. They were particularly concerned about the site at Shiprock, since the Navajo Engineering and Construction Authority (NECA), an enterprise of the Navajo Tribe, was headquartered at this site and was conducting a school there to train Navajos as heavy equipment operators. In addition, the State of Utah was conducting a trade school in the buildings on the Mexican Hat site, and various uses were being proposed for the buildings at the Tuba City site. In November 1973, the Navajo Tribe formally requested EPA's

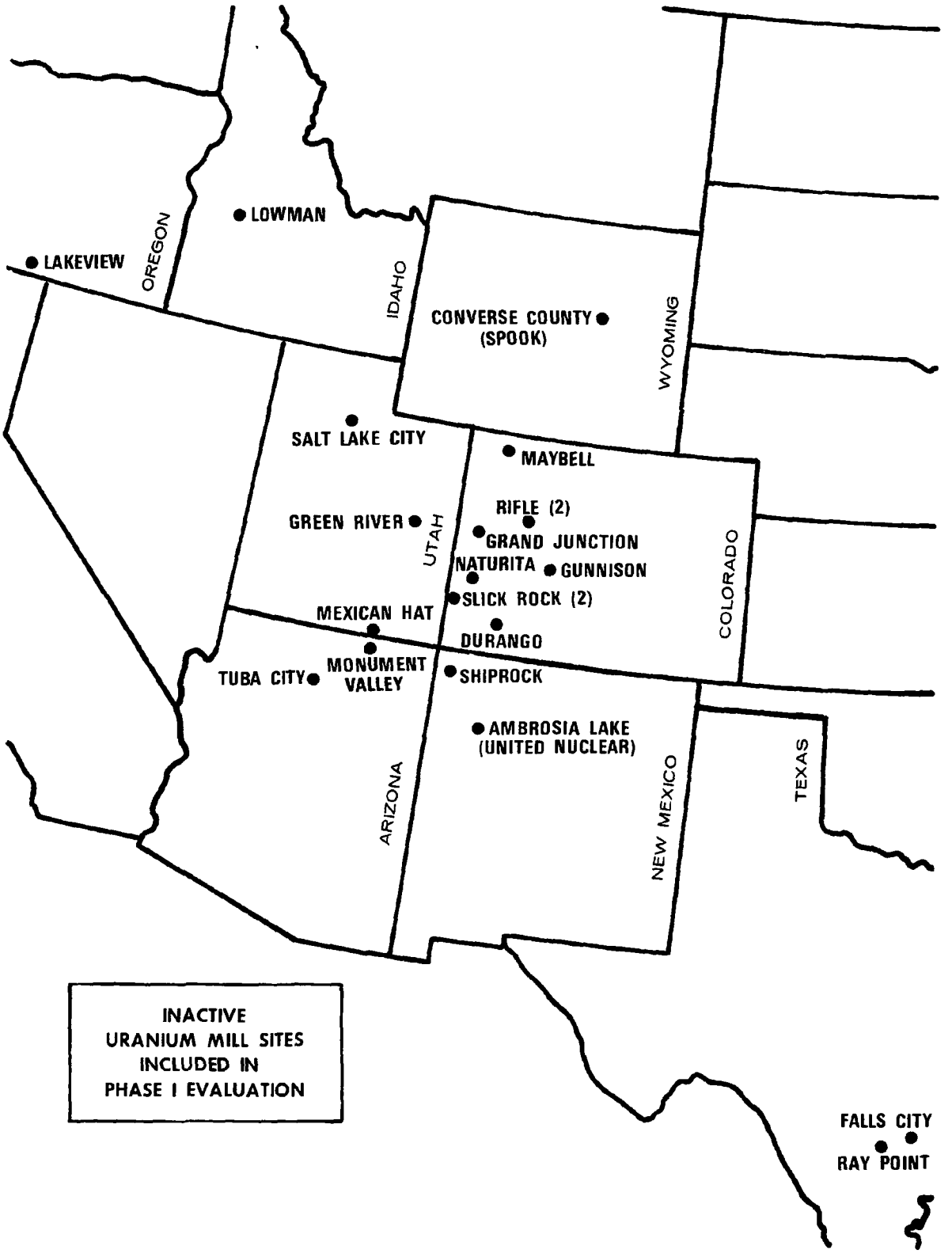
LOWMAN
LAKEVIEW
OREGON
IDAHO
CONVERSE COUNTY
(SPOOK)
WYOMING
SALT LAKE CITY
MAYBELL
RIFLE (2)
GREEN RIVER
UTAH
GRAND JUNCTION
NATURITA
GUNNISON
SLICK ROCK (2)
COLORADO
MEXICAN HAT
DURANGO
MONUMENT
VALLEY
TUBA CITY
SHIPROCK
AMBROSIA LAKE
(UNITED NUCLEAR)
ARIZONA
NEW MEXICO
TEXAS
INACTIVE
URANIUM MILL SITES
INCLUDED IN
PHASE I EVALUATION
FALLS CITY
RAY POINT

Figure 1

assistance in evaluating the radiological situation at all four sites. As a result of this request, ORP-LVF, in cooperation with the IHS, had initiated surveys of these sites before the organization of the Phase I/Phase II studies had been formalized. The gamma survey work at these four sites was completed by the end of April 1974.

A gamma survey was not done at the Lakeview, Oregon, site because Atlantic Richfield Company (ARCO), the owner of the site, in agreement with the Oregon Department of Human Resources, stabilized the pile during the summer of 1974. The State considered ARCO's stabilization effort to have effectively eliminated any radiological problems associated with the site, and therefore requested that the Lakeview site not be included in the Phase II gamma survey program.

As a result of the Lakeview exception, ORP-LVF made Phase II gamma surveys at only 20 of the 21 sites listed in Table 1.

TABLE 1. INACTIVE URANIUM MILL SITES INCLUDED IN PHASE I EVALUATION

Arizona:	New Mexico:
Monument Valley*	Ambrosia Lake (United Nuclear)
Tuba City*	Shiprock*
Colorado:	Oregon:
Grand Junction	Lakeview
Gunnison	
Slick Rock-North Continent	Texas:
Slick Rock-Union Carbide	Falls City
Rifle (Old)	Ray Point
Rifle (New)	
Durango	Utah:
Maybell	Salt Lake City
Naturita	Green River
	Mexican Hat*
Idaho:	
Lowman	Wyoming:
	Converse County (Spook)

* Indicates site located on Navajo Reservation

SURVEY METHODS

RADIOLOGICAL MEASUREMENTS

The purpose of the gamma radiation surveys was to locate "off-pile" areas contaminated with wind-eroded and water-eroded tailings. This required measuring gamma radiation originating from the tailings on the ground in the presence of gamma radiation originating from the pile itself. In order to separate these two components, a modified Baird-Atomic scintillometer (Model NE-148A) was used.

The NE-148A contains a 1 inch by 1½ inch NaI crystal detector calibrated with ^{226}Ra. The output is in microroentgens per hour (μR/h), with a range of 0 to 3,000 μR/h. The time constant of the scintillometers was increased to ten seconds in order to lessen the rapid meter fluctuation, thereby reducing the need for subjective averaging of readings by the operator. In addition, the instruments used in this study have a sliding lead shield attached which can be interposed between the detector and the ground. At a given location, two readings were taken with the scintillometer placed on the ground. One reading was taken with the shield between the detector and the ground ("closed" reading) and one with the shield removed ("open" reading). The effect of the shield on a "closed" reading is to significantly shield the detector from any gamma photons originating from the ground beneath the scintillometer, while having essentially no effect on gamma shine from a distant source, such as the pile. Therefore, if tailings are present at the location of the reading, there will be a significant difference between the "open" and "closed" readings. This differential gamma reading, referred to as "delta" (Δ), indicates the presence or absence of tailings at that particular location. It also provides an empirical estimate of the quantity of surface tailings present. While the units of the delta value are μR/h, it should be kept in mind that the delta value is not numerically equal to exposure rate.

Because of energy response and efficiency factors associated with the small NaI crystal, meter readings obtained with the scintillometer must be corrected to obtain the true exposure rate. The readings obtained during these surveys were not corrected; hence, the delta values are

designated in the legend of each map as "uncorrected" differential gamma readings. However, since the delta values are the difference between two readings, the fact that the readings were not corrected does not affect the numerical value of the delta.

Because of ambient background radiation, a small delta value will be obtained even in the absence of tailings. Through experience, this "background delta" has been found to be in the range of $\Delta 1$ to $\Delta 4$, with values at most locations of about $\Delta 2$ or $\Delta 3$.

Since the basic purpose of this project was to determine the extent of the spread of tailings, the pile itself and the former (or existing) mill site area were generally not surveyed in detail. These areas are known to be contaminated, and we did not consider a detailed survey of these areas to be within the scope of this project.

It should also be noted that these surveys do not provide information on the depth of the contamination. The delta measurement only provides information regarding tailings on the surface at that location, and does not define the depth to which the tailings may occur. In practice, however, windblown tailings were found to be located on or near the ground surface. This is not always true of contamination in such areas as drainage washes, mill yards, ore storage areas, and areas in close proximity to the tailings piles. In these areas, such factors as soil erosion, groundwater leaching, vehicular traffic, and earth work have often tended to move the radioactive material into the soil or partially bury it, often in a very erratic manner.

INTERPRETATION OF MEASUREMENTS

Delta values can be correlated with tailings surface contamination levels, and consequently with the above-ground exposure rate resulting from a given contamination level. The scintillometers were calibrated using mill tailings with a known radionuclide content in a surface contamination configuration. If the windblown tailings are on the ground surface (the most general case), delta can be related to activity per unit area, designated as ω. The units of ω are picocuries (pCi) of ^{226}Ra per square centimeter (cm^2). The details of this calibration are given in Appendix A.

Once Δ has been determined, the above-ground gamma exposure rate can be calculated, assuming that the ^{226}Ra progeny are in equilibrium with the ^{226}Ra. In practice the calibration and the exposure rate calculation were combined

so that delta is related directly to exposure rate without going through the separate step of determining ω. The relationship between delta and the above-ground exposure rate from surface tailings contamination is given in Appendix B.

The basic purpose of the gamma surveys was to delineate contaminated land areas to be considered for decontamination by earth removal. In order to facilitate decisions on outlining these areas, iso-exposure rate contour lines were located around each site. In keeping with current Environmental Protection Agency guidance (Appendix C), lines corresponding to 40 μR/h, 10 μR/h, and background were located. The significance of these lines is as follows:

If scattered tailings and ore are removed from inside a given line (toward the pile), and if the pile is removed or covered to provide essentially complete gamma shielding, then the remaining tailings outside the line (away from the pile) would produce a net gamma exposure rate, three feet above ground, approximately equal to that of the line designation.

Several assumptions, as listed on page 82 of Appendix B, were involved in the construction of these residual iso-exposure rates lines. It was also necessary to average the delta values on each radial. Because the real-life situation is different from the "average", it should be expected that, at any site, certain points may be found after cleanup where the exposure rate and/or the radium-226 concentration in soil might vary significantly from the average value. Such areas could only be found by exposure rate measurements taken during or after the cleanup operation. A monitoring program should, therefore, be designed and conducted as an integral part of the cleanup operation at each site.

PHYSICAL LOCATION OF RADIOLOGICAL MEASUREMENT POINTS

The gamma surveys for the four sites on Navajo lands were performed by locating points of predetermined delta value around the mill site. The points were physically located by working back and forth until the desired delta value was found. This point was then marked with a stake, and the stake was located by conventional land surveying methods performed by engineers of the Indian Health Service. The points were then plotted on a map and connected to form "iso-delta" lines around the site.

This technique was used at Green River which was the first site surveyed on the Phase II list. However, as more experience was accumulated, a variety of techniques were

employed depending upon terrain features, visibility, and the availability of physical landmarks such as roads, fences, etc. Frequently, radial lines were extended out from one or more control points located on the pile. Delta measurements were made (usually at approximately 200-foot intervals) along the radial lines, and the measurement points were located by using a theodolite and stadia rod. In some cases, a base line was chained or paced around the pile perimeter, and radial lines were extended out at right angles from the base line, with the measurement points usually being located by pacing. In areas where considerable residential or commercial development existed, and maps were available, measurement points were located by pacing along streets and roads. The specific technique of point location used at each site is described in the individual site summaries.

SUMMARY OF SURVEY RESULTS AT INDIVIDUAL SITES

This section presents the detailed results of the gamma surveys. For each site, a map shows the locations of the radiation measurements and the delta values at each location. Based on the delta values, the background, 10 μR/h and 40 μR/h lines have been constructed where possible, as described in the previous section and in Appendix B. These lines are also shown on the site map.

A short writeup has also been prepared for each site which provides:

- A brief summary of the operating history of the mill (obtained from the Phase I report).
- A brief description of the survey methods used at the site.
- A descriptive summary of the iso-exposure rate lines and the areas which they encompass.
- Comments on any unique features or problems associated with the site.

Table 2 summarizes the areas of the tailings piles and the areas within the iso-exposure rate lines at the various sites. At some sites, one or more of the lines were either not constructed or were not closed, thereby making an area measurement impossible. The areas were measured on the maps using a planimeter. Since a precise engineering survey was not made at each site, slight errors may have occurred in the construction of the maps. Therefore, the areas are listed as being approximate areas.

For some sites, the tailings pile areas listed in Table 2 vary somewhat from the nominal areas given in the corresponding site writeup. The latter areas were extracted from the Phase I reports, and variations may be due to such factors as changes in pile configuration due to stabilization efforts and difficulty in locating the precise pile boundaries.

TABLE 2. APPROXIMATE AREAS ENCLOSED BY THE ISO-EXPOSURE RATE LINES AT INACTIVE MILL SITES

Site	Approximate area, (acres)					
	Tailings Pile(s)	Within lines, but excluding tailings				
		40 μR/hr		10 μR/hr		Background
Monument Valley	15		N.C.	(Δ6)[1]	52	N.C.
Tuba City	27	(Δ15)[1]	128	(Δ7)[1]	169	(Δ3)[1] 202
Grand Junction	47		N.C.		N.C.	314
Gunnison	30		12		26	68
Slick Rock (NC)	7		N.C.		12	33
Slick Rock (UC)	19		3		41	81
Rifle (Old)	20		17		44	243
Rifle (New)	21		114		169	312
Durango	10		N.C.		N.C.	N.C.
Maybell	81		322		452	745
Naturita	15		N.C.		N.C.	N.C.
Lowman	7[2]		N.C.		11	16
Ambrosia Lake	104		210		390	617
Shiprock	118		N.C.	(Δ7)[1]	126	(Δ3)[1] 229
Falls City	142		139		256	411
Ray Point	48		19		39	94
Salt Lake City	94		114		198	510
Green River	9		N.C.	(Δ8)[1]	44	(Δ4)[1] 153
Mexican Hat	77		N.C.	(Δ7)[1]	127	(Δ3)[1] 457
Converse County	42[3]		N.C.		88	187

N.C. - Line was not constructed or was not closed (see site summary text for explanation)

(1) Delta line corresponding to appropriate iso-exposure line (see Appendix B)

(2) Mill residue stockpile areas

(3) - Includes tailings, overburden piles, and waste dumps (tailings only approximately 2-1/2 acres)

MONUMENT VALLEY, ARIZONA

The former Monument Valley uranium ore upgrading plant is located in Cane Valley on the Navajo Reservation approximately 17 miles southwest of Mexican Hat, Utah. The site was used for upgrading ore, batch leaching, and finally heap leaching. Most of the 1.1 million tons of tailings sands form a pile of approximately 20 acres in size and is estimated to contain 50 curies of radium-226. The remaining sands are scattered about an adjacent wash west of the pile.

The iso-exposure rate lines were constructed from staked points locating pre-determined delta values. Although wind and water erosion of the tailings are evident, the background and 10 μR/hr lines are located relatively close to the site. This may be attributed to the low radionuclide content of the tailings. Both lines extended further away from the pile on the north and east sides due to wind erosion and prior activities in the diked area on the east side.

The background line was terminated on both sides of the west end of the site because it became very irregular and difficult to locate because of rock outcroppings and scattered ore. The 10 μR/hr line beginning west of the points where the background line was terminated is not related to an above ground exposure rate for the same reasons the background line was terminated. It does, however, outline the ore scattered over that area.

TUBA CITY, ARIZONA

The Tuba City uranium mill site is located on the Navajo Reservation approximately six miles east of Tuba City, Arizona adjacent to the south side of U. S. Highway 164. The surrounding area is sparsely occupied except for the former mill housing area which is approximately 1000 feet away and uphill in a northerly direction from the tailings piles.

Approximately 0.8 million tons of ore were processed at this mill from 1956 until 1966, and the resulting tailings piles cover approximately 34.5 acres. In addition, lightly used evaporation ponds lie adjacent and south of the tailings piles. The radium-226 activity in the tailings piles is estimated to be 670 curies. Although the tailings piles were chemically stabilized in 1968, the stabilization has failed and extensive wind erosion has occurred in the northeasterly direction from the piles.

The iso-exposure rate lines were constructed from staked points locating pre-determined delta values. The background line is relatively close to the evaporation ponds to the south and extends approximately 500 feet away from the site on the west side. It crosses U. S. Highway 164 on the north side and runs approximately 3600 feet from the piles in the downwind northeasterly direction. Both the 10 and 40 μR/hr lines parallel the background line and exhibit a sharp departure from the site in the northeast direction.

GRAND JUNCTION, COLORADO

The Climax Uranium Company (now AMAX Uranium Corporation) processed approximately 2.2 million tons of uranium-vanadium ore at the Grand Junction mill between 1951 and 1970. An estimated 1.9 million tons of tailings remain in the 55-acre pile. The total estimated Ra-226 inventory is 1350 curies. The pile is located on the north bank of the Colorado River at the southeast edge of the city of Grand Junction.

A formal land survey to locate the gamma measurement points was not made because of the large area involved, and because of the considerable line-of-site interference due to buildings and trees. Instead, the measurement points were located by pacing along streets, and in reference to existing landmarks. The points were transferred to maps obtained from the city engineering department, and the final map was prepared by tracing from a mosaic of these maps.

AMAX property north of the mill and pile was purchased by Industrial Development, Incorporated (now Colorado West Improvement, Inc.). This area was not included in this survey because it had recently been surveyed and decontaminated for development as an industrial park. Several industrial buildings were in existence and others were under construction at the time of this survey.

The background delta value for the Grand Junction area was Δ3. Therefore, the background line was constructed at Δ4. The 10 and 40 μR/hr lines were not constructed at this site because sufficient survey points could not be obtained due to the extensive development surrounding the site.

In the residential and commercially developed area west and northwest of the site, the survey was conducted by taking readings on lawn or unpaved areas adjacent to the streets and sidewalks. No attempt was made to conduct a detailed survey in this area because of the extensive degree of development, and because the area had previously been surveyed on a house-to-house basis by the Public Health Service. In this area, the background line was located approximately one-half mile, or slightly more, from the center of the pile. This verifies the extent of windblown tailings reported in the Phase I report on Grand Junction. Some unusually high readings were found in this area (e.g., the Δ70 on Winters Avenue between 8th and 9th Streets) which are probably due to use of tailings.

Some indication of windblown tailings was found around the feedlot immediately west of the pile. Definitely elevated levels (Δ20-Δ50) were found below the corrals on the river bank. No other readings were obtained between Struthers Ave. and the river, so the background is shown as a dashed line in this area. If decontamination is to be undertaken, the area should be surveyed in more detail.

North of the site, the background line parallels the D & RGW tracks. Relatively low levels of windblown tailings were found between D Road and the tracks. Higher, but erratic, levels were found on the west side of 12th Street in open areas where readings could be made.

Northeast of the site, the area along 27½ Road and in the southwest corner of 27½ and D Roads consists largely of residential development. Readings were taken primarily along the roads. The open fields owned by the State and by AMAX immediately northeast of the site were surveyed on a grid basis. The tailings repository area was not surveyed.

Based on the readings obtained in this area, the background line crosses D Road at the intersection with 27½ Road, and proceeds south along the east side of 27½ Road. It makes a slight jog to the east at C½ Road, and then proceeds south to the river. As mentioned previously, if decontamination were to be undertaken in this area, the few open areas east of 27½ Road should be surveyed in more detail.

The state-owned areas north and east of the tailings repository were originally effluent ponds for the mill. This is reflected by the relatively high and randomly-distributed delta values which were obtained in these areas. The values obtained in the tract owned by AMAX fronting on 27½ Road are more indicative of windblown tailings.

On the south side of the river, readings were taken on top of the bluff at the Mesa County school property and in adjoining privately-owned areas. Most of the readings obtained were background. In view of the prevailing wind direction, and the results reported in the Phase I report on Grand Junction, no further readings were taken on this side of the river.

GUNNISON, COLORADO

The mill site and tailings are located near the south edge of Gunnison, adjacent to the Gunnison County airport. The tailings were impounded by a rectangular shaped dike 950 x 1440 feet approximately 12 feet high. The mill site encompassed approximately 62 acres, of which 30 acres is occupied by the tailings pile. The site has been covered with gravel and vegetated with grasses. Records indicate that 540,000 tons of ore, averaging 0.15% U_3O_8 was processed. The tailings are estimated to contain approximately 420 pCi/gm of radium-226.

Survey points for the Gunnison site were located using a theodolite and stadia rod. One instrument setup was made on the pile, and 17 radial lines were extended out from the pile. Readings were taken at approximately 200-foot intervals along the radials until approximate background delta values were obtained.

Tailings spread, as indicated by the background line, extend approximately 900 feet north of the pile. The background line in the northeast and southeast sections were approximated by extrapolation. The 10 μR/h line extends northward about 500 to 700 feet from the pile, closing to 160 to 200 feet on the east and west sides. The ore stockpile area almost completely lies within the 10 μR/h line.

The 40 μR/h line encompasses the north sides of the pile and lies approximately 100 feet inside the 10 μR/h line. It also merges with the pile midsection on the east and west sides. A 40 μR/h line was approximated on the ore storage area. However, previous studies indicate that ore storage areas are highly variable, probably due to location of the stockpiles.

SLICK ROCK (NORTH CONTINENT), COLORADO

The North Continent site is located on the Dolores River about one-half mile from Slick Rock in San Miguel County, Colorado. Approximately 37,000 tons of ore were fed to the mill for the extraction of uranium, vanadium, and radium. The estimated inventory of Ra-226 in the pile is about 30 curies. In 1971, the pile was contoured, covered with six inches of topsoil, and seeded and fertilized in accordance with State of Colorado regulations.

A preliminary survey of the site was conducted using the theodolite and stadia rod. These points are shown on the map as a dot enclosed by a square. A more detailed survey was then made by pacing lines off the fence which bounds the pile on the east and southeast sides. Readings were taken at approximately 50-foot intervals along these lines. These lines were extended out until background delta values were reached or until the terrain prevented further extension of the line. The background delta value for the area was found to be Δ2.

Since the pile had been covered with topsoil, it was difficult to determine its boundaries visually. Radiation readings on the pile area were erratic, ranging from Δ450 to background. This indicates, as is implied in the Phase I report, that the "pile" is not uniformly distributed. As a result, the entire area designated as the tailings pile on the map probably includes somewhat more area than the tailings actually occupy. In addition, some tailings material was found off the pile in the river flood plain to the northwest of the pile. This is apparently the result of water erosion, which possibly occurred before the pile was covered.

Some elevated readings were found along the road north of the site. These appeared to be due to ore haulage and/or operations of the Burro Mine across the road to the northeast of the site. Therefore, these areas were not included within the background line.

The background line was established at Δ3, with some minor adjustments made for terrain considerations. The entire bench within the curve of the Dolores River was included within the background line. This includes the area where the original residential and mill support buildings

were located. Although some of this area is at or near background, numerous hot spots (apparently due to mill operations) and some evidence of windblown tailings were found in this area. West of the pile, the background line was established on the east bank of the river. Additional readings, not shown on the map, were taken on the mesa west of the river and downstream along the river. These readings were at background.

The 10 μR/hr line lies within about 100 feet of the fence on the east side of the pile. It was joined with the background line at the bridge north of the site and at the end of the fence southwest of the site. West of the pile, the two lines run concurrently along the river.

A 40 μR/hr line was not located at this site because an insufficient number of elevated delta values were found off the pile area to allow construction of the line.

SLICK ROCK (UNION CARBIDE), COLORADO

This site is located at the community of Slick Rock in San Miguel County, Colorado. Approximately 350,000 tons of tailings remain from the operation of a uranium-vanadium upgrader which was operated here from 1957 through 1961. The tailings pile is located adjacent to the Dolores River. The estimated Ra-226 inventory of the pile is 70 curies.

Five control points were established on the pile and mill site. Radial lines were extended from these control points using a theodolite and stadia rod. Differential gamma readings were taken at approximately 100-foot intervals along the radials. The background delta value for the area was found to be $\Delta 2$.

The background line encloses most of the flood plain of the Dolores River east of the pile, lies along the base of the cliff northeast of the pile, and takes in the flood plain of the river north of the site. On the west and south sides, it closely follows the road which circumscribes the site, and includes a small portion of the housing area southwest of the site. The maximum distance of this line from the pile is about 1350 feet in the southwest direction.

The 10 μR/hr line roughly parallels the background line, but lies within an average of about 200 feet of the pile on the east, north, and northwest sides. It bisects the Rocky Mountain Natural Gas property, and includes the entire mill site area southwest of the pile.

The 40 μR/hr line is unique at this site in that it does not encircle the pile. It encloses an area of about three acres near the road south of the site. This is apparently the former location of the settling ponds shown in the Phase I report.

RIFLE (OLD), COLORADO

The old Rifle mill site and pile are located approximately 1/8 of a mile southeast of the town of Rifle in Garfield County, Colorado. The tailings pile covers an area of about 10 acres, and has been stabilized with a minimum depth of six inches of top soil. The pile contains about 350,000 tons of tailings material with an estimated Ra-226 inventory of 320 curies.

Survey points for the Rifle site were located using a stadia rod and theodolite. A control point was located on the pile and 16 radials were traversed. Measurements along each radial were taken at 200-foot intervals.

Tailings spread as indicated by the background line ($\Delta 4$) extends approximately 2700 feet northeast of the pile, 2200 feet northwest, and 1300 feet south.

The 10 μR/hr line remains within 700 feet of the pile and intersects the west end of the pile. The 40 μR/hr line parallels and lies approximately 200 feet inside the 10 μR/hr line. It intersects the pile at several locations including the west end.

All iso-exposure rate lines intercepted the Colorado River. Construction of the lines within the river area was based on readings taken on each side of the river.

RIFLE (NEW), COLORADO

The new Rifle pile is located about one mile southwest of the town of Rifle, Colorado. The mill on the site is presently being operated by Union Carbide Corporation for processing vanadium. The tailings are deposited in two adjacent piles that appear as one pile with two different levels. The older pile is 55 feet high and the newer pile is 40 feet high. Both piles have been seeded without soil cover. The piles are watered and presently show some grass cover. The pile complex is 21 acres in area and contains 2.7 million tons of tailings material with an estimated content of 2,130 curies of Ra-226.

The survey was carried out using theodolite and stadia techniques. Two setups were required on the pile and radials were constructed from these two base points. Readings were taken at approximately 200-foot intervals until background delta values were obtained.

The background line encompasses a rather large area, completely enclosing the mill site, a portion of the railroad, and the Colorado River to the east and south. The broken portion of the background line to the south indicates that the line location was estimated in this area due to the inaccessibility of the area.

The 10 μR/hr line enclosed the mill and tailings area to the west, north and east, and crosses the southern portion of the site property.

The 40 μR/hr line generally parallels the 10 μR/hr line. It also encompasses the tailings and mill site except on the south.

It should be noted that during the survey, Interstate 70 was under construction south of the site. This may affect the final location of the three lines once construction is completed.

DURANGO, COLORADO

This mill site and tailings pile is located at the base of Smelter Mountain immediately adjacent to the Animas River on the southern edge of the town of Durango. An estimated 1.627 million tons of ore were processed, and 1.555 million tons of tailings are estimated to remain, having a theoretical Ra-226 inventory of 1200 curies.

Survey points at the Durango site were located by pacing and by orientation relative to physical landmarks. The points were then transferred directly to a base map showing the site property and physical features, thereby eliminating the need for an engineering survey. The background delta value for the area was $\Delta 2$.

Remnants of the old diversion ditch are still apparent on the slope of Smelter Mountain, beginning about at the west property line, running southeasterly above the piles and mill site, and paralleling the Animas River to the old raffinate pond area. This ditch was arbitrarily selected as the approximate upper edge of the survey area because it was felt that decontamination above this point would be impractical due to the steepness of the slope.

Little contamination was found going up the canyon (Lightner Creek and U. S. 160-550) to the northwest of the site, nor upstream along the Animas River. Varying contamination levels were found along the Animas River downstream of the site, presumably due to erosion and/or discharges of mill effluents or tailings to the river in the past.

Generally, significant delta values were found below the millsite, down to and throughout the old raffinate pond area. Since the mill was shut down, the ponds have been leveled, covered with topsoil, and seeded. As a result, no particular contamination pattern appears from the surface readings obtained in this area. If measurements were made to some depth, it might be possible to better define the specific contaminated areas.

Only the background and 10 μR/hr lines were constructed at this site. Although several elevated delta values were

found, they occurred randomly and no general pattern which would allow construction of a 40 μR/hr line could be discerned.

North of the site, the background line begins at the base of the mountain about 1600 feet northwest of the small pile. It proceeds east to the D & RGW yards, then angles to the southeast through several blocks of the city of Durango. It crosses the river below the new bridge and proceeds generally south between the river and the county road, crossing this road slightly below the road to the city dump.

The 10 μR/hr line closely parallels the background line, but lies an average of 200 to 400 feet inside it. It terminates approximately at the industrial park which is being developed south of the site, but does not include the buildings currently located there. Another small area of elevated readings further south was included in a separate 10 μR/hr area.

The pattern of slightly elevated readings along the county road in this area is an apparently anomalous finding. It seems unlikely that this is due to windblown tailings, since areas much closer to the pile do not show similiar contamination levels. The cause for these readings is at present unexplained. Insufficient readings were obtained to the west of this area to allow closure of the background and 10 μR/hr lines. Therefore, they were terminated in this area on the basis of available data.

MAYBELL, COLORADO

The mill site and tailings pile are located 4 miles northeast of Maybell, Colorado, in Moffat County. The 70 acres of tailings have been contoured and covered to a depth of six inches with soil from the nearby area. Records indicate that 2.6 million tons of tailings material are deposited in the pile containing an estimated 640 curies of Ra-226. Open pit mines and their associated waste are located adjacent to the pile on all sides except to the east.

Using a theodolite and tape, a control traverse was established along the fence enclosing the pile. Radials were run from the traverse and measurements were taken at 200-foot intervals until background readings were encountered. Mine waste was not differentiated from blown tailings because of the close proximity of the mine wastes to the tailings pile. Therefore, it should be noted that, at this site, much of the area enclosed by the background and 10 and 40 μR/hr lines is due to the mining activities rather than to windblown tailings.

The background line (Δ4) extends 5000 feet west of the pile enclosing most of the mine area to the west. It returns to within 3000 feet north of the pile, and averages a distance of 2000 feet east of the pile. South of the pile, the background line goes around a small open pit mine and then returns to within 200 feet of the pile at the southwest corner.

The 10 μR/hr line lies an average of 700 feet inside the background line. It also encloses the open pit area to the west and encounters the small open pit mine to the south. The 10 μR/hr line intersects the pile on the southwest corner and emerges at the west side of the pile.

The 40 μR/hr line parallels the 10 μR/hr line on the west and north sides of the pile and lies approximately 50 to 100 feet within the 10 μR/hr line in these directions. On the east and south sides of the pile, the 40 μR/hr line stays within 700 feet of the pile and intersects it similarly to the 10 μR/hr line in the southwest corner of the pile. It then emerges from the pile on the west side.

NATURITA, COLORADO

The millsite and tailings are located two miles west of Naturita, Colorado in the narrow San Miguel Canyon. The tailings were impounded in a 20-acre area adjacent to the San Miguel River. After the mill shut down in 1963, it was partially dismantled and the tailings were stabilized in accordance with Colorado regulations. During the period that the present tailings pile was accumulated, 704,000 tons of ore were processed at the Naturita mill. The total estimated Ra-226 content in the pile is 490 curies.

The majority of the survey points for the Naturita site were located using a theodolite and stadia rod. Extensive contamination of the canyon caused by the plume from the old roaster stack was found in the down-valley direction, so it was necessary to place survey locations across the canyon for several miles downstream. The theodolite was set up at five different locations in order to cover the millsite area. The instrument locations were tied to one another using the instrument and the stadia rod. Instrument readings were taken at about 200-foot intervals along radials from the instrument locations.

The extent of contamination from the windblown tailings and/or the plume from the old roaster stack is indicated by the background line. In the area of the mill and tailings pile, the whole canyon from cliff to cliff has been contaminated. The contamination from the plume extends for several miles down the valley.

The 10 μR/hr line is within 200 feet of the pile to the southwest and 400 feet to the northeast. Due to extensive contamination both up-valley and down-valley, the 10 μR/hr line was not closed in these directions.

The 40 μR/hr line is within 100 feet of the pile to the southwest and 300 feet to the northeast. It extends 2200 feet from the pile up-valley and could not be closed down-valley due to the extensive contamination from the plume.

LOWMAN, IDAHO

This mill site is located near Lowman in Boise County, Idaho and is presently owned by Michigan Chemical Corp. of Chicago, Illinois. The 35-acre site is located in a steep-sided mountain valley, bordered on the west by Clear Creek and on the south by State Highway 21.

The mill was used for the recovery of concentrates of columbite-euxenite and monazite plus by-products of magnetite, ilmenite, zircon and garnet. Source material for the mill came from an area 20 miles north of Lowman. The majority of the material at this site consists of dense sand residues containing varying amounts of uranium and thorium and their radioactive progeny. This material is placed in a number of discrete piles largely south of the abandoned mill building foundation. The remainder of the material immediately adjacent to the foundation consists of ore pile residues, a small tailings pile, and pond dike.

Observations contained in the Phase I report indicate that erosion was minimal around the site and this was confirmed by the radiation survey. Delta measurement points were located with a theodolite and stadia rod. The background line is located close to the piles and mill yard. This line is estimated to bound the east side of the site at Clear Creek. Measurements, not shown on the map, were made approximately 1/4 mile to the north and the east to confirm that the background delta value was eight. Therefore, the background line was placed at a delta nine. The 10 μR/hr line encompasses the mill yard and joins the piles on the east and northwest sides of the site. It is assumed to be located on the bank of Clear Creek on the west side of the site.

A portion of the 40 μR/hr line was constructed through the mill-site area and terminated at the junction of the line and tailings piles. The northeast section of this line was approximated due to lack of additional data.

AMBROSIA LAKE (UNITED NUCLEAR), NEW MEXICO

The site of United Nuclear Corporation's mill and tailings pile is located about 25 miles north of Grants, New Mexico, in Section 28, Township 14 North, Range 9 West, New Mexico Principal Meridian. The tailings pile is west of the mill site, covers 100 acres, and has an average depth of 20 feet. The pile consists of approximately 2.6 million tons of tailings with an estimated Ra-226 content of 1,520 curies. The pile has not been stabilized, but the surface slimes have dried and have formed a fairly durable crust that resists wind erosion well.

Survey points at this site were located using a theodolite and stadia rod. An initial traverse was laid out around the pile. This traverse was a square 2500 feet per side. Perpendiculars were run from the traverse at 500-foot intervals and an additonal diagonal was run at each corner. Measurements were taken at 200-foot intervals along the perpendicular and diagonal lines, except on the east side of the pile where various mill buildings were encountered.

The background line (Δ4) encompasses the entire complex, including pile and mill. The west end of the site adjoins a mine and ore-storage location, and, during the survey, it became quite evident that background closure would not occur on the west side due to the deposition of ore in that area. This also applies to the 10 μR/hr line which also encounters the ore activity at the west end of the property.

The 40 μR/hr line encloses the pile as well as a major portion of the mill site. At the south end of the pile, this line encounters the main roadway into the mill site. This road is used for ore haulage and has generally elevated levels, represented by the 40 μR/hr line. This activity is the reason for the discontinuity in the 40 μR/hr line where it crosses the road at the southwest corner of the pile.

Several minor hot spots were encountered during the survey. These locations are evident from the readings shown on the map.

SHIPROCK, NEW MEXICO

This uranium mill site is located on the Navajo Reservation on the south side of the town of Shiprock, New Mexico adjacent to the south bank of the San Juan River. It was built by Kerr-McGee Oil Industries and operated from 1954 until 1963. Vanadium Corporation of America operated the mill until 1968. Tailings produced by the latter operator were stored in the northeast section of the site and stabilized with soil and river gravel. The remaining tailings were not stabilized.

The iso-exposure rate lines were constructed from staked points locating pre-determined delta values. The background line was located approximately 1400 feet from the piles on the southeast side of the site and about 800 feet on the southwest side. It closely follows the fence line of the ore-storage yard in the northeast and turns to the north on the north side of the site. The line was terminated on the north side and the southeast side at the river bluff, although some tailings are at the base of the bluff. The 10 μR/hr line follows the general shape of the background line and remains outside the site fence line except for a small portion in the north. It does not terminate at the river bluff, but follows the bluff down the entire length of the site.

Neither the background or 10 μR/hr lines could be established in the river bottom or across the river, although the strongest winds blow in this direction (northeast). The absence of a long downwind tail is probably due to greater dispersion of the windblown tailings as they are lifted over the combined height of the stabilized pile and river bluff.

FALLS CITY, TEXAS

The mill site is located in Karnes County, Texas, ten miles southwest of Falls City. Tailings have been impounded on the site at six different locations and solutions have been collected in an open pit mine known as Pond #6. Most of the tailings piles have been covered and seeded as described in the Phase 1 report. Records indicate that 2,500,000 tons of ore were processed averaging 0.16 percent U_3O_8. Tailings are estimated to contain 1,020 curies of Ra-226.

Survey points for the Falls City site were located by establishing base lines around both the major site and minor site (pile #3). The base lines were located along established landmarks and fences. Where necessary, the base lines were accurately measured to maintain the accuracy of the survey. Perpendicular traverses were paced from the base lines and delta measurements were made at specified intervals (usually 200 feet) until the background delta was found. Background delta values varied between 3 and 5 because of ore body locations close to the ground surface throughout the site area.

At the major site, which includes the mill, the background line encompasses the entire pile, pond and mill area. The 10 μR/hr line follows the pile contours quite closely at the north end of the site. On the west and east portions of the site, the 10 μR/hr line extends 1000 feet from the pile area and is indicative of drainage from the piles known to have occurred in both of these directions. The 40 μR/hr line gives further definition of these two drainage areas. The 40 μR/hr line west of pile #5 and east of pile #5 and the mill area extends away from the pile areas and is directly related to drainage from the piles in these two directions.

At the minor site (pile #3), the background line encompasses the pile and a stock pond to the east of the pile. The 10 μR/hr line essentially encompasses the pile but not the stock pond. The 40 μR/hr line intersects the pile on the north and south ends and routes around the west side of the pile. This would be indicative of wind-blown tailings in the predominant wind direction.

RAY POINT, TEXAS

The mill site and tailings pile are located in Live Oak County, Texas, one mile west of Ray Point and 7½ miles northeast of Three Rivers. The tailings disposal area consists of approximately 50 acres surrounded by a dike 5 to 6 feet high on the north end and 35 feet high on the south end. The dike consists of compacted native soil and is well covered with vegetation. The northern portion of the pile has been stabilized with asphalt and seeded. There is good plant growth at the present time. The pile consists of 490,000 tons of tailings estimated to contain 230 curies of Ra-226.

Survey points for the Ray Point site were located by measuring base lines along portions of the fences and dikes comprising the site and tailings pile. Perpendicular lines were paced off from these base lines. Accuracy was maintained because of the relatively short distances that were paced on the perpendiculars.

The background delta value was determined from measurements on site and varies from Δ3 to Δ4, which appears to be a normal variation for the site vicinity. The background line lies within 400 feet of the pile except in the northeast sector. The predominant wind direction is from the southeast, and the survey results indicate windblown tailings reside close to the pile. The northeast sector background boundary is probably related to mill operations and ore haulage and storage rather than to windblown tailings.

The 10 μR/hr line emerges from the pile on the northwest side, encompasses the mill and ore-storage areas and returns to the pile on the east side.

The 40 μR/hr line encloses the ore-storage area and a portion of the mill site. This line intersects a small portion of the pile on the northeast corner. There is a small emergence of the 40 μR/hr line on the northwest side of the pile due to blown tailings. This portion of the line remains within 75 feet of the pile, traverses approximately 600 feet and then returns to the pile.

SALT LAKE CITY, UTAH

The Vitro mill site and tailings piles are located near the intersection of Interstate 15 and 3300 South in Salt Lake City. The piles cover about 110 acres and contain approximately 1.7 million tons of tailings with an estimated Ra-226 inventory of 1380 curies.

The shaded areas on the map represent the general boundaries of areas which have been developed or which had, at the time of the survey, obviously been recently disturbed. In general, gamma measurements were not made in these areas due to the fact that much of these areas were paved, occupied by buildings or railroad tracks, or were otherwise considered unrepresentative. A formal land survey to locate the gamma measurement points was not made because of the large area involved and because of the considerable line-of-sight interference due to buildings and trees. Instead, the measurement points were located by pacing along and from streets and railroads, and the locations were transferred to copies of large-scale aerial photographs obtained from the county engineering office. The final map was prepared by tracing from a mosaic of these copies.

Although a few background delta values of one were obtained, the most consistent background delta for the area was found to be Δ2. Therefore, the background line was established at Δ3 (See Appendix B).

BACKGROUND LINE

East of the site, the background line parallels the west side of I-15. Its maximum easterly distance from the site is about 800 feet, at 3300 S. South of this street, it angles to the southwest, and reaches a maximum southerly distance of about 1200 feet from the site at, and immediately west of, 700 W. From this point, the line angles generally northwest, intersects 3300 S at 1000 W, and parallels 3300 S to 1100 W. Much of the area enclosed by this line south of 3300 S consists of residential, commercial, or industrial development. As a result, sufficient readings were not obtained in most of this area to be able to construct the line accurately. In such cases, the inferred location of the line between available points is indicated by a dashed line.

From the 3300 S and 1100 W intersection, the background line goes north along the east side of 1100 W to the point where the street ends at the Jordan River. Readings on the east side of the street were taken in the relatively undisturbed field, and were consistently Δ5. However, on the west side of the street, which is largely residential development, readings were Δ1 and Δ2. Presumably, factors associated with the residential use, such as traffic and establishment of lawns, have dispersed and/or incorporated tailings material into the soil, thus accounting for the abrupt change in the delta values. The maximum westerly distance of the line from the site is about 1600 feet.

At the end of 1100 W, the line proceeds north along the east bank of the Jordan River. This is shown as a dashed line, since some of the readings are greater than Δ3, but readings were not taken west of the river. The grid was stopped approximately 800 feet north of the confluence of Mill Creek and the Jordan River. The area from this point north was not thoroughly surveyed on a grid basis. Therefore, the background line was constructed due east of this point, although it might lie somewhat further north had more readings been taken.

The line angles northwest from a point just west of the developed area, crosses 900 W, and continues northwest to the railroad spur. It is shown as a dashed line along a section of the railroad, because two Δ6 readings were obtained along the tracks. It is then shown as a dashed line proceeding east through the developed area and the D & RGW switchyard, where it connects with the grid points in the field northeast of the site. The maximum northerly distance from the site is about 2100 feet.

The construction of the background line (and 10 and 40 μR/h lines, discussed below) was difficult in the northern sector due to the extensive development in this area. The few readings which were obtained are considered the least reliable of all those taken around the Vitro site, because, even in the undeveloped areas, the ground in many cases had obviously been disturbed since the mill operations began. The lines as shown are considered the best estimate of the situation existing at the time of the survey, although they are probably not representative of the situation before the extensive development took place. Undoubtedly, much of the windblown tailings material in this area has been covered, rearranged, or removed in the interim.

10 μR/HR LINE

On the east side of the site, the 10 μR/hr line roughly parallels the main D & RGW track, intersecting the D & RGW switchyard about 400 feet north of Mill Creek. It is then shown as a dashed line proceeding southwest through the switchyard. It parallels Mill Creek, then swings north into the field east of 900 W, and crosses 900 W just north of Mill Creek. The maximum northerly distance from the site is about 1000 feet. The same general difficulties discussed above were encountered in locating the 10 μR/hr line in this area.

From 900 W, the line angles to the southwest and crosses Mill Creek about 1300 feet west of the pile. It then angles to the southeast, crosses at the intersection of 3300 S and 900 W, and obtains a maximum southerly distance of about 900 feet below the center of the tailings pile. The few readings obtained in the developed area (automobile wrecking yards) south of 3300 S between 700 W and 500 W indicate that the 10 μR/hr line essentially parallels 3300 S all the way to the D & RGW overpass, where it connects with the grid points in the field east of the site.

40 μR/HR LINE

This line closely parallels the 10 μR/hr line all the way around the site. The same difficulties discussed previously were encountered in constructing the line in the northern and southeastern sectors. The maximum distances of this line from the site are approximately 700 feet to the north, 500 feet to the east, 600 feet to the south, and 500 feet to the west. The entire mill site and the sewage treatment plant are included within the 40 μR/hr line. Although no readings were taken on the property occupied by the concrete block plant immediately east of the mill site, readings around it indicate that it is probably not within the 40 μR/hr line.

GREEN RIVER, UTAH

The mill site and tailings are one-half mile east of the Green River and one mile east of the town of Green River, Utah. The tailings cover an area of about eight acres on a lower bench, 200 feet north of the mill site. Records indicate the pile contains 123,000 tons of tailings material containing approximately 20 curies of Ra-226. The pile has been covered, and diked on the eastern and northern sides. Some vegetation is beginning to grow on the cover material.

The survey of the Green River site consisted of locating the Δ4 and Δ8 lines around the pile using a survey instrument. Once a point on the Δ4 or Δ8 line was located by survey, the location was documented by use of a stadia rod and theodolite. The map was constructed from the survey data and shows both the Δ4 and Δ8 lines with respect to the pile.

The Δ4 line on the map is the background line and the Δ8 line is the 10 μR/hr line. A 40 μR/hr line was not determined for this site.

The background line encompasses the entire pile and mill complex. It extends 1800 feet to the south of the pile and 1600 feet to the northeast, which is indicative of extensive migration of windblown tailings.

The 10 μR/hr line encompasses the pile and intersects the mill site, enclosing process buildings but excluding the office building and water tank.

MEXICAN HAT, UTAH

The Mexican Hat uranium mill site is located approximately 1.5 miles southwest from the town of Mexican Hat, Utah on the Navajo Reservation. Texas-Zinc Minerals built the mill in 1957 and operated it until 1963, and Atlas Corporation operated it until 1965. During the eight years of operation, 2.2 million tons of ore was processed, resulting in approximately the same tonnage of tailings. These tailings were impounded in two adjoining piles, covering 18 and 32 acres. The total radium-226 content of the two piles is approximately 1560 Ci.

The iso-exposure rate lines were constructed from staked points locating pre-determined delta values. Wind and water erosion of the tailings has been extensive at this site. The background line was located 3600 feet away from the pile on the downwind or northeast side, and closed in to approximately 900 feet on the northwest side. It extends out to 1200 feet on the east and southeast side and encompasses the mill and ore-storage yards to the south.

The 10 μR/hr line lies approximately 300 feet away from the pile, except for the north and northeast directions where it ranges out to 900 feet. It closely follows the boundaries of the ore-storage and mill yards to the south.

A 40 μR/hr line was established around the northeast pile and remained close to its east side and ranged out to 800 feet in a northerly direction. It closed to the west side of the pile and was generally erratic. This is probably due to previous scraping operations from repairing or building a base dike on this side of the pile.

CONVERSE COUNTY, WYOMING

The Spook upgrader millsite and tailings are located in a remote area of Converse County about 23 miles north of Glenrock, Wyoming. The tailings were dumped over the lip of the open pit mine forming a V-shaped talus slope. The tailings have not been stabilized in any way. Several overburden and mine waste piles are also located in the area and these are stabilized only very sparsely with natural vegetation. The records indicate 187,000 tons of ore averaging 0.12 percent U_3O_8 were fed to the upgrader. The total estimated Ra-226 content in the pile is 60 curies.

The majority of the survey points for the Spook site were located using a theodolite and stadia rod. A few points were paced where it was not possible to see the stadia rod because of ridges. The instrument was set up at four different locations in order to cover the entire area. The instrument locations were tied to one another using the instrument and the stadia rod. Instrument readings were taken at about 200-foot intervals along radials from the instrument locations.

Tailings and/or mine waste spread, as indicated by the background line, varies from 600 feet north of the pile to 2200 feet east of the pile and 2400 feet south of the pile. A small area of hauled tailings was located near the trailer about 3000 feet south of the pile. An area about 2000 feet southeast of the pile had slightly elevated readings which were probably caused by low-grade ore close to the surface.

The 10 μR/hr line varies from 400 feet north of the pile to 1800 feet east of the pile and 2000 feet south of the pile. All but one of the overburden and mine waste piles lie within the 10 μR/hr line. Two small areas of elevated readings 1100 and 1700 feet south of the pile were probably caused by low-grade ore close to the surface. The 10 μR/hr line could not be closed in the area of the open pit, since no readings were taken in the pit.

The 40 μR/hr line varied from 300 feet southwest to 1500 to 1600 feet east of the pile. This location of the 40 μR/hr line was estimated south of the pile because an insufficient number of readings were taken to properly

establish the location of this line around the small mine waste pile. The 40 μR/hr line could not be closed in the area of the open pit, since no readings were taken in the pit.

Extensive tailings spread to the east was caused by the frequent high winds from the west. The lower level contamination to the south of the pile is probably the result of the general spread of the low-level mine waste that was dumped in that area.

TO MEXICAN HAT , UTAH 18 MILES
FORMER MILL AREA
INTERMITTENT STREAM
OLD TAILINGS AREA
TAILINGS PILE
N
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL SITE
MONUMENT VALLEY , ARIZONA
U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
▲ 2 UNCORRECTED DIFFERENTIAL GAMMA READING - μR/h
SURVEY DATE - APRIL 1974
SCALE IN FEET
0 100 200 300 400
DRAWN BY ANB 1 - 17 - 75

Figure 2

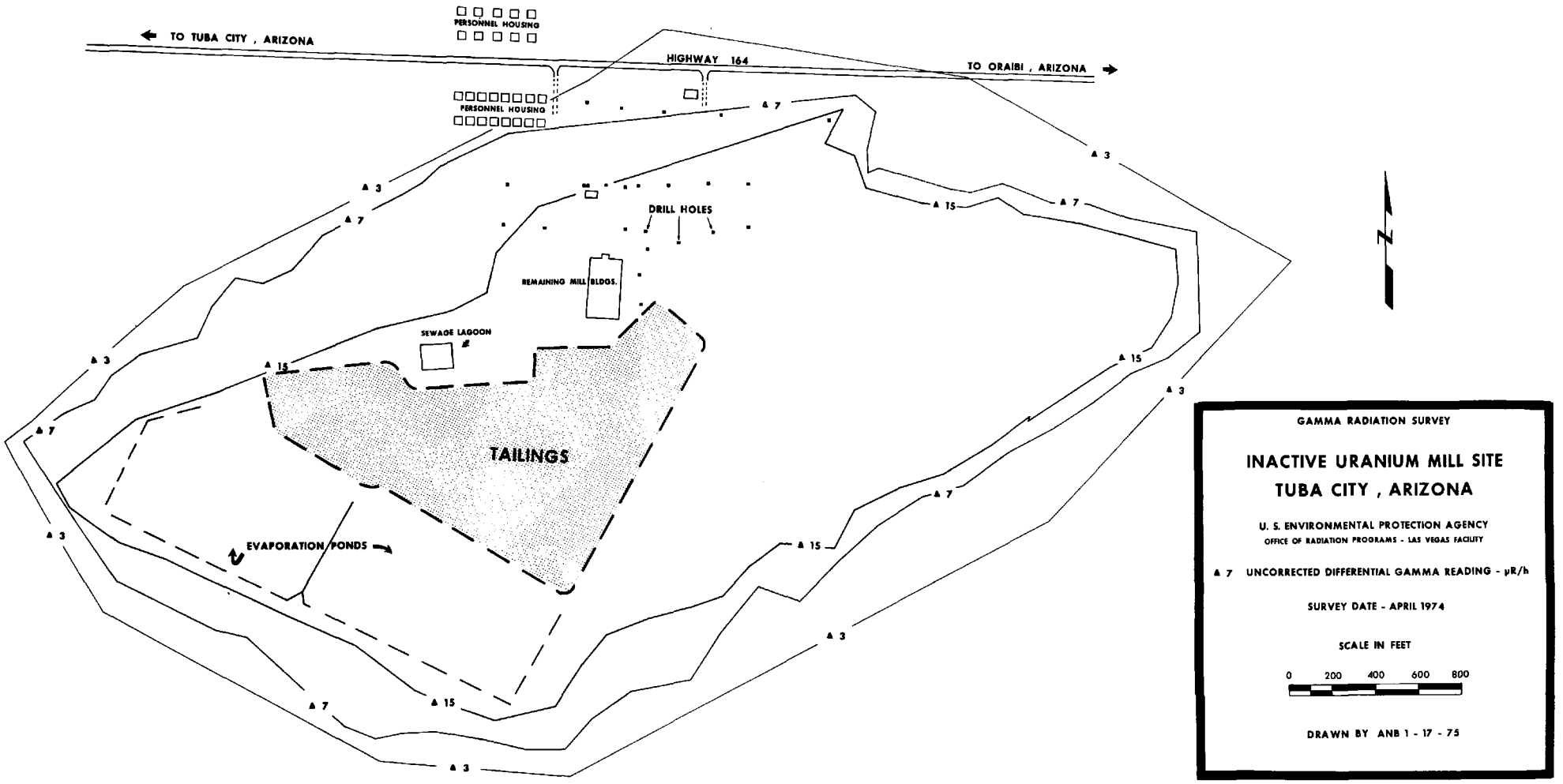
TO TUBA CITY , ARIZONA
PERSONNEL HOUSING
HIGHWAY 164
TO ORAIBI , ARIZONA
PERSONNEL HOUSING
DRILL HOLES
REMAINING MILL BLDGS.
SEWAGE LAGOON
TAILINGS
EVAPORATION PONDS
N
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL SITE
TUBA CITY , ARIZONA
U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
▲ 7 UNCORRECTED DIFFERENTIAL GAMMA READING - μR/h
SURVEY DATE - APRIL 1974
SCALE IN FEET
0 200 400 600 800
DRAWN BY ANB 1 - 17 - 75

Figure 3

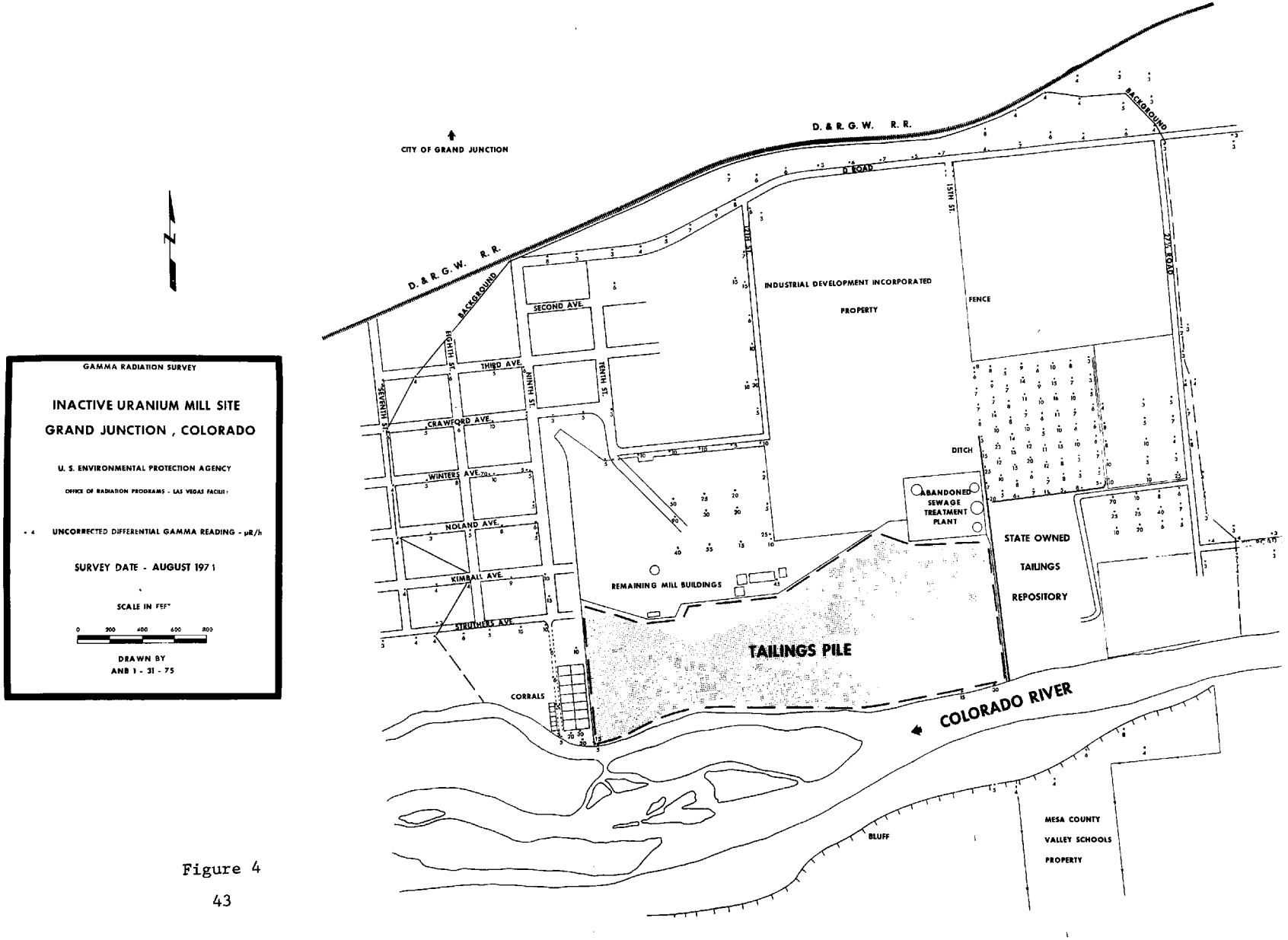
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL SITE
GRAND JUNCTION , COLORADO
U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
UNCORRECTED DIFFERENTIAL GAMMA READING - μR/h
SURVEY DATE - AUGUST 1971
SCALE IN FEET
0 200 400 600 800
DRAWN BY
ANB 1 - 31 - 75
N
CITY OF GRAND JUNCTION
D. & R. G. W. R. R.
BACKGROUND
D ROAD
15TH ST.
27 1/2 ROAD
INDUSTRIAL DEVELOPMENT INCORPORATED
PROPERTY
FENCE
SECOND AVE.
THIRD AVE.
CRAWFORD AVE.
WINTERS AVE.
NOLAND AVE.
KIMBALL AVE.
STRUTHERS AVE.
SEVENTH ST.
EIGHTH ST.
NINTH ST.
TENTH ST.
DITCH
ABANDONED SEWAGE TREATMENT PLANT
STATE OWNED
TAILINGS
REPOSITORY
REMAINING MILL BUILDINGS
TAILINGS PILE
CORRALS
COLORADO RIVER
BLUFF
MESA COUNTY
VALLEY SCHOOLS
PROPERTY

Figure 4

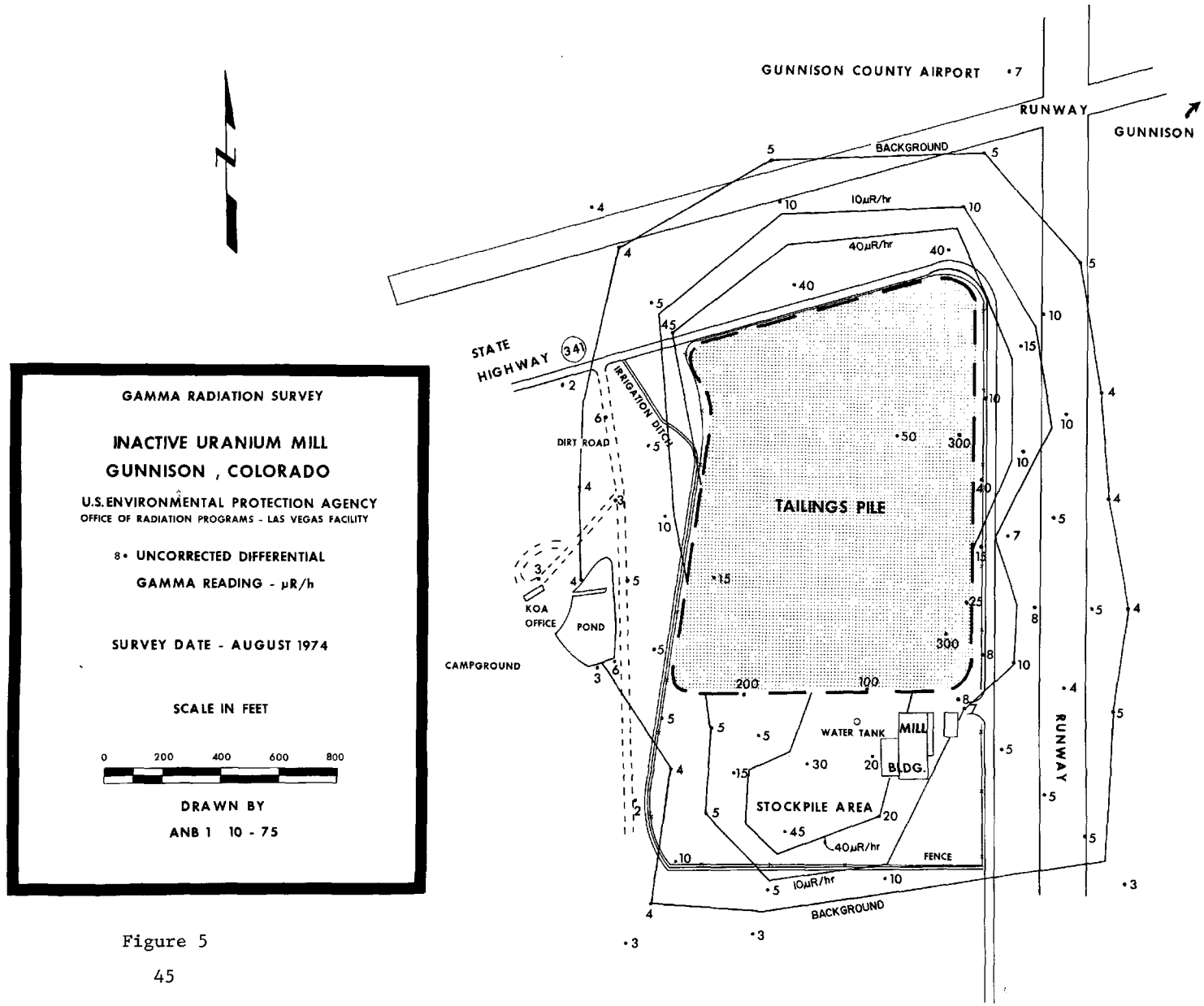
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL
GUNNISON , COLORADO
U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
8• UNCORRECTED DIFFERENTIAL
GAMMA READING - μR/h
SURVEY DATE - AUGUST 1974
SCALE IN FEET
0 200 400 600 800
DRAWN BY
ANB 1 10 - 75
GUNNISON COUNTY AIRPORT
RUNWAY
GUNNISON
BACKGROUND
10μR/hr
40μR/hr
STATE HIGHWAY 341
IRRIGATION DITCH
DIRT ROAD
TAILINGS PILE
KOA OFFICE
POND
CAMPGROUND
WATER TANK
MILL BLDG.
STOCKPILE AREA
FENCE
RUNWAY

Figure 5

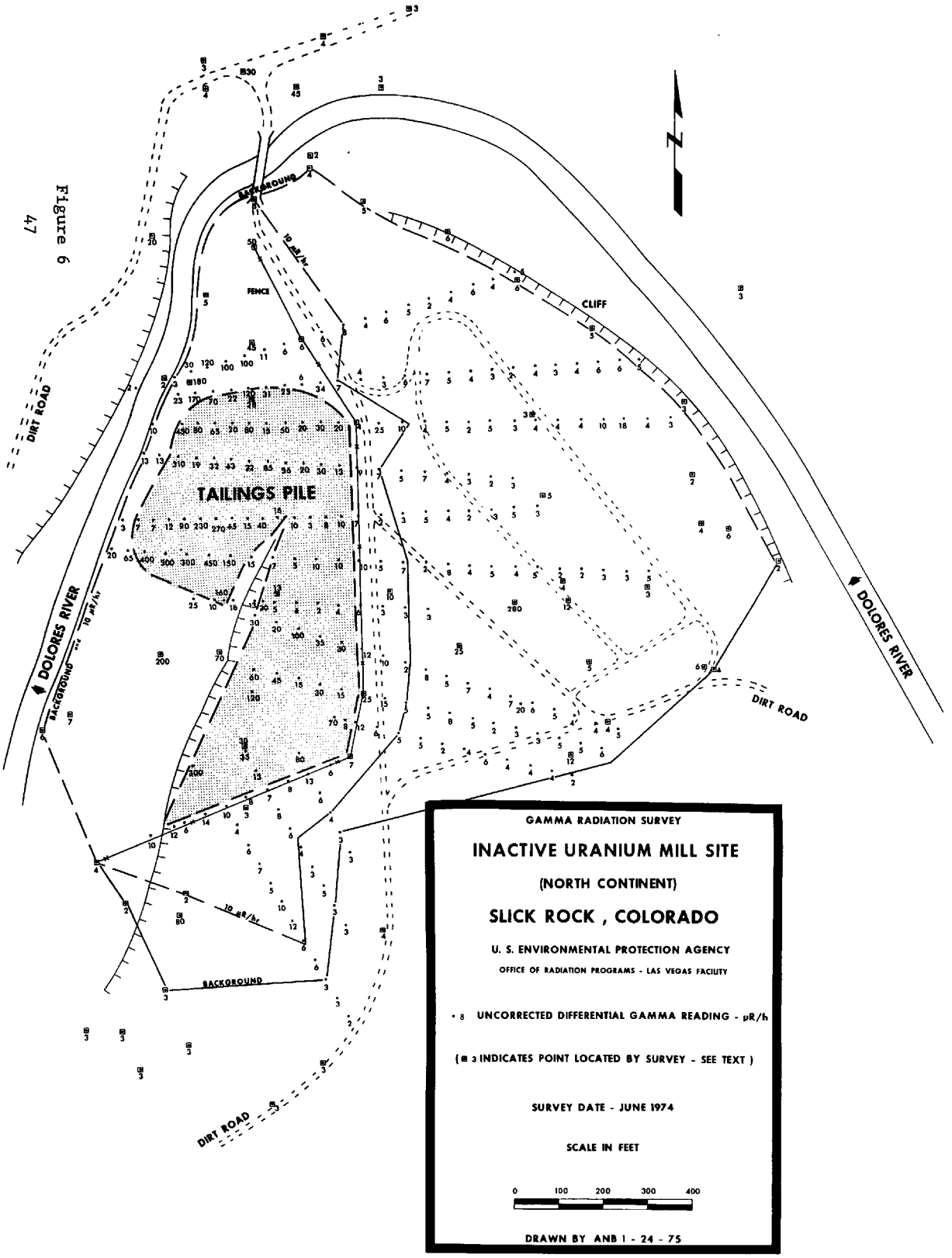
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL SITE
(NORTH CONTINENT)
SLICK ROCK , COLORADO
U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
• 8 UNCORRECTED DIFFERENTIAL GAMMA READING - μR/h
(▣ 3 INDICATES POINT LOCATED BY SURVEY - SEE TEXT)
SURVEY DATE - JUNE 1974
SCALE IN FEET
0 100 200 300 400
DRAWN BY ANB 1 - 24 - 75
TAILINGS PILE
DOLORES RIVER
DOLORES RIVER
DIRT ROAD
DIRT ROAD
DIRT ROAD
CLIFF
FENCE
BACKGROUND
10 μR/hr
N

Figure 6

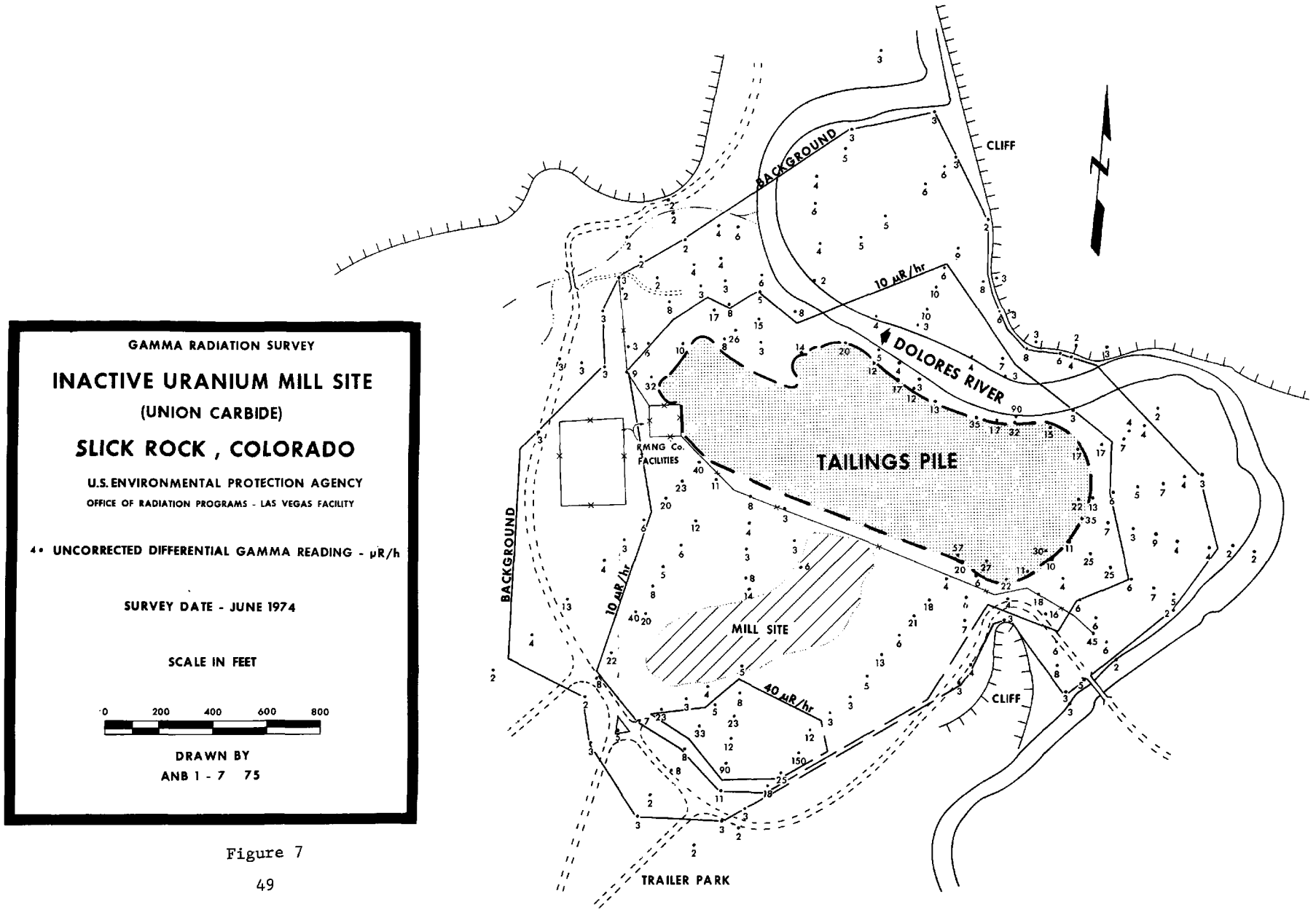
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL SITE
(UNION CARBIDE)
SLICK ROCK , COLORADO
U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
4• UNCORRECTED DIFFERENTIAL GAMMA READING - μR/h
SURVEY DATE - JUNE 1974
SCALE IN FEET
0 200 400 600 800
DRAWN BY
ANB 1 - 7 75
BACKGROUND
CLIFF
10 μR/hr
DOLORES RIVER
TAILINGS PILE
RMNG Co. FACILITIES
BACKGROUND
10 μR/hr
MILL SITE
40 μR/hr
CLIFF
TRAILER PARK

Figure 7

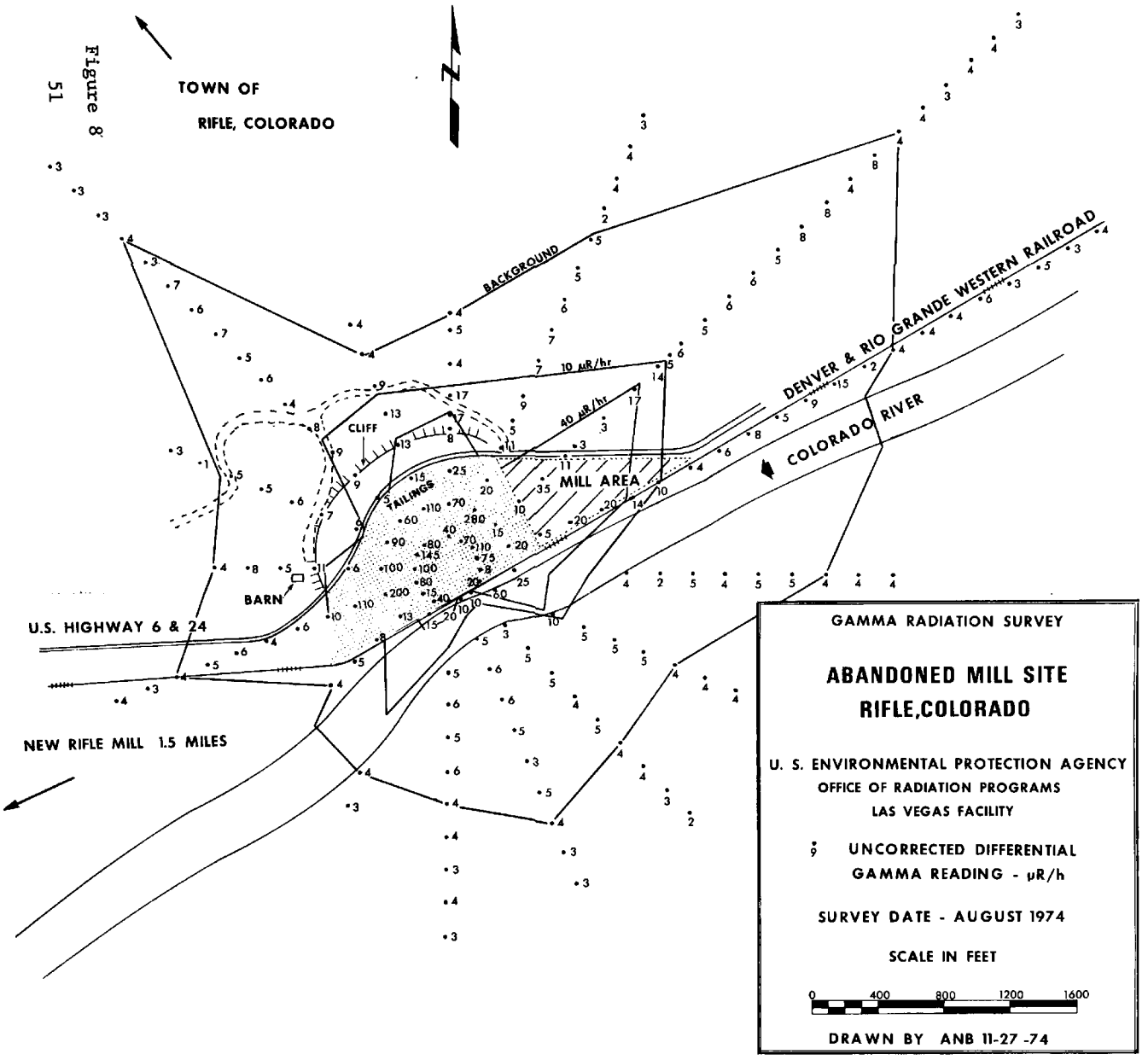
TOWN OF
RIFLE, COLORADO
N
BACKGROUND
10 μR/hr
40 μR/hr
CLIFF
TAILINGS
MILL AREA
BARN
U.S. HIGHWAY 6 & 24
NEW RIFLE MILL 1.5 MILES
DENVER & RIO GRANDE WESTERN RAILROAD
COLORADO RIVER
GAMMA RADIATION SURVEY
ABANDONED MILL SITE
RIFLE,COLORADO
U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS
LAS VEGAS FACILITY
UNCORRECTED DIFFERENTIAL
GAMMA READING - μR/h
SURVEY DATE - AUGUST 1974
SCALE IN FEET
0 400 800 1200 1600
DRAWN BY ANB 11-27-74

Figure 8

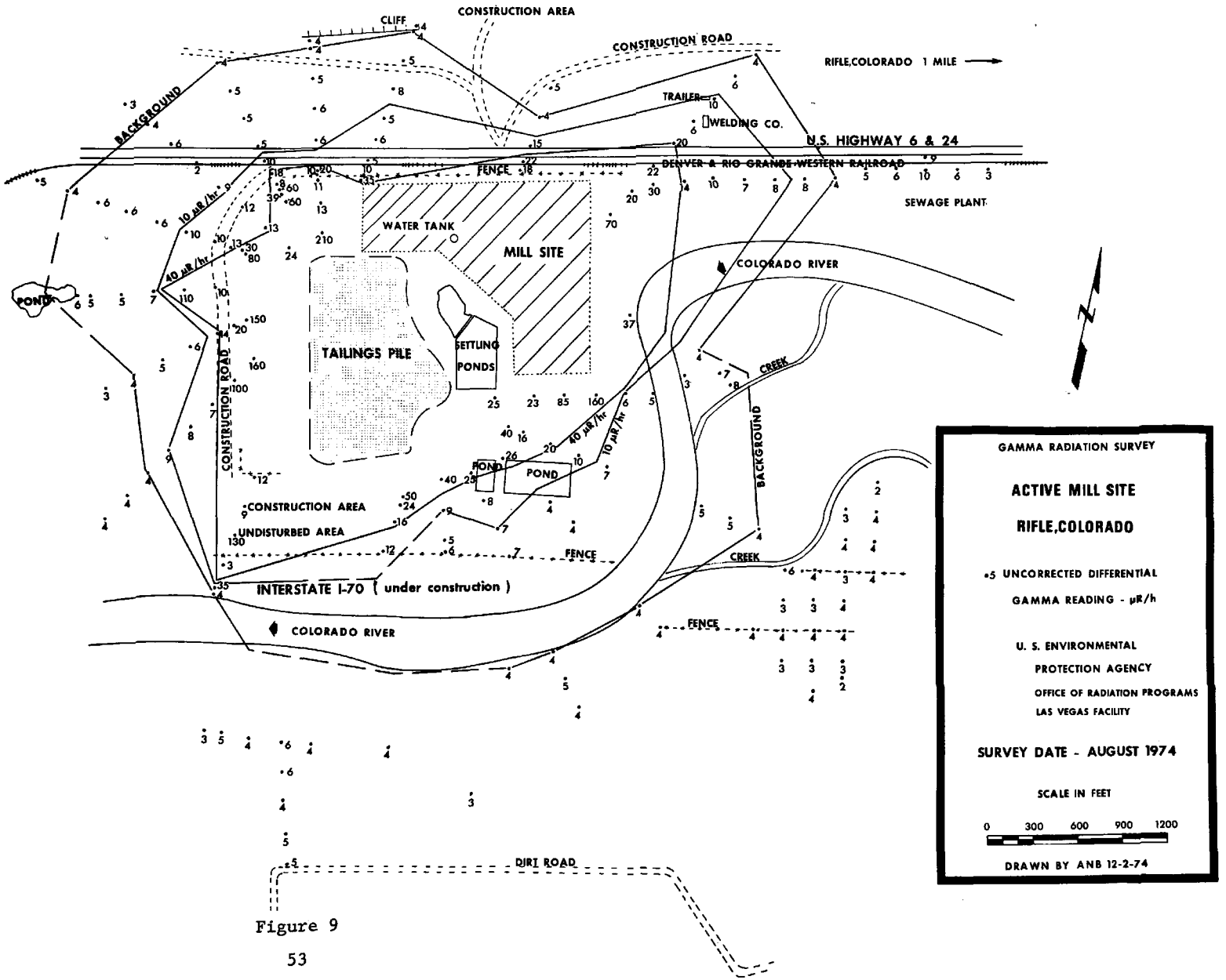
CLIFF
CONSTRUCTION AREA
CONSTRUCTION ROAD
RIFLE,COLORADO 1 MILE
TRAILER
WELDING CO.
U.S. HIGHWAY 6 & 24
DENVER & RIO GRANDE WESTERN RAILROAD
FENCE
SEWAGE PLANT
BACKGROUND
10 µR/hr
40 µR/hr
WATER TANK
MILL SITE
COLORADO RIVER
POND
TAILINGS PILE
SETTLING PONDS
CONSTRUCTION ROAD
CREEK
BACKGROUND
POND
POND
CONSTRUCTION AREA
UNDISTURBED AREA
FENCE
CREEK
INTERSTATE I-70 (under construction)
COLORADO RIVER
FENCE
DIRT ROAD
GAMMA RADIATION SURVEY
ACTIVE MILL SITE
RIFLE,COLORADO
•5 UNCORRECTED DIFFERENTIAL GAMMA READING - µR/h
U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS
LAS VEGAS FACILITY
SURVEY DATE - AUGUST 1974
SCALE IN FEET
0 300 600 900 1200
DRAWN BY ANB 12-2-74

Figure 9

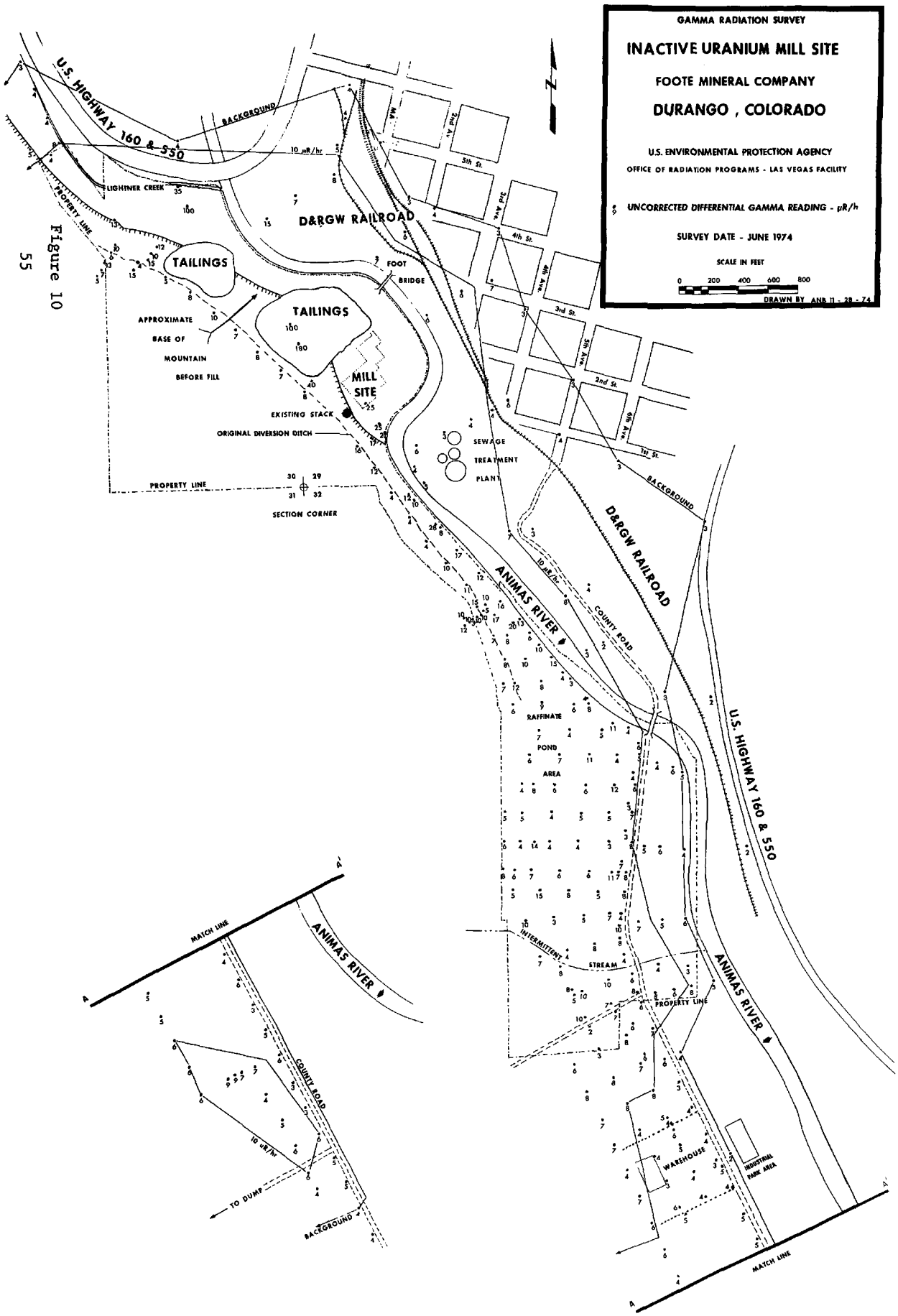
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL SITE
FOOTE MINERAL COMPANY
DURANGO , COLORADO
U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
UNCORRECTED DIFFERENTIAL GAMMA READING - μR/h
SURVEY DATE - JUNE 1974
SCALE IN FEET
0 200 400 600 800
DRAWN BY ANB 11 - 28 - 74
U.S. HIGHWAY 160 & 550
BACKGROUND
10 μR/hr
LIGHTNER CREEK
PROPERTY LINE
D&RGW RAILROAD
TAILINGS
TAILINGS
FOOT BRIDGE
APPROXIMATE BASE OF MOUNTAIN BEFORE FILL
MILL SITE
EXISTING STACK
ORIGINAL DIVERSION DITCH
SEWAGE TREATMENT PLANT
SECTION CORNER
ANIMAS RIVER
COUNTY ROAD
RAFFINATE POND AREA
INTERMITTENT STREAM
WAREHOUSE
INDUSTRIAL PARK AREA
MATCH LINE
TO DUMP
5th St.
4th St.
3rd St.
2nd St.
1st St.
2nd Ave.
3rd Ave.
4th Ave.
5th Ave.
6th Ave.

Figure 10

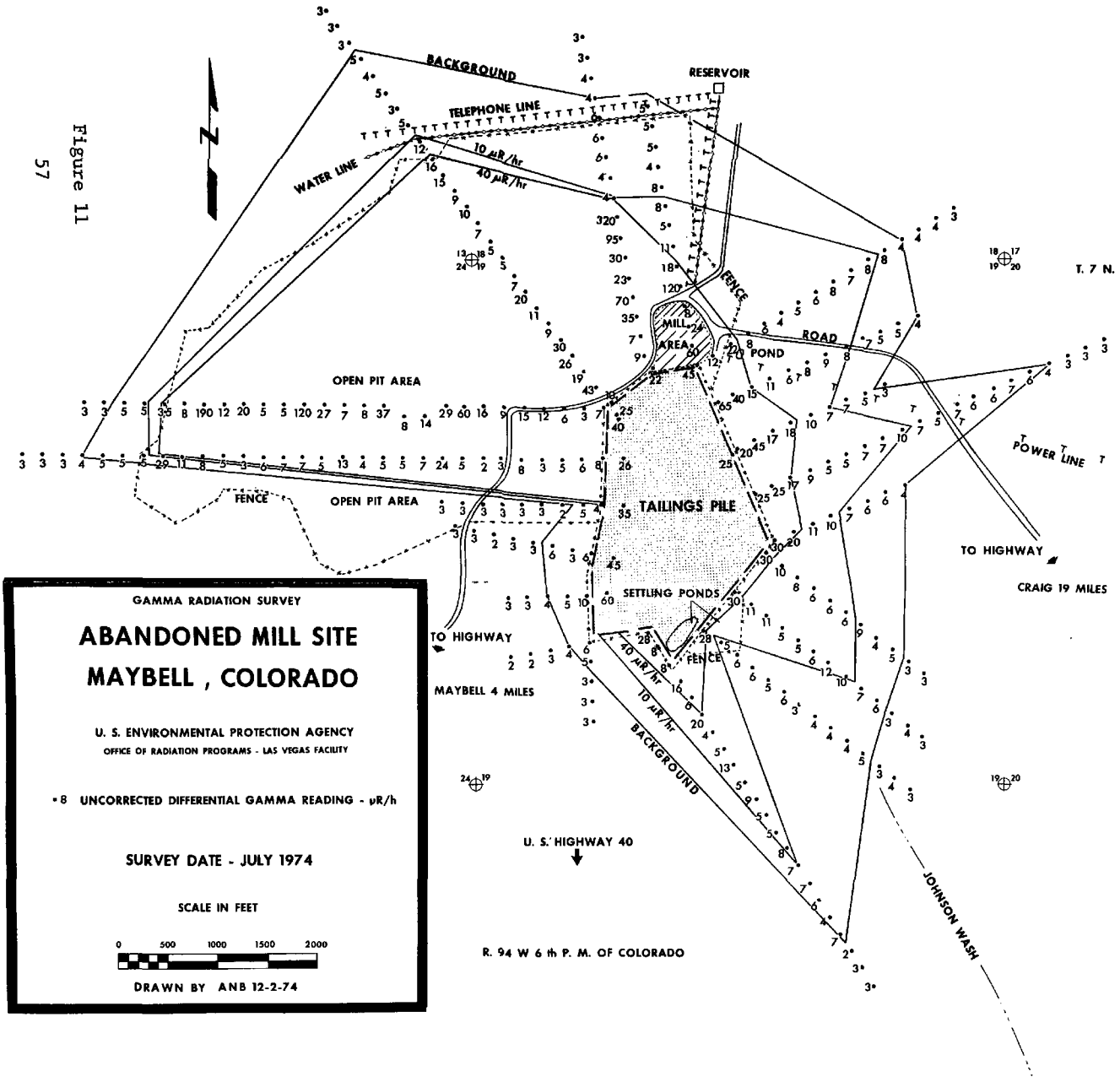
GAMMA RADIATION SURVEY
ABANDONED MILL SITE
MAYBELL , COLORADO
U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
•8 UNCORRECTED DIFFERENTIAL GAMMA READING - μR/h
SURVEY DATE - JULY 1974
SCALE IN FEET
0 500 1000 1500 2000
DRAWN BY ANB 12-2-74
BACKGROUND
RESERVOIR
TELEPHONE LINE
WATER LINE
10 μR/hr
40 μR/hr
FENCE
MILL AREA
POND
ROAD
OPEN PIT AREA
TAILINGS PILE
SETTLING PONDS
POWER LINE
TO HIGHWAY
CRAIG 19 MILES
MAYBELL 4 MILES
U. S. HIGHWAY 40
JOHNSON WASH
T. 7 N.
R. 94 W 6 th P. M. OF COLORADO

Figure 11

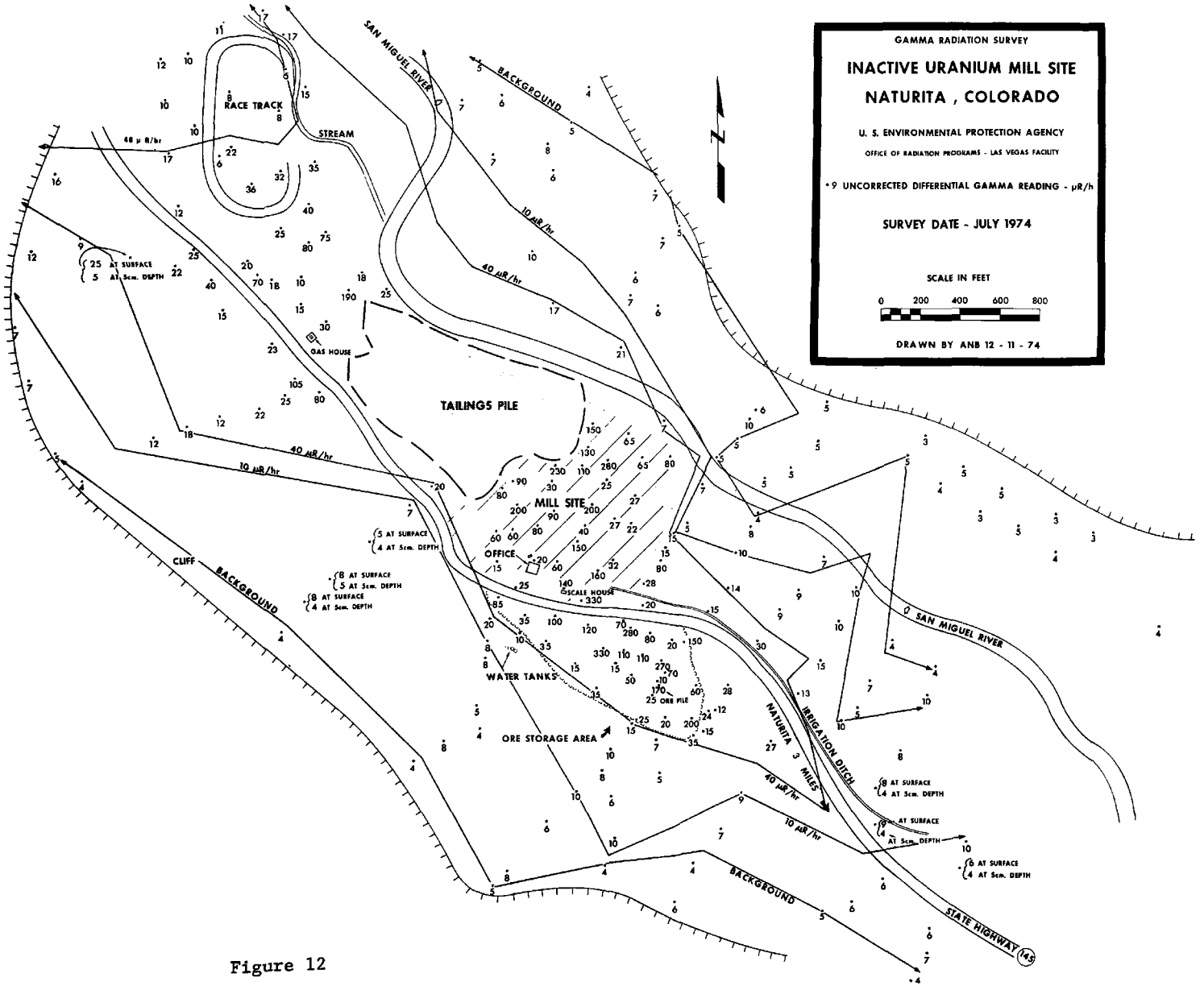
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL SITE
NATURITA , COLORADO
U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
•9 UNCORRECTED DIFFERENTIAL GAMMA READING - μR/h
SURVEY DATE - JULY 1974
SCALE IN FEET
0 200 400 600 800
DRAWN BY ANB 12 - 11 - 74
N
SAN MIGUEL RIVER
BACKGROUND
RACE TRACK
STREAM
40 μ R/hr
10 μR/hr
40 μR/hr
25 AT SURFACE
5 AT 5cm. DEPTH
GAS HOUSE
TAILINGS PILE
MILL SITE
OFFICE
SCALE HOUSE
5 AT SURFACE
4 AT 5cm. DEPTH
8 AT SURFACE
5 AT 5cm. DEPTH
8 AT SURFACE
4 AT 5cm. DEPTH
CLIFF
WATER TANKS
ORE PILE
ORE STORAGE AREA
NATURITA 3 MILES
IRRIGATION DITCH
8 AT SURFACE
4 AT 5cm. DEPTH
AT SURFACE
4 AT 5cm. DEPTH
6 AT SURFACE
4 AT 5cm. DEPTH
STATE HIGHWAY 145

Figure 12

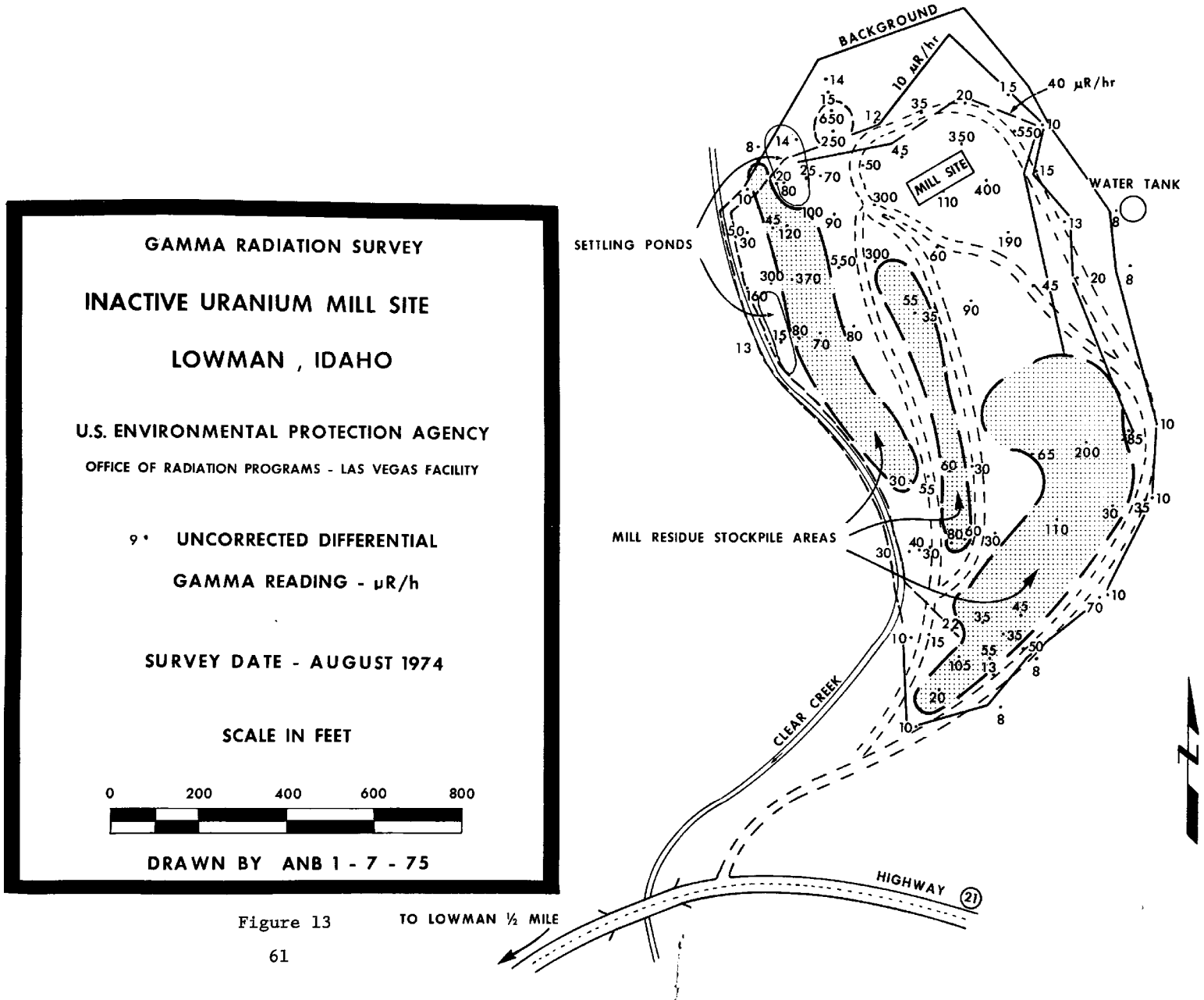
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL SITE
LOWMAN , IDAHO
U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
9 • UNCORRECTED DIFFERENTIAL
GAMMA READING - μR/h
SURVEY DATE - AUGUST 1974
SCALE IN FEET
0 200 400 600 800
DRAWN BY ANB 1 - 7 - 75
BACKGROUND
10 μR/hr
40 μR/hr
MILL SITE
WATER TANK
SETTLING PONDS
MILL RESIDUE STOCKPILE AREAS
CLEAR CREEK
HIGHWAY 21
TO LOWMAN ½ MILE
N

Figure 13

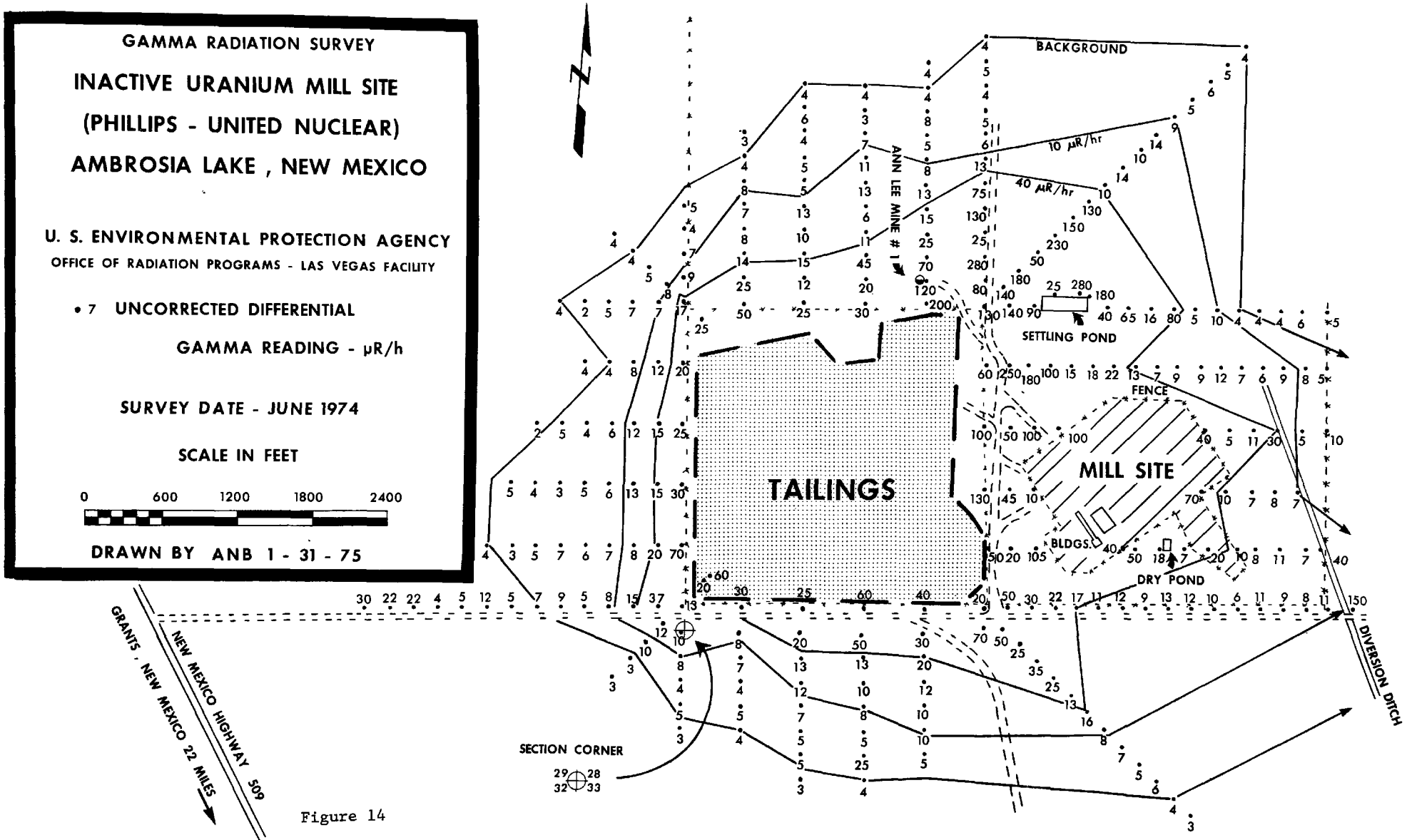
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL SITE
(PHILLIPS - UNITED NUCLEAR)
AMBROSIA LAKE , NEW MEXICO
U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
• 7 UNCORRECTED DIFFERENTIAL
GAMMA READING - μR/h
SURVEY DATE - JUNE 1974
SCALE IN FEET
0 600 1200 1800 2400
DRAWN BY ANB 1 - 31 - 75
N
BACKGROUND
10 μR/hr
40 μR/hr
ANN LEE MINE # 1
SETTLING POND
FENCE
TAILINGS
MILL SITE
BLDGS.
DRY POND
DIVERSION DITCH
SECTION CORNER
29 28
32 33
NEW MEXICO HIGHWAY 509
GRANTS , NEW MEXICO 22 MILES

Figure 14

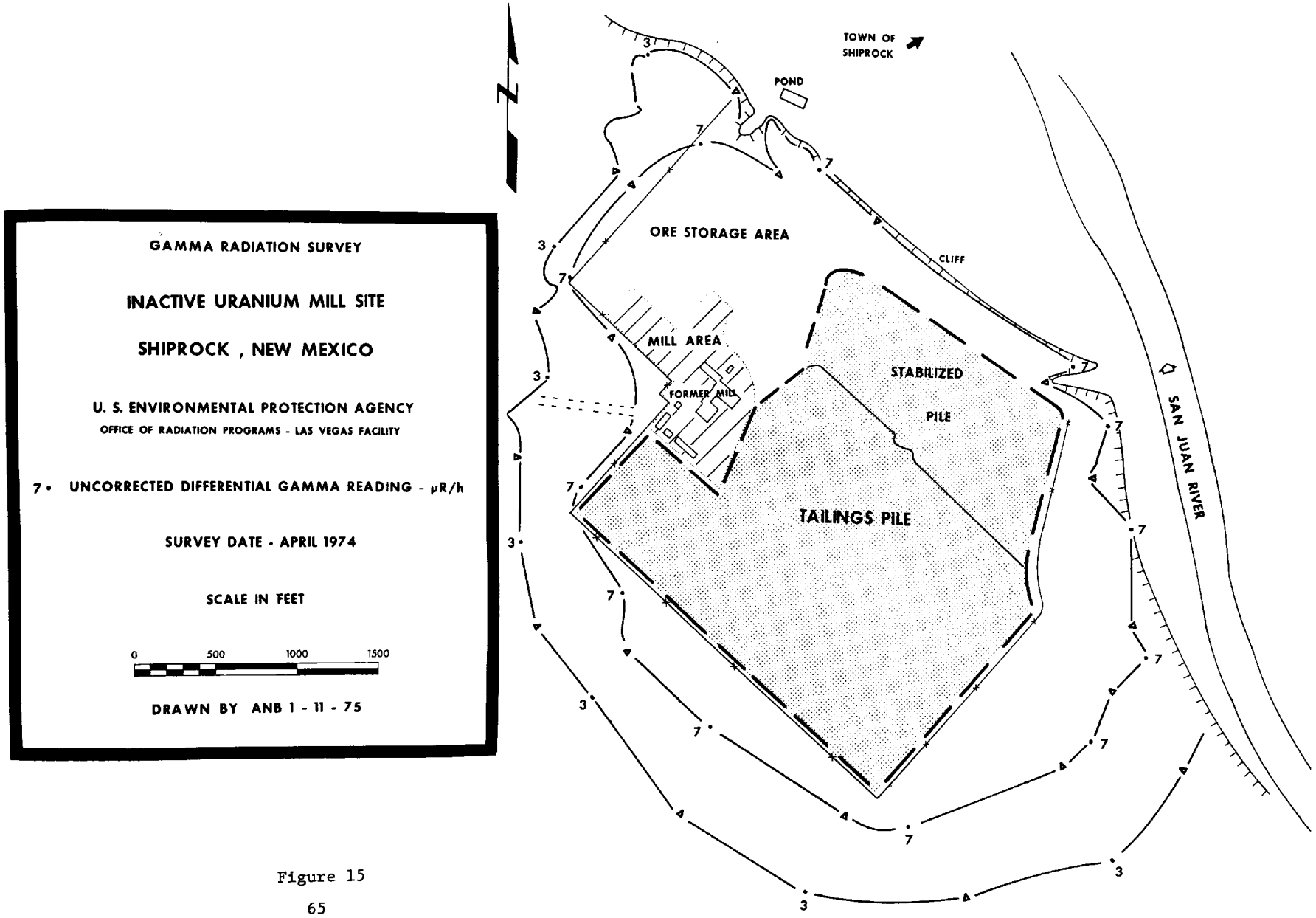
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL SITE
SHIPROCK , NEW MEXICO
U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
7 • UNCORRECTED DIFFERENTIAL GAMMA READING - μR/h
SURVEY DATE - APRIL 1974
SCALE IN FEET
0 500 1000 1500
DRAWN BY ANB 1 - 11 - 75
N
TOWN OF SHIPROCK
POND
ORE STORAGE AREA
CLIFF
MILL AREA
FORMER MILL
STABILIZED PILE
TAILINGS PILE
SAN JUAN RIVER

Figure 15

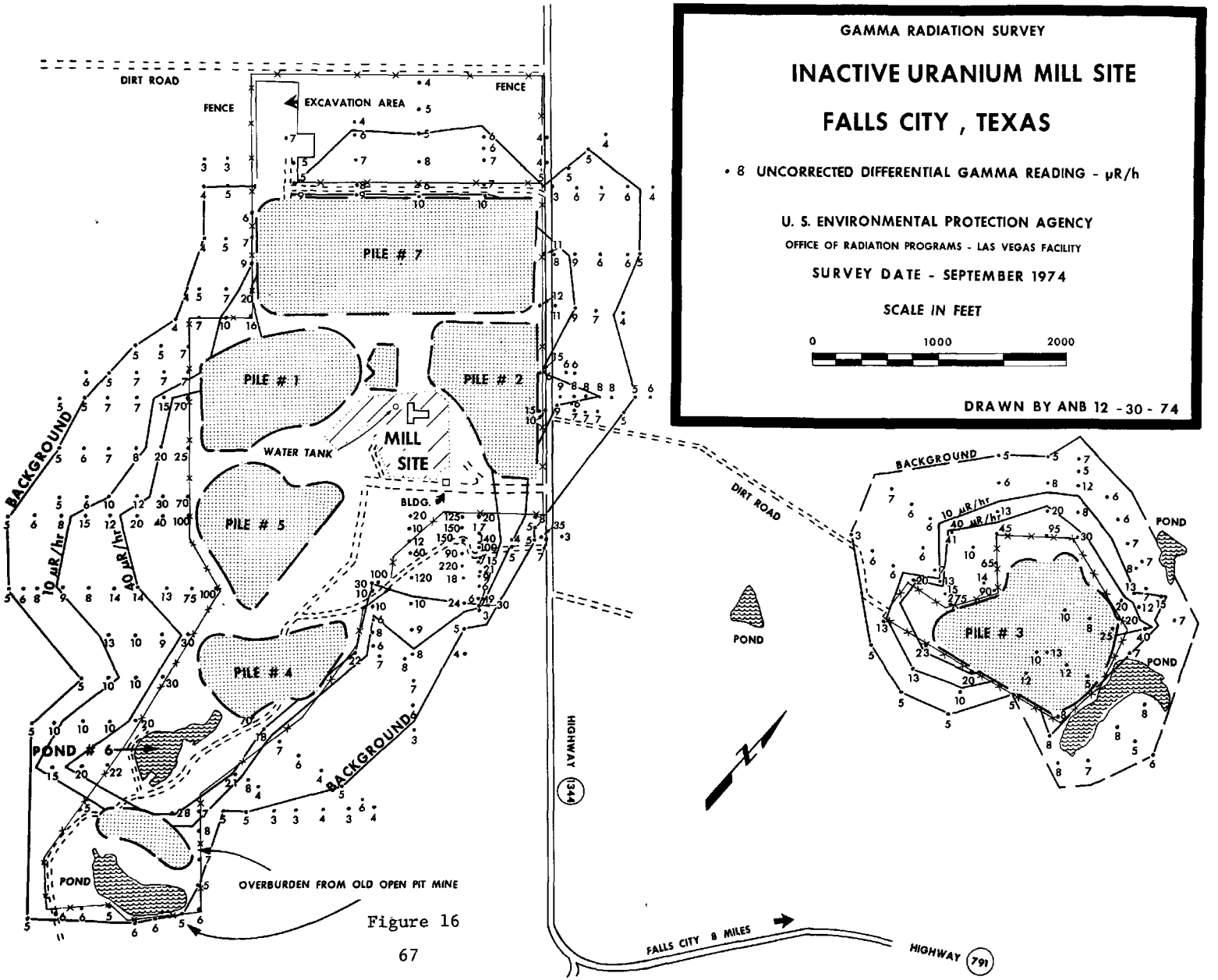
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL SITE
FALLS CITY , TEXAS
• 8 UNCORRECTED DIFFERENTIAL GAMMA READING - μR/h
U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
SURVEY DATE - SEPTEMBER 1974
SCALE IN FEET
0
1000
2000
DRAWN BY ANB 12 - 30 - 74
DIRT ROAD
FENCE
EXCAVATION AREA
PILE # 7
PILE # 1
PILE # 2
PILE # 5
PILE # 4
PILE # 3
WATER TANK
MILL SITE
BLDG.
BACKGROUND
10 μR/hr
40 μR/hr
POND # 6
POND
OVERBURDEN FROM OLD OPEN PIT MINE
HIGHWAY 344
FALLS CITY 8 MILES
HIGHWAY 791

Figure 16

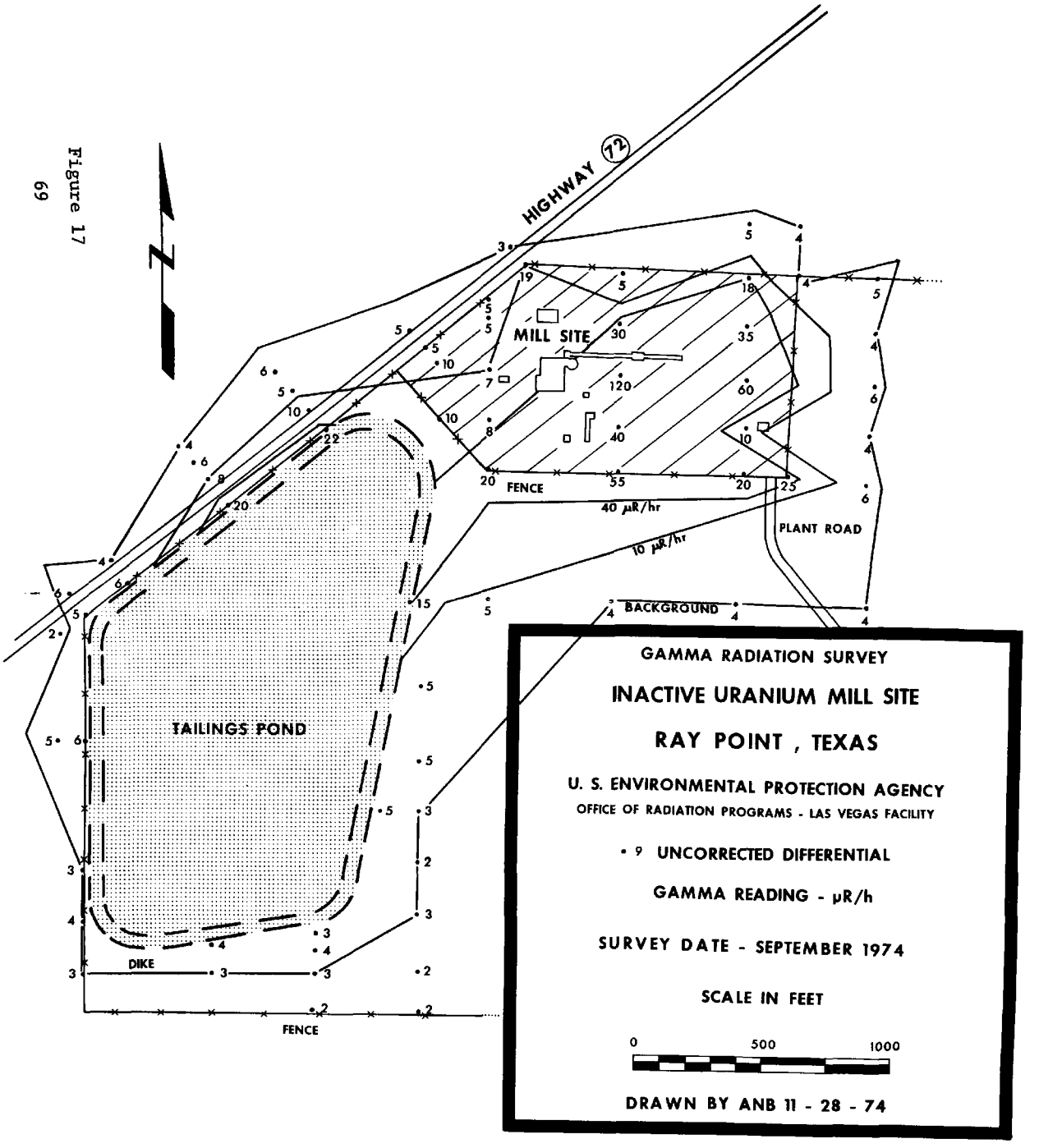
HIGHWAY 72
MILL SITE
TAILINGS POND
DIKE
FENCE
FENCE
40 μR/hr
10 μR/hr
BACKGROUND
PLANT ROAD
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL SITE
RAY POINT , TEXAS
U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
• 9 UNCORRECTED DIFFERENTIAL
GAMMA READING - μR/h
SURVEY DATE - SEPTEMBER 1974
SCALE IN FEET
0
500
1000
DRAWN BY ANB 11 - 28 - 74

Figure 17

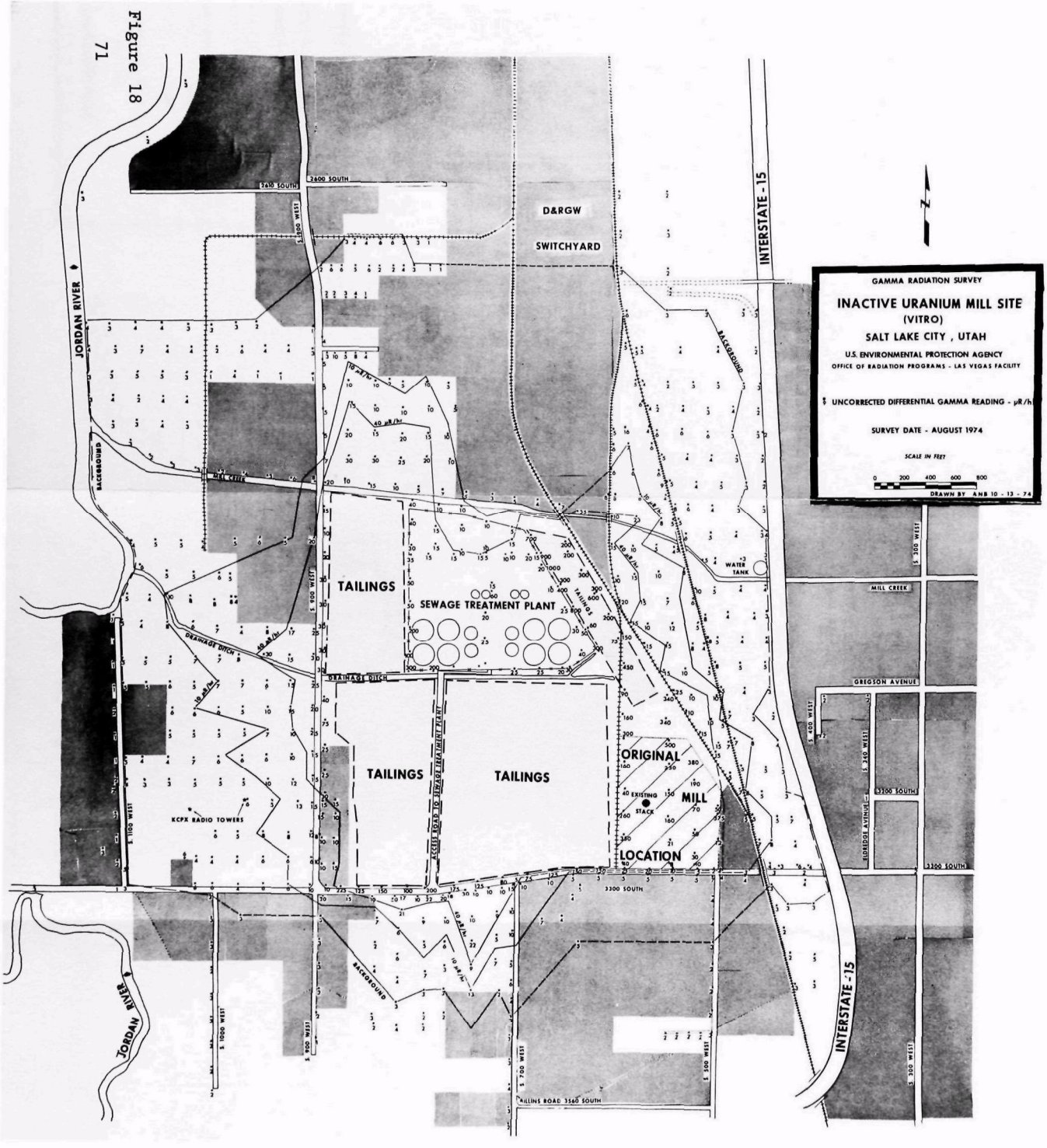
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL SITE
(VITRO)
SALT LAKE CITY , UTAH
U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
UNCORRECTED DIFFERENTIAL GAMMA READING - μR/h
SURVEY DATE - AUGUST 1974
SCALE IN FEET
0 200 400 600 800
DRAWN BY ANB 10 - 13 - 74
D&RGW
SWITCHYARD
INTERSTATE - 15
JORDAN RIVER
TAILINGS
SEWAGE TREATMENT PLANT
TAILINGS
TAILINGS
ORIGINAL
MILL
LOCATION
EXISTING STACK
WATER TANK
KCPX RADIO TOWERS
DRAINAGE DITCH
MILL CREEK
GREGSON AVENUE
3300 SOUTH
2600 SOUTH
BACKGROUND
40 μR/hr
10 μR/hr

Figure 18

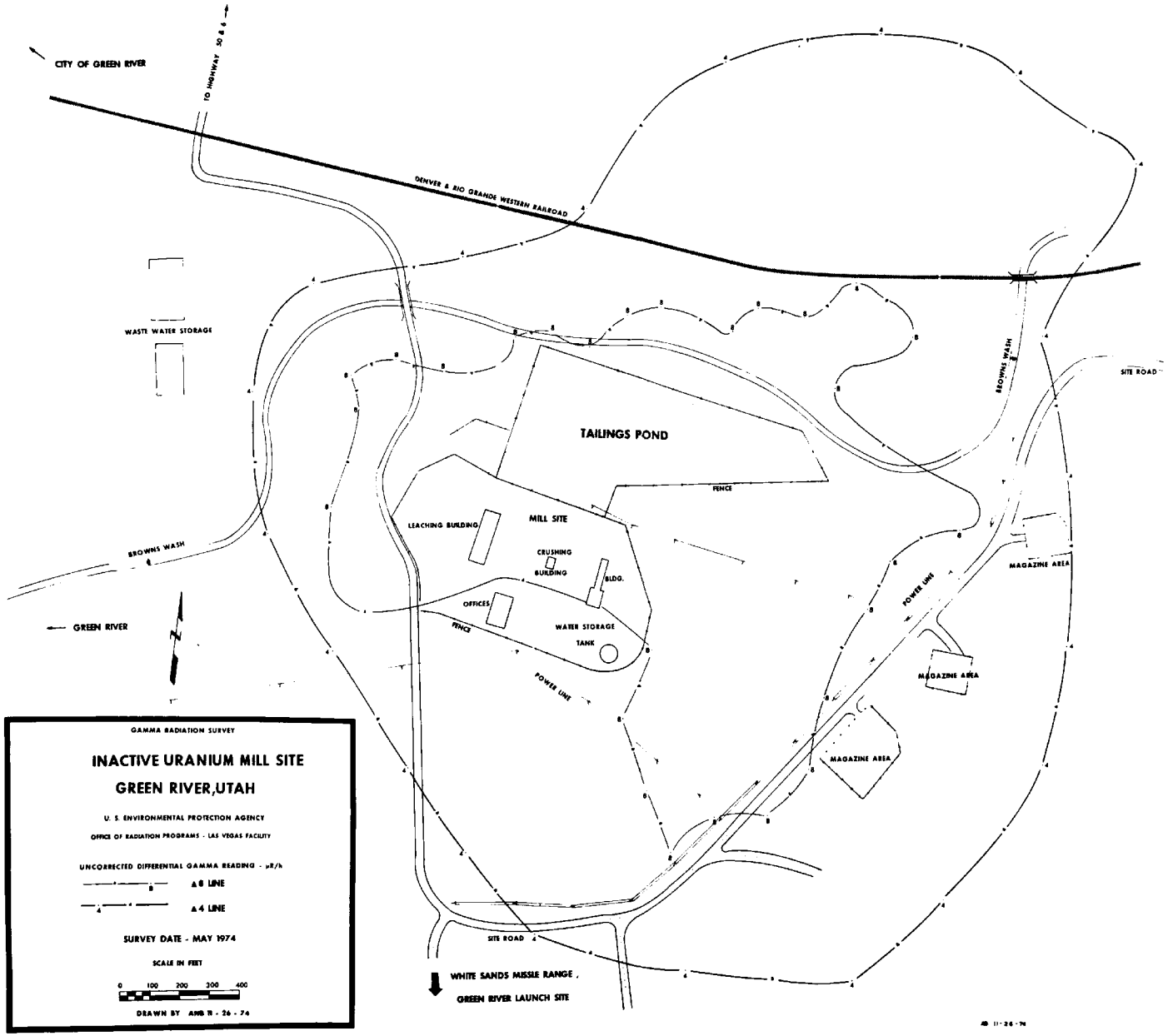
CITY OF GREEN RIVER
TO HIGHWAY 50 & 6
DENVER & RIO GRANDE WESTERN RAILROAD
WASTE WATER STORAGE
TAILINGS POND
FENCE
BROWNS WASH
SITE ROAD
LEACHING BUILDING
MILL SITE
CRUSHING BUILDING
BLDG.
OFFICES
WATER STORAGE TANK
FENCE
POWER LINE
MAGAZINE AREA
MAGAZINE AREA
MAGAZINE AREA
BROWNS WASH
GREEN RIVER
SITE ROAD
WHITE SANDS MISSLE RANGE, GREEN RIVER LAUNCH SITE
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL SITE
GREEN RIVER, UTAH
U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
UNCORRECTED DIFFERENTIAL GAMMA READING - μR/h
Δ 8 LINE
Δ 4 LINE
SURVEY DATE - MAY 1974
SCALE IN FEET
0 100 200 200 400
DRAWN BY AMB 11 - 26 - 74

Figure 19

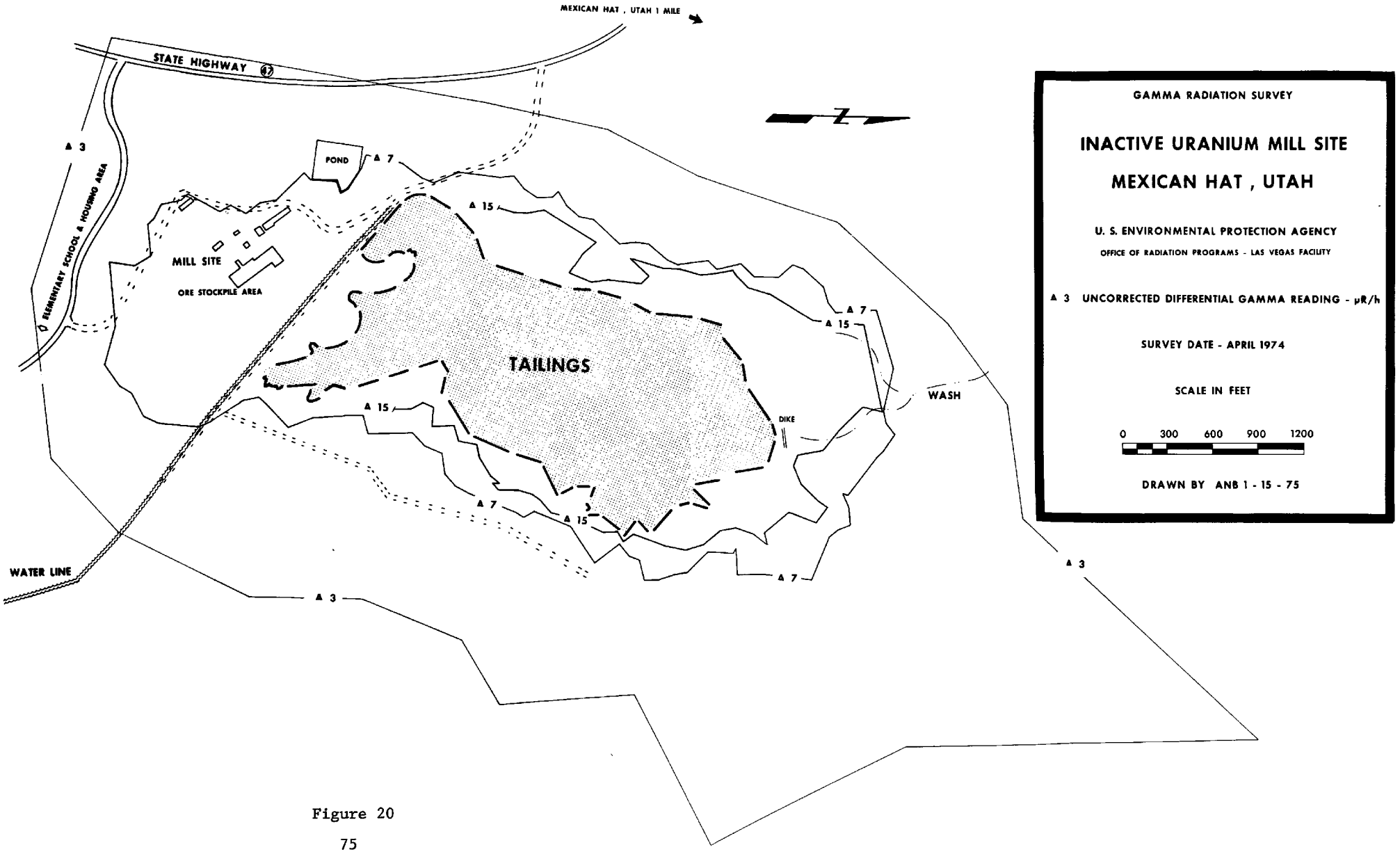
MEXICAN HAT , UTAH 1 MILE
STATE HIGHWAY 163
ELEMENTARY SCHOOL & HOUSING AREA
POND
MILL SITE
ORE STOCKPILE AREA
TAILINGS
DIKE
WASH
WATER LINE
N
GAMMA RADIATION SURVEY
INACTIVE URANIUM MILL SITE
MEXICAN HAT , UTAH
U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
▲ 3 UNCORRECTED DIFFERENTIAL GAMMA READING - μR/h
SURVEY DATE - APRIL 1974
SCALE IN FEET
0 300 600 900 1200
DRAWN BY ANB 1 - 15 - 75

Figure 20

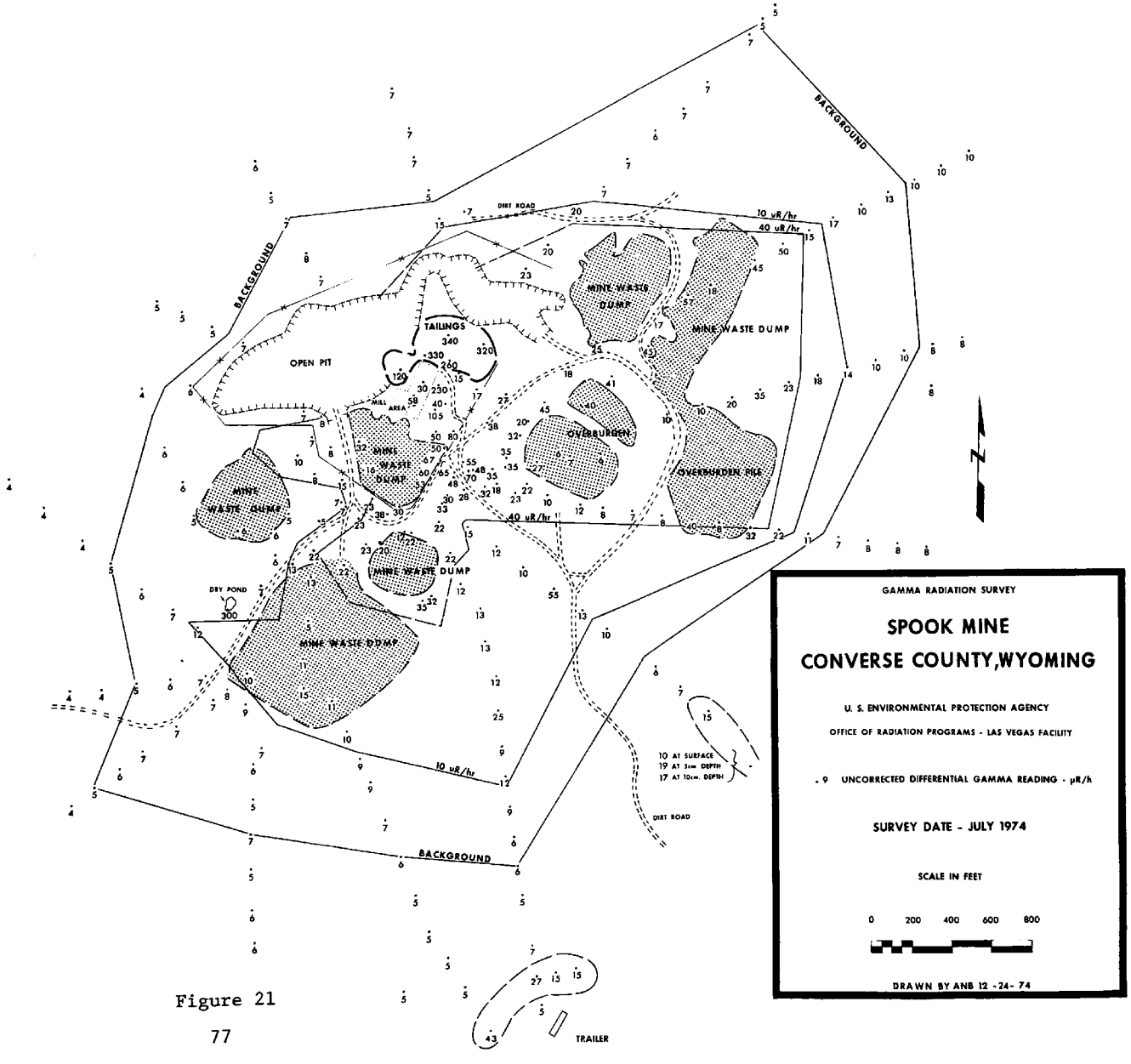
GAMMA RADIATION SURVEY
SPOOK MINE
CONVERSE COUNTY, WYOMING
U. S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS - LAS VEGAS FACILITY
• 9 UNCORRECTED DIFFERENTIAL GAMMA READING - μR/h
SURVEY DATE - JULY 1974
SCALE IN FEET
0 200 400 600 800
DRAWN BY ANB 12-24-74
BACKGROUND
DIRT ROAD
10 uR/hr
40 uR/hr
TAILINGS
OPEN PIT
MILL AREA
MINE WASTE DUMP
OVERBURDEN
OVERBURDEN PILE
DRY POND
10 AT SURFACE
19 AT 5cm DEPTH
17 AT 10cm. DEPTH
TRAILER

Figure 21

APPENDIX A

CALIBRATION OF SCINTILLOMETER

The assessment of above-ground exposure rates from wind-and water-eroded tailings around the tailings pile is complicated because of interfering radiation from the pile. In order to compensate for the interfering components, indirect measurements were made. The measurements were made by taking two instrument readings at ground level. One reading was made with a shield interposed between the detector and the ground surface (closed measurement). The other reading was made with the shield removed (open measurement). The difference between the two readings (open minus closed, or delta (Δ)) can be related to surface contamination present under the instrument.

After the surface contamination has been evaluated over an area, the above-ground exposure rate can be computed using conventional calculations and simplifying assumptions. The relationship between the delta reading and the surface contamination level, ω (pCi $^{226}Ra/cm^2$) was established by plotting delta values vs. ω under a controlled calibration procedure. For the calibration, a disc having a radius of 22 inches and depth of one-half inch was filled with assayed mill tailings. Delta measurements were then made in the center of the disc. The tailings were then diluted twice with clean sand, with delta measurements made after each dilution. This procedure established three points on a curve relating Δ to ω (Figure A-1).

Absorbed dose rates were calculated for a point three feet above the center of a disc with various radii and a uniform surface contamination of 1 pCi $^{226}Ra/cm^2$ (with its progeny in equilibrium) using the following equation:

$$D\gamma = 0.254\ \omega\ \overline{E}\gamma\ \mu_a\ [E_1(\mu_o X) - E_1(\mu_o \sqrt{R^2+X^2})]$$

where:

$D\gamma$ = absorbed dose rate (rads/sec)

ω = Ci/m^2

$\overline{E}\gamma$ = average gamma ray energy per disintegration (MeV/dis)

μ_a = linear energy absorption coefficient for air (m^{-1})
$E_1(X)$ = exponential integral
R = disc radius (m)
X = distance above disc center (m)
μ_o = total absorption coefficient for air (m^{-1})

Absorbed dose rates vs. disc radius are shown in Figure A-2. Delta values corresponding to an above-ground exposure rate can be obtained from Figures A-1 and A-2.

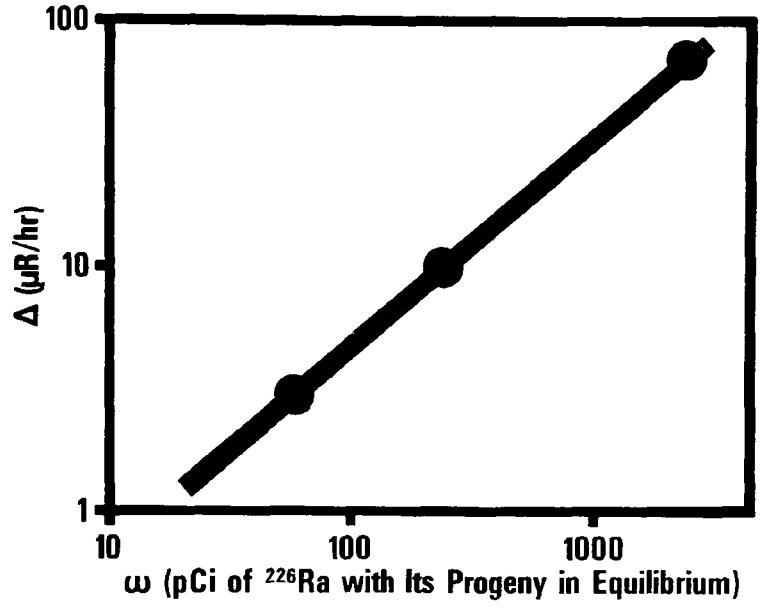

Figure A-1
Differential Gamma Reading (Δ) vs Surface Contamination Level (ω).

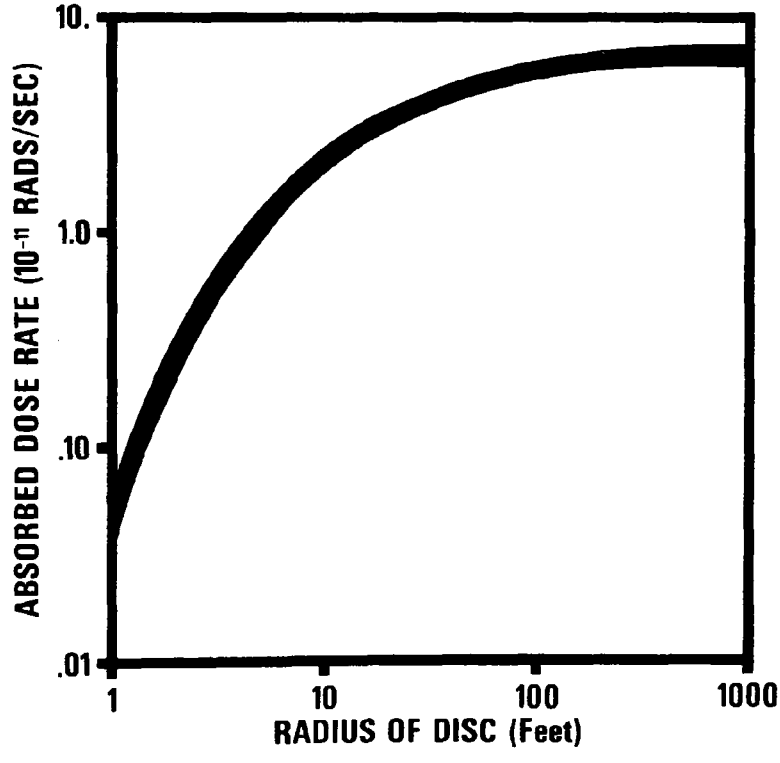

Figure A-2
Gamma Absorbed Dose Rate on the Axis (3 feet above disc) of a Plane Disc from a Uniform Surface Contamination (ω) of 1 pCi/cm^2 of ^{226}Ra with its Progeny in Equilibrium vs Radius of Disc.

APPENDIX B

TECHNICAL BASIS OF INTERPRETATION OF FIELD MEASUREMENTS

NAVAJO NATION AND GREEN RIVER SITES

The background lines around the sites were located by determining a delta value caused by natural background and fallout. These values were obtained as close to the site as possible without adding in a component from tailings on the ground. Since the background delta will occur at an infinite number of places around the sites, one delta unit was added to it in order to define an inflection point where background ended and tailings deposition began. For example, if the highest ambient background delta value was two, tailings were assumed to be present when a delta three was measured. The latter was arbitrarily defined as background delta for a particular site.

The 10 μR/h line was located using the following assumptions:

- Delta values decreased linearly with increasing distance near the proximity of the background line.

- The exposure rate measured at three feet above an infinite plane with a uniform surface contamination of ^{226}Ra and progeny will come from a disc with a radius of 100 feet. (Calculations indicate that on a smooth surface, approximately 65% of the exposure rate will come from a disc with a 100 foot radius. However, surface roughness factors will increase the effective percentage to above 90%.)

- Direct or indirect exposure from the pile is not considered.

- Approximately 100% of the contamination would be removed from inside the line (i.e., toward the pile).

- The average above-ground residual exposure rate after decontamination would result from contamination remaining outside the line. This exposure rate is assumed to come from a disc having a radius of 100 feet and its axis 100 feet behind the line.

The average distance between the 10 μR/h and the background lines for the sites is approximately 400 feet. In cases where the distances exceed 400 feet, the location of the 10 μR/h line may be slightly underestimated and vice versa. Since delta decreases with increasing distance from the sites, a uniformly contaminated plane condition does not exist on the outside of the 10 μR/h line. Assuming a linear decrease of delta from the 10 μR/h line to the background line over a distance of 400 feet, the delta value 100 feet behind the 10 μR/h line will be about three. The surface contamination corresponding to a net delta of three will result in an above-ground exposure rate of 11 μR/h on a disc with a radius of 100 feet.

A 40 μR/h iso-exposure rate line was located at the Tuba City and Mexican Hat sites in case a relaxation of the decontamination criteria was necessary because of practical aspects and rough terrain. The average distance between this line and the 10 μR/h line is approximately 200 feet. Using the same assumptions as for the 10 μR/h line, the exposure rate 100 feet behind this line is approximately 35 μR/h. A more precise location of this line was not possible because pile shine increased the meter readings and necessitated using a scale factor that could only be interpreted to delta increments of five.

ALL OTHER SITES

Survey techniques were changed for the remaining sites whereby delta measurements were made at increasing distances from the pile on straight lines or radials. Each radial or line (where possible) was analyzed to locate background, 10 μR/h and 40 μR/h points. These points on the radials or lines were then connected from iso-exposure rate contour lines around the sites.

Delta values for background were determined by examining radial end point values or by measurements taken as close to the site as possible, generally in the upwind direction. If several values of delta were observed for background, the highest value was used.as the background delta. Tailings were assumed to be present when measurements were equal to the background delta plus one delta unit.

In order to locate the 10 μR/h point on the radial, the delta values for each radial were plotted as a function of distance from the pile. Each delta value was connected with a straight line. A delta value corresponding to an exposure rate of 10 μR/h at three feet above a uniformly surface contaminated disc with a radius of 100 feet was determined.

A point on the radial was located where the averages of the delta values 100 feet in front of and behind the point plus the point value equaled the pre-determined delta value. The 10 μR/h line point was then established 100 feet in front (toward the pile) of the point used for averaging. The 40 μR/h point was established in the same manner as the 10 μR/h line.

APPENDIX C

RADIOLOGICAL CRITERIA FOR DECONTAMINATION OF INACTIVE URANIUM MILL SITES*

GENERAL

Radiological criteria for an engineering assessment of possible remedial actions applicable to uranium mill tailings piles and for the decontamination of inactive uranium mill sites are provided herein. These criteria are applicable to the sites, to their surrounding areas which have been contaminated by radioactive materials from the sites, and to buildings in which the materials have been used.

Critical radiation exposure pathways from inactive uranium mill sites to members of the general population are:

1. Radon escaping from the tailings pile carried by the wind into habitable structures where the holdup time is long enough, resulting in buildup of radon daughters to levels greater than the ambient air.

2. Tailings material used for construction of habitable structures can result in a buildup of radon daughters and increased gamma levels.

3. Gamma rays from tailings material cause whole body radiation exposure. This includes not only the "gamma shine" from the tailings pile that exposes people living nearby, but also the radiation exposure from tailings material that has been eroded off the pile onto surrounding land. The mill sites always show elevated gamma exposure levels because of contamination by ore, tailings solids, and process solutions.

4. ^{226}Ra, Th, and other radionuclides from tailings piles can be leached into ground water and thereafter into public and irrigation water supplies.

5. Windblown particulate material (Ra and Th) from the tailings pile can be inhaled causing a radiation dose to the lung.

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* Prepared by U. S. Environmental Protection Agency, Office of Radiation Programs, December 1974.

Remedial actions may be required on inactive uranium mill tailings piles to reduce or prevent excess radiation exposure from radon progeny, gamma radiation, ^{226}Ra, and radioactive particulate material. If tailing material has been used as a building material, remedial actions may be required to reduce radon concentrations and/or gamma activity levels. Remedial actions performed on tailings piles and decontamination of mill sites and surrounding contaminated areas should result in residual exposures that are as low as practicable. There is no single permissible exposure level applicable to all such cases. An evaluation should be made on a case-by-case basis of the risk involved, balanced against (1) the cost of reducing the residual contamination, and (2) the economic effect on alternatives such as restricting the use of the land. The result of such an analysis can be used by all concerned to define the "as low as practicable" residual level of contamination that will be acceptable and determine whether restrictions will be required on the use of any contaminated land.

TAILINGS PILE OR POND

The operation of uranium mills result in the generation of waste material which is disposed of in tailings piles and ponds. Environmental contamination has occurred at those sites where measures were not taken to control the movement of the radioactive material. In order to restore the environmental quality and provide for protection of the public, such sites should be decontaminated and result in residual gamma radiation levels which are as low as practicable. For most situations this would require decontamination of the area by (1) removal of radioactive material to a location where the material would be isolated from the biosphere, or (2) providing sufficient cover such that the resultant gamma radiation levels are as low as practicable, preferably at background. However, under certain topographical conditions and economic considerations wherein complete removal is not practicable, the residual levels should not exceed 40 μR/hr above background. This value is arbitrarily chosen for the purpose of providing an engineering estimate on cleanup of contaminated areas. It is considered to be sufficiently low that any expected exposures occurring after any remedial action taken at this level would not constitute a public concern. However, this should not be considered as the final criterion.* The gamma radiation level is the net, corrected measurement at 3 feet above the ground.

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* When all phase II information is complete and the health impact of remedial actions identified an overall determination of as low as practicable protection levels can be assessed appropriately. Therefore, the above numbers are subject to change.

For each site a determination should be made of the radium concentration in the soil. Cleanup should reduce the soil concentration to less than two times the radium background specific for the area.

If the radioactive material remains in place and stabilized, the area should be designated as a controlled area. Due to the difficulty of controlling radon diffusion and the existing state-of-the-art of stabilization, the land should be restricted as to human occupancy and be properly fenced to limit access.

The ^{226}Ra activity contribution from the site in ground or surface water should meet applicable State or Federal standards.

OPEN LAND AREAS

This area refers to all land beyond the fence of the sites where tailings are located. As with the tailings areas, decontamination of the uranium mill site and other areas contaminated by wind or water eroded tailings should result in residual gamma levels which are as low as practicable. Cleanup of the area would require returning of the windblown tailings material to the site and establishing a controlled area, or moving all the material to a location that will isolate the material from the biosphere.

If the residual gamma levels are less than 10 μR/hr above background, the land may be released for unrestricted use. If residual levels are equal to or greater than 10 μR/hr above background at a given site a determination should be made of the radium concentration in the soil. Cleanup should reduce the soil concentration to no more than two times the radium background specific for the area. Under certain topographical conditions wherein complete removal of tailings is not possible or practicable, the residual levels should be as low as practicable but should not exceed 40 μR/hr above background and access should be controlled. This value is arbitrarily chosen for the purpose of providing an engineering estimate on cleanup of contaminated areas. The gamma radiation level is the net, corrected measurement at 3 feet above the ground.

STRUCTURES

It is possible that there will be several industrial and residential structures where tailings have been utilized for construction purposes. When it has been determined that tailings were used in the construction, the lower limits of the guidelines established by the Surgeon General for structures in Grand Junction, Colorado, will be used.

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(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report presents the results of gamma radiation surveys conducted by the Office of Radiation Programs--Las Vegas Facility (ORP-LVF) of the U.S. Environmental Protection Agency (EPA) at twenty inactive uranium mill sites in the Western United States. The purpose of these surveys was to measure the extent to which radioactive material had been spread into the environment from the sites by the action of wind and/or water erosion, and by milling activities. The results indicate that hundreds of acres of land exclusive of the tailings piles have been contaminated to above-background levels. Some of the contaminated land is private, off-site property.

Survey techniques were developed to locate the spread radioactive materials and to estimate the gamma exposure rates resulting from them. These measurements were complicated by the presence of direct gamma radiation from the tailings piles. Iso-exposure rate lines were located around each site and plotted on site maps to facilitate site decontamination decisions. These lines, corresponding to post-cleanup exposure rates of background, 10 microroentgens per hour and 40 microroentgens per hour and 40 microroentgens per hour, were selected to correspond to current ORP criteria for decontamination of inactive uranium mill sites.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Radioactive Wastes Radium Environmental Surveys	Uranium milling Inactive uranium mill sites, Uranium mill tailings piles	1807 0702 0510

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