KAISER ALUMINUM
CORPORATE ENVIRONMENTAL

December 12, 2001

40-2377

U. S. Nuclear Regulatory Commission
Washington, DC 20555
Attn: Document Control Desk

Technical Report
Historical Site Assessment
Operational Area
Former Kaiser Aluminum Specialty Products Facility
Tulsa, Oklahoma
Kaiser Aluminum & Chemical Corporation

Dear Sir or Madam:

Kaiser Aluminum & Chemical Corporation (Kaiser) is submitting one copy of the above-referenced technical report which presents the results of an historical site assessment performed for Kaiser's former Specialty Products facility located in Tulsa, Oklahoma. The Historical Site Assessment focused on an approximate 3.5-acre land area of the facility known as the former "operational area." Plant processes and operations occurred in this area. The results of the Historical Site Assessment will be used to design characterization and/or decommissioning events for the former operational area of the facility. If you have any questions concerning the enclosure, please do not hesitate to call me at (225) 231-5116.

Sincerely,

J.W. Vinzant/cak

J.W. (Bill) Vinzant, P.E.
Manager, Corporate Environmental Affairs

JWV:cak

Enclosure

cc: J. Buckley – U.S. Nuclear Regulatory Commission
D. Chamberland – U.S. Nuclear Regulatory Commission
P. Bishop – Oklahoma Department of Environmental Quality
K. Hunter Burch – State of Oklahoma
L. Max Scott – ADA Consultants
J. Donnan – Houston
R. Buller - Tulsa
M. David Tourdot – Earth Sciences
A. Gutterman – Morgan, Lewis & Bockius
P. Handa – Tulsa
R. Fowlkes – Ann Green Communications
S. Van Loo – City of Tulsa

w:\5072k\corr\USNRC1.doc

9141 INTERLINE AVENUE, SUITE 1A BATON ROUGE, LA 70809-1957

NMSS01 Public

Historical Site Assessment
Operational Area

Former Kaiser Aluminum Specialty Products Facility
Tulsa, Oklahoma

Kaiser Aluminum & Chemical Corporation
Tulsa, Oklahoma

Project No. 5427K
December 2001

Earth Sciences Consultants, Inc.

Providing Environmental Consulting Services Since 1979

Historical Site Assessment
Operational Area

Former Kaiser Aluminum Specialty Products Facility
Tulsa, Oklahoma

Kaiser Aluminum & Chemical Corporation
Tulsa, Oklahoma

Project No. 5427K
December 2001

Earth Sciences Consultants, Inc.
One Triangle Lane
Export, PA 15632
724/733-3000
FAX: 724/325-3352

Table of Contents

Table of Contents
(Continued)

Historical Site Assessment
Operational Area
Former Kaiser Aluminum Specialty Products Facility
Tulsa, Oklahoma
Kaiser Aluminum & Chemical Corporation

1.0 Introduction

This technical report was prepared by Earth Sciences Consultants, Inc. (Earth Sciences) on behalf of Kaiser Aluminum & Chemical Corporation (Kaiser) to present the results of an historical site assessment (HSA) performed for the former Kaiser Aluminum Specialty Products facility located in Tulsa, Oklahoma (Figure 1). The HSA focused on an approximate 3.5-acre land area of the facility known as the former "operational area." The former operational area is located to the north of 41st Street and south of the Union Pacific Railroad right-of-way (see Figure 2). Plant processes and operations occurred in this area. The former operational area currently houses several structures including the North Extrusion, Office, Maintenance, Warehouse, Crusher, and Crusher Addition buildings. The "land areas" of the former operational area consist mainly of paved concrete surfaces. The Flux Building, located to the northeast of the triangular parcel, is also included as part of the former operational area. The results of the HSA will be used to design characterization and/or decommissioning events for the former operational area of the facility.

1.1 Facility Operational Background

The subject facility, which was built by the Standard Magnesium Corporation (SMC) in the early to mid-1950s, currently is owned by Kaiser. Historical operations at the facility included the smelting of scrap magnesium alloy for the production of magnesium anodes. To facilitate these operations, SMC obtained a source materials license (C-4012) from the Atomic Energy Commission (AEC) in March 1958 to recycle magnesium alloy aircraft scrap with up to 4 percent natural thorium content. This license was renewed and amended several times, and was superceded by License No. STB-472 in 1961. In 1968, STB-472 was amended to also authorize possession and processing of uranium-bearing materials, but there is no record that uranium materials ever were received on site. Available site characterization data support this finding. Thorium alloy material comprised only a fraction of the total magnesium refined on site. Kaiser purchased the facility in 1964 and magnesium operations continued to around 1985. Aluminum replaced magnesium in smelting and anode manufacture, and the plant continued operating until the 1997-1998 time frame. However, the radiological license was terminated in 1971 by the AEC at

Kaiser's request. Magnesium-thorium alloy reprocessing had been halted at that time for more than a year.

The scrap magnesium alloy refining process consisted of placing the sheered material into large melting pots, heating the material until molten, and then siphoning off the pure magnesium. Impurities from the mixture, including thorium, separated from the magnesium and floated on the surface. This residue material was removed, allowed to cool, and crushed. The crushed material was returned to the heating pots for a second recovery process. Once refined, the metallic dross residue material was crushed and disposed on site in accordance with license conditions.

1.2 Historical Site Assessment

The HSA was performed using guidance outlined in the Multi – Agency Radiation Survey and Site Investigation Manual (MARSSIM). The conclusions presented in this HSA are a result of compiling and evaluating site information. The information sources used for the HSA are as follows:

- MARSSIM, 2000
- A Radiological Report, American Radiation Services, Inc. (ARS), 2000
- Local and Regional Environmental Data Report, Roberts/Schornick & Associates, Inc., 1996
- Decommissioning Plan, Tulsa Facility, Tulsa Oklahoma, June 2001, Earth Sciences
- Adjacent Land Remediation Plan (ALRP), Final Status Survey Report, Earth Sciences, 2001
- Proposed Characterization Plan, Decommissioned Facilities, Kaiser Aluminum & Chemical Corporation, Tulsa, Oklahoma, Earth Sciences, February 2001
- Historical Hydrological Impacts Shown on Aerial Photographs, A&M Engineering and Environmental Services (A&M Engineering), 1999
- Technical Document, Measurement of Thorium and Thoron Hazards (Appendix B)
- Arial photo progression review from 1950 to present
- Investigation on the basic plant process as well as site-specific process knowledge (Kaiser)
- Review of available site records
- Interviews with Mr. Robert Teel, Kaiser employee from 1963 to present

- Interviews with Mr. Bobby A. Holmes, Kaiser plant manager from 1982 to 1991
- Information gathered during the Additional Site Characterization Activities (ASCA), 2001, prepared by Earth Sciences

1.3 Report Structure

The format utilized for this report was provided by MARSSIM (Section 3, Page 3-26, Figure 3.2). The remainder of this document provides general background information on the facility, the approach that was used to gather historical information, and the results of the assessment of historical information that was gathered. Conclusions based upon the results of the investigation and review of historical information are also provided.

2.0 Purpose of the HSA

Extensive site characterization activities have been conducted since 1994 within a 14.0-acre land area of the facility known as the "pond parcel." These characterization activities have indicated the presence of residual radioactive material within a 10-acre portion of the pond parcel. The radioactive material identified within this portion of land is a thorium-bearing dross containing the isotopes thorium-232 (Th-232), thorium-230 (Th-230), and thorium-228 (Th-228). The impacted portion of the parcel contains the retention pond, former reserve pond area, and Flux Building area. The nonimpacted portion of the pond parcel contains a freshwater pond. A plan was prepared to address the decommissioning of the pond parcel land area. The decommissioning plan (DP) was submitted in June 2001 to the Nuclear Regulatory Commission (NRC) (Reference 1). The HSA focuses on the former operational area of the facility, which was not addressed in the June 2001 DP.

Over time, certain portions of the original SMC property were transferred to other entities. Consequently, some contamination existed on property adjacent to current Kaiser property boundaries. As a result, Kaiser prepared and submitted to the NRC an ALRP. This plan was approved by the NRC on April 4, 2000. Kaiser conducted off-site remediation activities from October 2000 through May 2001. Contamination of the adjacent properties was found to occur at the ground surface and to depths of up to 15 feet. The extent of the contamination was limited to the following properties: Union Pacific Railroad right-of-way; northwest corner of Specific Systems (formerly Unarco) property; along Fulton Creek on the Beejay, Inc. property; north of the North Extrusion Building; north of the Smalley Equipment property; and the Red Man Pipe & Supply Company (Red Man) (formerly Premier) property. Contamination also was found along the north side of East 41st Street, between the roadway and the Crusher Addition Building. In addition, contamination was found south of Kaiser's Flux Building, outside the retention pond property fence, and on Kaiser property between the Flux Building and the Union Pacific Railroad property. Remediation was performed in these areas to achieve unrestricted release of the adjacent land areas. A final status survey report for the ALRP was submitted to the NRC in July 2001.

The most recent characterization effort (ASCA, October 2001 [Reference 2]) investigated parts of the former operational area of the facility. As previously mentioned, the former operational area is defined as the concrete surfaces and structures where plant processes and operations occurred. The areas are those that fall in the triangular parcel of land north of 41st Street and south of the railroad right-of-way. The Flux Building is included as part of the former operational area (Figure 2), since it is a related structure

and will require appropriate classification according to MARSSIM (Reference 3). The HSA was conducted as the first step toward decommissioning the former operational area of the Kaiser facility. The objective was to compile as much historical information as possible for the site and, using (MARSSIM) guidelines, categorize the land areas and structures of the former operational area of the facility as either impacted or nonimpacted.

3.0 Property Identification

3.1 Site Location and Description

The former Kaiser Aluminum Specialty Products facility is located at 7311 East 41st Street in Tulsa, Oklahoma. It is situated in Tulsa County, Oklahoma, about 5 miles southeast of the downtown center of the City of Tulsa. The site initially occupied approximately 23 acres of land on both sides of 41st Street (Figure 3). Currently, a 3-acre parcel south of 41st Street contains an active aluminum extrusion and fabrication facility. North of East 41st Street are several parcels of land previously devoted to refining, processing, and waste disposal functions. This acreage is split by the Union Pacific Railroad right-of-way. An approximate 3.5-acre parcel south of the railroad houses an active office building and several inactive operational structures. An approximate 14.0-acre pond parcel north of the railroad contains a freshwater pond, a retention pond, a former reserve pond area and the Flux Building area (Figure 3).

3.1.1 Site Topography and Stratigraphy

The site is located in the Northwest Oklahoma Cherokee Platform Physiographic Province, which is a region with low relief. Originally, the site topography ranged from elevations above 710 feet above mean sea level south of the tracks to below 690 feet at the retention pond and below 680 feet at the reserve pond. The current topography range of the site has not changed from the original calculations. This is illustrated in Figure 3.

3.2 Environmental Setting

Information contained in this section of the HSA was previously gathered for the DP. The information presented here was carried over from the appropriate sections of the DP. However, figures which illustrate the descriptions of the environmental setting were excluded from this report due to repetitiveness and length. If needed, the illustrations can be obtained from Reference 1.

3.2.1 Geology

In general, the site is underlain by Quaternary Age alluvial soil deposits. Large portions of the rocks that outcrop in northeastern Oklahoma are Pennsylvanian in age. The Pennsylvanian System is divided into five major series. These series, in descending order, are as follows:

- Virgilian Series (youngest rocks)
- Missourian Series
- Desmoinesian Series

- Atokan Series
- Morrowan Series (oldest rocks)

Figure 3-5 of the DP illustrates the general west-to-east cross section for Tulsa County.

Areal geology features a bedrock of mostly flatlying soft shales, interbedded with thin resistant beds of limestone and sandstone. The retention pond parcel is located in an area overlying a buried stream valley filled with recently deposited sediments. Borehole data indicate that the pond parcel is situated over a series of stream-deposited clayey silty sands that directly overlie the Nowata Shale bedrock. In turn, the sand units are covered by silty to sandy clays which, together with clayey fill material, form the surface features of the site. The shale bedrock, which underlies much of the area, has been eroded along the original valley axis to average depths of 15 to 20 feet and locally to depths of 25 to 30 feet. Clay and silt sediments have some peat content, and localized thick organic peaty silt (Unit 4, A&M Engineering, July 1999) deposits are known from boreholes across the northern part of the retention pond.

The clay-to-silt sand unit (Unit 1) is a stream channel fill that ranges from 0 to 10 feet in thickness with the thickest areas under the east end of the retention pond. The silt-to-sandy clay unit (Unit 2) ranges from 5 to 15 feet in thickness with the thickest section under the freshwater pond. Along the axis of the stream valley, the top of the clayey sand layer is at a near-uniform elevation of 682 feet (ground elevation on the retention pond peninsula is approximately 696 feet) with changes in thickness due to fill in previously existing topography on the eroded shale. The silt clay unit directly overlies the sand and reaches an elevation of 692 feet. Fill (Unit 3) and dross (Unit 5) fill in low spots on this unit. Dross is present in deposits that range in thickness from inches to 10-plus feet. This dross material possesses a characteristic metallic gray color in sand to gravel particle sizes, when found in sediments, and was described as sludge by ARS (1995) when found in pond-bottom sediments.

Geologic and boring log descriptions indicate that the dross, clay, and sand units possess little shear strength. The dross, when saturated with groundwater, as exists under ponded water conditions, has little mechanical strength. The dross has been observed to run into drilled boreholes within or adjacent to the retention pond. Hammer blow counts for the soil surrounding and underlying the dross generally are low, in single digits, indicating minimal shear strength. Reasonable bearing strength is found in the shale bedrock and, to a lesser degree, in the clayey sand. Particle-size distributions for sand units indicate generally well-sorted sand with 5 to 20 percent fines and less than 10 percent gravel. For the clay units, more than 45 percent of the material passes through the No. 200 sieve; the sand fraction composes another 40

to 45 percent of the sediment. Atterberg tests on the fines indicate a low- to medium-plastic clay. More details on site geotechnical properties are presented in the Geotechnical Brief (Earth Sciences, 2000).

3.2.2 Surface Water Hydrology

The freshwater pond, Fulton Creek, and the retention pond dominate the site surface hydrology. The 274-acre Fulton Creek drainage basin, upstream of the retention pond, is located to the southwest, west, and northwest of the Kaiser facility. With increasing urbanization, the flow into the pond and creek has changed to receive surface runoff and storm water from an area largely taken over by light industrial and commercial development. Downstream, Fulton Creek connects to Mingo Creek, Bird Creek, and the Verdigris River which ultimately empties into the Arkansas River. Mingo Creek basin waters have been designated by the Oklahoma Water Resources Bureau (OWRB) for beneficial use as an emergency water supply, fish and wildlife propagation, agriculture, industrial and municipal process and cooling waters, recreation, and aesthetics. Some flood control is provided within one-half mile downstream from Kaiser's property; however, none of the ponds or structures that are on Kaiser property are designated as part of this system.

On-site features associated with the Fulton Creek drainage include the embankment that forms the eastern edge of the freshwater pond and the excavated ditch carrying Fulton Creek along the northern edge of Kaiser's pond parcel. A deteriorating concrete weir at the northeast corner of the freshwater pond controls flow into Fulton Creek. At the east edge of the property line, another deteriorating concrete weir is used to control flow exiting the property. Both weirs are reported to pass water beneath the structures, making measurements of discharge quantities unreliable. In addition, three concrete weirs are present on Kaiser property along Fulton Creek and create small ponds. Discharge varies with season and local precipitation events.

The retention pond covers approximately 8 acres and is bounded on the north and east by embankments and higher ground elsewhere. The pond, permitted by the OWRB (Permit No. CW-72-131) as a nondischarging retention pond, formerly received both industrial process cooling water and solid dross wastes. Liquid wastewater from plant operations was carried to the retention pond through an underground pipe and a pumping station.

Surface runoff from Kaiser's former operational area, south of the railroad, is directed to the north beneath the railbed and through three culverts. In addition, surface runoff from the pond parcel is diverted either into the pond or off site through a ditch just north of the Flux Building and paved area.

These structures convey water toward the pond area, toward a ditch along the north edge of the paved area around the Flux Building, or to an off-site area south of the Flux Building. Adjacent to the Flux Building, surface flow is collected in a ditch which enters a pipe at the east fenceline. This pipe passes around the northwest corner of Specific Systems' property and enters a concrete-lined ditch, which connects with Fulton Creek upstream of a weir at the northeast corner of Kaiser property.

The reserve pond was excavated and diked at the northeast corner of the site. It was put into service in 1964, operated to post-1967, and was backfilled circa 1972. This pond was approximately 1.5 acres in area and reportedly up to 15 feet deep.

Figure 3 is a current topographic map of the site. Surface water typically leaves the facility moving north to Fulton Creek. From Fulton Creek, the flow proceeds east.

3.2.3 Groundwater Hydrology

The hydrogeologic setting was determined for Kaiser by A&M Engineering (July 1999), based on data from 23 boreholes and piezometers drilled in and adjacent to the pond parcel. Piezometers and monitoring wells were installed to monitor groundwater in shallow fine-grained sediments, in deeper sandy units comprising the basal part of the buried valley fill, and in deep stratigraphic holes drilled into the Nowata Shale unit. Groundwater elevation monitoring, hydraulic conductivity (slug) tests, and groundwater chemical analyses were performed. A hydrologic budget was estimated for surface and groundwater inflows and outflows of the site.

In general, groundwater flow is from west to east, along the axis of the buried stream valley. Groundwater was found to lie fairly close (within 3 to 5 feet) to the ground surface but was recognized to vary considerably in response to short- and long-term precipitation patterns. Groundwater is suspected to occur both in shallow perched/mounded conditions and in deeper unconfined to semiconfined conditions. Groundwater elevations in piezometer pairs in deep and shallow aquifers/sediments may differ at locations around the pond by 0.1 foot to 5 feet. Downward vertical groundwater flow through the upper fine-grained units into the lower sandy units was reported. There is little evidence of downward migration between near-surface sediments into the Nowata Shale (see Figures 3-8 and 3-9 of the DP).

Water level data in wells and ponds were interpreted by A&M Engineering (July 1999) to indicate that the freshwater pond has a relatively insignificant impact on the groundwater table. This was attributed to the impermeability of the embankment dam and, to a lesser degree, to silting of the pond bottom and

controlled outflow through a weir from the pond into Fulton Creek. Retention pond and downstream groundwater elevations were observed to correlate closely during seasonal climate changes. Elevation changes of water in the Fulton Creek ditch were observed to correlate well with both retention pond levels and levels in deeper sand units, suggesting a link between them (A&M Engineering, 1998).

3.2.4 Meteorology and Climatology

Meteorological and climatological data for the facility were obtained from the Oklahoma Climatological Survey and the National Climate Data Center. A general description of Tulsa's climate follows.

The City of Tulsa lies along the Arkansas River at an elevation of about 700 feet above sea level. The surrounding terrain is gently rolling.

At Latitude 36°, Tulsa is far enough north to escape long periods of heat in summer, yet far enough south to miss extreme winter cold. The influence of warm moist air from the Gulf of Mexico is often noted, due to the high humidity, but the climate is essentially continental, characterized by rapid changes in temperature. Generally, winter months are mild. Temperatures occasionally fall below 0°Fahrenheit (F), but last for a very short time. Temperatures of 100°F or higher often are experienced from late July to early September, but usually are accompanied by low relative humidity and a good southerly breeze. The fall season is long with a great number of pleasant sunny days and cool nights.

Rainfall is ample for most agricultural pursuits and is distributed favorably throughout the year. Spring is the wettest season, having an abundance of rain in the form of showers and thunderstorms. The steady rains of fall are a contrast to the spring and summer showers and provide a good supply of moisture and good conditions for growth of winter grains and pastures. The greatest amounts of snow are received in January and early March. Snow usually is light and remains on the ground only for brief periods.

The average date of the last 32°F temperature occurrence is late March and the average date of the first 32°F occurrence is early November. The average growing season is 216 days.

The Tulsa area occasionally is subjected to large hail and violent windstorms that occur mostly during spring and early summer, although occurrences have been noted throughout the year. Prevailing surface winds are southerly during most of the year. Heavy fogs are infrequent. Sunshine is abundant.

3.2.5 Wind

The predominant wind direction is from the south. The prevailing monthly wind speed varies from 9 to 12 knots. The highest 1-minute sustained wind speed was 52 miles per hour (mph). This occurred in April 1982. The highest peak gust was 70 mph, recorded in June 1992.

3.2.6 Temperature

Average annual temperature for the years 1948 through 1990 was 61°F. The daily average temperature varies from 83°F in July to 36°F in January. Monthly extremes vary from minus 8°F in December to 112°F in July.

3.2.7 Precipitation

Average annual precipitation is 38.9 inches of rainfall. The wettest year recorded during the period 1948 through 1990 was 69.9 inches of rainfall, while the driest year received 23.2 inches. May is the wettest month with an average of 5.6 inches of precipitation, while January is the driest month with an average of 1.6 inches of precipitation.

Storm events have an average duration of 9.2 hours. There is an average of 48 storm events per year. The average storm produces 0.744 inch of rainfall at an intensity of 0.11 inch per hour.

Annual snowfall averages 10 inches. Monthly snowfall exceeding 0.5 inch occurs in November, December, January, February, and March. Trace amounts (less than 0.5 inch and greater than 0.05 inch) occur in October and April. The remaining months typically are void of snowfall. Figure 3-4 of the DP depicts the monthly average snowfall for the years 1948 through 1990.

3.2.8 Relative Humidity

The average annual morning and afternoon relative humidities compiled from readings taken at 0600 hours and 1500 hours for the years 1948 through 1990 are 81 percent and 49 percent, respectively. Monthly averages vary from 85 percent in May, June, and September to 46 percent in April, August, and October.

3.2.9 Evapotranspiration

Average monthly potential evapotranspiration varies from 3 millimeters (mm) in January to 188 mm in July. During the months of February through May, the soil is at its maximum water-holding capacity and precipitation exceeds evapotranspiration. Therefore, a water surplus occurs during these 4 months.

During the June through September time frame, potential evapotranspiration exceeds actual evapotranspiration. This is due to the soil moisture content being below its maximum storage capacity, thereby limiting the water uptake of the vegetation. The amount of moisture removed from the soil by vegetation during this time frame is dependent upon the ratio of the actual soil moisture content to potential soil moisture content. In other words, actual evapotranspiration equals potential evapotranspiration, multiplied by the ratio of actual soil moisture content to potential soil moisture content. This exceedance of potential evapotranspiration to actual evapotranspiration results in a water deficit from June through September.

4.0 HSA Methodology

This section presents the areas of concern, regulatory guidance, and site assessment approach that was used to assess the operational area at the facility. The areas of concern have been categorized based on a review of historical operations and data generated during prior site activities. The site assessment approach has been extracted from MARSSIM, Chapter 3.

4.1 Approach and Rationale

The HSA was designed to obtain and review information about the potential distribution of residual radioactive material on the operational area of the site. The information was of two types: historical information regarding past operations at the facility and analytical data generated during past site characterization and remediation activities. The information was reviewed to support classification of land areas and structures as impacted or nonimpacted, in accordance with MARSSIM. The information reviewed is listed below.

- An investigation of the basic plant process as well as site-specific process knowledge (Kaiser)
- Review of available site records
- Aerial photo progression review from 1950 to present (Appendix A)
- Interviews with Mr. Robert Teel (Kaiser employee from 1963 to present)
- Interviews with Mr. Bobby A. Holmes (Kaiser plant manager from 1982 to 1991)
- Information gathered during the ALRP, Final Status Survey prepared by Earth Sciences (Reference 4)
- Information gathered during the ASCA prepared by Earth Sciences (Reference 2)

Information regarding initial building construction, additions, and/or deconstruction was reviewed to aid in the assessment. An aerial photograph progression review was performed to provide an understanding of plant design and redesign. Also, interviews of former facility employees were conducted to clarify the facility's operational history.

The information gathered was evaluated and cross referenced to develop a conceptual model of the operational area during the time period of magnesium-thorium alloy reprocessing. The conceptual model was used to classify the structures and land areas of the former operational area.

4.2 Boundaries of the Site

The former operational area of facility, with the exception of the Flux Building, is bounded to the north by the Union Pacific Railroad, to the south by 41st Street, to the east by a small parcel of Kaiser property, and to the west by the Smalley Equipment property. The railroad right-of-way, 41st Street right-of-way, and small parcel of Kaiser property located to the east of the former operational area were addressed during the ALRP.

4.3 Documents Reviewed

Documents reviewed for the HSA of the operational area of the Kaiser facility include the following:

- A Radiological Report, ARS, 2000 (Appendix B)
- Local and Regional Environmental Data Report, Roberts/Schornick & Associates, Inc., 1996 (Reference 6)
- DP, Tulsa Facility, Tulsa, Oklahoma, Earth Sciences, 2001 (Reference 1)
- ALRP, Final Status Survey Report, Earth Sciences, 2001 (Reference 4)
- Technical Document, Measurement of Thorium and Thoron Hazards (Appendix B)
- Historical Hydrological Impacts Shown on Aerial Photographs, A&M Engineering, 1999 (Reference 7)

4.4 Property Inspections

Property inspections included the following:

- Earth Sciences' oversight of the ALRP from October 2000 through May 2001. During the ALRP, information was obtained on the subsurface conditions of the site and characteristics of the residual radioactive material on site.
- Earth Sciences' oversight of the additional site characterization event in May 2001. The additional site characterization was conducted to provide further information on subsurface conditions beneath certain structures within the former operational area.
- Earth Sciences' site reconnaissance in October 2001. Details of the facility layout, and building configurations, construction, and current conditions were obtained during the site reconnaissance.

4.5 Employee Interviews

Mr. Teel has worked at the facility from 1963 to present. His interview provided knowledge of plant processes related to magnesium-thorium alloy recovery operations. Interviews with Mr. Teel provided information on which buildings were used during the recovery process and waste management activities of thorium-bearing materials.

Mr. Holmes worked at the facility from 1982 to 1991 as the plant manager. His interview provided supporting information on historical plant processes and facility design.

5.0 History and Current Usage

5.1 License History and Land Use

The Kaiser plant in Tulsa, Oklahoma was built by SMC in the early to mid-1950s to manufacture magnesium products. Kaiser purchased the facility in 1964. SMC received a source materials license (C-4012) from the AEC in March 1958 to receive possession and title to magnesium-thorium alloy with up to 4-percent thorium content for processing. The quantity of material SMC, and later Kaiser, was authorized to possess at one time was amended from time to time, but generally was limited to 30,000 pounds of magnesium-thorium alloy containing no more than 4 percent thorium. Scrap magnesium-thorium alloy was smelted, along with other magnesium materials, to recover the magnesium. Thorium alloy material comprised a small fraction of the total magnesium refined on site.

License C-4012 was superceded by License STB-472 in November 1961. License STB-472 was amended in June 1968 to add uranium to the list of authorized materials, but there is no record that uranium-bearing materials were ever received on site. Available site characterization data support this finding.

The AEC license was terminated in 1971 by the AEC, at Kaiser's request. Magnesium-thorium alloy reprocessing had been halted at that time for more than a year.

The scrap magnesium alloy refining process consisted of placing the sheered material into large melting pots, heating the material until molten, and then siphoning off the pure magnesium. Impurities from the mixture, including thorium, separated from the magnesium and floated on the surface. This residue material was removed, allowed to cool, and crushed. The crushed material was returned to the heating pots for a second recovery process. Once refined, the metallic dross residue material was crushed and disposed on site in accordance with license conditions.

Structures known to have been used to process thorium-bearing materials included the Smelter Building, the Crusher Building, and the Slag Storage Building. The smelting of magnesium alloy for purification occurred in the Smelter Building. The Smelter Building was demolished in October 2000, following completion of survey activities which indicated no contamination within the building. Operations conducted within the Crusher Building included the crushing of the dross/slag residue material from the smelting operations. The Crusher Building was razed and rebuilt in the early 1970s to accommodate aluminum smelting operations at the facility. The current structure identified as the Crusher Building was

not used to process thoriated material. The Slag Storage Building, constructed circa 1964, was used for the storage of dross/slag residue materials prior to the second magnesium recovery step. The building was removed in 1977.

Extensive characterization activities conducted since 1994 have established that Th-228, Th-230, and Th-232 are present in dross/soil residues on the Kaiser property. No elevated uranium has been detected. Th-228 and Th-232 have been determined to be in secular equilibrium. In addition, a ratio of Th-230 to (Th-228 + Th-232)/2 of 3.5 has been calculated from characterization data.

5.2 Current Land Use

No licensed activities are currently conducted at the site, nor have any licensed activities been conducted since 1971. The site is currently inactive with the exception of site management (Office Building) and intermittent facility maintenance activities. Figure 4 is a 1995 aerial photograph depicting land uses within the area during that period. Figure 5 provides a current zoning map of the facility and areas of interest. As shown, the facility actually lies within two separate zones - Industrial Moderate District (the area between the railroad and East 41st Street) and Industrial Light District (the area north of the railroad). Zoning within the vicinity of the plant is not expected to change. Therefore, future use of the site is expected to be restricted to commercial or light industrial use.

5.3 Adjacent Land Use

The adjacent properties are zoned as stated above (Industrial Moderate District and Industrial Light District). Current growth projections, property demands, and property location do not indicate that this zoning status will change. However, the immediate adjacent property which was once part of the original SMC property was found to contain low levels of contamination. This contamination was detected by the NRC in 1993. The extent of the contamination was limited to the following properties: Union Pacific Railroad right-of-way; northwest corner of Specific Systems (formerly Unarco) property; along Fulton Creek on the Beejay, Inc. property; north of the North Extrusion Building; north of the Smalley Equipment property; and the Red Man (formerly Premier) property. Contamination also was found along the north side of East 41st Street, between the roadway and the Crusher Addition Building. In addition, contamination was found south of Kaiser's Flux Building, outside the retention pond property fence, and on Kaiser property between the Flux Building and the Union Pacific Railroad property.

Kaiser prepared and submitted to the NRC an ALRP. This plan was approved by the NRC on April 4, 2000. Kaiser conducted off-site remediation activities from October 2000 through May 2001. Remedia-

tion was performed to achieve unrestricted release of the adjacent land areas. The Final Report for the ALRP is currently being reviewed and is expected to be accepted in the near future.

6.0 Findings

6.1 Potential Contaminants

Extensive characterization activities conducted since 1994 have established that Th-228, Th-230, and Th-232 are present in dross/soil residues on the Kaiser property. No elevated uranium has been detected. Th-228 and Th-232 have been determined to be in secular equilibrium. In addition, a ratio of Th-230 to (Th-228 + Th-232)/2 of 3.5 has been calculated from characterization data.

6.2 Potential Contaminated Areas

The facility was built in the early to mid-1950s by SMC. Licensed operations involving the recovery of magnesium-thorium alloy began in 1958 and continued through 1970. Plant operations continued until the 1997-1998 time frame. Characterizations for the site began in the mid-1990s, followed by remediation of the adjacent land areas in late 2000 and early 2001. This established time frame for facility construction and licensed operations was used to develop a conceptual model for the initial classification of the former operation area.

The following criteria were used in the model to classify areas as nonimpacted.

Nonimpacted Land Areas

- Land areas beneath buildings and concrete paving constructed prior to the initiation of licensed operations (1958)

Nonimpacted Structures

- Structures constructed following license termination in 1971
- Structures not involved with the reprocessing of magnesium-thorium alloy

As previously mentioned, the former operational area currently houses several structures including the North Extrusion, Office, Maintenance, Warehouse, Crusher, Crusher Addition, and Flux Buildings. The "land areas" of the former operational area consist mainly of land beneath paved concrete surfaces. Each of these structures and the land areas are discussed in the following sections.

6.2.1 Structures

None of the current site structures located within the former operational area were involved with the reprocessing of magnesium-thorium alloy. However, the Flux Building has been identified as an area of concern. The identification of this structure as an area of concern is not due to historical plant processes, but because it has been utilized as a storage and packaging area for radioactive materials (samples) during the ALRP, as well as prior characterization events.

6.2.2 Land Areas

Modifications to site facilities (buildings, parking lots, driveways, etc.) may have resulted in the covering of residual radioactive material beneath several currently paved surface and building floor areas. These areas of concern include the land areas beneath the Maintenance Building, the Crusher Building, the Crusher Building Addition, the North Extrusion Building, the Warehouse Building, and the former Smelter Building No. 5, as well as concrete paved areas completed post-1958. Residual radioactive material beneath these structures, if present, is not expected at great depths.

6.3 Impacted Areas

An impacted area, as defined by MARSSIM, is an area with the possibility of containing residual radioactivity in excess of natural background or fallout levels. Residual radioactivity is defined as radioactivity in structures, materials, soils, groundwater, and other media at the site resulting from activities under the cognizant organization's control. Residual radioactivity also includes radioactive materials remaining at the site as a result of routine or accidental release of radioactive material at the site and previous burials at the site. The following sections present the initial classifications of the land areas and current structures for the operational area at the facility.

6.3.1 Impacted Land Areas

Land areas within the operational area which fall into this category include the following:

- Areas covered by concrete post-1958
- Area beneath the former Smelter Building No. 5
- Area beneath the Crusher Addition Building
- Area beneath the Crusher Building
- Area beneath the North Extrusion Building
- Area beneath the Warehouse Building
- Area beneath the Maintenance Building

6.3.1.1 Land Areas Covered by Concrete Post-1958

Available records indicate that the land areas between structures were graded and paved with concrete post-1958. As a result, the grading and paving activities conducted during this period may have covered residual radioactive materials.

Sampling of the subsurface materials beneath the concrete pavement at several locations during the ASCA revealed the presence of residual radioactive material. Figure 6 illustrates the change in building size and presents ACSA sample locations with associated Th-232 activity concentrations.

6.3.1.2 Land Area Beneath the Crusher Addition Building

The Crusher Addition Building was constructed circa 1977 in the area immediately south of the Crusher Building. As previously mentioned, the Crusher Addition Building was constructed over the area which once housed a large sheering machine. The sheering machine was used to chop large pieces of scrap magnesium alloy into more manageable sizes for melting. The land area beneath this building could contain residual radioactive material from the shearing process. Site inspections conducted by Earth Sciences also indicated that the area was graded to accommodate the construction of the building.

6.3.1.3 Land Area Beneath the Crusher Building

Available information indicates that the Original Crusher Building was expanded sometime between 1958 and 1964. This building renovation may have resulted in the covering of residual radioactive material beneath the building floor expansion area. Sampling of the subsurface materials beneath the building floor during the ASCA revealed the presence of residual radioactive material. Figure 6 illustrates the change in building size and presents ACSA sample locations with associated Th-232 activity concentrations.

Crusher Building Dimension Changes Between 1958 and 1964	
1958	85 feet by 55 feet
1964	130-feet-by-65-feet addition added to the north and east of the original structure.

6.3.1.4 Land Area Beneath the North Extrusion Building

Available information indicates that the North Extrusion Building was expanded sometime between 1958 and 1964. This building renovation may have resulted in the covering of residual radioactive material beneath the building floor expansion area. The addition was approximately 105 feet by 150 feet. In addition, site characterization activities conducted in the vicinity of the building suggest that this once

low-lying area had been partially filled with on-site material. Figure 7 presents a comparison of the North Extrusion Building area for the years of 1958 and 1964.

North Extrusion Building Dimension Changes Between 1958 and 1964	
1958	110 feet by 60 feet
1964	100-feet-by-145-feet addition added to the north of original structure.

6.3.1.5 Land Area beneath the Warehouse Building

Available information indicates that the Warehouse Building was expanded sometime between 1958 and 1964. This building renovation may have resulted in the covering of residual radioactive material beneath the building floor expansion area. Sampling of the subsurface materials beneath the building floor during the ASCA revealed the presence of residual radioactive material. Figure 6 illustrates the change in building size and presents ACSA sample locations with associated Th-232 activity concentrations.

Warehouse Building Dimension Changes Between 1958 and 1964	
1958	West Complex 100 feet by 55 feet , East Complex 110 feet by 35 feet
1964	One Complex 250 feet by 55 feet

6.3.1.6 Land Area Beneath the Maintenance Building

Available information indicates that the Maintenance Building was expanded sometime between 1958 and 1964. This building renovation may have resulted in the covering of residual radioactive material beneath the building floor expansion area. Figure 6 illustrates the change in building size. Samples taken during the ASCA revealed residual radioactive material within close proximity of the building's footprint.

Maintenance Building Dimension Changes Between 1958 and 1964	
1958	Original Complex 132 feet by 45 feet
1964	With Addition of Scale House, 132 feet by 65 feet

6.3.1.7 Land Area Beneath the Former Smelting Building No. 5

Available information indicates that the Smelter Building No. 5 was constructed sometime between 1960 and 1961. This building's construction may have resulted in the covering of residual radioactive material beneath the building floor area. Figure 6 presents an approximate location of the building.

6.3.2 Impacted Structures

The only current structure located within the former operational area which falls into this category is the Flux Building. The Flux Building was classified as impacted due to the utilization of the building as a

sample storage and packing facility during characterization events and the ALRP. However, the potential for residual radioactive material in this building is minimal.

6.4 Nonimpacted Structures

A nonimpacted area, as defined by MARSSIM, is an area with no reasonable possibility of containing residual radioactivity in excess of natural background or fallout levels. Residual radioactivity includes radioactive materials remaining at a site as a result of routine or accidental release of radioactive material at the site and previous burials at the site. Current structures within the former operational area classified as nonimpacted include the following:

- Maintenance Building
- Office Building
- Warehouse Building
- Crusher Building
- Crusher Addition Building
- North Extrusion Building

6.4.1 Maintenance Building

Although currently referred to as the Maintenance Building, this structure's original function was for the manufacturing and packaging of underground anodes. Maintenance activities for the plant were moved to this area around 1985. Neither of these activities required the handling or storage of radioactive materials. Current activities in this area are minimal and are concentrated solely around the maintenance of the facilities.

6.4.2 Office Building

The Office Building is an original facility structure separate from the operational buildings. Available records indicate that this building has been utilized for administrative purposes exclusively.

6.4.3 Warehouse Building

The Warehouse Building has been renovated several times including a major renovation between 1958 and 1964. Available information indicates that area was once used for maintenance, but has been the central location for the warehousing of finished products.

6.4.4 Crusher and Crusher Addition Buildings

The structures currently identified as the Crusher Building and the Crusher Addition Building were rebuilt after thorium-magnesium alloy processing had ceased at the facility. These structures were used for the aluminum smelting operations exclusively.

6.4.5 North Extrusion Building

The North Extrusion Building was not at any time part of the magnesium refining process. The building was constructed circa 1961 and used for anode extrusion and storage of pure magnesium billets.

6.5 Potential Contaminated Media

Potential contaminated media within the former operational area of the facility includes the following:

- shallow subsurface materials located beneath existing concrete paved areas;
- shallow subsurface materials located beneath current building footprints; and
- structural surfaces of the Flux Building.

7.0 Conclusions

Two separate conceptual models were developed for the initial classification of the former operational area, one for the land areas, and the one for current structures. Land areas were classified using the following criteria:

- Land area usage related to magnesium-thorium alloy processing.
- Potential for residual radioactive material to have been covered by building expansion.
- Potential for residual radioactive material to have been covered by concrete paving events conducted post-1958.

The areas identified through these screening methods are illustrated in Figure 8. The impacted land areas are as follows:

- Areas covered by concrete post-1958
- Area beneath the former Smelting Building No. 5
- Area beneath the Crusher Addition Building
- Area beneath the Crusher Building
- Area beneath the North Extrusion Building
- Area beneath the Warehouse Building
- Area beneath the Maintenance Building

The second conceptual model focused on the current structures within the former operational area. These structures were screened using the following criteria:

- Historical building usage related to magnesium-thorium alloy processing
- Current building usage related to radioactive materials management.

The structures identified through these screening methods are illustrated in Figure 9. None of the current site structures located within the former operational area were involved with the reprocessing of magnesium-thorium alloy. The Flux Building was classified as impacted due to the utilization of the building as a sample storage and packing facility during characterization events and the ALRP.

8.0 References

1. Earth Sciences, June 2001, Decommissioning Plan, Tulsa Facility, Tulsa, Oklahoma, Kaiser Aluminum and Chemical Corporation, Baton Rouge, Louisiana.

2. Earth Sciences, October 2001, Additional Site Characterization Activities, Former Kaiser Aluminum Specialty Products Facility, Tulsa, Oklahoma, Kaiser Aluminum & Chemical Corporation, Baton Rouge, Louisiana.

3. NUREG/CR-1575, August 2000, MARSSIM, Rev. 1.

4. Earth Sciences, July 2001, ALRP, Final Status Survey Report, Tulsa, Oklahoma Facility, Kaiser Aluminum & Chemical Corporation, Baton Rouge, Louisiana.

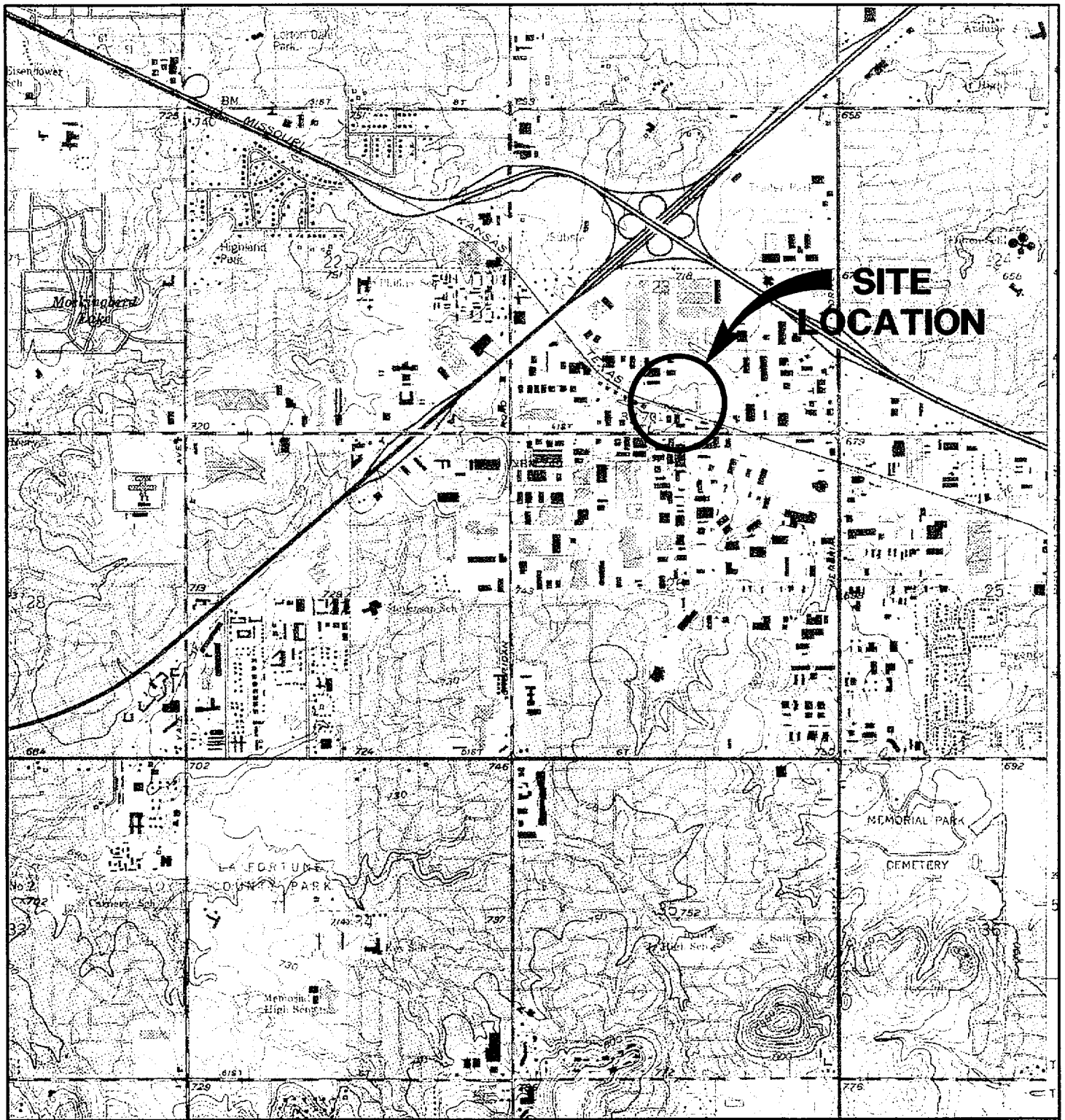
5. Federal Registry.

6. Roberts/Schornick and Associates, Inc., 1996, Local and Regional Environmental Data Report.

7. A&M Engineering, 1999, Historical Hydrological Impacts Shown on Aerial Photographs.

w:\5427K\rpt\HSAreport\Hist1.doc

Figures



SCALE – FEET

0 2000

N

FIGURE 1
SITE LOCATION MAP
FORMER KAISER ALUMINUM SPECIALTY PRODUCTS FACILITY TULSA, OKLAHOMA

PREPARED FOR

KAISER ALUMINUM & CHEMICAL CORPORATION
BATON ROUGE, LOUISIANA

APPROVED	11/2/01
CHECKED	11/2/01
DRAWN	GVA 10/1/01
DRAWING NUMBER	5427039

Earth Sciences Consultants, Inc.

REFERENCE
USGS 7.5-MIN TOPOGRAPHIC QUADRANGLE
JENKS, OKLAHOMA
DATED 1952, PHOTOREVISED 1982

THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

THAT CAN BE VIEWED AT THE RECORD TITLED:

DRAWING NO. 5427A442, "FIGURE 2 FORMER OPERATIONAL AREA FORMER KAISER ALUMINUM SPECIALTY PRODUCTS FACILITY TULSA, OKLAHOMA"

WITHIN THIS PACKAGE... OR BY SEARCHING USING THE DOCUMENT/REPORT NUMBER 5427A442

- **NOTE: Because of these page's large file size, it may be more convenient to copy the file to a local drive and use the Imaging (Wang) viewer, which can be accessed from the Programs/Accessories menu.**

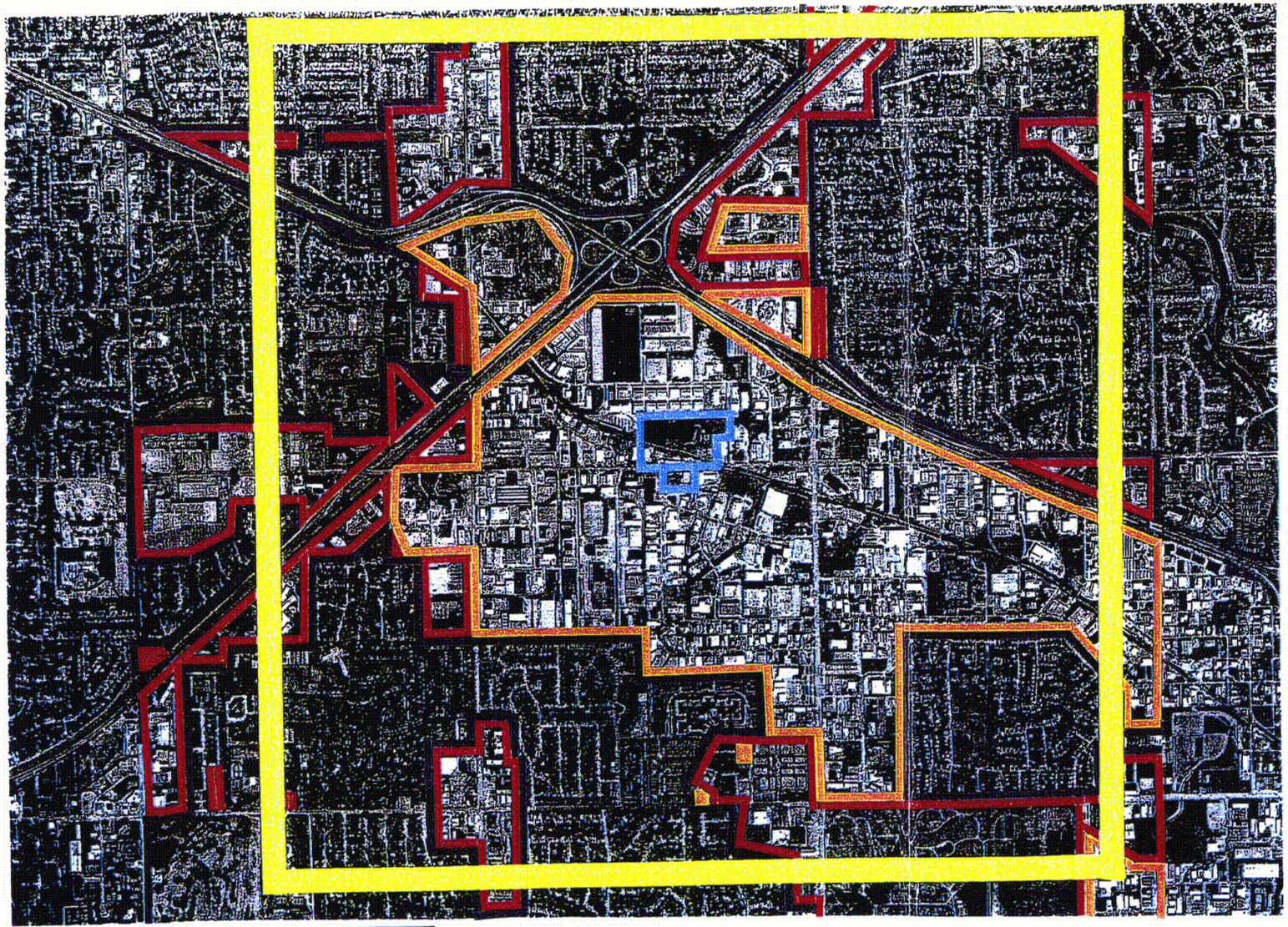
THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

THAT CAN BE VIEWED AT THE RECORD TITLED:

DRAWING NO. 5427A434, "FIGURE 3 SITE MAP FORMER KAISER ALUMINUM SPECIALTY PRODUCTS FACILITY TULSA, OKLAHOMA"

WITHIN THIS PACKAGE... OR BY SEARCHING USING THE DOCUMENT/REPORT NUMBER 5427A434

NOTE: Because of these page's large file size, it may be more convenient to copy the file to a local drive and use the Imaging (Wang) viewer, which can be accessed from the Programs/Accessories menu.



LEGEND:

- RESIDENTIAL LAND USE
- INDUSTRIAL LAND USE
- COMMERCIAL LAND USE
- AREA BOUNDARY (ENCOMPASSES 2 KM RADIUS)
- FACILITY BOUNDARY

N

AERIAL DATA SERVICE, INC. ADS
10822 EAST NEWTON PLACE • TULSA, OKLAHOMA 74116 • 918-437-8453

C01

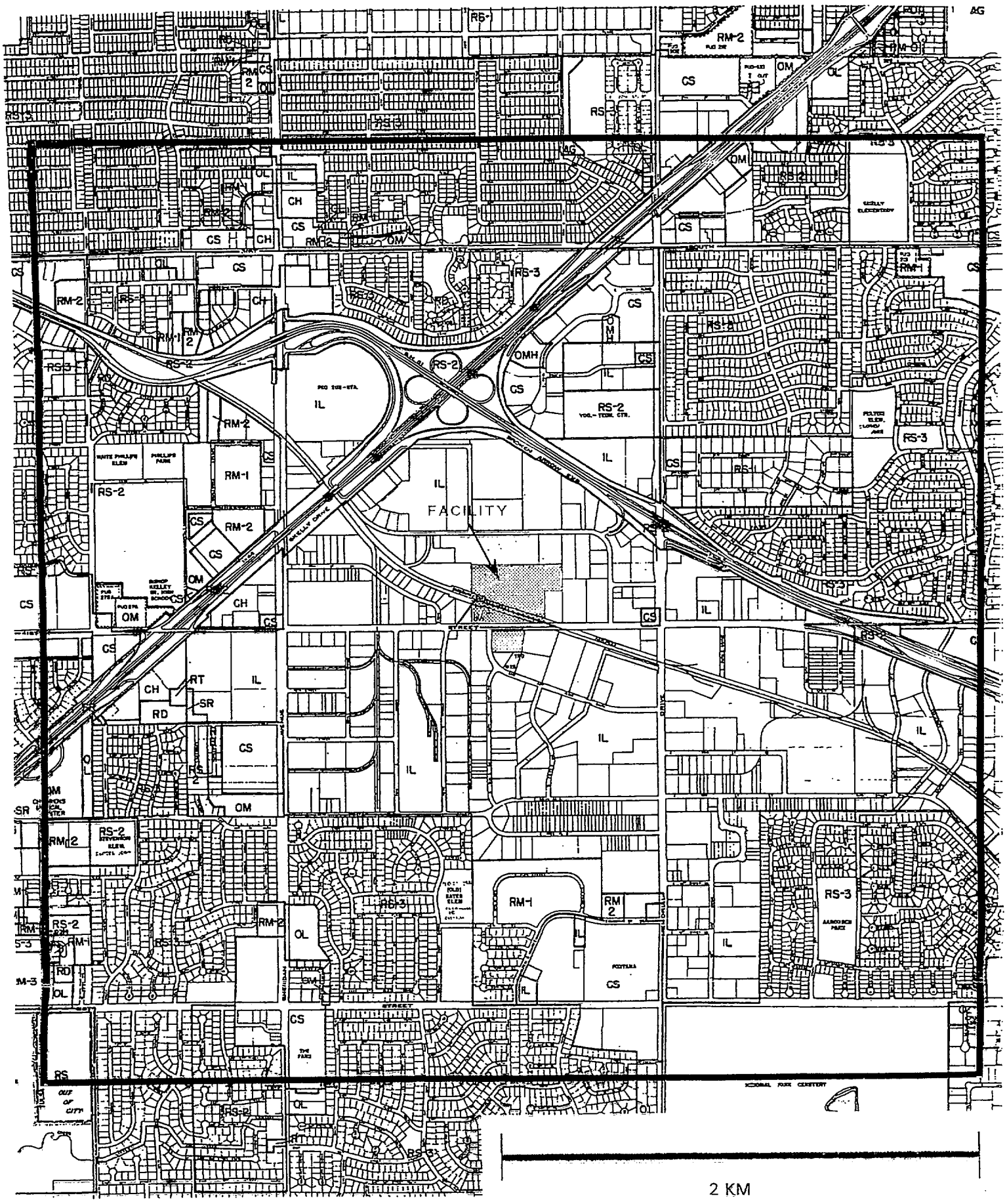
FIGURE 4

PHOTOGRAPH TAKEN NOVEMBER 15, 1992

Client:	KAISER ALUMINUM EXTRUDED PRODUCTS	Figure Title:	LAND USE WITHIN THE AREA, 1995
Location:	7311 EAST 41ST STREET TULSA, OKLAHOMA	Document Title:	LOCAL AND REGIONAL ENVIRONMENTAL DATA REPORT

ROBERTS/SCHORNICK & ASSOCIATES, INC.
Environmental Consultants
5314 South Yale, Suite 1100
Tulsa, Oklahoma 74135
(918) 496-0069

DATE: 11/1/95		PREPARED BY:	KE
SCALE: 1" = 2000'		CHECKED BY:	KE
		DRAFTED BY:	GS
PROJECT NO: 9515901 F02		FIGURE NO.:	10



TULSA/TULSA COUNTY ZONING CLASSIFICATIONS

AG	AGRICULTURE GENERAL DISTRICT
AG-R	AGRICULTURE-RESIDENTIAL SINGLE-FAMILY, RURAL DEVELOPMENT
RE	RESIDENTIAL SINGLE-FAMILY, ESTATE DISTRICT
RS	RESIDENTIAL SINGLE-FAMILY DISTRICT
RS-1	RESIDENTIAL SINGLE-FAMILY LOW DENSITY DISTRICT
RS-2	RESIDENTIAL SINGLE-FAMILY MEDIUM DENSITY DISTRICT
RS-3	RESIDENTIAL SINGLE-FAMILY HIGH DENSITY DISTRICT
RS-4	RESIDENTIAL SINGLE-FAMILY HIGHEST DENSITY DISTRICT
RD	RESIDENTIAL DUPLEX DISTRICT
RT/ RM-T	RESIDENTIAL TOWNHOUSE DISTRICT
RM-0	RESIDENTIAL MULTIFAMILY LOWEST DENSITY DISTRICT
RM-1	RESIDENTIAL MULTIFAMILY LOW DENSITY DISTRICT
RM-2	RESIDENTIAL MULTIFAMILY MEDIUM DENSITY DISTRICT
RM-3	RESIDENTIAL MULTIFAMILY HIGH DENSITY DISTRICT
RMH	RESIDENTIAL MANUFACTURED HOME DISTRICT
P/PK	PARKING DISTRICT
OL	OFFICE LOW INTENSITY DISTRICT
OM	OFFICE MEDIUM INTENSITY DISTRICT
OMH	OFFICE MEDIUM-HIGH INTENSITY DISTRICT
OH	OFFICE HIGH INTENSITY DISTRICT
CS	COMMERCIAL SHOPPING CENTER DISTRICT
CG	COMMERCIAL GENERAL DISTRICT
CH	COMMERCIAL HIGH INTENSITY DISTRICT
CBD	CENTRAL BUSINESS DISTRICT
CO	CORRIDOR DISTRICT
SR	SCIENTIFIC RESEARCH AND DEVELOPMENT DISTRICT
IL	INDUSTRIAL LIGHT DISTRICT
IM	INDUSTRIAL MODERATE DISTRICT
IH	INDUSTRIAL HEAVY DISTRICT
IR	INDUSTRIAL RESEARCH AND DEVELOPMENT DISTRICT
FD	FLOODWAY DISTRICT
PUD	PLANNED UNIT DEVELOPMENT (SUPPLEMENTAL ZONING DISTRICT)
HP	HISTORIC PRESERVATION (SUPPLEMENTAL ZONING DISTRICT)

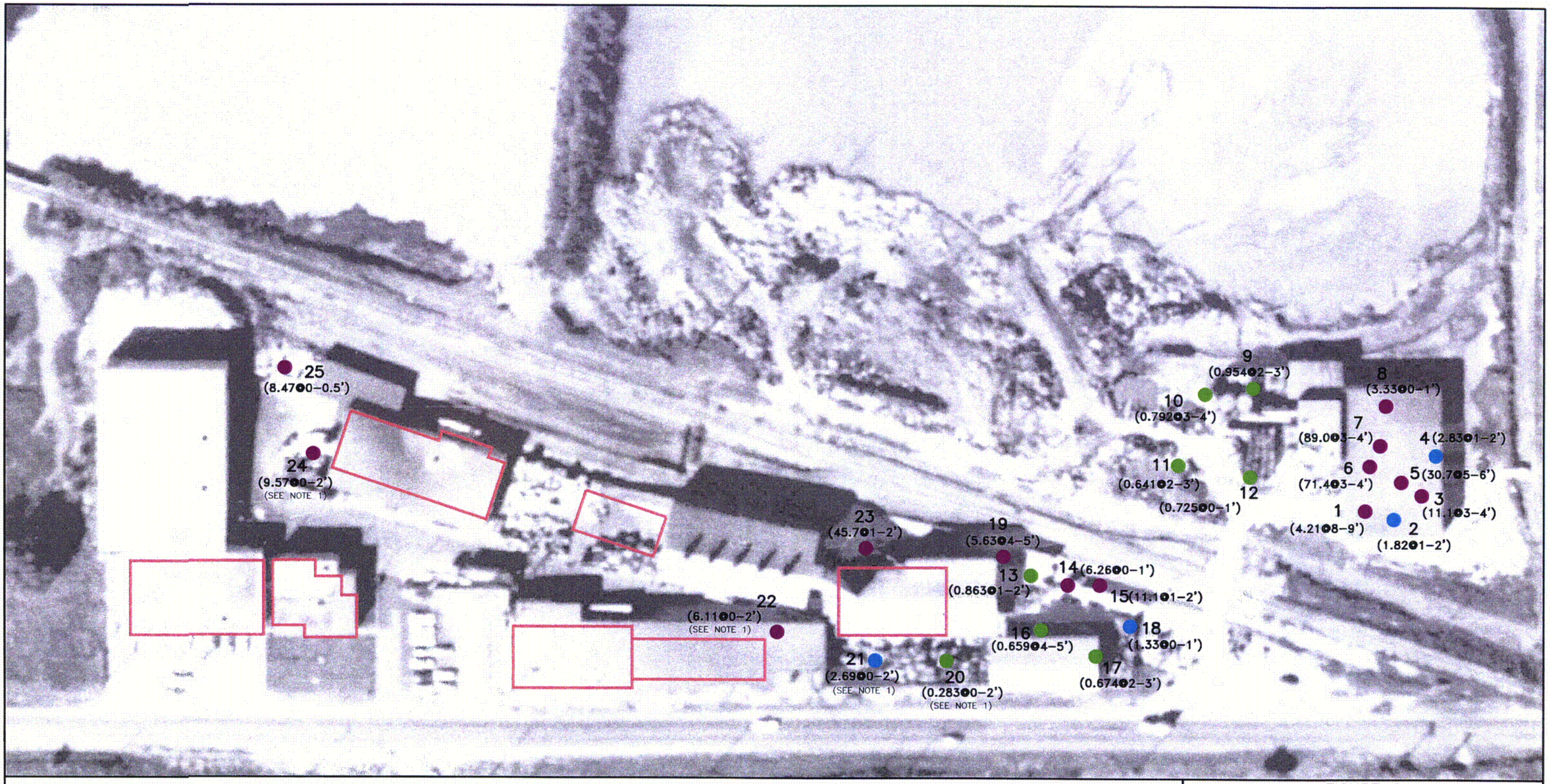
FIGURE 5

SOURCE: INDIAN NATIONS COUNCIL OF GOVERNMENTS, 07/92

Client:	KAISER ALUMINUM EXTRUDED PRODUCTS	Figure Title:	COMPREHENSIVE ZONING, CITY OF TULSA
Location:	7311 EAST 41ST STREET TULSA, OKLAHOMA	Document Title:	LOCAL AND REGIONAL ENVIRONMENTAL DATA REPORT

ROBERTS/SCHORNICK & ASSOCIATES, INC.
Environmental Consultants
6314 South Yale, Suite 1100
Tulsa, Oklahoma 74136
(918) 496-0059

DATE: 11/1/95		PREPARED BY: KE	
SCALE: 1" = 1760'		CHECKED BY: KE	
		DRAFTED BY: GS	
PROJECT NO: 9515901 F02		FIGURE NO.: 11	



LEGEND

- 1958 BUILDING FOOTPRINT
- SAMPLE POINT WITH Th–232 ACTIVITY CONCENTRATION ≤ ESTABLISHED SITE BACKGROUND OF 1.1 pCi/g TH–232
- SAMPLE POINT WITH Th–232 ACTIVITY CONCENTRATION > BACKGROUND OR <3.0 pCi/g
- SAMPLE POINT WITH Th–232 ACTIVITY CONCENTRATION ≥ 3.0 pCi/g

(2.33●0–1') TH–232 CONCENTRATION (pCi/g) AT SAMPLE DEPTH (FEET)

N

SCALE – FEET

0 80

FIGURE 6
CHANGES TO BUILDINGS BETWEEN 1958 AND 1964
FORMER KAISER ALUMINUM SPECIALTY PRODUCTS FACILITY
TULSA, OKLAHOMA

PREPARED FOR

KAISER ALUMINUM & CHEMICAL CORPORATION
BATON ROUGE, LOUISIANA

APPROVED	RFD 2/01
CHECKED	AJL 12/01
DRAWN	GJA 10/18/01
DRAWING NUMBER	5427A253

C02

Earth Sciences Consultants, Inc.

1958 AERIAL PHOTOGRAPH

1964 AERIAL PHOTOGRAPH

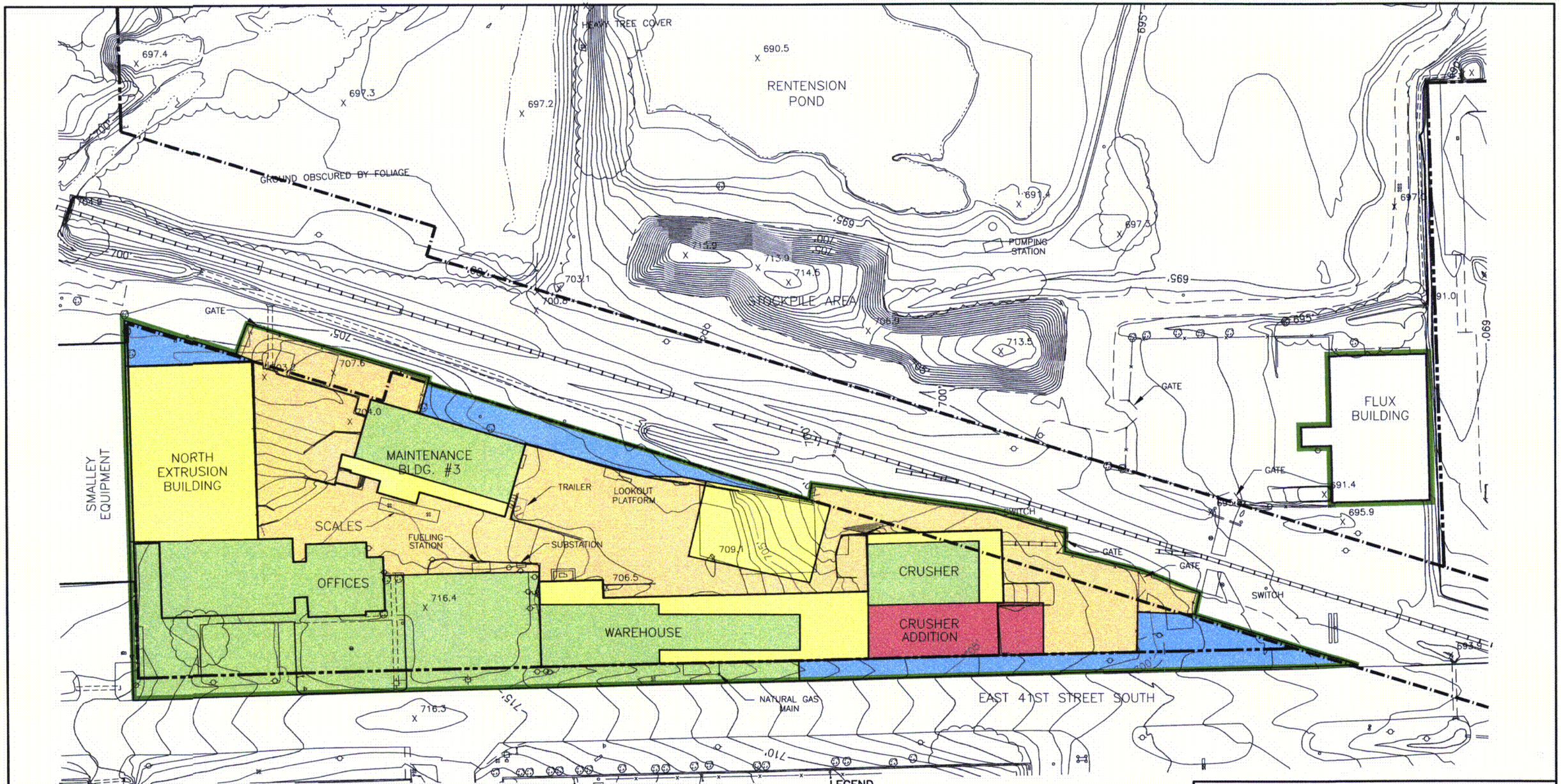
N

FIGURE 7
AERIAL COMPARISON OF N. EXTRUSION BUILDING AREA 1958 AND 1964
FORMER KAISER ALUMINUM SPECIALTY PRODUCTS FACILITY
TULSA, OKLAHOMA

PREPARED FOR
KAISER ALUMINUM & CHEMICAL CORPORATION
BATON ROUGE, LOUISIANA

APPROVED	RFO 12/07
CHECKED	ASL 12/01
DRAWN	GJA 10/26/01
DRAWING NUMBER	5427A259

Earth Sciences Consultants, Inc.



N

SCALE – FEET

0 80

LEGEND

- FORMER OPERATIONAL AREA
- APPROXIMATE PROPERTY LINE
- APPROXIMATE RIGHT–OF–WAY
- AREAS REMEDIATED DURING ALRP
- NON–IMPACTED AREAS
- POTENTIALLY IMPACTED AREAS DUE TO HISTORICAL PLANT OPERATIONS
- POTENTIALLY IMPACTED AREAS DUE TO BUILDING RENOVATION BETWEEN 1958–1964
- POTENTIALLY IMPACTED AREAS DUE TO CONCRETE PAVING POST 1958

REFERENCES

1. DIGITAL MAPPING ASSOCIATES, INC.; AUG. 16, 2001
2. THE RIGHT–OF–WAY AND PROPERTY LINES WERE OBTAINED FROM A PLAT PREPARED BY DENTON AND WHITE SURVEYING COMPANY ON FEBRUARY 14, 1964.

FIGURE 8
CONCEPTUAL MODEL OF LAND AREAS
FORMER KAISER ALUMINUM SPECIALTY PRODUCTS FACILITY
TULSA, OKLAHOMA

PREPARED FOR

KAISER ALUMINUM & CHEMICAL CORPORATION
BATON ROUGE, LOUISIANA

APPROVED	RFD 12/01
CHECKED	JSB 12/01
DRAWN	GJA 12/3/01

DRAWING NUMBER

5427275

C03

Earth Sciences Consultants, Inc.

REFERENCES

1. DIGITAL MAPPING ASSOCIATES, INC.; AUG. 16, 2001
2. THE RIGHT–OF–WAY AND PROPERTY LINES WERE OBTAINED FROM A PLAT PREPARED BY DENTON AND WHITE SURVEYING COMPANY ON FEBRUARY 14, 1964.

LEGEND

- FORMER OPERATIONAL AREA
- APPROXIMATE PROPERTY LINE
- APPROXIMATE RIGHT–OF–WAY
- NON–IMPACTED STRUCTURES
- STRUCTURE IMPACTED DUE TO CURRENT SITE ACTIVITIES

FIGURE 9
CONCEPTUAL MODEL OF STRUCTURES
FORMER KAISER ALUMINUM
SPECIALTY PRODUCTS FACILITY
TULSA, OKLAHOMA

PREPARED FOR
KAISER ALUMINUM & CHEMICAL CORPORATION
BATON ROUGE, LOUISIANA

APPROVED	RHD 12/01
CHECKED	ASL 12/01
DRAWN	GJA 12/3/01

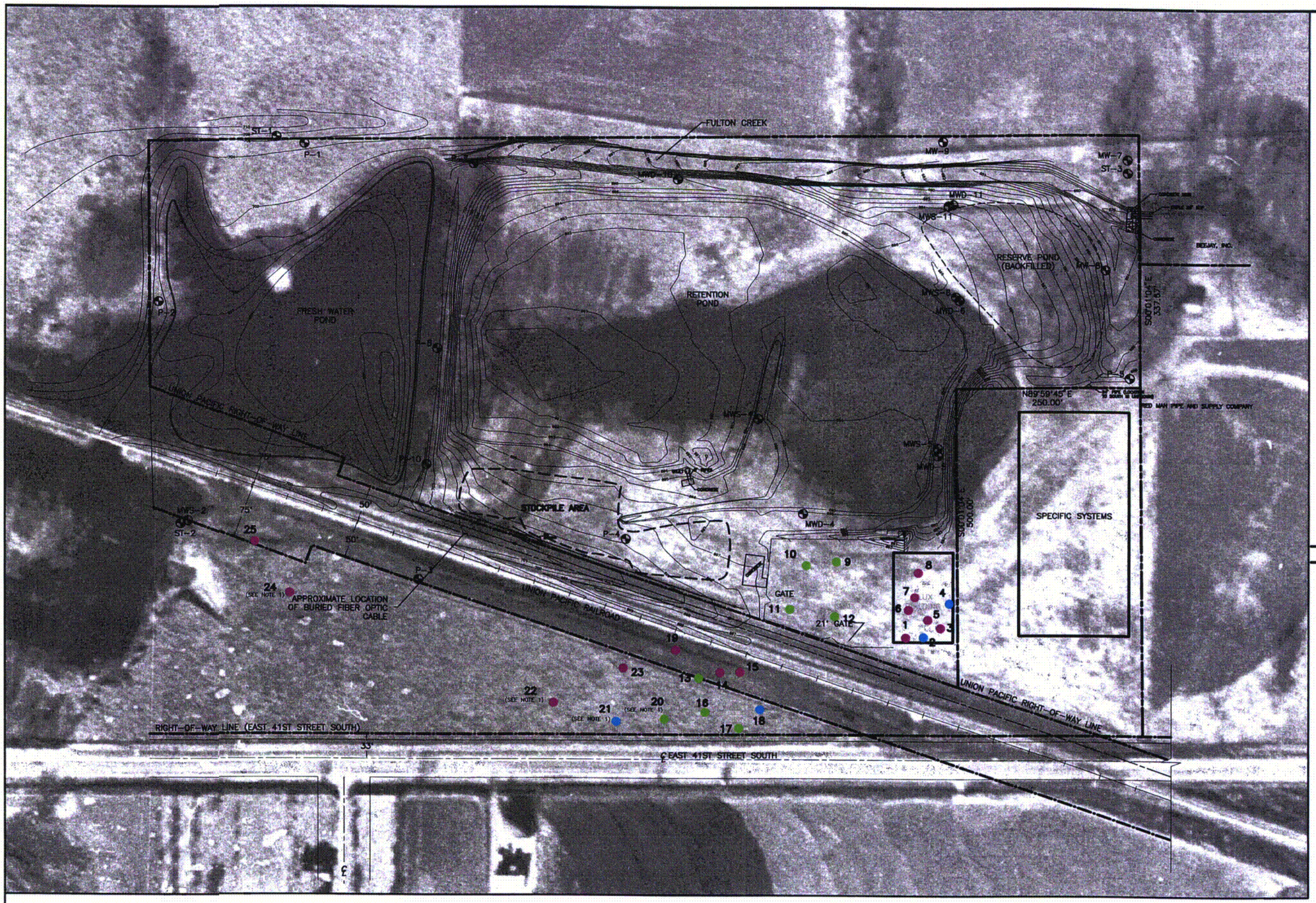
DRAWING NUMBER
5427276

C04

Earth Sciences Consultants, Inc.

Appendix A

Aerial Photograph Progression
(1950 to Present)



N

NOTE

1. CORING OF AREA WAS LIMITED DUE TO CONCRETE OR SIMILAR MATERIAL AT DEPTH.

LEGEND

RCP REINFORCED CONCRETE PIPE

OVERHEAD UTILITIES

POWER POLE

MONITORING WELL

FENCE LINE

PROPERTY LINE

RIGHT-OF-WAY

SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≤ ESTABLISHED SITE BACKGROUND OF 1.1 pCi/g TH-232

SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION > BACKGROUND OR <3.0 pCi/g

SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≥ 3.0 pCi/g

REFERENCES

1. THE RIGHT-OF-WAY AND PROPERTY LINES WERE OBTAINED FROM PLAT OF SURVEY PREPARED BY DENTON & WHITE SURVEYING COMPANY SEALED ON FEBRUARY 14, 1984.
2. TOPOGRAPHIC INFORMATION WAS OBTAINED FROM TOPOGRAPHIC SURVEY OF PART OF THE SE/4 OF SECTION 23 TOWNSHIP 19 NORTH RANGE 13 EAST, OF THE I.B. & M., TULSA COUNTY, STATE OF OKLAHOMA, ACCORDING TO THE U.S. GOVERNMENT SURVEY THEREOF, AND KNOWN AS 7311 EAST 41st STREET SOUTH. (FILE: NFSK003.DWG REV. A)
3. 1950 AERIAL PHOTOGRAPH USED TO ALIGN CULTURAL FEATURES WITH KAISER PROPERTY LINES.
4. THE STOCKPILE AREA WAS OBTAINED FROM A TOPOGRAPHICAL SURVEY BY DIGITAL MAPPING ASSOCIATES, INC.; AUG. 16, 2001

C05

SCALE - FEET

0 60 120 180

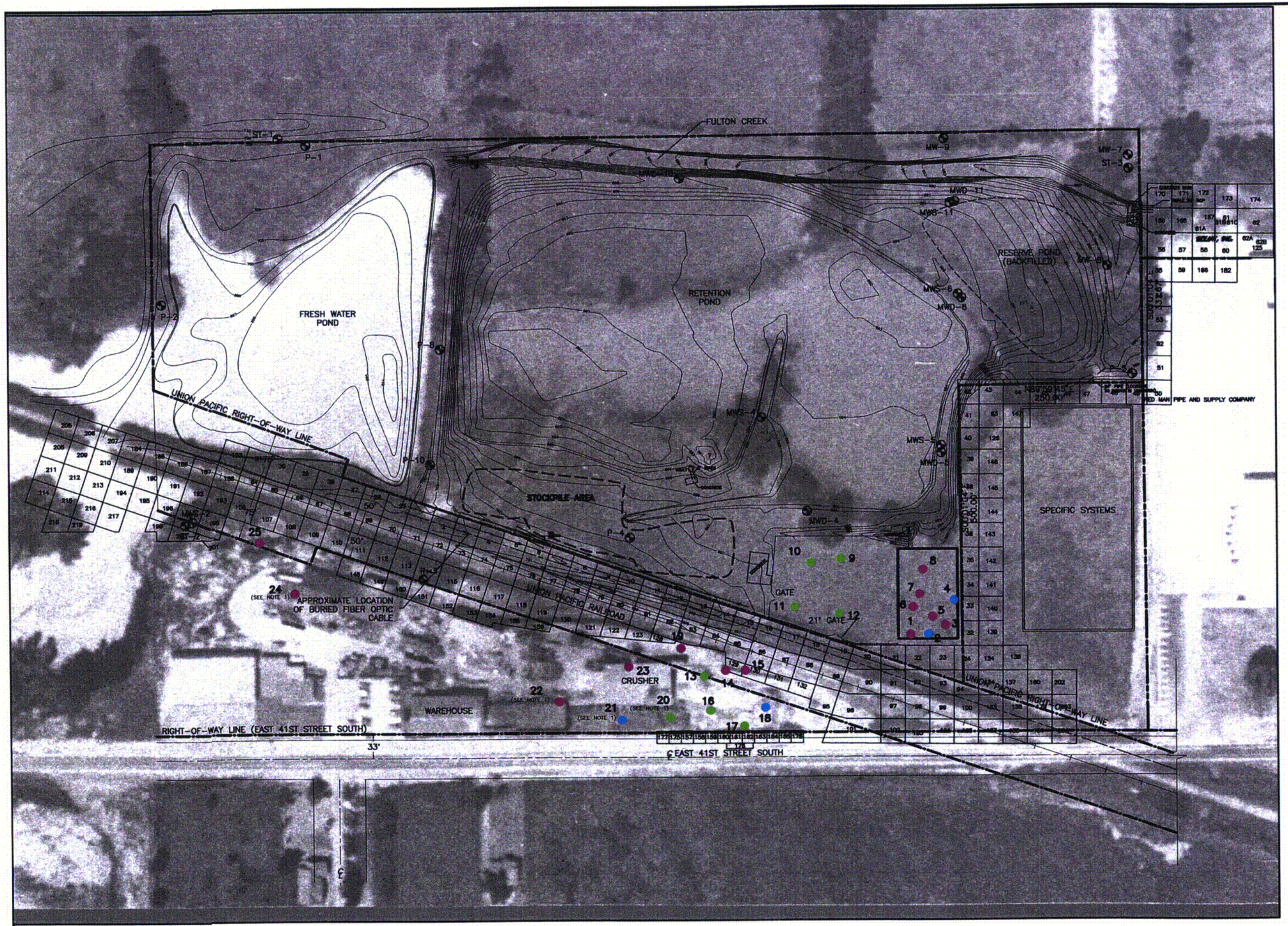
REVISION	DATE	DESCRIPTION

FIGURE A-1
PHOTO PROGRESSION DATE 12/28/50
ADDITIONAL SITE CHARACTERIZATION
FORMER KAISER ALUMINUM
SPECIALTY PRODUCTS FACILITY
TULSA, OKLAHOMA

PREPARED FOR
KAISER ALUMINUM & CHEMICAL CORPORATION
BATON ROUGE, LOUISIANA

APPROVED	KJD 1/31
CHECKED	DSS 1/31/01
DRAWN	GJA 1/31/01
DRAWING NUMBER	5427A426

Earth Sciences Consultants, Inc.



N

NOTE

1. CORING OF AREA WAS LIMITED DUE TO CONCRETE OR SIMILAR MATERIAL AT DEPTH.

LEGEND

- RCP REINFORCED CONCRETE PIPE
- OVERHEAD UTILITIES
- POWER POLE
- MONITORING WELL
- FENCE LINE
- PROPERTY LINE
- RIGHT-OF-WAY
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≤ ESTABLISHED SITE BACKGROUND OF 1.1 pCi/g TH-232
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION > BACKGROUND OR <3.0 pCi/g
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≥ 3.0 pCi/g

REFERENCES

1. THE RIGHT-OF-WAY AND PROPERTY LINES WERE OBTAINED FROM PLAT OF SURVEY PREPARED BY DENTON & WHITE SURVEYING COMPANY SEALED ON FEBRUARY 14, 1964.
2. TOPOGRAPHIC INFORMATION WAS OBTAINED FROM TOPOGRAPHIC SURVEY OF PART OF THE SE/4 OF SECTION 23 TOWNSHIP 19 NORTH RANGE 13 EAST, OF THE I.B. & M. TULSA COUNTY, STATE OF OKLAHOMA, ACCORDING TO THE U.S. GOVERNMENT SURVEY THEREOF, AND KNOWN AS 7311 EAST 41st STREET SOUTH. (FILE: NFSK003.DWG REV. A)
3. 1958 AERIAL PHOTOGRAPH USED TO ALIGN CULTURAL FEATURES WITH KAISER PROPERTY LINES.
4. THE STOCKPILE AREA WAS OBTAINED FROM A TOPOGRAPHICAL SURVEY BY DIGITAL MAPPING ASSOCIATES, INC.; AUG. 16, 2001

C06

SCALE – FEET
0 60 120 180

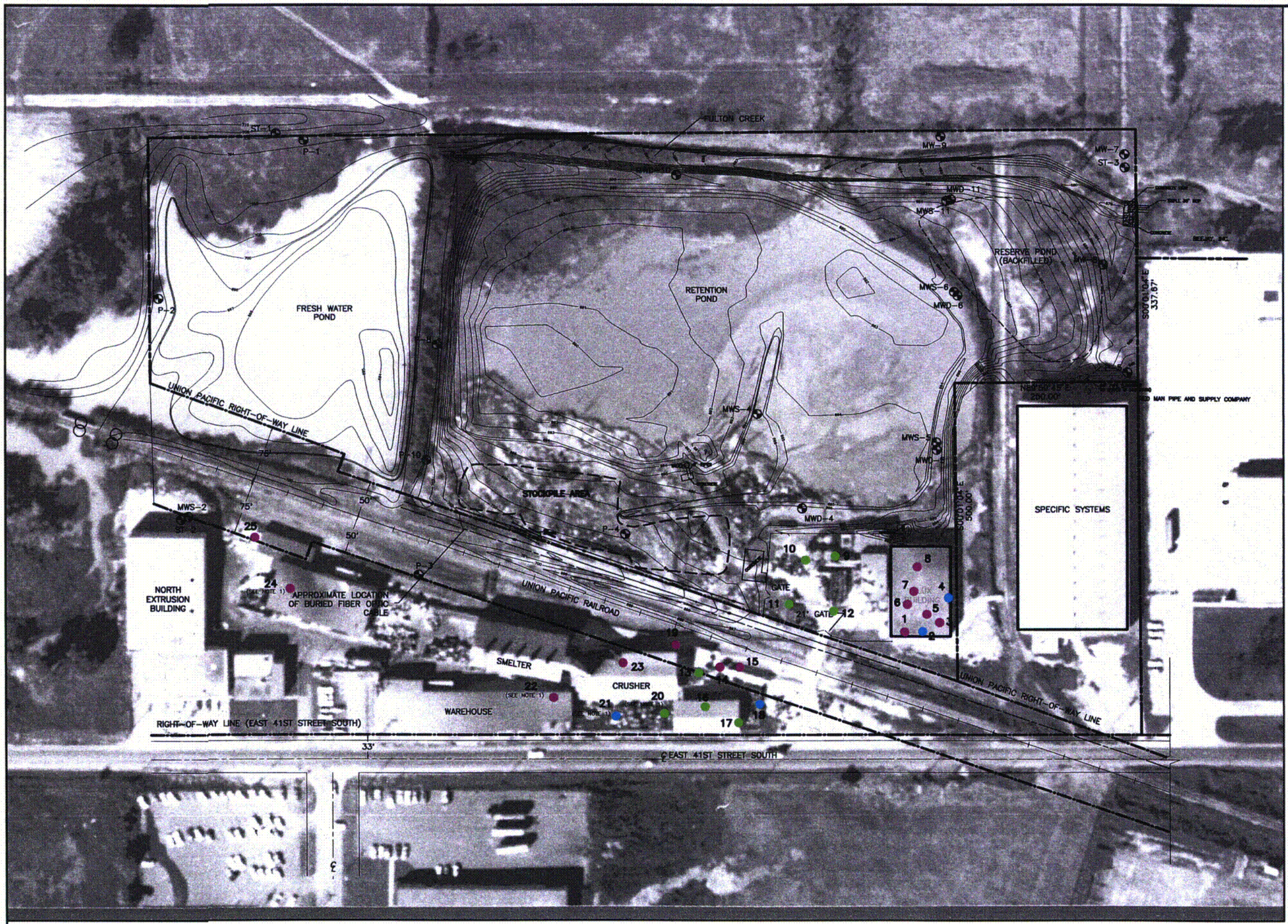
REVISION	DATE	DESCRIPTION

FIGURE A-2
PHOTO PROGRESSION DATE 7/23/58
ADDITIONAL SITE CHARACTERIZATION
FORMER KAISER ALUMINUM
SPECIALTY PRODUCTS FACILITY
TULSA, OKLAHOMA

PREPARED FOR
KAISER ALUMINUM & CHEMICAL CORPORATION
BATON ROUGE, LOUISIANA

APPROVED	BBD 12/18
CHECKED	ASL 12/01
DRAWN	GJH 7/31/01
DRAWING NUMBER	5427A430

Earth Sciences Consultants, Inc.



N

NOTE

1. CORING OF AREA WAS LIMITED DUE TO CONCRETE OR SIMILAR MATERIAL AT DEPTH.

LEGEND

- RCP REINFORCED CONCRETE PIPE
- OVERHEAD UTILITIES
- POWER POLE
- MONITORING WELL
- FENCE LINE
- PROPERTY LINE
- RIGHT-OF-WAY
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≤ ESTABLISHED SITE BACKGROUND OF 1.1 pCi/g TH-232
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION > BACKGROUND OR <3.0 pCi/g
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≥ 3.0 pCi/g

REFERENCES

1. THE RIGHT-OF-WAY AND PROPERTY LINES WERE OBTAINED FROM PLAT OF SURVEY PREPARED BY DENTON & WHITE SURVEYING COMPANY SEALED ON FEBRUARY 14, 1964.
2. TOPOGRAPHIC INFORMATION WAS OBTAINED FROM TOPOGRAPHIC SURVEY OF PART OF THE SE/4 OF SECTION 23 TOWNSHIP 19 NORTH RANGE 13 EAST, OF THE I.B. & M., TULSA COUNTY, STATE OF OKLAHOMA, ACCORDING TO THE U.S. GOVERNMENT SURVEY THEREOF, AND KNOWN AS 7311 EAST 41st STREET SOUTH. (FILE: NFSK003.DWG REV. A)
3. 1964 AERIAL PHOTOGRAPH USED TO ALIGN CULTURAL FEATURES WITH KAISER PROPERTY LINES.
4. THE STOCKPILE AREA WAS OBTAINED FROM A TOPOGRAPHICAL SURVEY BY DIGITAL MAPPING ASSOCIATES, INC.; AUG. 16, 2001

C07

SCALE - FEET
0 60 120 180

REVISION	DATE	DESCRIPTION

FIGURE A-3
PHOTO PROGRESSION DATE 10/08/84
ADDITIONAL SITE CHARACTERIZATION
FORMER KAISER ALUMINUM
SPECIALTY PRODUCTS FACILITY
TULSA, OKLAHOMA

PREPARED FOR
KAISER ALUMINUM & CHEMICAL CORPORATION
BATON ROUGE, LOUISIANA

APPROVED	RJO 12/01
CHECKED	AM 12/01
DRAWN	GJA 7/31/01
DRAWING NUMBER	5427A427

Earth Sciences Consultants, Inc.

NOTE

1. CORING OF AREA WAS LIMITED DUE TO CONCRETE OR SIMILAR MATERIAL AT DEPTH.

LEGEND

- RCP REINFORCED CONCRETE PIPE
- OVERHEAD UTILITIES
- POWER POLE
- MONITORING WELL
- FENCE LINE
- PROPERTY LINE
- RIGHT-OF-WAY
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≤ ESTABLISHED SITE BACKGROUND OF 1.1 pCi/g TH-232
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION > BACKGROUND OR <3.0 pCi/g
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≥ 3.0 pCi/g

C08

SCALE – FEET
0 60 120 180

REFERENCES

1. THE RIGHT-OF-WAY AND PROPERTY LINES WERE OBTAINED FROM PLAT OF SURVEY PREPARED BY DENTON & WHITE SURVEYING COMPANY SEALED ON FEBRUARY 14, 1964.
2. TOPOGRAPHIC INFORMATION WAS OBTAINED FROM TOPOGRAPHIC SURVEY OF PART OF THE SE/4 OF SECTION 23 TOWNSHIP 19 NORTH RANGE 13 EAST, OF THE I.B. & M., TULSA COUNTY, STATE OF OKLAHOMA, ACCORDING TO THE U.S. GOVERNMENT SURVEY THEREOF, AND KNOWN AS 7311 EAST 41st STREET SOUTH. (FILE: WF5X0X03.DWG REV. A)
3. 1972 AERIAL PHOTOGRAPH USED TO ALIGN CULTURAL FEATURES WITH KAISER PROPERTY LINES.
4. THE STOCKPILE AREA WAS OBTAINED FROM A TOPOGRAPHICAL SURVEY BY DIGITAL MAPPING ASSOCIATES, INC.; AUG. 16, 2001

REVISION	DATE	DESCRIPTION

FIGURE A-4
PHOTO PROGRESSION DATE 1/28/65
ADDITIONAL SITE CHARACTERIZATION
FORMER KAISER ALUMINUM
SPECIALTY PRODUCTS FACILITY
TULSA, OKLAHOMA

PREPARED FOR
KAISER ALUMINUM & CHEMICAL CORPORATION
BATON ROUGE, LOUISIANA

APPROVED	RED 5/21
CHECKED	ASL 12/21
DRAWN	GM 6/24/01
DRAWING NUMBER	5427A435

Earth Sciences Consultants, Inc.

NOTE

1. CORING OF AREA WAS LIMITED DUE TO CONCRETE OR SIMILAR MATERIAL AT DEPTH.

LEGEND

- RCP REINFORCED CONCRETE PIPE
- OVERHEAD UTILITIES
- POWER POLE
- MONITORING WELL
- FENCE LINE
- PROPERTY LINE
- RIGHT-OF-WAY
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≤ ESTABLISHED SITE BACKGROUND OF 1.1 pCi/g TH-232
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION > BACKGROUND OR <3.0 pCi/g
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≥ 3.0 pCi/g

C09

SCALE - FEET
0 60 120 180

REFERENCES

1. THE RIGHT-OF-WAY AND PROPERTY LINES WERE OBTAINED FROM PLAT OF SURVEY PREPARED BY DENTON & WHITE SURVEYING COMPANY SEALED ON FEBRUARY 14, 1984.
2. TOPOGRAPHIC INFORMATION WAS OBTAINED FROM TOPOGRAPHIC SURVEY OF PART OF THE SE/4 OF SECTION 23 TOWNSHIP 19 NORTH RANGE 13 EAST, OF THE I.B. & M., TULSA COUNTY, STATE OF OKLAHOMA, ACCORDING TO THE U.S. GOVERNMENT SURVEY THEREOF, AND KNOWN AS 7311 EAST 41st STREET SOUTH. (FILE: NFSK003.DWG REV. A)
3. 1967 AERIAL PHOTOGRAPH USED TO ALIGN CULTURAL FEATURES WITH KAISER PROPERTY LINES.
4. THE STOCKPILE AREA WAS OBTAINED FROM A TOPOGRAPHICAL SURVEY BY DIGITAL MAPPING ASSOCIATES, INC.; AUG. 16, 2001

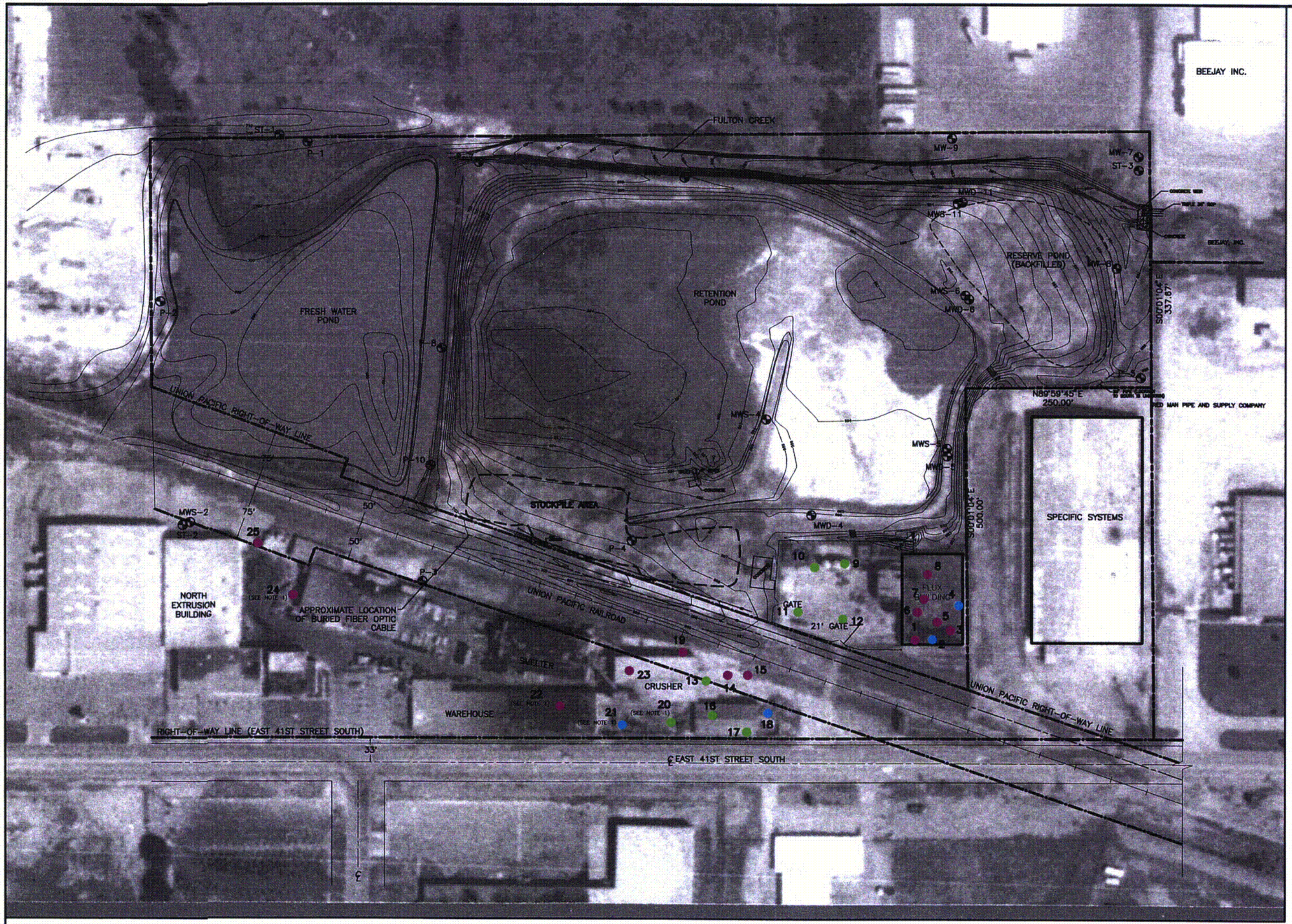
REVISION	DATE	DESCRIPTION

FIGURE A-5
PHOTO PROGRESSION DATE 9/10/67
ADDITIONAL SITE CHARACTERIZATION
FORMER KAISER ALUMINUM
SPECIALTY PRODUCTS FACILITY
TULSA, OKLAHOMA

PREPARED FOR
KAISER ALUMINUM & CHEMICAL CORPORATION
BATON ROUGE, LOUISIANA

APPROVED	RHO 11/01
CHECKED	AJL 11/01
DRAWN	GJH 8/1/01
DRAWING NUMBER	5427A431

Earth Sciences Consultants, Inc.



NOTE

1. CORING OF AREA WAS LIMITED DUE TO CONCRETE OR SIMILAR MATERIAL AT DEPTH.

LEGEND

- RCP REINFORCED CONCRETE PIPE
- OVERHEAD UTILITIES
- POWER POLE
- MONITORING WELL
- FENCE LINE
- PROPERTY LINE
- RIGHT-OF-WAY
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≤ ESTABLISHED SITE BACKGROUND OF 1.1 pCi/g TH-232
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION > BACKGROUND OR <3.0 pCi/g
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≥ 3.0 pCi/g

C10

SCALE – FEET
0 60 120 180

REFERENCES

1. THE RIGHT-OF-WAY AND PROPERTY LINES WERE OBTAINED FROM PLAT OF SURVEY PREPARED BY DENTON & WHITE SURVEYING COMPANY SEALED ON FEBRUARY 14, 1984.
2. TOPOGRAPHIC INFORMATION WAS OBTAINED FROM TOPOGRAPHIC SURVEY OF PART OF THE SE/4 OF SECTION 23 TOWNSHIP 19 NORTH RANGE 13 EAST, OF THE I.B. & M., TULSA COUNTY, STATE OF OKLAHOMA, ACCORDING TO THE U.S. GOVERNMENT SURVEY THEREOF, AND KNOWN AS 7311 EAST 41st STREET SOUTH. (FILE: NFSK003.DWG REV. A)
3. 1972 AERIAL PHOTOGRAPH USED TO ALIGN CULTURAL FEATURES WITH KAISER PROPERTY LINES.
4. THE STOCKPILE AREA WAS OBTAINED FROM A TOPOGRAPHICAL SURVEY BY DIGITAL MAPPING ASSOCIATES, INC.; AUG. 16, 2001

REVISION	DATE	DESCRIPTION

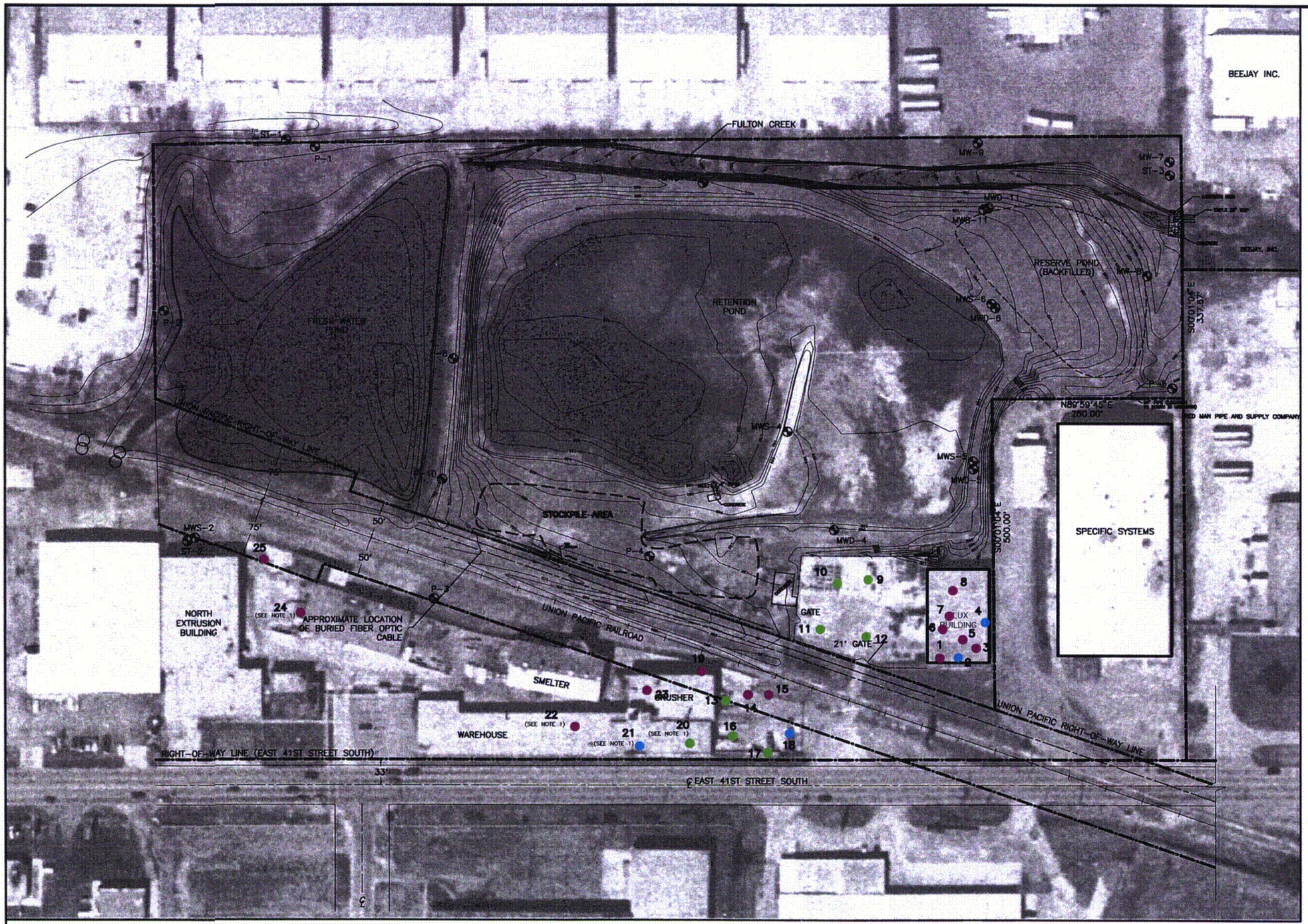
FIGURE A-8
PHOTO PROGRESSION DATE 4/16/72
ADDITIONAL SITE CHARACTERIZATION
FORMER KAISER ALUMINUM
SPECIALTY PRODUCTS FACILITY
TULSA, OKLAHOMA

PREPARED FOR
KAISER ALUMINUM & CHEMICAL CORPORATION
BATON ROUGE, LOUISIANA

APPROVED	RHD 12/7/1
CHECKED	AS 11/7/1
DRAWN	GJH 7/31/01

DRAWING NUMBER
5427A429

Earth Sciences Consultants, Inc.



NOTE

1. CORING OF AREA WAS LIMITED DUE TO CONCRETE OR SIMILAR MATERIAL AT DEPTH.

LEGEND

- RCP REINFORCED CONCRETE PIPE
- OVERHEAD UTILITIES
- POWER POLE
- MONITORING WELL
- FENCE LINE
- PROPERTY LINE
- RIGHT-OF-WAY
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≤ ESTABLISHED SITE BACKGROUND OF 1.1 pCi/g TH-232
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION > BACKGROUND OR <3.0 pCi/g
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≥ 3.0 pCi/g

REFERENCES

1. THE RIGHT-OF-WAY AND PROPERTY LINES WERE OBTAINED FROM PLAT OF SURVEY PREPARED BY DENTON & WHITE SURVEYING COMPANY SEALED ON FEBRUARY 14, 1964.
2. TOPOGRAPHIC INFORMATION WAS OBTAINED FROM TOPOGRAPHIC SURVEY OF PART OF THE SE/4 OF SECTION 23 TOWNSHIP 19 NORTH RANGE 13 EAST, OF THE I.B. & M., TULSA COUNTY, STATE OF OKLAHOMA, ACCORDING TO THE U.S. GOVERNMENT SURVEY THEREOF, AND KNOWN AS 7311 EAST 41st STREET SOUTH. (FILE: NFSK003.DWG REV. A)
3. 1991 AERIAL PHOTOGRAPH USED TO ALIGN CULTURAL FEATURES WITH KAISER PROPERTY LINES.
4. THE STOCKPILE AREA WAS OBTAINED FROM A TOPOGRAPHICAL SURVEY BY DIGITAL MAPPING ASSOCIATES, INC.; AUG. 16, 2001

C11

SCALE – FEET
0 60 120 180

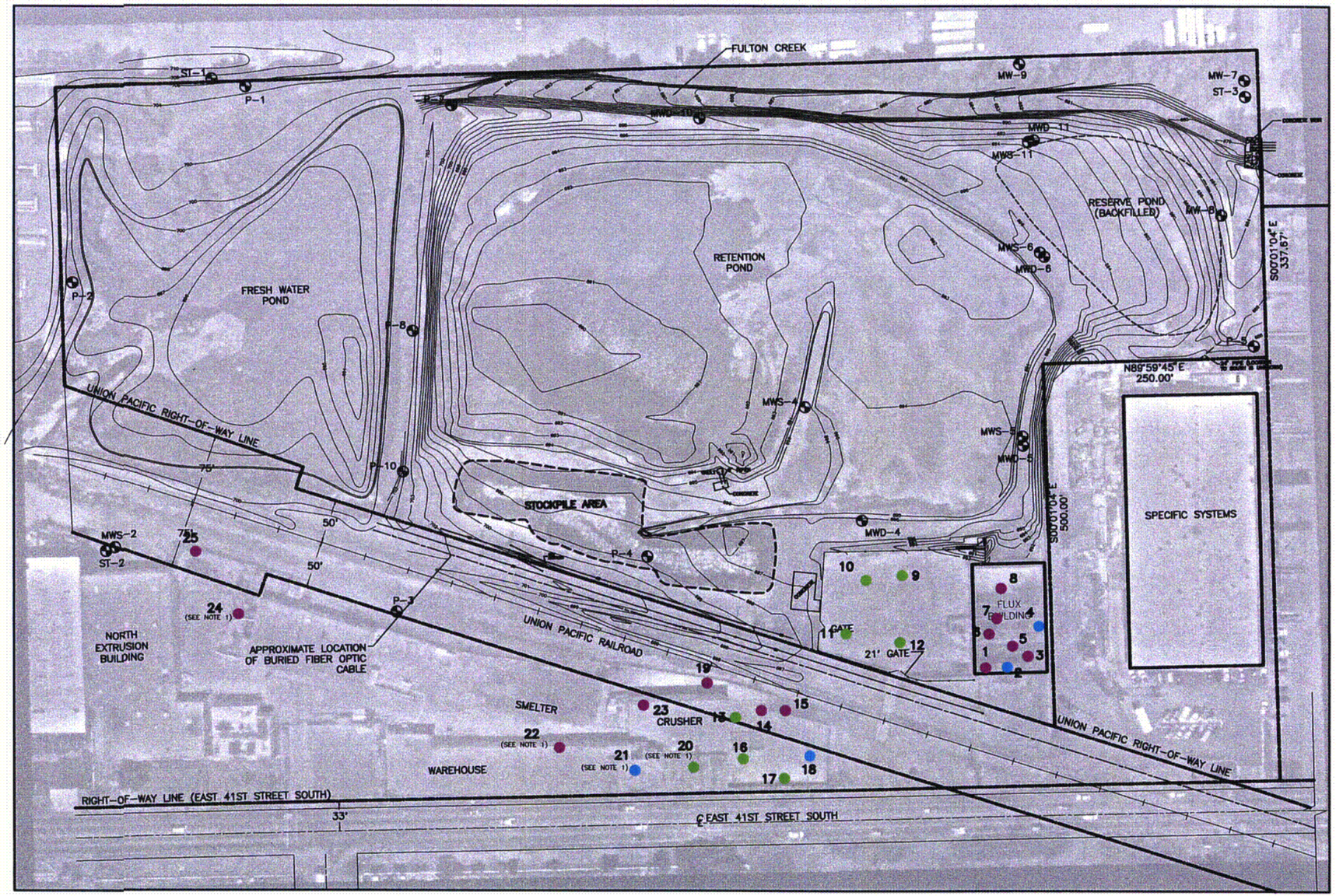
REVISION	DATE	DESCRIPTION

FIGURE A-7
PHOTO PROGRESSION DATE 3/23/91
ADDITIONAL SITE CHARACTERIZATION
FORMER KAISER ALUMINUM
SPECIALTY PRODUCTS FACILITY
TULSA, OKLAHOMA

PREPARED FOR
KAISER ALUMINUM & CHEMICAL CORPORATION
BATON ROUGE, LOUISIANA

APPROVED	[illegible]
CHECKED	[illegible]
DRAWN	GM 7/31/91
DRAWING NUMBER	5427A428

Earth Sciences Consultants, Inc.



N

NOTE

1. CORING OF AREA WAS LIMITED DUE TO CONCRETE OR SIMILAR MATERIAL AT DEPTH.

LEGEND

- RCP — REINFORCED CONCRETE PIPE
- OVERHEAD UTILITIES
- POWER POLE
- MONITORING WELL
- FENCE LINE
- PROPERTY LINE
- RIGHT-OF-WAY

- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≤ ESTABLISHED SITE BACKGROUND OF 1.1 pCi/g TH-232
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION > BACKGROUND OR <3.0 pCi/g
- SAMPLE POINT WITH Th-232 ACTIVITY CONCENTRATION ≥ 3.0 pCi/g

C12

SCALE – FEET
0 60 120 180

REFERENCES

1. THE RIGHT-OF-WAY AND PROPERTY LINES WERE OBTAINED FROM PLAT OF SURVEY PREPARED BY DENTON & WHITE SURVEYING COMPANY SEALED ON FEBRUARY 14, 1964.
2. TOPOGRAPHIC INFORMATION WAS OBTAINED FROM TOPOGRAPHIC SURVEY OF PART OF THE SE/4 OF SECTION 23 TOWNSHIP 19 NORTH RANGE 13 EAST, OF THE I.B. & M., TULSA COUNTY, STATE OF OKLAHOMA, ACCORDING TO THE U.S. GOVERNMENT SURVEY THEREOF, AND KNOWN AS 7311 EAST 41st STREET SOUTH. (FILE: NFSK003.DWG REV. A)
3. 1972 AERIAL PHOTOGRAPH USED TO ALIGN CULTURAL FEATURES WITH KAISER PROPERTY LINES.
4. THE STOCKPILE AREA WAS OBTAINED FROM A TOPOGRAPHICAL SURVEY BY DIGITAL MAPPING ASSOCIATES, INC.; AUG. 16, 2001

REVISION	DATE	DESCRIPTION

FIGURE A-8
PHOTO PROGRESSION DATE 8/16/01
ADDITIONAL SITE CHARACTERIZATION
FORMER KAISER ALUMINUM
SPECIALTY PRODUCTS FACILITY
TULSA, OKLAHOMA

PREPARED FOR
KAISER ALUMINUM & CHEMICAL CORPORATION
BATON ROUGE, LOUISIANA

APPROVED	AP 12/7/1
CHECKED	ASL 12/01
DRAWN	GJH 8/5/01
DRAWING NUMBER	5427A438

Earth Sciences Consultants, Inc.

Appendix B

Measurement of Thorium and Thoron Hazards

17. E. D. Arnold, Radiation Limitations on Recycle of Power Reactor Fuels, *Proc. 2nd Intern. Conf. Peaceful Uses At. Energy, Geneva 1958*, 13: 241 (1958).
18. J. N. P. Lawrence, Health Aspects of Handling Uranium-233 Feed Material, *Proc. 2nd Intern. Conf. Peaceful Uses At. Energy, Geneva 1958*, 23: 330 (1958).
19. A. J. Breslin and W. B. Harris, Use of Thoriated Tungsten Electrodes in Inert Gas Shielded Arc Welding—Investigation of Potential Hazard, *Am. Ind. Hyg. Assoc. Quart.*, 13: 4 (1952).
20. W. L. Sutton, Eastman Kodak Company, Rochester, N.Y., personal communication, 1965.

CHAPTER 11

Measurement of Thorium and Thoron Hazards

1. Air Monitoring

1.1. Dust Sampling Methods

Filter paper is the most commonly used sampling medium for thorium and thoron daughters although various sampling devices are available, including filters, inertial samplers (conifuges, cyclones, and cascade impactors), electrostatic dust samplers, thermal precipitators, optical analyzers, and elutriators. Membrane filters are particularly suitable for collecting thoron daughters because of their high efficiency; since they become optically transparent under immersion oil, they are useful for particle size measurements.[1]

There are two general methods of air sampling: (1) breathing zone sampling and (2) general air sampling. General air samples integrate the air concentrations in areas of the plant outside the immediate vicinity of process equipment and include places ordinarily not considered as contaminated, e.g., rest or smoking areas and change rooms. Air contamination and residence times in such areas frequently contribute significally to the weighted average exposure.

Breathing zone samples provide an estimate of the effective exposure to the individual worker.

The most meaningful measure of an airborne hazard is the weighted average exposure, which is defined as "the sum of the different exposure rates encountered in an individual's working environment multiplied by the length of time that he will be exposed to these various exposure rates; all of these are then averaged over the entire work period of concern."[2] The weighted average exposure is therefore derived from breathing zone and general air samples and is based on an analysis of the work cycle of each employee.

The hazard to the lung from airborne radioactive dust depends on its aerodynamic behavior; this in turn depends on the size distribution of the particles, as well as their shape and density. Two-stage samplers have been designed to simulate the particle retention characteristics of the lung.

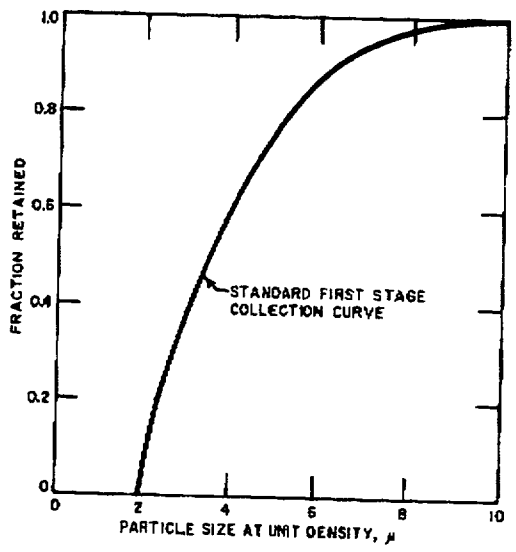
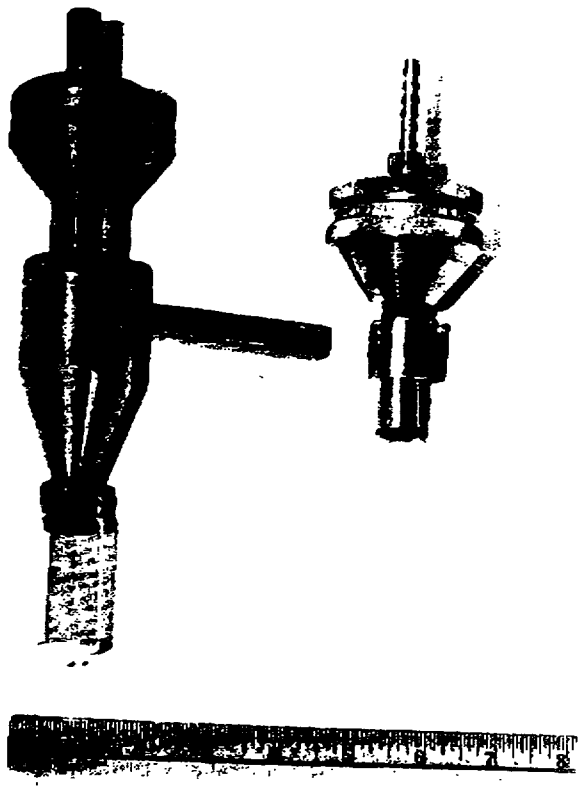


Fig. 11.1 (left). Curve showing collection efficiency of the first stage of a two-stage particulate sampler. After Hyatt, *Radiol. Health Safety Mining Milling Nucl. Mater. Proc. Symp., Vienna, 1963.*[4]

Fig. 11.2 (below). Photograph of a pair of two-stage particular samplers. (Courtesy Los Alamos Scientific Laboratory, Los Alamos, N.M.)



Particles are collected in two fractions, one of which represents "respirable" dust and the other, "nonrespirable" dust. Respirable dust includes those particles which are deposited in the nonciliated portion of the lung. Nonrespirable dust is deposited in the nose or on the ciliated part of the bronchial tree and is cleared from the lung rapidly. The data of Brown and Hatch[3] have been used to characterize respirable dust in terms of the particle size of unity density spheres; this curve (Fig. 11.1) serves as a standard for the performance of two-stage samplers.[4] Particle sizes to left of this curve are respirable and are deposited on the second stage of the collector. Figure 11.2 shows a pair of two-stage air samplers.[4] In both instruments, the sampled air passes first through a cyclone and then a filter paper; the collection efficiency of the cyclone approximates the curve in Fig. 11.1.

1.2. Thoron Decay Products

Thoron gas has a half-life of only about 1 min. The first decay product, Po^{216} (thorium A), is very short-lived (half-life, 0.16 sec) and is not present in air in significant quantities. The second decay product, Pb^{212} (thorium B), (half-life, 10.6 hr) controls the decay of subsequent members of the series, of which the longest lived member is Bi^{212} (thorium C) (half-life, 60.6 min).

Two alpha particles are emitted in the decay of Rn^{220} (thoron) to Pb^{212} (thorium B). After Pb^{212}, one alpha and two beta particles are emitted to yield stable Pb^{208}.

When an atmosphere containing thoron decay products is drawn through a collector, and R_1 and R_2 are the collection rates for Pb^{212} and Bi^{212} (in atoms per minute), the number of Pb^{212} atoms on the collector for a sampling time is given by

$$P = \frac{R_1}{\lambda_B}(1 - e^{-\lambda_B t})$$

where λ_B is the decay constant of Pb^{212} (thorium B) and t is the sampling time in minutes.

The number of Bi^{212} (thorium C) atoms formed on the collector from the decay of Pb^{212} is given by

$$Q_1 = R_1\lambda_C \frac{1 - e^{-\lambda_B t}}{\lambda_B(\lambda_C - \lambda_B)} + \frac{1 - e^{-\lambda_C t}}{\lambda_C(\lambda_B - \lambda_C)}$$

where λ_C is the decay constant of Bi^{212}. The number of thorium C atoms collected directly is given by

$$Q_2 = \frac{R_2}{\lambda_C}(1 - e^{-\lambda_C t})$$

The total number of thorium C atoms on the collector is

$$Q = Q_1 + Q_2$$

The growth of activity of thorium B and thorium C relative to thoron in a source whose activity is held constant by a continuous fresh supply of thoron is shown in Fig. 11.3.[5] After the sampling is stopped, the collected thorium C decays with a 1-hr half-life while the thorium C alpha activity builds up from the decay of thorium B as shown in Fig. 11.4.[5] The total thorium C alpha activity is the sum of these two curves.

The decay curve of alpha activity varies in shape depending on the relative amounts of thorium B and thorium C. By 5 hr after the end of sampling, the thorium C collected from the air is completely decayed and the alpha activity curve follows the 10.6-hr half-life of thorium B.

The energy released by the complete decay of thorium B is about ten times greater than that of thorium C for equal initial microcurie activities, because the number of atoms of thorium B is ten times greater than thorium C. Hence, the hazard from thoron daughters is not very dependent on the amount of airborne thorium C and the levels can be accurately measured in terms of thorium B. To do this, the sample measurement is delayed for about 5 hr after the end of the collection period.

The alpha activity may reflect the presence of long-lived decay products as well as thoron daughters. If the sample is recounted several hours after the 5-hr measurement, the long-lived activity may be calculated[6] from the following equation

$$A = \frac{(d_2 - d_1)e^{-\lambda_{ThB}}}{1 - e^{-\lambda_{ThB}}}$$

where A equals the long-lived activity in disintegrations per minute; d_1, measured disintegrations per minute at first count; d_2, measured disintegrations per minute at second count; t, time between counts (λ and t are in same units); λ_{ThB}, decay constant for Pb^{212}.

After correction for the long-lived activity, the thorium B activity is extrapolated to the start of the collection period.

It has been suggested (Chapter 9, Section 3) that the permissible exposure level for thoron should be equal to that for radon and expressed in terms of the "working level" of radon (10^{-10} c/liter in equilibrium with daughters or 1.3×10^5 Mev of potential alpha energy per liter).[7] The potential alpha energy per disintegration of each thorium B atom is 7.84 Mev; one working level is $(1.3 \times 10^5$ Mev$)/7.84 = 1.65 \times 10^4$ atoms of thorium B per liter. This number of thorium B atoms is equivalent to 17.6 dis/min or 8 pc/liter. As a convenience for field work, the measured alpha activity of the example can be multiplied by the appropriate

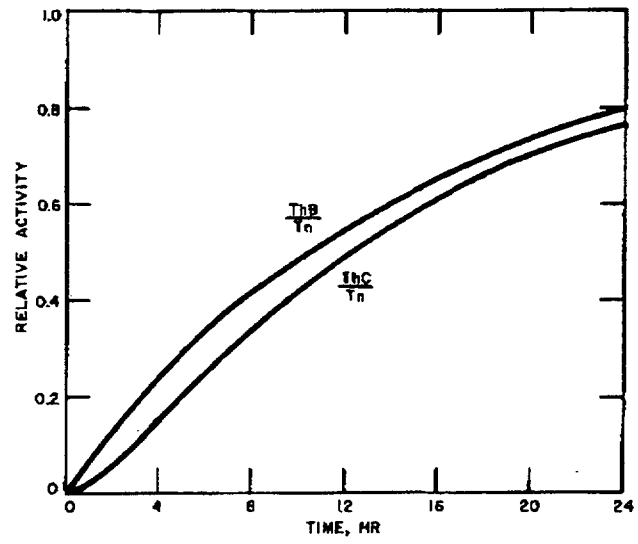


FIG. 11.3. The growth of activity of thorium B and thorium C relative to thoron in a source whose activity is held constant by a continuous fresh supply of thoron from thorium X. After Aub *et al.*, *Medicine*.[5]

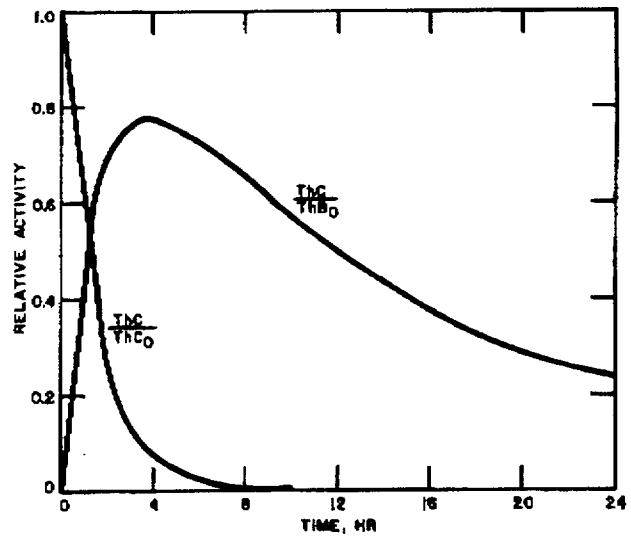


FIG. 11.4. The alpha activity from thorium C after removal of a constant source of thoron which had caused, in an observed time, the accumulation of activities ThB and ThC_0. After Aub *et al.*, *Medicine*.[5]

factor[7] (shown in Fig. 11.5) to derive an estimate of the atmospheric activity in terms of multiples of the suggested working level.

Although the relative concentration of thorium B and thorium C in the air is not a particularly important factor in the inhalation hazard from

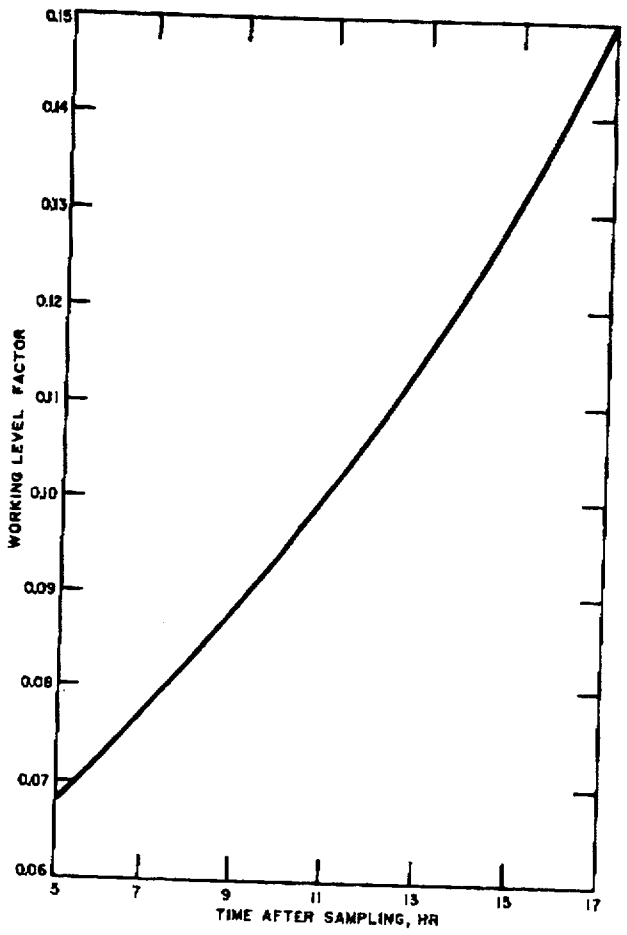


FIG. 11.5. The working level factor curve for thoron daughters. After Blanchard and Holaday, *Am. Ind. Hyg. Assoc. J.*[7]

thoron daughters, the ratio of these two decay products can be used as a measure of ventilation. Equilibrium activities of thorium B and thorium C occur only in nonventilated air; ventilation depresses the concentration of thorium C to a greater extent than that of ThB. If ρ is the number of air changes per minute, it will be seen[8] in Fig. 11.6 that the shape of the

alpha decay curve is remarkably sensitive to variations of ρ in the ra from 10^{-4} to about 1. Hence, the ratio of counts at 30 and 150 min co be used for estimating effective ventilation in areas where thoron released into the atmosphere.

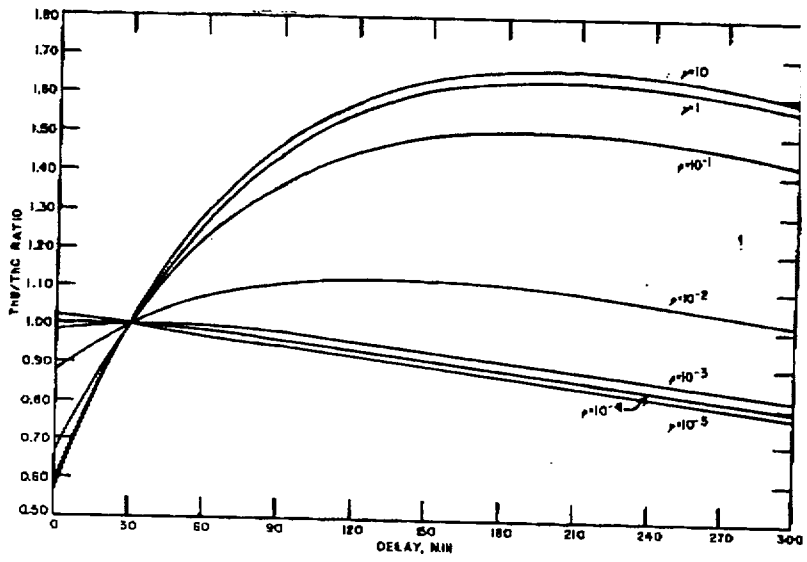


FIG. 11.6. Alpha decay curves of filter paper air samples for various degrees ventilation. After Somayaju, *Health Phys.*[8]

The shape of the decay curve after electrostatic sampling is similar t that for filter paper sampling and also reflects the variation in the rati of thorium B to thorium C ions due to ventilation.

1.3. MEASUREMENT OF ATMOSPHERIC THORIUM

The interpretation of airborne thorium activity in terms of maximum permissible limits is complicated. Unlike most other important industrial radioactive materials, thorium consists of several different isotopic subseries, each of which has its own MPC in air. Freshly separated natural uranium does not develop appreciable daughter alpha activity for many years because the daughter isotopes of U^{234} have very long half-lives. However, there are no "stoppers" in the Th^{232} decay series, and the decay chain isotopes form rapidly.

As indicated in Chapter 9, Section 4, the ICRP permissible limit calculations assume that each parent of a decay series in the Th^{232} chain enters the body alone. From the standpoint of hazard, the important

isotopes in the Th^{232} series are Th^{232}, Th^{228}, Ra^{228}, and Ra^{224}, each of which has its own MPC in air. The relative magnitudes of the MPC values for these isotopes in the form of insoluble particles are Th^{232}, 1.0; Th^{228}, 0.6; Ra^{228}, 4.0; and Ra^{224}, 70.0. For soluble particles the MPC ratios are Th^{232}, 1.0; Th^{228}, 4.5; Ra^{228}, 35.0; and Ra^{224}, 2500.

It is apparent that the important parent isotopes are Th^{232}, Th^{228}, and Ra^{228}. If the entire Th^{232} decay chain were in equilibrium, as is the case for "natural thorium," six alpha particles would be emitted for each disintegration of Th^{232}. One microcurie of natural thorium, by definition, consists of 1 μc each of Th^{232} and Th^{228}. The alpha activity on an air sample of equilibrated natural thorium dust can be readily interpreted in terms of the MPC for natural thorium. However, when the Th^{232}/Th^{228} ratio becomes greater than unity, as occurs with repeated chemical separations, the contribution of Th^{232} to the measured alpha activity would be abnormally large and hence the hazard would be increased relative to natural thorium.

Since heat treatment of thorium can volatilize and segregate radium daughters, the aerosol may be enriched or depleted in Ra^{228} and Ra^{224}. A high alpha activity from radium enrichment would be less hazardous than the equivalent activity from natural or depleted thorium. However, if the airborne activity arose from radium-enriched material which had been aged for several weeks, the beta-emitting Ra^{228} would predominate because of its relatively long half-life compared to Ra^{224} and the alpha activity could seriously underestimate the inhalation hazard. It is apparent that a meaningful assessment of the isotopic composition of thorium dust may require detailed analysis.

Five hours after the end of the collection period, the radon daughter activity on the air sample has disappeared and the thoron daughters have reached equilibrium. The thoron daughter activity is eliminated by decay in another 3 or 4 days. Thereafter, one or more repeated alpha counts over a period of weeks permits the estimation of Ra^{224} unsupported by Th^{228}. The formula for calculating unsupported Ra^{224} activity[9] is

$$C_L = \frac{C_2 - C_1 e^{-0.19t}}{1 - e^{-0.19t}}$$

where C_1 and C_2 are the first and second counts and t is the time in days between the two counts. This method has some value for determining whether or not most of the activity is short-lived, but it is not very precise.

Thorium-232 can be measured by chemical or radiometric methods; however, the required sensitivity is very high. The MPC in air for natural thorium in unrestricted areas is 2×10^{-12} $\mu c/cm^3$, which is equal to 9 $\mu g/m^3$ or an alpha activity of 8.8 dis/min/m^3. Because of its low specific activity, the chemical determination of Th^{232} (discussed in Section 2) is the method of choice.

The degree of Ra^{224} enrichment in an air sample can be determined by combining the results of the chemical analysis and alpha activity measurement. The alpha counting is generally done with a proportional gas flow counter or a scintillation counter with a thin layer of powdered phosphor covering the face of the photomultiplier tube.[10] Both methods have high efficiencies (~33%) with low backgrounds (3–5 counts/min).

As an alternative to the combined chemical and gross alpha measurement of air samples, the analysis can be done by alpha spectroscopy. The alpha spectrometer that is useful for materials of very low specific activity (e.g., about 10^{-12} counts/g), consists of a pulse ionization chamber using either a cylindrical or parallel plate Frisch grid electrode system.[11] A half-width resolution of 50 to 80 kev is obtainable on air samples that have been collected by electrostatic precipitation. The background counting rate, in the energy range from 4 to 6 Mev, is about 2 counts/min.

An average of six alpha particles are emitted per disintegration of Th^{232} from seven of the members in the equilibrated Th^{232} decay chain. The alpha energies range from 3.947 to 9.78 Mev. Figure 11.7 shows an alpha spectrum[9] from a sample of thorium having a Th^{232}–Th^{228} ratio of about 2. The energy peaks of the individual alpha emitters are quite distinct. In practice, alpha spectrometry has been found to be somewhat imprecise for the measurement of Th^{232} and Th^{228} in the presence of large amounts of Ra^{224} and its daughters.[10]

Gamma spectroscopy is useful for determining the degree of enrichment of radium daughters in thorium on the basis of the gamma activity of Ac^{228} (0.9 Mev) and Tl^{208} (2.6 Mev). Figure 11.8 shows the gamma spectra[9] from two thorium samples, one of which is depleted of radium daughters. The ratio of gamma-ray activities in the 0.9 and 2.6 Mev energy regions is used to determine the activity ratio of Ra^{228} to Ra^{224}. In radium-enriched material, the Ra^{224} is unsupported by Th^{228} and decays much faster than Ra^{228}, causing a high Ra^{228} to Ra^{224} ratio. In radium-depleted material, the Ra^{224} grows rapidly, unlike Ra^{228}, causing a low Ra^{228} to Ra^{224} ratio.

In a radium fraction which is devoid of thorium the Ra^{228} to Ra^{224} ratio builds up to a peak in about 35 days and then falls off slowly,[12] as shown in Fig. 11.9, because of the slow production of Th^{228} from the decay of Ra^{228}.

The procedure for analyzing air samples for thorium[13] in the Oak Ridge Y-12 Plant is as follows.

The samples are alpha counted after a 48-hr delay period to allow for decay of thoron daughters. A screening limit of 10^{-11} $\mu c/cm^3$ is used on the empirical basis that samples with less than this activity level seldom have a thorium concentration greater than 2×10^{-12} $\mu c/cm^3$. Moreover,

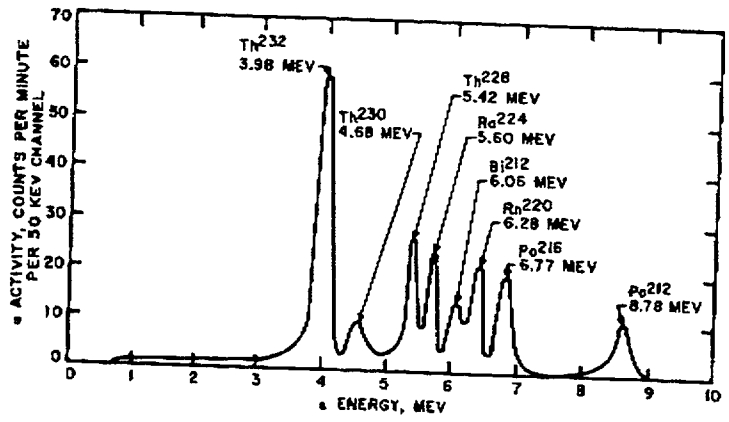


FIG. 11.7. Alpha spectrum of thorium and its daughters for a Th^{232}–Th^{228} ratio of 2.23. After West, *Health Phys.*[9]

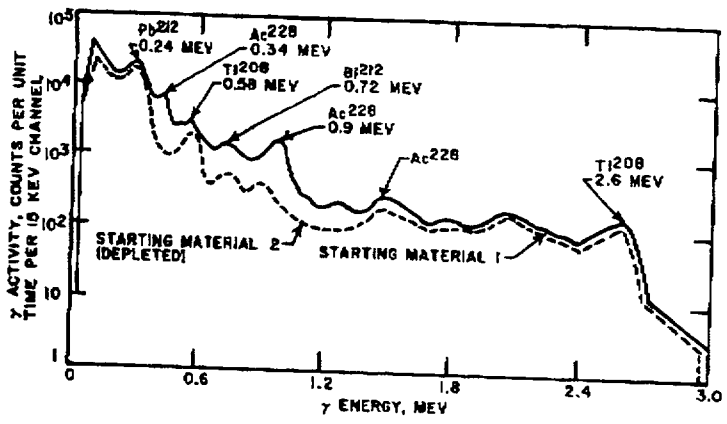


FIG. 11.8. Gamma spectra from two starting materials, normalized at 2.6 Mev. Starting material 2 is depleted of radium daughters. After West, *Health Phys.*[9]

10^{-11} $\mu c/cm^3$ is less than the MPC in air for either Ra^{224} or Ra^{228}. If the screening limit is exceeded, a chemical analysis for thorium is done by an adaptation of the colorimetric procedure of Thomason *et al.*[14] The Ra^{224} concentration is then calculated and a beta count is used to estimate the level of Ra^{228}.

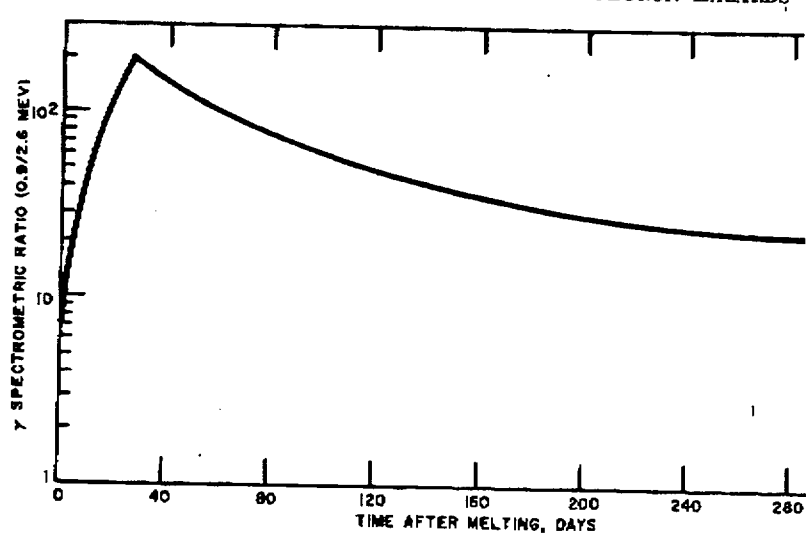


FIG. 11.9. Long-term behavior of gamma ratio for a thorium-free radium fr After Cofield, *Health Phys.*[12]

2. Bioassay

There are three potentially useful methods of estimating the burden of thorium: analysis of the breath for thoron, measureme gamma emission from the chest, and urinalysis. Thorium in the fe not a good measure of the body burden since it represents inhaled tho which has impacted on the pharynx and therefore never reached the l thorium particles which were deposited in the bronchial tree and cle by ciliary action and swallowed, and thorium which was ingested dire

2.1. Breath Thoron

Breath thoron measurements were used from 1930 to 1936 to mo the body burdens of several persons who were engaged in refining n thorium at the University of Missouri.[15,16] The maximum atmospl thoron levels in this installation were about 10^{-9} c/liter, but no meas ments were made for airborne thorium or thoron daughters.

Breath thoron was measured by collecting expired air in an ioniza chamber attached to a gold-leaf electroscope. The breath thoron le appeared to reflect the severity of exposure and also declined du vacations. A series of observations on one individual showed an incre level of breath thoron whenever he had an upper respiratory infect

Since then, breath thoron measurements have not been used for rou bioassay in industry. Evans measured breath thoron with an electrost

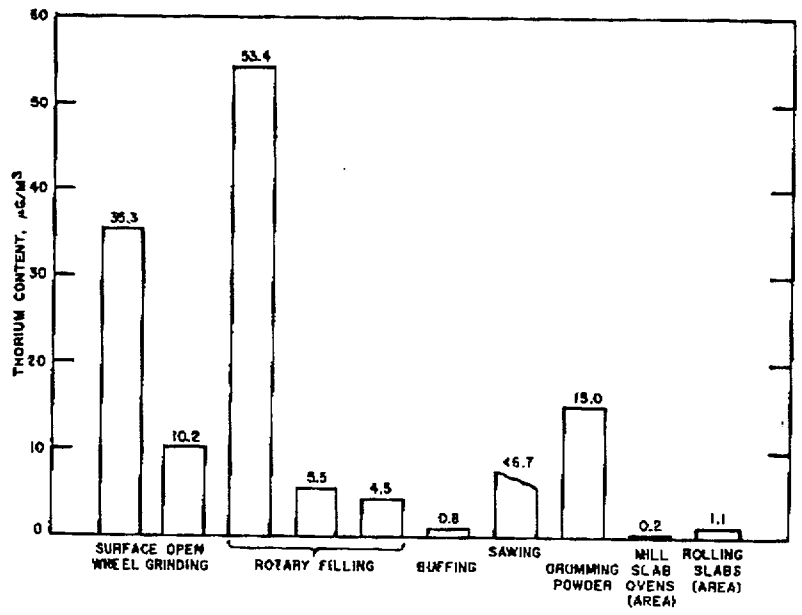


FIG. 10.6. Results of air samples taken with an electrostatic precipitator at some of the mechanical operations involved in processing thorium-magnesium alloys. (Courtesy the Dow Chemical Company, Midland, Michigan.[14])

8. Thoriated Tungsten

The production of 1 to 2% thoriated tungsten involves mixing or "doping" tungsten powder with thorium nitrate and conversion of the powder to the oxide at 600°C. The powder is pressed into bars and sintered at high temperatures in the presence of hydrogen. The metal bars are reduced to thin rods by swaging. The bars are heated white hot and passed repeatedly through the swaging dies, which pound the rods to a smaller diameter from which thoriated tungsten wire can be drawn.

Information on the operational experience with the control of thorium hazards is available for one of the major producers of thoriated tungsten. At this plant, standard industrial hygiene control measures are carried out in the above processes. Most of the operations are done under hoods or near exhaust vents. The operators wear gloves and aprons. Monitoring procedures include breathing zone air samples, as well as smear samples taken on surfaces. The operators wear film badges.

Film badge readings for a 6-month period on employees most directly concerned with the thoriated tungsten process averaged 10 mr/month, with occasional readings as high as 120 mr/month. Air concentrations of thorium were variable, but did not exceed 10^{-11} μc/ml.

One survey showed levels which ranged from 5 to 36.5 × Other survey reports had intermediate values. The most operations in the fabrication of thoriated tungsten were: (1) t of thorium nitrate, (2) the transfer of the blended thorium n sten powder to the oxide conversion furnace, (3) the sieving ated tungsten metal powder, and (4) the pressing of the metal ingots prior to the sintering step. It is apparent from the air s that the control of exposure is primarily a matter of care by th operators in the handling of the materials.

9. Handling Neutron-Irradiated Thorium and U^{233} Feed Material

The purpose of irradiating thorium with neutrons is to fissionable isotope U^{233}. The neutron reactions that produ discussed in Chapter 4, Section 1.2.

For neutron bombardment in a reactor, thorium can b blanket around the core of fuel or mixed together with the reactor core (U^{235} or Pu^{239}). In either case, the irradiated highly radioactive since it contains large quantities of fissi It requires decontamination by remote chemical separation

After removal of fission products, the radiation hazard fr irradiated thorium and uranium is largely determined by th tions of U^{232} (half-life of 73.6 years) and Th^{234} (half-life of Thorium-234 is the immediate daughter of U^{238} and dec through Pa^{234} to the long-lived U^{234} (2.6×10^5 years), with of 60 to 90 kev gamma rays.

Uranium-232 decays to Th^{228} (1.9 years), which is a me Th^{232} decay series. The decay of Th^{228} and its daughters is ass the emission of high energy gamma radiation.

Following the end of irradiation, the Th^{234} activity diminis active decay and that of Th^{228} builds up from the decay of the greater the delay between the end of irradiation and chen tion, the more Th^{228} and the less Th^{224} are carried along wit

The generation rate of Th^{234} is dependent on the neutron flu up to an equilibrium level in less than half a year. For examp of Th^{234} to Th^{232}, on a mole basis, after the attainment of eq a flux of 10^{14} neutrons per square centimeter per second is abo the activity of Th^{234} per gram of Th^{232} at the end of irradiat 10 mc.[16]

If the Th^{234}–Pa^{234} chain is permitted to decay, the Th^{228} ch the important source of radiation hazard. The build-up of Th to the total exposure, the number of recycles, and the cooli

Thorium rods and wires have been successfully produced by drawing. Very small wire has been made from arc-melted thorium sheathed in copper.

The machining qualities of high purity thorium are similar to those of copper. The machining qualities of graphite-melted thorium are comparable to those of mild steel. Thorium is considerably softer than uranium but, in most respects, the properties of the two metals are quite similar. Shops that are familiar with uranium have no difficulty machining thorium.

7.5. Powder Metallurgy

Powder metallurgy techniques have been developed extensively for thorium. These techniques permit fabrication of high reactivity metals and metals of widely different densities into dense homogeneous shapes that are impossible to produce by other methods. The disadvantages of powder metallurgy are the high costs and the hazards of handling pyrophoric, radioactive powders.

Powdered thorium has been obtained by calcium reduction and electrolysis, as described in Section 5, and by the decomposition of thorium hydride.

In the hydride process, thorium powder is made by reacting massive thorium metal, in the form of chips or sponge, with hydrogen at 1 atm. At 600° to 650°C ThH_2 is formed. During this step, the charge swells but remains solid; when the temperature is lowered to 250°C, ThH_2 is converted to Th_4H_{15}, which is a coarse powder. The Th_4H_{15} reverts to ThH_2 at 500°C, and then under vacuum at 700°C, ThH_2 decomposes to thorium powder.

Electrolytically deposited thorium, prepared from anhydrous thorium chloride fused with sodium chloride, can be stripped from the electrode and pulverized into a powder.

Metal shapes are readily fabricated by cold compacting, hot compacting, and sintering.

8. Thorium-Magnesium Alloys

Thorium imparts some very desirable heat-resistant characteristics to magnesium; as a result, this alloy has had considerable use in the last decade for the construction of aircraft engines, airplane frames, and missiles.[18]

The alloy manufacturing normally takes place in two steps. First, a master alloy containing roughly equal parts of thorium and magnesium is prepared. Subsequently, the master alloy is remelted and further diluted with magnesium to a maximum concentration of 4% thorium.

Standard magnesium foundary practices are used for melting, casting, grinding, and welding operations.

9. Thoriated Tungsten Electrodes

Thoriated tungsten alloy is used principally for inert gas, shielded arc welding electrodes. These welding electrodes contain 1 to 2% thoria.[19] The thorium confers the advantageous properties of instant arc starting and improved arc stability.[20] The ability of thorium to produce high electron emission with relatively little energy expenditure (low work function) is utilized in thoriated tungsten electrodes for several types of electron tubes.

The first step in the production of 1 or 2% thoriated tungsten involves "doping" or mixing a thorium nitrate solution with tungsten powder. The thorium nitrate, in preweighed plastic bags, containing 5–10 kg each, is added to water in a stirred vat. The thorium nitrate solution is then fed through a hose into the blender containing the tungsten powder during the mixing operation. The doped tungsten powder is loaded into pans and fired at 900°C in an open furnace to convert the thorium nitrate to the oxide. The thoriated tungsten oxide is pulverized in a grinder and drummed for storage, pending the reduction process. The conversion to metal is done in hydrogen reduction (graded temperature zone) tube furnaces. The thoriated tungsten oxide is loaded into crucibles and pushed through the furnace and is then put through a tumbler and sieving operation. The powder is pressed into 2-kg bars in the same type of operation that is used for the pure thorium metal. The sintering of the pressed bars is done in vertical induction furnaces under a hydrogen atmosphere at a temperature of about 2500°C.

10. Thoria Refractories

Thorium oxide is the most refractory of the ceramic oxides, having a melting point of 3300°C. It is used for those applications where temperatures may exceed the melting points of the other more common ceramic oxide refractories. These applications include components for magneto hydrodynamic generators, magneto plasmadynamic generators, and thermionic generators.

The refractoriness of thorium oxide and its chemical inertness combine to make it useful as a crucible material in many metallurgical applications. Its chemical inertness makes thorium oxide suitable for chemical fuel cells, both as a porous membrane and as a container material for molten salts at elevated temperatures. These properties are also useful for thermocouple insulation although the electrical conductivity of thoria be

comes appreciable at very high temperatures. Applications such as these are increasing rapidly, and the demand for thoria refractorics is rising.

Thorium oxide ceramics may be fabricated by many of the common ceramic fabrication techniques, including cold pressing, hot pressing, slip casting, extrusion, isostatic pressing, tamping, and injection molding. The same types of binder, lubricating agents, and plasticizers are required in fabricating thorium oxide ceramics as have been found necessary with pure oxide fabrication of alumina, beryllia, and similar materials.

II. Fabrication of Thorium Mantles

The process for manufacturing thorium mantles has not changed substantially over the years. It is a hand operation that is currently done on a small scale. The essential features of the production method are as follows. A highly absorbent rayon stocking (or webbing) is dipped in a concentrated solution of thorium nitrate containing about 1% cerium nitrate, for luminosity, and some aluminum and beryllium nitrate to add strength to the mantle. The impregnated web is exposed to ammonia fumes, which convert the thorium and other nitrates to the insoluble hydroxide. The rayon stocking is rinsed to remove ammonium nitrate and is dried.

At this stage, the mantle can be finished in either of two ways. (1) To make "soft" mantles, the stocking is cut off, sewn shut at one end, and then packaged for use. (2) "Hard" mantles, which are currently used for some kerosene lamps and are the type that were used in old-fashioned street lamps, are made by igniting the rayon. The open end of the impregnated mantle is fastened to a nichrome mounting base and the mantle is passed through a gas flame which ignites the rayon, leaving a skeleton of oxides. The oxide skeleton is fragile and is therefore dipped in collodion to prevent breakage during shipment. The collodion burns off in use.

References

1. I. B. Roll, Thorium and Its Alloys, in *Nuclear Reactor Fuel Elements* (A. R. Kaufmann, Ed.), p. 147, John Wiley and Sons, Inc. (Interscience Publishers), New York, 1962.
2. R. D. Nininger, *Minerals for Atomic Energy: A Guide to Exploration for Uranium, Thorium and Beryllium*, 2nd ed., D. Van Nostrand Company, Inc., Princeton, New Jersey, 1956.
3. J. W. Frande and M. Fluscher, Glossary of Uranium and Thorium Bearing Minerals *U.S. Geol. Surv. Bull.* **1009-F**, 3rd ed., (1955).
4. W. C. Lilliendahl, *Rare Metals Handbook*, p. 430, Reinhold Publishing Corporation, New York, 1956.
5. B. Prakash, S. R. Kantan, and N. K. Rao, *Metallurgy of Thorium Production*. Rev. Ser., No. 22, International Atomic Energy Agency, Vienna, 1962.
6. *Major Activities in the Atomic Energy Programs*, p. 175, U.S. Atomic Energy Commission, Superintendent of Documents, Washington, D.C., 1962.

7. H. N. Sethna and S. Fareeduddin, *Symposium on Rare Metals*, pp. 68–77, Atomic Energy Establishment, Trombay, India, and the Indian Institute of Metals, 1957.
8. S. Fareeduddin, R. K. Garg, and H. N. Sethna, Production of Nuclear Grade Thorium Nitrate, in *Proc. 2nd Intern. Conf. Peaceful Uses At. Energy, Geneva, 1958*, 4: 208 (1958).
9. P. Krumholz and F. Gottdenker, The Extraction of Thorium and Uranium from Monazite, in *Proc. 1st Intern. Conf. Peaceful Uses At. Energy, Geneva*, 8: 126 (1956).
10. F. L. Cuthbert, *Thorium Production Technology*, Addison-Wesley Publishing Company, Inc., Reading, Mass., 1958.
11. C. Braun, Ch. Lorrain, R. Mahut, R. Mariette, J. Muller, and J. Prugnard, The Manufacture of Pure Thorium Nitrate at Le Bouchet Plant, in *Proc. 2nd Intern. Conf. Peaceful Uses At. Energy, Geneva, 1958*, 4: 202 (1958).
12. G. A. Meyerson, Powder Metallurgy of Thorium, in *Proc. 1st Intern. Conf. Peaceful Uses At. Energy, Geneva, 1955*, 8: 188 (1956).
13. A. R. Gibson, J. H. Buddery, J. R. Chalkley, and R. D. Marshall, Thorium Metal Production by a Chlorination Process, in *Proc. 2nd Intern. Conf. Peaceful Uses At. Energy, Geneva, 1958*, 4: 237 (1958).
14. D. E. Scaife and A. W. Wylie, A Carbide-Iodide Process for High-Purity Thorium, in *Proc. 2nd Intern. Conf. Peaceful Uses At. Energy, Geneva, 1958*, 4: 215 (1958).
15. R. R. Lowery, Radiation Hazards Encountered in Arc Melting Thorium, *U.S. Bur. Mines Repl. Invest.*, 5969 (1962).
16. T. C. Runion, B. A. Rogers, and S. H. Paine, Thorium, in *Reactor Handbook* (C. R. Tipton, Jr., Ed.), 2nd ed., Vol. 1, p. 211, John Wiley and Sons, Inc. (Interscience Publishers), New York, 1960.
17. P. Lowenstein, P. D. Corzine, and J. Wong, *Fabrication of Core Materials*, John Wiley and Sons, Inc. (Interscience Publishers), New York, 1962.
18. Thorium-Improved Magnesium Alloys, *Steel*, 133: 126 (1953).
19. A. J. Breslin and W. B. Harris, Use of Thoriated Tungsten Electrodes in Inert Gas Shielded Arc Welding: Investigation of Potential Hazard, *Am. Ind. Hyg. Assoc. Quart.*, 13: 4 (1952).
20. W. Lilliendahl, Thoriated-Tungsten Electrodes, *Metal Progr.*, 71: 104 (1957).