RAC V

RESPONSE ACTION CONTRACT FOR

Remedial, Enforcement Oversight, and Non-Time Critical Removal Activities at Sites of Release or Threatened Release of Hazardous Substances in Region V

PREPARED FOR

U.S. Environmental Protection Agency

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FINAL REMEDIAL INVESTIGATION REPORT

KERR-MCGEE RESIDENTIAL AREAS SITE
West Chicago, Illinois

Remedial Investigation/Feasibility Study

WA No. 109-RICO-05QV/Contract No. 68-W6-0025

July 2003

Executive Summary

In 1990, the U.S. Environmental Protection Agency (USEPA) placed the Kerr-McGee Residential Areas Site (RAS) on the National Priorities List. The RAS consists of residential, institutional, commercial, industrial, and municipal properties in the area of West Chicago, Illinois, about 30 miles west of Chicago. The RAS had been contaminated with radioactivity from thorium and its decay products that originated from ore processing operations at the Rare Earths Facility, which operated in the center of West Chicago from 1932 through 1973.

On April 14, 1994, the USEPA sent Kerr-McGee Chemical Corporation a general notice of potential liability formally apprising Kerr-McGee that it was considered to be a potentially responsible party under Section 107(a) of the Comprehensive Environmental Response, Compensation and Liability Act. After deciding to accelerate cleanup at the site consistent with the Superfund Accelerated Clean-up Model, the USEPA completed a Preliminary Focused Risk Assessment, an Engineering Evaluation/Cost Analysis and an Action Memorandum to support the decision to order non-time-critical removal of contaminated materials at the RAS. In those documents, the USEPA identified constituents related to the radioactive tailings as contaminants incurring potentially unacceptable levels of risk, including radium 226 (Ra-226), radium 228 (Ra-228), radon, thoron, and the associated metals barium, chromium, and lead. The USEPA also specified soil cleanup levels for total radium at background plus 5 picocuries per gram (pCi/g); preliminary remediation goals of 400 mg/kg for lead, 832 mg/kg chromium, and 11,600 mg/kg barium; and indoor action levels of 0.02 working levels for combined radon and thoron decay products.

The USEPA attempted to negotiate an Administrative Order on Consent with Kerr-McGee, but negotiations failed and in November 1994, the USEPA issued a Unilateral Administrative Order requiring Kerr-McGee to conduct a non-time-critical removal action at the site. The non-time-critical action consists of three stages: characterization to be performed by the USEPA and its contractor, CH2M HILL, to identify contaminated properties requiring removal action and to support the USEPA's remedial investigation (RI); removal and property restoration work to be performed by Kerr-McGee; and verification sampling to assure attainment of cleanup levels to be performed by the Illinois Department of Nuclear Safety. This RI report summarizes the results of the characterization efforts conducted by the USEPA and CH2M HILL, documents decision rules used to implement the USEPA's cleanup levels, and describes the results of a baseline risk assessment for site conditions prior to the removal action. RAS characterization results and associated estimates of incremental lifetime cancer risks (ILCR) are summarized, as follows:

- Gamma surveys using a global positioning system (GPS), performed on transects at 5-foot intervals, were conducted by CH2M HILL over roughly 945 acres of residential, institutional, commercial, industrial, and municipal properties in the RAS. Thirty-five acres of the properties surveyed were determined to exceed the USEPA's cleanup levels of 7.2 pCi/g total radium based on gamma levels exceeding a predetermined action level. Soil samples quantified for radiological constituents ranged from background levels (approximately 2.2 pCi/g) to a maximum of 966 pCi/g. With the exception of a single outlier, preliminary remediation goals for metals were not exceeded in soil samples collected. Indoor sampling for radon and thoron showed that any exceedances of USEPA's action levels were due to elevated radon, not thoron, and were not attributed to thorium materials. These results supported removal of the metals, radon, and thoron from further consideration as contaminants of potential concern (COPCs).

- A conceptual model for the RAS was developed that illustrates the environmental pathways of concern by depicting the various media, transport pathways, and exposure pathways that could be completed as a result of the contamination within the RAS. Those pathways included external gamma radiation emitted from soil through radioactive decay, presence of contamination in residential soil allowing direct contact to the COPCs through dermal contact, uptake of COPCs in vegetables and fruits grown in contaminated soils where the fruits and vegetables could then be ingested, inhalation of soil particulates; and soil ingestion. Scenarios were limited to current conditions (future conditions being considered comparable) as represented by residential-rural exposures. Best estimate and reasonable maximum exposures (RME) were calculated using survey data from properties representative of mid-range and upper limits on COPC concentrations and surface areas of contaminated materials.

- On the basis of mobility data (vertical mobility of the COPCs in soil is 0.022 foot per year) and past groundwater testing conducted by IDNS at residential properties throughout the West Chicago area at the owners request (where no elevated Ra-228 and Ra-226 have been detected in private surficial groundwater wells), the groundwater pathway was eliminated as a potential exposure pathway.

- ILCR was estimated using best and RME estimates of gamma activity and surface areas from the representative properties. Total radium concentrations were predicted from gamma activity and, with associated surface areas for the best and RME properties, modeled using a radiological dose model (RESRAD, developed by Argonne National Laboratory). The model estimated doses then converted dose to incremental lifetime cancer risk. ILCR results for the best estimate of properties in the RAS ranged from 4×10^{-4} to 7×10^{-4}. ILCR results for RME properties ranged from 1×10^{-3} to 7×10^{-3}. RAS results, in comparison to the USEPA's range of 1×10^{-6} to 1×10^{-4} for acceptable ILCR, indicate need for removal of contaminated material at the site.

- The baseline risk assessment limited consideration of risks to human health and did not evaluate ecological risks based upon (1) prevailing consensus within the scientific community that radiation levels adequate to protect human health are considered protective of the environment and (2) the predominantly residential demography of the RAS.

- The thorium-contaminated materials exceeding the cleanup criterion have been removed from the 670 properties remediated to date and replaced with clean backfill. As a result, with the exception of 6 known contaminated properties that remain to be remediated (as of the writing of this report), there are no known residual risks remaining at the site.

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Acronyms and Abbreviations

AEC	Atomic Energy Commission
ALARA	As Low As Reasonably Achievable
ANL	Argonne National Laboratory
AOC	Administrative Order on Consent
ARARs	applicable or relevant and appropriate requirements
ARMS	aerial radiological monitoring survey
ASCII	American Standard Code of Information Interchange
ATSDR	Agency for Toxic Substances and Disease Registry
BEIR	Biological Effects of Ionizing Radiation (NAS Report)
°C	degrees Celsius
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
CLP	Contract Laboratory Program
cm	centimeter
cm/s	centimeters per second
COPC	contaminant of potential concern
cpm	counts per minute
Cs-137	cesium-137
DMS	data management system
DOE	U.S. Department of Energy
DU	deliverable unit
EE/CA	Engineering Evaluation/Cost Analysis
EERL	Eastern Environmental Radiation Laboratory
EP	extraction procedure
ESRI	Environmental Systems Research Institute
°F	degrees Fahrenheit
GI	gastrointestinal
GIS	geographic information system
GPS	global positioning system
HCl	hydrochloric acid
HEAST	Health Effects Assessment Summary Tables
HF	hydrofluoric acid
HNO_3	nitric acid
HPGe	high-purity germanium
H_2SO_4	sulfuric acid
ICRP	International Commission on Radiological Protection
ID	identification number
IDNS	Illinois Department of Nuclear Safety

ILCR	increased lifetime cancer risk
K_d	distribution coefficient
kBq	kilo Becquerel
KCK	Kress Creek/West Branch of DuPage River Site
km	kilometer
L	liter
LL	lower limit
μR/hr	microRoentgen per hour
M1	in situ gamma spectroscopy
MDA	minimum detectable activity
MeV	million electron volts
mg/kg	milligrams per kilogram
mL/g	milliliters per gram
NaI	sodium iodide
NaOH	sodium hydroxide
NAS	National Academy of Sciences
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NCRP	National Council on Radiation Protection and Measurements
NPL	National Priorities List
NRC	U.S. Nuclear Regulatory Commission
ORIA	Office of Radiation and Indoor Air
Pb-206	lead-206
Pb-208	lead-208
Pb-214	lead-214
PC	personal computer
pCi/g	picoCuries per gram
pCi/L	picoCuries per liter
PIC	pressurized ion chamber
Po-216	polonium-216
Po-218	polonium-218
PRG	preliminary remediation goal
QAPjP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
Ra-226	radium-226
Ra-228	radium-228
Ra^{2+}	radium ion
RAGS	*Risk Assessment Guidance for Superfund, Part A, Volume I*
RAO	removal action objective
RAS	Residential Areas Site
RE	total radium equivalents (Ra-226 + Ra-228)
REF	Rare Earths Facility
RESRAD	Residual Radioactive Material Guidelines Model
RfD	reference dose

RI/FS	remedial investigation/feasibility study
RKP	Reed-Keppler Park Site
RME	reasonable maximum exposure
Rn-220	thoron
Rn-222	radon
ROD	Record of Decision
ROW	right of way
RPD	relative percent difference
RPISU	radon progeny integrating sampling unit
SAB	Science Advisory Board
SACM	Superfund Accelerated Clean-up Model
SARA	Superfund Amendments and Reauthorization Act
SF	slope factor
SOW	Statement of Work
STP	Sewage Treatment Plant Site
TAG	Thorium Action Group
Th-232	thorium-232
U-238	uranium-238
UAO	Unilateral Administrative Order
UCL	upper confidence limit
UL	upper limit
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USEPA	U.S. Environmental Protection Agency
WL	working level

SECTION 1

Introduction

In October 1984, the U. S. Environmental Protection Agency (USEPA) proposed placing the Kerr-McGee Residential Areas Site (RAS) on the National Priorities List (NPL). The RAS consists mainly of residential properties but includes institutional, commercial, industrial, and municipal properties within the area of West Chicago, Illinois. The RAS is contaminated with radioactivity from thorium and its decay products that originated from ore processing operations at the Rare Earths Facility (REF). The REF is located south of downtown West Chicago. Also in October 1984, USEPA proposed three other West Chicago sites for inclusion on the NPL, specifically, Reed-Keppler Park (RKP), the Sewage Treatment Plant (STP), and Kress Creek/West Branch of DuPage River (KCK). These sites also are contaminated with radioactive thorium from the REF. The REF was operated from 1932 to 1973 as a thorium extraction facility—first by Lindsay Light and Chemical Company (1932 to 1958), followed by American Potash and Chemical Company (1958 to 1967), then by the Kerr-McGee Chemical Corporation (1967 until the facility's closure in 1973).

The REF was licensed by the U.S. Nuclear Regulatory Commission (NRC), so it was not proposed for the NPL. The Illinois Department of Nuclear Safety (IDNS) assumed regulatory authority for the REF from NRC in November 1990, when the state of Illinois became an "agreement state." The REF subsequently has been undergoing cleanup and decommissioning under a license issued by IDNS. USEPA maintains regulatory responsibility for the NPL sites. USEPA has established and maintained active coordination with IDNS in the characterization and verification phases of the RAS as well as in the Remedial Investigation/Feasibility Study (RI/FS) investigations of the other three West Chicago NPL sites.

USEPA finalized the RAS NPL designation in 1990 (the other three sites were finalized in 1990 and 1991), and RI activities were undertaken at the site beginning in 1993. The investigations were conducted in accordance with the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), as codified in the *Code of Federal Regulations* (CFR), Title 40, Part 300 (40 CFR 300). USEPA Region 5 chose to apply the Superfund Accelerated Clean-up Model (SACM) for the RAS and, thus, decided to conduct cleanup of the site under a non-time-critical removal action. As a result, USEPA developed action criteria (November 1993) in support of non-time-critical removal actions at the RAS. In August 1994, USEPA finalized the requisite Engineering Evaluation/Cost Analysis (EE/CA) to identify the objectives of the removal action, to compare alternatives to achieve those objectives, and to document the selection process. Public involvement in the selection process was facilitated by a public meeting held on August 17, 1994, to summarize EE/CA results. That meeting was held near the beginning of the public comment period, which ran through September 1994. The public comment period allowed the public time to review the EE/CA and to submit comments.

On April 14, 1994, USEPA sent Kerr-McGee Chemical Corporation a general notice of potential liability formally apprising Kerr-McGee that, in regard to the West Chicago RAS, it is considered to be a potentially responsible party under Section 107(a) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

USEPA attempted to negotiate an Administrative Order on Consent (AOC) with Kerr-McGee, but negotiations failed and on November 18, 1994, USEPA issued a Unilateral Administrative Order (UAO) to Kerr-McGee that required Kerr-McGee to conduct the non-time-critical removal action at the RAS.

In November 1994, USEPA issued an action memorandum that selected excavation and offsite disposal as the non-time-critical removal action to be implemented at the site. The memorandum also contained a summary of USEPA's responses to the comments it received during the public comment period.

The USEPA assigned CH2M HILL to conduct a RI/FS at the RAS. As part of the RI/FS, CH2M HILL was tasked with developing and performing RAS characterization procedures and investigations of properties within the study area. The investigations supported not only the RI/FS but also the non-time-critical removal action. The investigations began with a pilot study in March 1994, and results of the study were used to develop decision rules to be implemented throughout the RAS characterization phase to target locations requiring remediation on the basis of USEPA's action levels. Kerr-McGee began removal action construction work the following year (1995), and IDNS performs verification sampling following removal to ensure that USEPA's action levels are being met at each property which requires cleanup.

This RI report summarizes results from the characterization phases of the RI/FS, provides an evaluation of risks at the RAS for site conditions that existed before the removal action, and provides the documentation required to generate a site Record of Decision (ROD).

The remainder of Section 1 describes the purpose and the scope of the RI process and report, the background and setting of the site, and the major investigations and activities that have been conducted at the residential properties prior to and following the placement of the site on the NPL in 1990.

1.1 Purpose, Regulatory Background, and Report Organization

This section presents the purpose and regulatory background of the characterization activities and this RI report. Additionally, because USEPA's non-time-critical removal action resulted in an approach that was atypical of conventional RIs, the RI field activities are presented in the context of the non-time-critical removal actions that began in 1995 and that are scheduled to be completed during 2003. The final subsection describes the content and organization of the remainder of the report.

1.1.1 Purpose

The purpose of this RI report is to present information on (1) the RAS background and setting, (2) previous investigations, (3) RI field activities, (4) physical characteristics of the RAS, (5) nature and extent of contamination, (6) fate and transport of contaminants, and (7) health and ecological risks associated with the site.

1.1.2 Regulatory Background

According to CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA), the USEPA is authorized to take appropriate response action whenever a threat exists to public health or welfare of the environment. In general, a response action may be taken to abate, prevent, minimize, stabilize, mitigate, or eliminate a release or threat of release. USEPA Region 5 chose to apply the SACM, which encourages early actions (such as non-time-critical removal actions) to be taken at sites (U.S. EPA 1992b, and U.S. EPA 1992c). This approach allows focused actions that reduce risk to be taken sooner at sites that already have been characterized or for which remedial alternatives are known or are limited.

In 1993, USEPA completed a preliminary focused risk assessment concluding that excess lifetime carcinogenic health risks at the RAS were a concern. Subsequently, USEPA set specific remediation goals for the site intended to (1) minimize potential health hazards, (2) minimize potential environmental impacts, (3) maintain cost effectiveness, and (4) comply with applicable or relevant and appropriate requirements (ARARs).

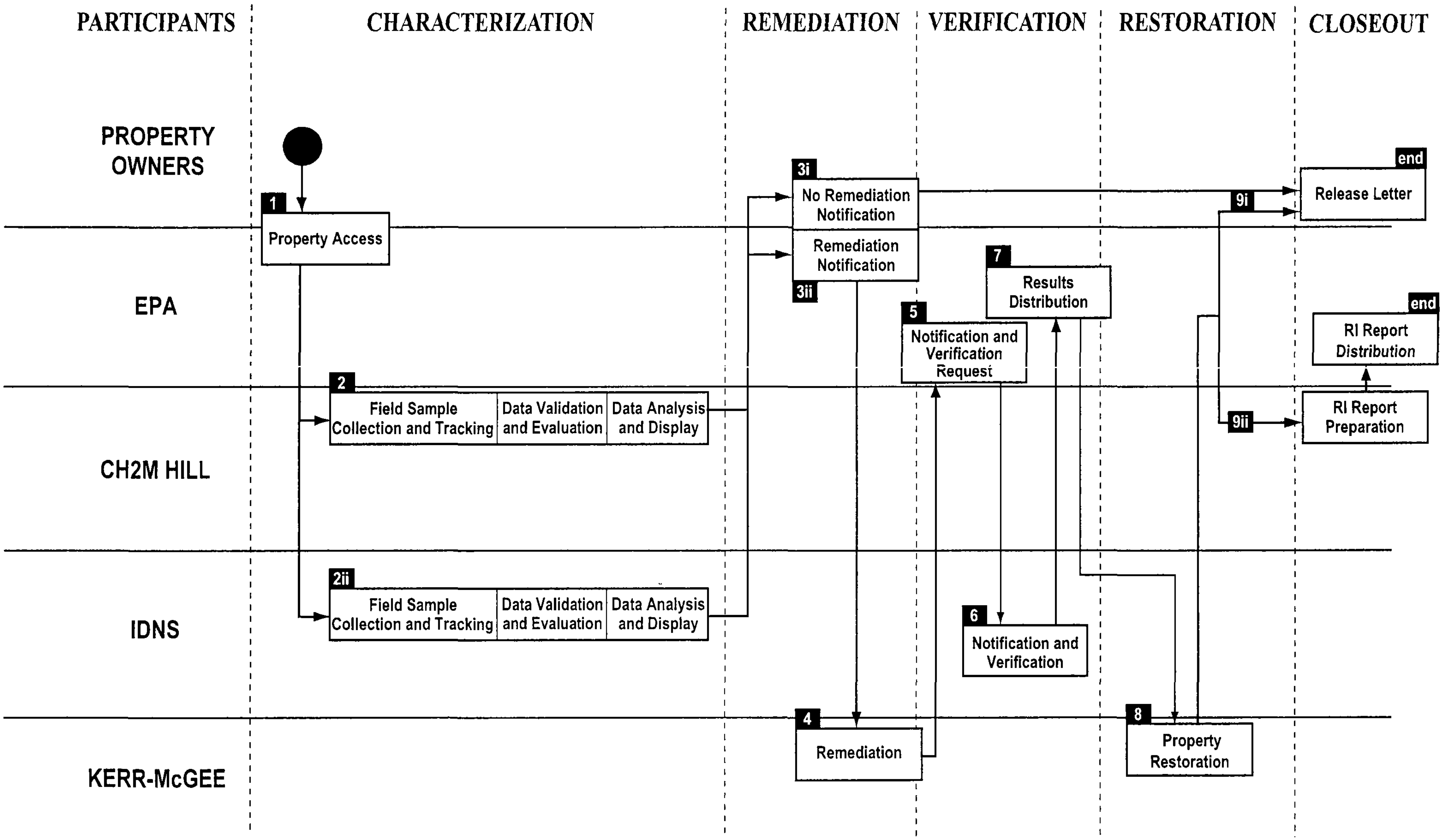
In 1994, CH2M HILL conducted an EE/CA for the RAS. The EE/CA, required by the NCP prior to conducting non-time-critical removal actions, was used to evaluate removal action alternatives. The general purposes of the EE/CA were as follows:

- To identify the objectives of the removal action
- To analyze and compare various alternatives that may be used to satisfy these objectives
- To document the proposed selection of an alternative
- To provide a vehicle for public involvement in the removal selection process

The EE/CA resulted in a recommended cleanup approach for the non-time-critical removal action, consisting primarily of excavation and offsite disposal of contaminated materials. USEPA then documented that cleanup approach as its selected removal action in the Action Memorandum signed in November 1994. USEPA then ordered Kerr-McGee to remove contaminated soils from the RAS properties needing cleanup. IDNS agreed to conduct followup confirmation work, including verification surveys and collection and analysis of soil samples to document the attainment of USEPA's cleanup levels at each property.

Figure 1-1 schematically illustrates the characterization, remediation, and verification activities for the RAS properties. The left side of the figure shows participants critical to the removal, including property owners, USEPA, CH2M HILL, IDNS, and Kerr-McGee. The body of the figure is divided into the phases of characterization, remediation, verification, and closeout. The schematic is applicable to individual properties as well as to the entire RAS. Briefly, the sequence consists of nine steps:

1. USEPA obtains access from each property owner to test the property.
2. USEPA directs CH2M HILL to perform field activities that include radioactive measurements, sample collection and tracking, validation and verification of resulting information, and analysis, interpretation, and presentation of results. (Late in the project, as USEPA obtains access to properties that had not previously granted access, IDNS performs the above activities instead of CH2M HILL.)



i, ii - Step where one of two options may be pursued, depending upon results

Figure 1-1
Non-Time-Critical Removal Action Schematic
Kerr-McGee West Chicago

3. USEPA either notifies the owner that the property requires no remediation or notifies the owner and Kerr-McGee that the property requires removal of contaminated soils.
4. Where removal is required, Kerr-McGee contacts the owner to arrange and complete the removal.
5. Upon completion of the excavation, Kerr-McGee apprises USEPA of completion, and requests verification of the property.
6. USEPA contacts IDNS, and IDNS conducts independent sampling to verify that USEPA's cleanup criteria have been achieved.
7. IDNS notifies USEPA that verification is complete and submits results to USEPA.
8. If verified as clean, USEPA authorizes Kerr-McGee to back fill and restore the property.
9. For closeout on an individual property requiring remediation, USEPA sends a release letter to the property owner. For closeout on the RAS as a whole, CH2M HILL prepares and USEPA finalizes and distributes this RI report.

The RI field activities performed by CH2M HILL (and later by IDNS) resulted in the characterization of all properties within the RAS (with the exception of 3 properties that, as of the writing of this report, had not yet been tested due to access issues). Additionally, the RI field activities provided the basis for the development of real-time decision rules to implement USEPA's action levels. The property-specific results are available only to the property owner and are not included in this RI report. The remainder of this document focuses on the methods and results of field data collection and on the application of those data to the decision rules for characterization.

1.1.3 Report Organization

The remainder of the RI report is organized as follows:

- Section 2 presents the physical characteristics of the study area.
- Section 3 describes the study area field investigation.
- Section 4 presents the contaminant nature and extent.
- Section 5 describes the contaminant fate and transport.
- Section 6 presents the baseline risk assessment.
- Section 7 presents a summary of the non-time-critical removal action.
- Section 8 describes the conclusions drawn from the RI.

1.2 Site Background and Setting

This section describes the general location of the RAS and maps the relative positions of the NPL sites within West Chicago. It also provides a brief history of the REF, including a description of contaminant transport scenarios that resulted in the movement of mill tailings from the REF to the surrounding community.

1.2.1 Location

The RAS encompasses residential, institutional, commercial, industrial and municipal properties in and around the city of West Chicago, Illinois, which lies approximately 30 miles west of Chicago (see Figure 1-2). West Chicago is primarily suburban, consisting mainly of high density, single-family residential housing built before 1960. The RAS is divided into individually owned properties, some comprising more than one parcel. There are 2,174 properties and 2,589 parcels within the RAS study area, each targeted by the USEPA for characterization of potentially contaminated soils. To facilitate the tracking of the surveys and studies and to facilitate the subsequent remedial activities, properties were aggregated geographically into deliverable units (DUs). In general DUs are discrete plots of land within the RAS that are physically separated from other DUs by roadways, railroads or bodies of water and that typically coincide with city blocks. Investigations and removal actions were identified by DUs and parcels. The nomenclature applied to DUs typically was derived from the first seven digits of the parcel-specific tax identifier developed by County records. Some exceptions to this general rule arose as the result of later subdivision of parcels, which were assigned parcel identifiers that were not consistent within blocks.

In 1989, EG&G performed an aerial radiological survey for the IDNS in and around West Chicago that identified general zones of elevated gamma readings. The flyover showed contamination in the areas of the RKP, STP, and KCK sites, as well as around the REF and within other residential areas of West Chicago. The resulting "footprint" of elevated gamma readings is shown in Figure 1-3. Most of the footprint area includes two areas centered around the REF and along Kress Creek, which account for roughly 600 of the 692 total acres, or 87 percent of the surface area. The remaining acreage occurs in localized, discrete areas to the west, north, and east.

The results of the flyover served as the preliminary boundary for investigating the RAS. Because the resolution of the aerial flyover boundary of elevated gamma readings is less definitive than actual ground level measurements, the footprint that resulted from the flyover served only as the starting point for ground level investigations and defined the initial RAS study area. Following a comprehensive ground level radiological survey of all individual properties (for which access was granted) within the RAS covered by the flyover footprint, the USEPA began to assess whether the boundary of the flyover footprint adequately defined the extent of surface soil contamination. As a result, the USEPA undertook the following processes:

- Surveying the remaining properties in DUs that were only partially within the flyover footprint. The completion of the characterization of all properties within a DU partially falling under the footprint is referred to as step-out surveys and accounted for 214 acres of the total survey area.
- Contracting the USEPA's Office of Radiation and Indoor Air (ORIA) facility in Las Vegas to conduct gamma activity surveys in areas of West Chicago outside the flyover footprint boundaries. The ORIA Las Vegas facility operated a van equipped with radiation measurement equipment, similar to (but much larger than) the instrumentation used in characterization surveys, that was driven along streets outside the flyover footprint. The surveys, referred to as *scan van surveys,* covered 17,056 acres. Figure 1-4 shows the scan van survey area.

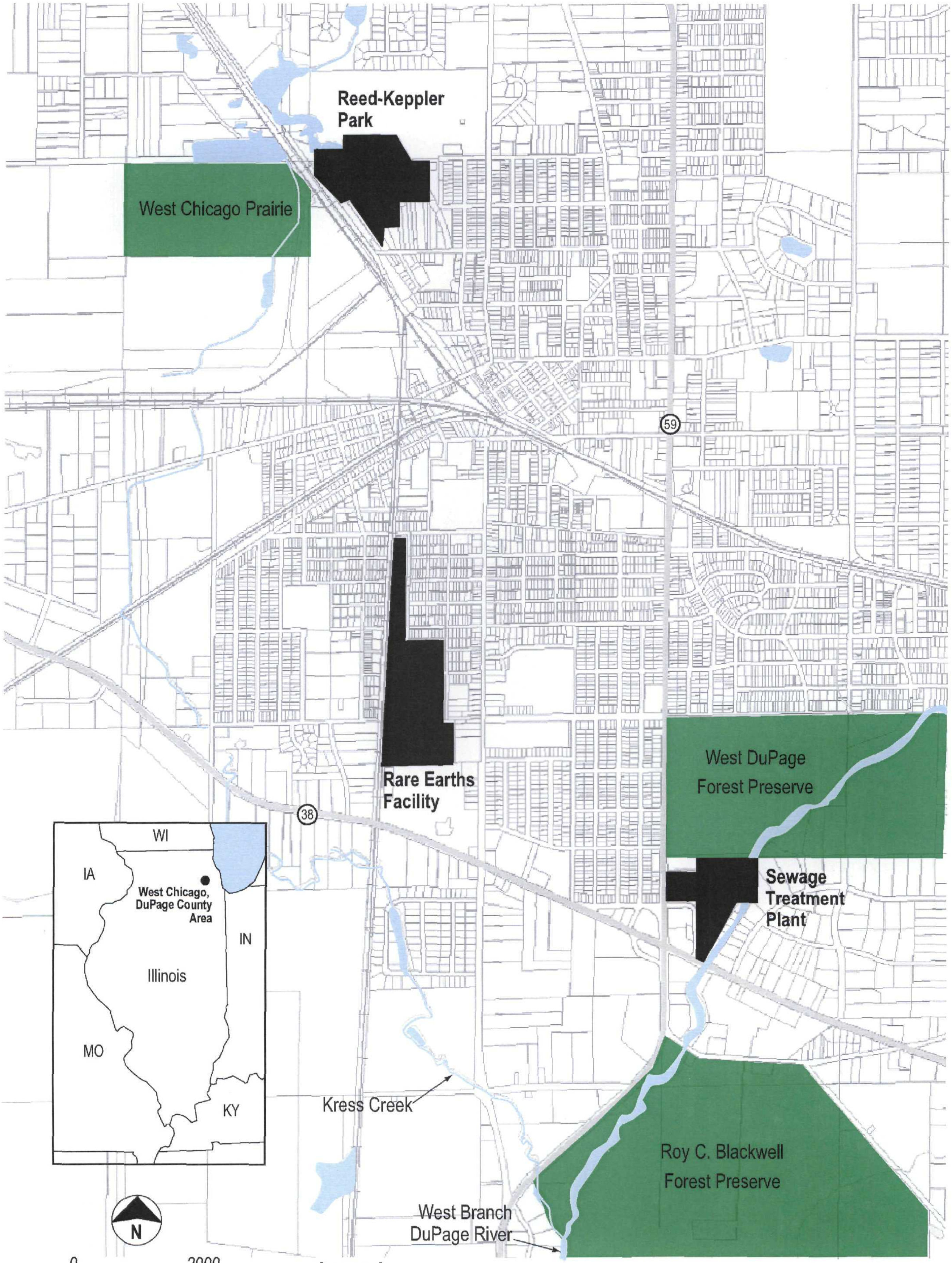


Figure 1-2
Location Map of West Chicago
Kerr-McGee West Chicago

E052003006MKE 160587.RR.01 Location Map 6-23-03 tll

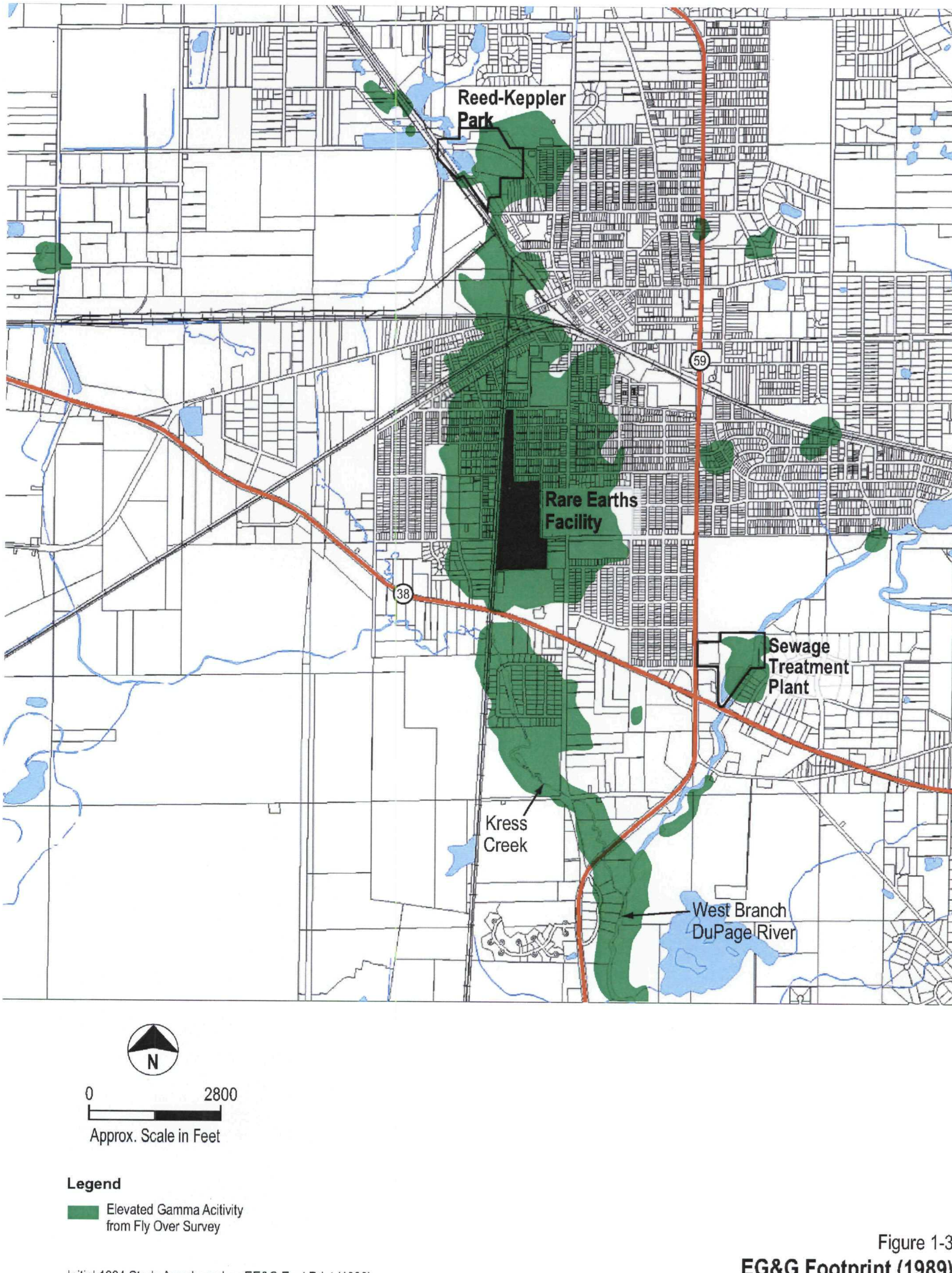


Figure 1-3
EG&G Footprint (1989)
Kerr-McGee West Chicago

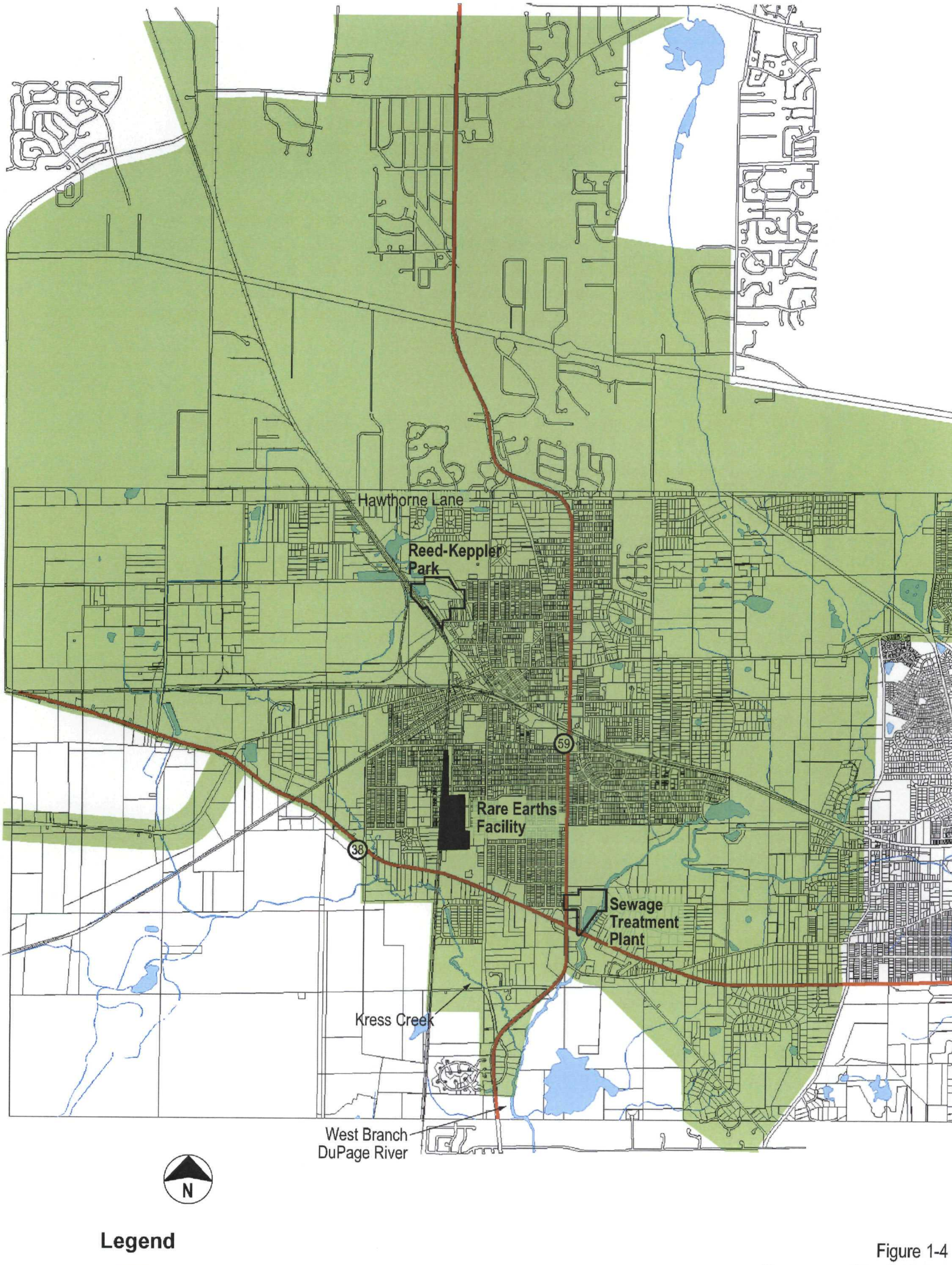


Figure 1-4
Scan-van Study Area
Kerr-McGee West Chicago

E052003006MKE 160587.RR.01 Scan-van Study Area 7-1-03 tll

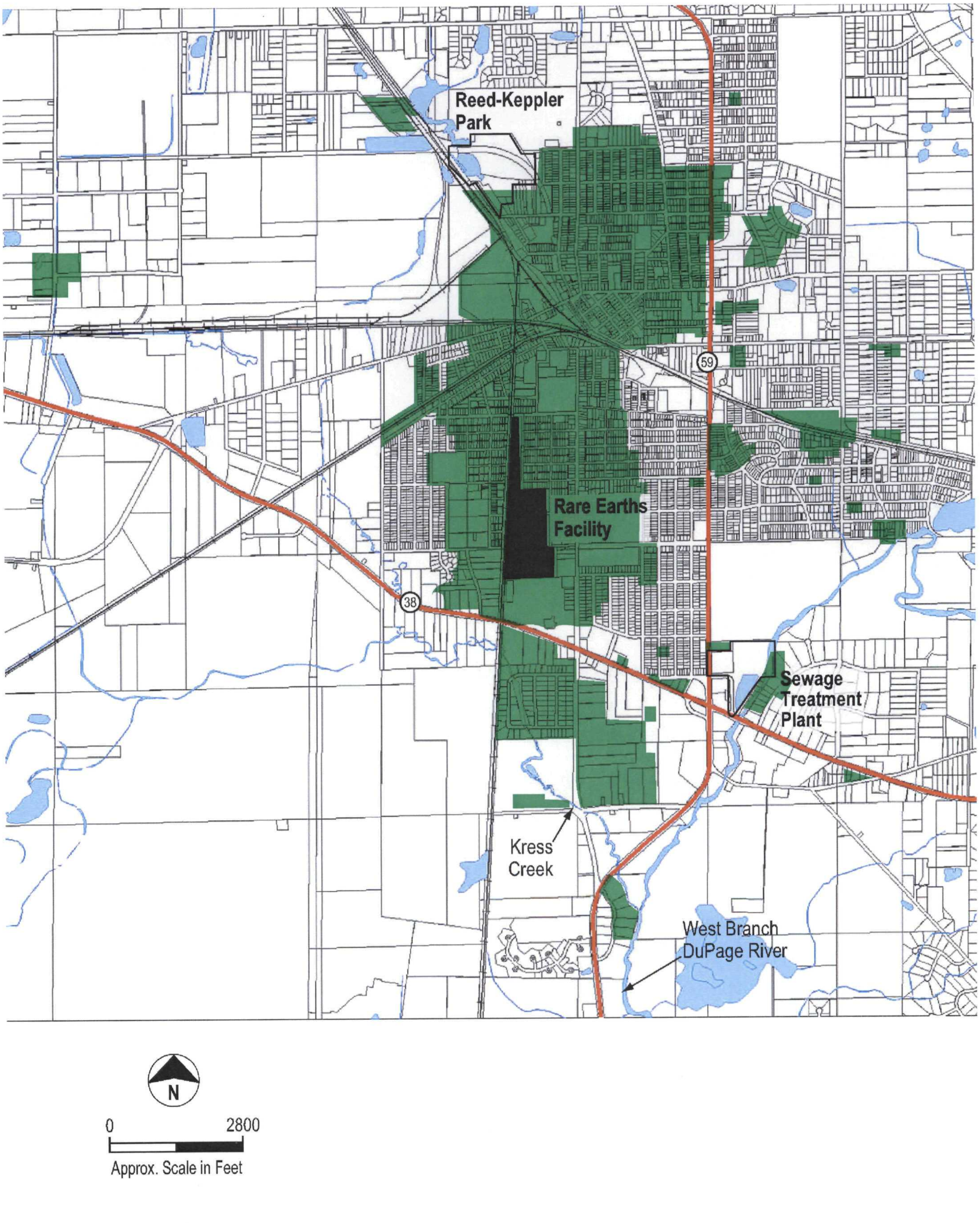
During the time USEPA was conducting its testing of properties in the initial RAS study area, IDNS was conducting property surveys, at the owners request, for properties located outside the USEPA site study area. Additionally, the City of West Chicago was conducting radiological surveys of areas located outside the study area that were scheduled for city construction work. After evaluating the results of the step-out surveys and the surveys conducted as a result of the scan van findings, and after taking into consideration the results of numerous IDNS property surveys and city construction-related surveys in areas outside the study area, USEPA decided in 1998 that it needed to expand the site study area to adequately characterize the extent of contamination at the RAS. Figure 1-5 shows the final site study area, including the initial study area, the step-out surveys, and the areas added as a result of the scan van surveys and the 1998 site expansion.

1.2.2 History

From 1932 until 1973, the REF was operated as a thorium extraction facility. Lindsay Light and Chemical Company operated the REF from 1932 to 1958, extracting thorium and other elements from monazite sands, bastnasite (rare earth ore), and other ores. The ores were processed with sulfuric acid (H_2SO_4), hydrofluoric acid (HF), hydrochloric acid (HCl), or nitric acid (HNO_3) and, after 1969, with sodium hydroxide (NaOH) (USEPA 1986). The extracted elements, such as thorium, mesothorium (commercial radium-228) and rare earths, were supplied to private parties and to the General Services Administration. The REF was also used for the manufacture of gas mantles that contain thorium and the production of HF. Ownership of the processing facility changed through corporate mergers, becoming American Potash and Chemical Company in 1958, while the production of thorium continued. In 1967, Kerr-McGee purchased the facility and operated it until it closed in 1973.

Production of thorium, a naturally occurring radioactive material, yielded radioactive tailings —containing primarily thorium-232 (Th-232) and residual levels of radium (Ra-226 and Ra-228)—which were stockpiled at the REF. The radioactive tailings and associated radioactive contamination were then dispersed throughout the RAS by the following methods:

- Until at least 1954, when the Atomic Energy Act was enacted and regulation of mill tailings began, the stockpiled tailings at the REF were made available for use as fill material at residential, municipal, and other properties throughout the West Chicago area. Widespread radioactive contamination of the subject properties thus resulted from application of the mill tailings as fill.
- Winds passing through West Chicago dispersed particulate matter from waste piles of tailings stored on the REF, depositing the material on properties downwind.
- The piles of tailings generally were uncovered and consequently exposed to rain. Stormwater runoff from the exposed piles transported particulates from the site to nearby stormwater drainage areas. The particulates eventually were deposited as sediments in and around Kress Creek, contaminating some nearby residential properties.



Legend

EPA's Approximate Site Study Area

Figure 1-5
Gamma Survey Study Area
Kerr-McGee West Chicago

In addition to the transport of contaminated mill tailings from the REF to properties and watershed areas, radioactive "shine" from the materials still stored on the REF resulted in elevated levels of gamma radioactivity near the REF. Therefore, even the storage of radioactive tailings affected the immediate area with elevated radiation levels. These radiation levels resulted in "background" gamma radiation levels near the REF well above the levels observed in areas of West Chicago distant from the REF.

In 1974, under the Energy Reorganization Act, the Atomic Energy Commission (AEC) was abolished and the licensing and regulatory authority of the REF was transferred to the NRC. The state of Illinois later petitioned the NRC for amendment of the agreement-state licensing program to include licensing control of REF material. IDNS gained licensing authority on November 1, 1990.

After the commercial closure of the REF, numerous investigations and response activities occurred within the four West Chicago NPL sites. Table 1-1 lists the key participants (other than USEPA) in those actions and the RI/FS investigations, and briefly summarizes the roles and responsibilities of each party. The following chronological list identifies the most notable investigations, responses, and other activities performed before and in association with the RAS RI/FS. Where appropriate, the activity appears with a citation to an original public document.

1. Initial characterization and aerial radiological survey, performed by Argonne National Laboratory (ANL) for the NRC from 1976 to 1978 (Frigerio et al. 1978)
2. "An Aerial Radiological Survey of West Chicago, Illinois" (NUREG-1183-1730), prepared by EG&G for the NRC (September 1977)
3. External gamma exposure rate survey by the NRC over selected areas (1981)
4. "Groundwater Sampling from Community Wells around West Chicago, Illinois." prepared by Fermi Lab, et al. National Accelerator Laboratory (July 1981)
5. "Hydrologic Studies West Chicago Thorium Plant," prepared by Law Engineering Testing Company for Kerr-McGee Corporation (August 1981)
6. Rn-222 monitoring in 10 homes by ANL for USEPA (1983)
7. Radiation screening survey of 30 residences in the area of the REF by USEPA (1984)
8. Voluntary surveys and soil excavation by Kerr-McGee for 30 microRoentgens per hour (μR/hr) exceedances (completed in 1984 and 1985 for properties within the city limits)
9. *Remedial Investigation Report, Kerr-McGee Radiation Sites, West Chicago, Illinois* (WA No. 82-5L94.0), prepared by CH2M HILL for the USEPA (September 1986)
10. Second aerial radiological survey by EG&G for IDNS (1989)
11. Residential and school surveys by IDNS (since 1989).
12. Miscellaneous groundwater surveys performed by IDNS at request of property owners (since 1989)

13. "Preliminary Focused Risk Assessment for West Chicago Vicinity Properties," prepared by S. Cohen & Associates and Rogers and Associates Engineering Corporation for USEPA (January 1993)
14. "Action Criteria for Superfund Removal Actions at the Kerr-McGee Residential Areas Site: West Chicago, Illinois" (USEPA 1993)
15. RAS RI/FS characterization of properties within the initial RAS study area and anomalous scan van areas conducted by CH2M HILL from 1994 through 1997.
16. Scan van surveys conducted by USEPA's ORIA Las Vegas facility of areas outside the EG&G aerial footprint in 1995 and 1996.
17. RAS RI/FS characterization of additional properties within the expanded study area conducted by CH2M HILL from 1998 through 2000.

Studies 1 through 10 above were conducted before the RAS was listed on the NPL in 1990. Studies 11 and 12 were initiated before the listing and continue through the present. Section 1.3 describes these studies. Section 1.4 describes the activities directed or performed by the USEPA since the finalized listing of the RAS on the NPL (items 13 through 17).

TABLE 1-1
West Chicago RAS Major Participants (other than the USEPA)

Kerr-McGee Chemical Corporation	Named by the USEPA as a Potentially Responsible Party. Owner of the facility where the material that contaminated the RAS originated. Under UAO issued by USEPA, responsible for removal actions and restoration of RAS properties.
The City of West Chicago	Owner of contaminated municipal properties included in the RAS. Conducts radiological surveys before construction work in areas outside RAS study area. Assisted with USEPA's attempts to obtain access from property owners.
IDNS	State regulatory agency supporting USEPA conducting post removal action verification sampling and analysis. Regulatory agency in charge of the REF. Conducted residential characterization surveys for USEPA late in project as access to additional properties was obtained.
CH2M HILL	USEPA contractor responsible for characterization of vast majority of properties within the RAS site.
EG&G, NRC, U. S. Department of Energy (DOE)	Other agencies and companies involved in previous investigations conducted at the West Chicago NPL Sites.
Thorium Action Group (TAG)	Community action group of residents in the West Chicago area. Identified public concerns throughout the investigations and provided USEPA with assistance in developing content and format of letters to property owners following parcel surveys. Assisted with USEPA's attempts to obtain access from property owners.

1.3 Previous Studies

As noted, numerous investigations and response activities have been conducted at the RAS. The major investigations and response actions are summarized below.

1.3.1 Initial Characterization and Aerial Radiological Survey by ANL for the NRC (1976 to 1978)

ANL conducted the initial base study to identify and briefly characterize properties outside the REF from March 1976 to May 1978 for the NRC (Frigerio et al. 1978). Frigerio et al. identified 75 thorium-processing waste deposits within RKP, the property owned by the STP, the area adjacent to Kress Creek, and properties east of the REF. Fourteen of the sites identified were outside city limits. Techniques used to delineate contaminated areas included an aerial radiological monitoring survey (ARMS) flyover in 1977, a street-by-street vehicle survey, an external gamma exposure rate survey, and soil contamination measurements using subsurface sampling.

1.3.2 "An Aerial Radiological Survey of West Chicago, Illinois" (NUREG-1183-1730), Prepared by EG&G for the NRC (September 1977)

EG&G Aerial Measurements conducted an aerial radiological survey of the West Chicago area for the NRC. This survey identified several areas exhibiting elevated gamma radiation levels (radiological anomalies) in a number of residential areas.

1.3.3 External Gamma Exposure Rate Survey by the NRC Over Selected Areas (1981)

The NRC Office of Inspection and Enforcement, Region III, reported external gamma exposure rates at a 1-meter height at the REF fenceline and surrounding residential neighborhoods north, east, and west of the REF. Data collection indicated that exposure rates to detectors resulted from both on- and off-REF sources. However, the relative contribution of each was not established. Exposures of residents in the area were determined to be less than the NRC regulatory limits set forth in 10 CFR 20, which were applicable at that time.

1.3.4 "Groundwater Sampling from Community Wells around West Chicago, Illinois," Prepared by Fermilab et al. (National Accelerator Laboratory) (July 1981)

Six deep community wells and nine shallow private wells surrounding Kerr-McGee's REF were sampled. The samples were shipped to the USEPA's Eastern Environmental Radiation Laboratory (EERL) in Montgomery, Alabama, for total radioactivity scan and radium, uranium, and thorium determinations. In accordance with the current standards, results from four of the community wells showed elevated concentrations of Ra-226 (see Section 2.9.4). Uranium and thorium concentrations in the six community wells were within their respective limits. Private wells were found to contain radium, thorium, and uranium levels near regional background levels taken from Lake Michigan.

1.3.5 "Hydrologic Studies West Chicago Thorium Plant," Prepared by Law Engineering Testing Company for Kerr-McGee Corporation (August 1981)

Data included in this report were derived from 13 onsite borings and from offsite water wells located within a 1.5-mile radius originating at the REF. All onsite borings were completed as wells to obtain groundwater data. Parameters measured included static water levels, transmissivity, hydraulic conductivity, formation and well loss coefficients, and groundwater velocity. Tables in the report contain data pertaining to DuPage County and REF site groundwater quality, hydraulic data for shallow wells, permeability test results, and equilibrium distribution coefficients. An appendix on soils characterization is included.

1.3.6 Radon Monitoring in 10 Homes by ANL for USEPA (1983)

ANL conducted indoor radon measurements in 10 homes for USEPA (c. 1983) prior to any mitigation efforts (ANL 1983). Working levels (WLs) for radon (Rn-222) and thoron (Rn-220) generally were less than 0.02 WL in living areas. (Note: One WL is the quantity of Rn-222 progeny in 1 liter [L] of air that will result in 1.3×10^5 million electron volts [MeV] of emitted alpha energy. See Appendix A.)

1.3.7 Radiation Screening Survey of 30 Residences in the Area of the REF (1984)

Jensen et al. performed a radiation screening of 30 residential properties in the area of the REF in 1984. The results of this study are unpublished.

1.3.8 Voluntary Surveys and Soil Excavation for 30 μR/hr Exceedances by Kerr-McGee (1984 to 1985)

Subsequent to the NRC's surveys of 1977, Kerr-McGee conducted radiation surveys throughout the city and identified 117 properties with radiation exposure rates exceeding 30 μR/hour at 1 meter, the level the company established for initiation of cleanup. In 1984 and 1985, Kerr-McGee and the City of West Chicago began a voluntary residential cleanup program, remediating the most highly contaminated properties in the incorporated areas of West Chicago. The removed thorium residuals were placed at the REF, which lies within the incorporated area of the city. Properties on which surface readings exceeded the company's cleanup level but located outside the city limits (unincorporated properties) were not remediated. Therefore, even after the voluntary surveys were completed, thorium residuals still existed throughout the area in deposits both above and below 30 μR/hr at 1 meter. Thorium residuals from decades of production also remained in mill tailing piles at the REF.

1.3.9 "Remedial Investigation Report, Kerr-McGee Radiation Sites, West Chicago, Illinois" (WA No. 82-5L94.0), Prepared by CH2M HILL for the USEPA (September 1986)

This report focused on the RKP, STP, and KCK sites as well as residential properties within the City of West Chicago. Data assessment and summary conclusions indicated several routes of potential risks to the environment and public health resulting from exposure to media on the subject sites that had been contaminated with wastes from the REF. These include but are not limited to direct external radiation exposure, inhalation exposure, and ingestion of contaminated soil, groundwater, and surface water.

The document further concluded that the hazardous characteristics of the thorium residuals primarily were due to the radioactive constituents and that, on the basis of the RI activities and assessments, the potential for release of heavy metals to the groundwater appeared to be minimal. With reference to the second point, validation tests using the extraction procedure (EP) toxicity test to determine the leachability of hazardous substances exhibited a low potential for significant mobility through soils and subsequent groundwater pollution.

The report identified that the primary radionuclides that are present are Th-232 and uranium-238 (U-238) and their associated decay products. The principal potential risks to man include external gamma radiation exposure and radiation exposure from inhalation of airborne decay products of Rn-220 and Rn-222. The REF wastes, which are the original source of contamination, contain concentrations of Th-232 (as high as 4,000 picoCuries per gram [pCi/g]) with U-238 concentrations of about one-tenth the Th-232 values. The decay products of Th-232 and U-238 in the wastes are generally in radioactive equilibrium.

1.3.10 Second Aerial Radiological Survey by EG&G (1989)

EG&G conducted a second aerial radiological survey in 1989 for IDNS which identified several additional thorium anomalies The identification of these sites and Kerr-McGee's petition to the NRC for permanent disposal of the thorium residuals to the factory site focused new attention on the radioactive contamination problem in West Chicago.

1.3.11 Ground Level Investigations of Residential and School Properties by IDNS (since 1989)

Following the 1989 aerial radiological survey by EG&G, IDNS performed screening-level surveillance of residential properties in the areas identified as anomalies to identify the cause of the anomalies. IDNS also performed radiological testing of residential properties, upon owner request, as part of its environmental program in and around West Chicago. These surveillances in general consisted of outdoor gamma walkover surveys and, if elevated gamma readings were observed, collection of soil samples, typically at the location on the property where the highest reading was obtained. At the request of the school districts, IDNS conducted radiological surveys of seven schools. From 1989 to the present, IDNS surveyed numerous properties (including schools and residences) in the City of West Chicago and unincorporated DuPage County.

1.3.12 Groundwater Surveys Performed by IDNS (since 1989)

Since 1989, IDNS has provided sampling and analysis of private water wells at residential properties in the West Chicago area. Residential water samples have been collected at the request of homeowners and screened for gross alpha and gross beta activity. Positive results for gross alpha/beta activity would have been indicators for the presence of thorium, radium, uranium or other radioactive contamination in water. All screening results for samples collected from residential wells off the REF, including wells on residential properties with known thorium contamination in the soils on the property, were below the lower limits of detection for the IDNS radiochemistry laboratory. The lower limits of detection for gross alpha and gross beta are typically 3 to 5 picoCuries per liter (pCi/L). Since there has been no measurable radioactivity attributable to Kerr-McGee identified in any residential water well, neither IDNS nor USEPA have deemed it necessary or appropriate to develop and conduct a formal water well study for the RAS.

1.4 Overview of RI/FS Activities

The investigation and study activities conducted at the RAS since its placement on the final NPL have focused on (1) the preliminary focused risk assessment produced for the USEPA, (2) the USEPA's action criteria document, ultimately integrated into the EE/CA prepared by CH2M HILL, (3) RAS characterization based on outdoor and indoor surveys, and (4) scan van surveys to help refine the site study area.

1.4.1 Preliminary Focused Risk Assessment Performed by USEPA (1993)

The USEPA initiated a preliminary focused risk assessment, completed in 1993, for seven contaminated properties in West Chicago (four residences and three schools) based on limited sampling data available at the time. The assessment was conducted to assess the risk to human health posed by contaminated soils in yards and the risk that might result from placing the contaminated soils at a temporary storage location. This assessment was conducted prior to the availability of a permanent licensed disposal site.

The results of the preliminary study indicated that health risks at the contaminated residential properties were of potential concern for current and future land uses, as evidenced by calculated incremental cancer risks that exceeded what USEPA considers acceptable. Risk on the school properties appeared to be considerably less, especially for current land use. Future risks on the school properties would be expected to increase if land use changes were to occur and homes were built on top of the contamination. Finally, the study indicated that the option of temporarily storing wastes on the REF would result in a small incremental increase in risks to residents living adjacent to that facility.

1.4.2 "Action Criteria for Superfund Removal Actions at the Kerr-McGee RAS: West Chicago, Illinois" (USEPA 1993)

The USEPA established goals intended to minimize health hazards to humans living or working on contaminated properties, to minimize potential environmental impacts from the soil contamination, to be cost-effective, to use permanent solutions to the maximum extent practical, and to establish soil conditions that comply with all ARARs. The Action Criteria document explains in detail the various criteria (action levels) that USEPA established for use during the discovery/characterization phase (to identify properties requiring remediation) and the verification phase (to ensure that properties were properly remediated). USEPA established criteria for outdoor soil concentration, outdoor gamma exposure rates, indoor gamma exposure rates, and indoor radon and thoron decay product concentrations. USEPA also included the principle of "As Low As Reasonably Achievable" (ALARA).

As explained in the Action Criteria Document, the primary criterion used to designate a property as requiring remediation is outdoor soil concentration; the other criteria are used only as "finding tools" to help locate contaminated areas, but will not trigger cleanup unless the outdoor soil concentration criterion is exceeded. The main discovery/ characterization criterion is as follows:

- Outdoor Soil Concentration -- exceedance of 5 pCi/g total radium (Ra-226 plus Ra-228), dry soil, above background in any 15-centimeter (cm) depth.

The "finding tools" used during the discovery/characterization phase are as follows:

- Outdoor Gamma Exposure Rate -- statistical exceedance of background.
- Indoor Gamma Exposure Rate -- statistical exceedance of background.

- Indoor Radon and Thoron Decay Product Concentration -- exceedance of 0.02 WL combined radon and thoron decay products (including background).

During the verification phase, some criteria are applied during and immediately following the excavation work (prior to backfilling), and some are applied after the excavation is backfilled with clean soil. The verification phase criteria are as follows:

- Outdoor Soil Concentration (applied prior to backfilling) – soil concentrations not to exceed 5 pCi/g total radium (Ra-226 plus Ra-228), dry soil, above background, averaged over areas up to 100 square meters, in any 15-cm depth.
- Outdoor Gamma Exposure Rate (applied after backfilling) – outdoor gamma exposure rates not to statistically exceed background at a distance of 100 cm from the surface.
- Indoor Gamma Exposure Rate (used as a "finding tool" during cleanup only for contaminated properties that had elevated indoor gamma levels due to thorium contamination) – indoor gamma exposure rates not to statistically exceed background.
- Indoor Radon and Thoron Decay Product Concentrations (applied following cleanup only for contaminated properties that had elevated indoor radon/thoron levels due to thorium contamination) – reasonable effort shall be made to achieve an annual average (or equivalent) combined radon and thoron decay product concentration (including background) not to exceed 0.02 WL; in any case, the combined radon and thoron decay product concentration (including background) shall not exceed 0.03 WL.

1.4.3 RAS RI/FS Characterization by CH2M HILL (1994 through 2000, Intermittent)

CH2M HILL conducted outdoor and indoor RI activities at the RAS from 1994 through 2000. Those activities and all field investigations were performed in accordance with the following planning documents:

- "Work Plan for the EE/CA and RI/FS," CH2M HILL, February 1994
- "Quality Assurance Project Plan," CH2M HILL, February 1994
- "Work Plan for Task 3.2.2, Phase I Indoor Radon/Thoron Decay Product Monitoring and Gamma Radiation Measurements, Kerr-McGee Residential Areas Site Engineering Evaluation/Cost Analysis and Remedial Investigation Feasibility Study, West Chicago, Illinois," CH2M HILL, January 1994

Initial outdoor surveys from 1994 through 1996 at properties within the RAS study area were performed to:

- Collect outdoor gamma walkover data, outdoor gamma exposure rates and soil radionuclide information by soil sampling and using pressurized ionization chambers, gamma scintillation detectors and in situ gamma spectroscopy to identify properties where USEPA's cleanup criteria were exceeded
- Collect outdoor gamma walkover data, outdoor gamma exposure rates, soil radionuclide information, and metals-in-soil information to support a baseline risk assessment in the RI report

CH2M HILL conducted indoor studies at some residences within the RAS study area from 1994 through 1996 in order to:

- Evaluate the indoor measurements as a discovery tool for locating contamination outside exterior walls and under the foundation of a structure
- Examine the potential exposure to radon and thoron in residences resulting from contaminated soils on the property
- Conduct indoor exposure measurements to support a baseline risk assessment in the RI report.

CH2M HILL conducted additional outdoor surveys from 1998 through 2000 at properties and right-of-ways (ROWs) within the expanded study area. These additional surveys were performed to collect outdoor gamma walkover data and outdoor gamma exposure rates, and to collect soil radionuclide information by soil sampling to identify properties that exceeded USEPA's cleanup criteria.

CH2M HILL summarized details of data collection, analyses, and interpretation from the field efforts in the following documents:

- **Data Processing Documentation.** CH2M HILL prepared a document that outlines the data process and documentation protocols for the RI/FS field investigations. It outlined the processing and management of the data collected in support of the RAS characterization. File structures and coding specifications, procedures used in preprocessing and postprocessing of raw data, and the output algorithms used to generate maps and graphical and tabular outputs, were identified. The document is called "Kerr-McGee West Chicago Sites, Data Processing Documentation," CH2M HILL, October 1994.
- **Pilot Study/Outdoor Survey Results.** CH2M HILL prepared a technical memorandum that summarized the development and application of decision rules to characterize the RAS. The memorandum defined the data used to develop the decision rules, specified factors included in the analyses, and schematically described the analytical strategy taken. It also described the application of the analytical results and decision rules developed to characterize properties within the study. The document is called "Decision Rule Development and Application, Kerr-McGee Residential Areas Site, West Chicago, Illinois," CH2M HILL, 1995.
- **Indoor Radon/Thoron Results.** The results and interpretation of the indoor studies were published in the technical memorandum "Radon/Thoron Surveys, 1994-96, Kerr-McGee Residential Areas," CH2M HILL, September 1997.

1.4.4 Scan Van Surveys by ORIA-Las Vegas (1995 and 1996)

To help refine the RAS study area, the USEPA contracted with the USEPA's ORIA Las Vegas facility to conduct scan van surveys of the West Chicago area in 1995 and 1996. The scan van surveyed areas of West Chicago located south of Hawthorne Lane in 1995 and identified a number of radiological "anomalies" that required further ground-level investigations. As a result, USEPA added the properties in these "anomalous" areas to the study area to identify the cause of the anomalies. The scan van returned in 1996 to survey areas of West Chicago located north of Hawthorne Lane. No radiological anomalies were identified during the 1996 scan van survey.

SECTION 2

Physical Characteristics of the Study Area

This section discusses the physical characteristics of the RAS necessary for evaluating potential pathways of contaminant migration. Background information on the RAS and adjoining areas is presented on land use and demographics, topography, meteorology, surface water hydrology, geology, soils, hydrogeology, environmental setting and ecological characteristics, and naturally occurring levels of radiation within the surrounding area. Potential contaminant migration pathways that result from the physical characteristics of the study area include soil and groundwater and are described in Section 5.

2.1 Surrounding Land Use and Demographics

The RAS encompasses residential, institutional, commercial, industrial, and municipal properties in and around West Chicago, which is roughly 30 miles west of Chicago. As described in Section 1, West Chicago is mainly a suburban area, consisting primarily of high-density single-family residential housing to the northwest, north, northeast, east, and south of the REF. Most of the residences were built before 1960. Each lineal block typically has 10 or more residences, with an average block length of 700 feet north-south. Scattered development and primarily industrial land use are present for about 1 mile to the north of the REF.

The 2000 Block Statistics for DuPage County, as prepared by the Bureau of Census, provides an approximate demographic profile of the City of West Chicago. According to the 2000 census, the population of West Chicago is 23,469. There are 6,739 households in the city, and the median age of the populace is about 28 years.

2.2 Topography

West Chicago lies within the Great Lake and Till Plains sections of the central Lowland Province, about 30 miles west of Lake Michigan. That part of DuPage County is characterized by gently rolling topography (Figure 2-1), with greater relief near rivers and creeks. Elevations there range from 810 feet above mean sea level north of West Chicago to 700 feet southeast of West Chicago on the West Branch DuPage River. Much of the area is open ground. Asphalt, concrete, and buildings and other structures are present, and the area is being developed.

2.3 Meteorology

The climate of Illinois is typically continental with warm summers, cold winters, and frequent periods of temperature, humidity, and wind direction fluctuations caused by easterly migrating weather systems. The West Chicago area, situated about 30 miles west of Lake Michigan, experiences some climate modifications from the lake. The annual average temperature is 48.9 degrees Fahrenheit (°F) with an average precipitation of 84.9 cm. The predominant wind direction is out of the southwest quadrant, with a predominance of generally westerly winds. The average wind speed is 11 miles per hour.

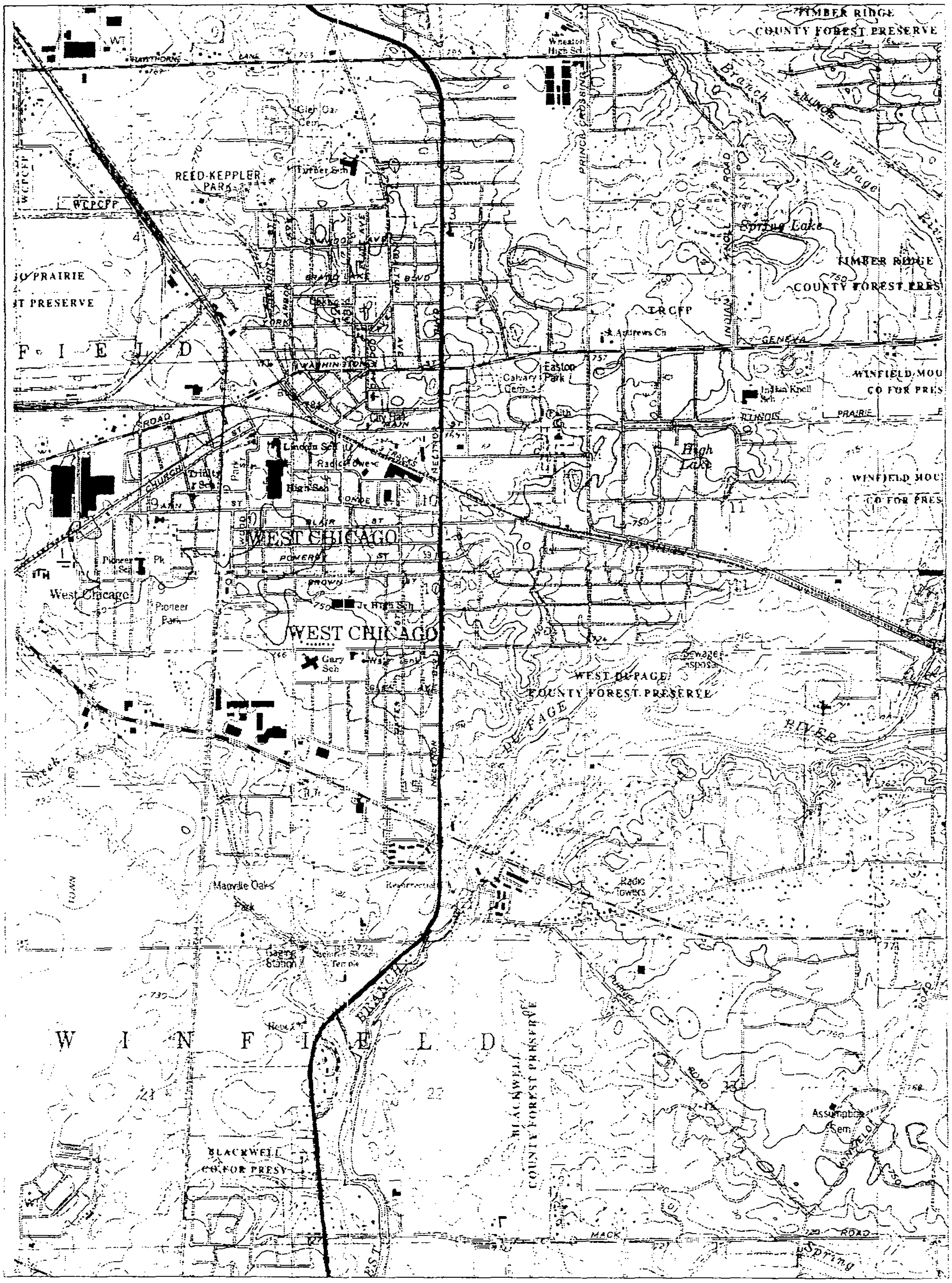


Figure 2-1
Topographic Map
Kerr-McGee West Chicago

2.4 Surface Water Hydrology

The West Branch DuPage River and Kress Creek are the two main water bodies near the RAS (see Figure 2-2).

The DuPage River, in northeastern Illinois within the greater Chicago metropolitan region, flows through Cook, DuPage, and Will counties. The rivers' headwaters consist of two branches: the West Branch DuPage River originating in Cook County and the East Branch originating in DuPage County. The land through which the DuPage River flows is characterized as topographically flat to rolling prairie with some marshy areas in the northern parts of the watershed. The DuPage River is a part of the 1,386-square-mile Des Plaines River Drainage Basin as it flows southward about 58 miles from its origin into the Des Plaines River at Channahon, Illinois.

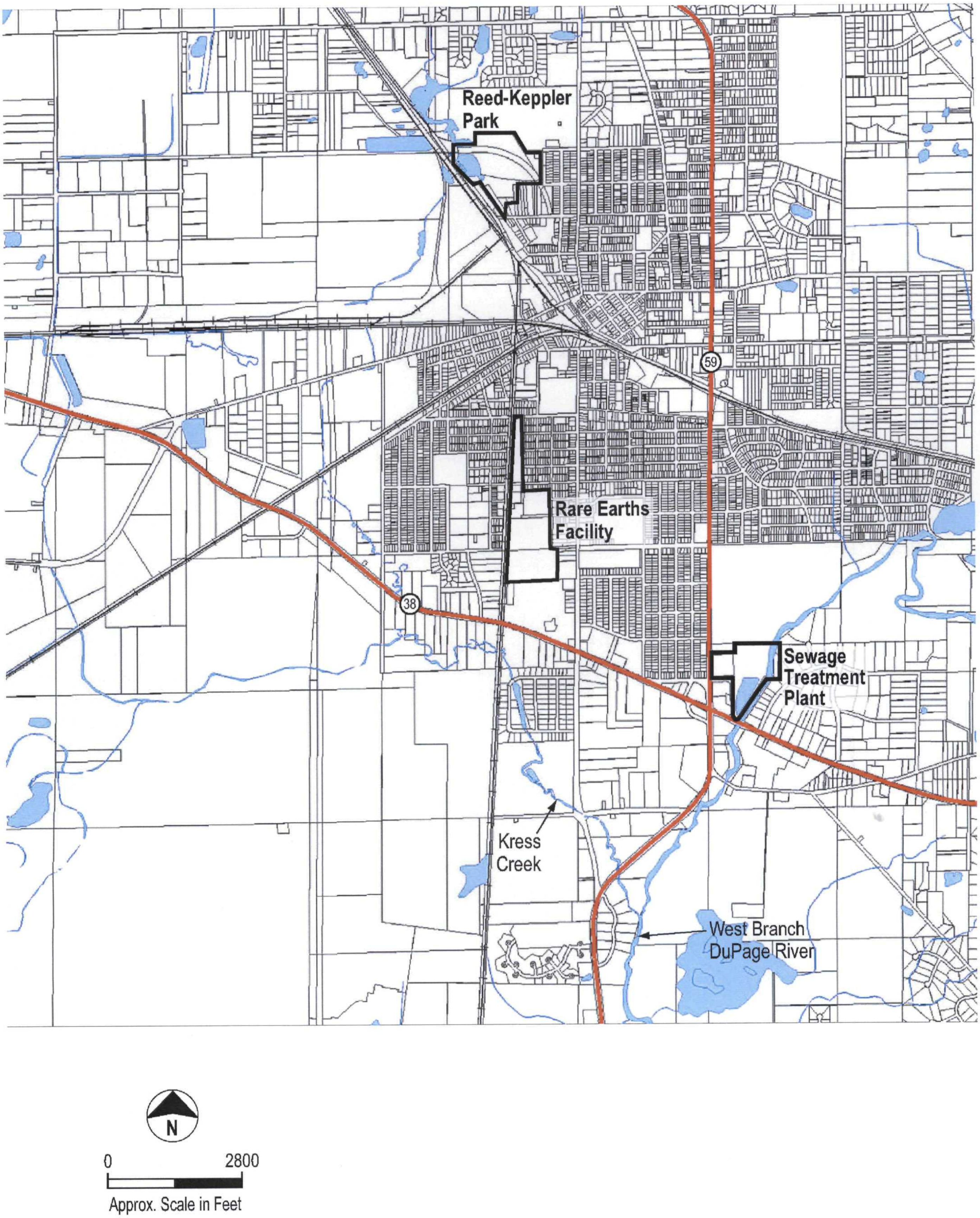
The West Branch DuPage River, which flows from its origin in Cook County and through DuPage County and parts of Will County, is 28.3 miles long and has an average gradient of 3.7 feet per mile and a drainage area of 380 square miles (Northeastern Illinois Planning Commission 1980). The West Branch DuPage River flows southward through forest preserve districts, agricultural lands, and urbanized areas toward its junction with the East Branch DuPage River, about 7.5 miles south of the junction of Kress Creek and the West Branch DuPage River.

In the vicinity of the RAS study area, the West Branch DuPage River is fairly consistently 40 to 50 feet wide and 2 to 5 feet deep (Frame 1984). At one point along the river's length, the east bank is bordered by a forest preserve and the west bank by undeveloped land and residential properties. The river has gravel banks and a stream bed that is stony and covered with vegetation.

Kress Creek originates in an industrial area north of the Fermi National Accelerator Laboratory and about 1.7 miles due west of the REF. From the origination point, Kress Creek flows south toward the Fermilab property. Beyond the Fermilab grounds, Kress Creek flows east under the tracks of the Elgin, Joliet, and Eastern Railroad, about 1,000 feet south of Route 38. Several feet beyond these tracks, a storm sewer outfall (which in the past carried stormwater runoff from the REF) and a track-side drainage ditch carry water into the creek. The creek continues easterly and then south again until it reaches its confluence with the West Branch DuPage River.

From the headwaters, Kress Creek is 7.5 miles long and has an average gradient of 6.61 feet per mile and an approximate drainage area of 19 square miles. The creek varies from 10 to 45 feet (Gunness Lake) in width and is generally 1 to 2 feet in depth (though it is deeper in some areas). The creek banks are heavily vegetated in some sections and vary in height and slope, ranging from low to 2-foot vertical banks. The creek bed is mostly sand and rock with some regions of hard clay and limited amounts of aquatic vegetation. Along both Kress Creek and the West Branch DuPage River, wet areas are connected to the water bodies only during high flows.

Portions of Kress Creek and the West Branch DuPage River are being investigated under the KCK and STP sites. Although important to understanding the hydrogeologic and geographic issues related to the West Chicago area, this RAS RI report does not address contamination or risk associated with either Kress Creek or the West Branch DuPage River.



Legend

Hydrologic Features

Figure 2-2

Water Bodies in West Chicago Area

Kerr-McGee West Chicago

2.5 Geology

The surficial geology of the region is characterized by glacial drift that was deposited by the Lake Michigan Lobe of a Wisconsinan-age glacier. The drift varies in composition from clay tills to gravels and sands. The thickness of glacial sediments ranges from less than 50 feet south of West Chicago to 150 to 200 feet north of West Chicago (Zeizel et al. 1962).
The surficial stratigraphy is characterized by generally alternating layers of silts/clays and sands/gravels. At the bottom of the glacial drift is a laterally persistent basal sand consisting of gravel grading upward to sands and silts. Above the basal sand is clay/silt till, which is overlain by a well-sorted sand and gravel outwash with some silt and clay.
The sand and gravel outwash is laterally discontinuous. Overlying the outwash, or contiguous with the lower till where the outwash is absent, a poorly sorted clay/silt with some sand and gravel is present. The clayey till is the uppermost unit within the ground (Law Engineering Test Company 1981).

The bedrock geology of this region consists of alternating formations of dolomites, shales, sandstones, and siltstones. Figure 2-3 presents a stratigraphic cross section of the regional geology in the area of West Chicago.

2.6 Soils

Soils are derived from underlying glacial drift—primarily till, glaciofluvial and lucustrine deposits, and outwash gravels. Samples from test borings collected from the area varied significantly in clay content (the active fraction), cation exchange capacity, exchangeable sodium, and mineralogy. The pH values of all samples were 7.0 or greater, ranging from 7.0 to 7.8. The effect of pH on ion exchange or trace ion adsorption in this range is expected to be negligible. The sum of the exchangeable bases greatly exceeds the cation exchange capacity due to the presence of slightly soluble compounds containing calcium and magnesium, in addition to ions displaced from the soil exchange system. Under natural groundwater conditions the trace ions will be competing primarily against calcium for exchange sites. In one sample, extractable sodium was present at a concentration considered significant. Montmorillonite is the dominant expanding mineral among the samples; however, vermiculite is also indicated (Law Engineering Test Company 1981).

2.7 Hydrogeology

2.7.1 Regional Hydrogeology

The surface bedrock system is the Silurian, which contains what is sometimes called the Silurian Aquifer. The Silurian, a dolomite aquifer (see Figure 2-3), is used for many local wells and, as of 1976, the deep public supply wells for the City of West Chicago (Rempo 1976). Those wells are screened at depths of roughly 1,300 feet. The Silurian Aquifer is an important nonpotable and, in some cases, potable water resource for the area.

SYSTEM	SERIES	GROUP OR FORMATION	GEOHYDROLOGIC UNITS	LOG	THICKNESS (FT)	DESCRIPTION
QUATERNARY	PLIESTOCENE	Glacial drift aquifers	Glacial drift aquifers		0 – 200±	Unconsolidated glacial deposits — pebbly clay (till), silt, sand and gravel Alluvial silts and sands along streams
DEVONIAN					Fissure fillings	Shale, sandy, brown to black
SILURIAN	NIAGARAN	Racine Waukesha Joliet	Niagaran aquifer (Silurian dol. aquifer)		0 – 170	Dolomite, very pure to highly argillaceous, silty, cherty; reefs in upper part Dolomite, shaly, and shale, dolomitic; maroon, green, pink
	ALEXANDRIAN	Kankakee Edgewood	Alexandrian aquifer (Silurian dol. aquifer)		0 – 90	Dolomite, glauc.; thin grn. shale partings Dolomite, argillaceous; silty and/or sandy, cherty
ORDOVICIAN	CINCINNATIAN	Neda	Confining beds of the Mequoketa Formation		0 – 20	Shale, red; oolites
		Mequoketa			85 – 230	Shale, silty, dolomitic; greenish, gray, weak (Upper unit) Dolomite and limestone, which light gray, interbedded shale (Middle unit) Shale, dolomitic, brown gray (Lower unit)
	MOHAWKIAN	Galena Decorah Platteville	Galena-Platteville (Cambrian-Ordovician aquifer)		300 – 350	Dolomite, and/or limestone, cherty Dolomite, shale partings, speckled Dolomite and/or limestone, cherty, sandy at base
		Glenwood	Glenwood-St. Peter (Cambrian-Ordovician aquifer)		200 – 375	Sandstone, fine and coarse grained; little dolomite; shale at top Sandstone, fine to medium grained; locally cherty red shale at base
	CHAZYAN	St. Peter				
	PRAIRIE DU CHIEN	Shakopee New Richmond Oneota	Prairie du Chien (Cambrian-Ordovician aquifer)		0 – 200	Dolomite, sandy, cherty (oolitic); sandstone Sandstone interbedded with dolomite Dolomite, white to pink, coarse grained cherty (oolitic), sandy at base
CAMBRIAN	CROIXAN	Trempealeau	Trempealeau (Cambrian-Ordovician aquifer)		80 – 190	Dolomite, white, fine grained; geodic quartz, sandy at base
		Franconia	Franconia (Cambrian-Ordovician aquifer)		70 – 100	Dolomite, sandstone and shale, glauconitic, green to red, micaceous
		Ironton	Ironton-Galesville (Cambrian-Ordovician aquifer)		175 – 200	Sandstone, fine to coarse grained, well sorted; upper part dolomitic
		Galesville				
		Eau Claire	Confining beds of the Eau Claire formation (upper and middle beds)		300 – 400	Shale and siltstone, dolomitic, glauconitic; sandstone, dolomitic, glauconitic
		Mt. Simon	Eau Claire (lower beds) and Mt. Simon formations (Mt. Simon aquifer)		2,000±	Sandstone, coarse grained, while, red in lower half; lenses of shale and siltstone, red, micaceous
						Precambrian

Source: Zeizel et al., 1962

Figure 2-3

General Stratigraphic Section for the West Chicago Site Region

Kerr-McGee West Chicago

The Ordovician and Cambrian systems lie below the Silurian (see Figure 2-3). They contain higher quality aquifers that are generally used for larger production wells. The city wells draw primarily from the Cambrian system, primarily the Ironton-Galesville Aquifer. However, because these wells are cased only to the bottom of the Maquoketa Shale, they are open to the Galena Platteville and St. Peter sandstone. Prior to 1974, one of the city's wells produced from the Niagaran and Alexandrian dolomite. The well was extended into the deeper aquifers in 1974. A city well near the STP produces from the Niagaran and Alexandrian dolomite of the Silurian system. However, the water currently produced from this well is treated with a grated stripping tower to improve water quality because natural gas is produced if the well is drawn down (Rempo 1976). The gradient of the bedrock aquifer for the area generally is southerly to possibly southeasterly.

2.7.2 Site Hydrogeology

Privately owned groundwater wells 80 to 200 feet deep are situated in the unincorporated parts of the RAS study area. West Chicago has an ordinance prohibiting the use of private wells for potable water supply within the city limits. Eleven monitoring well locations were tested and sampled at RKP in the area of the RAS. All the monitoring wells installed in the area are shallow, ranging from 15 to 40 feet in depth, and depth to top of groundwater ranges from 5 to 29 feet. The general surficial groundwater flow direction in the area of RKP is to the southeast. Although there are no available data to define discharge locations, the most likely eventual discharge locations for the surficial groundwater in the West Chicago area are Kress Creek and the West Branch DuPage River. Results of slug tests performed in December 1996 on wells installed at RKP showed the hydraulic conductivity of the shallow aquifer to range from 2×10^{-3} to 5×10^{-2} centimeters per second (cm/s).

Currently there are nine public wells in operation providing potable water to residents within the West Chicago service area. The wells include five deep wells 800 to 1,300 feet deep and four shallow wells with depths ranging from 200 to 400 feet.

2.8 Environmental Setting and Ecological Characteristics

As noted, the RAS encompasses residential, institutional, commercial, industrial and municipal properties in and around West Chicago. Most of the property in the RAS is single-family residential housing in the areas surrounding the REF and east and southeast of RKP. Sediments and banks associated with water bodies in the West Chicago area are being evaluated under the KCK and STP RI studies. Because this study focuses primarily on residential properties, ecological components are not addressed in this RI report and thus will not be addressed by the risk assessment presented in Section 6.

2.9 Natural Background Radiation

This section describes and quantifies background radioactivity for exposure levels, soil, and indoor air media addressed in this report. Figures 2-4 and 2-5 present the radioactive decay chains for Th-232 and U-238, which are natural radioactive components of the earth's crust. Th-232 decays to produce Ra-228; U-238 eventually decays to produce Ra-226. For the RAS characterization, concentrations of Ra-226 and Ra-228 are combined (i.e., total radium equivalents [RE] [Ra-226 + Ra-228]), and the total RE is used to indicate radioactive contamination in the soil. Measurement methods and reporting units for radionuclides used throughout this section have been described and defined in Appendix A.

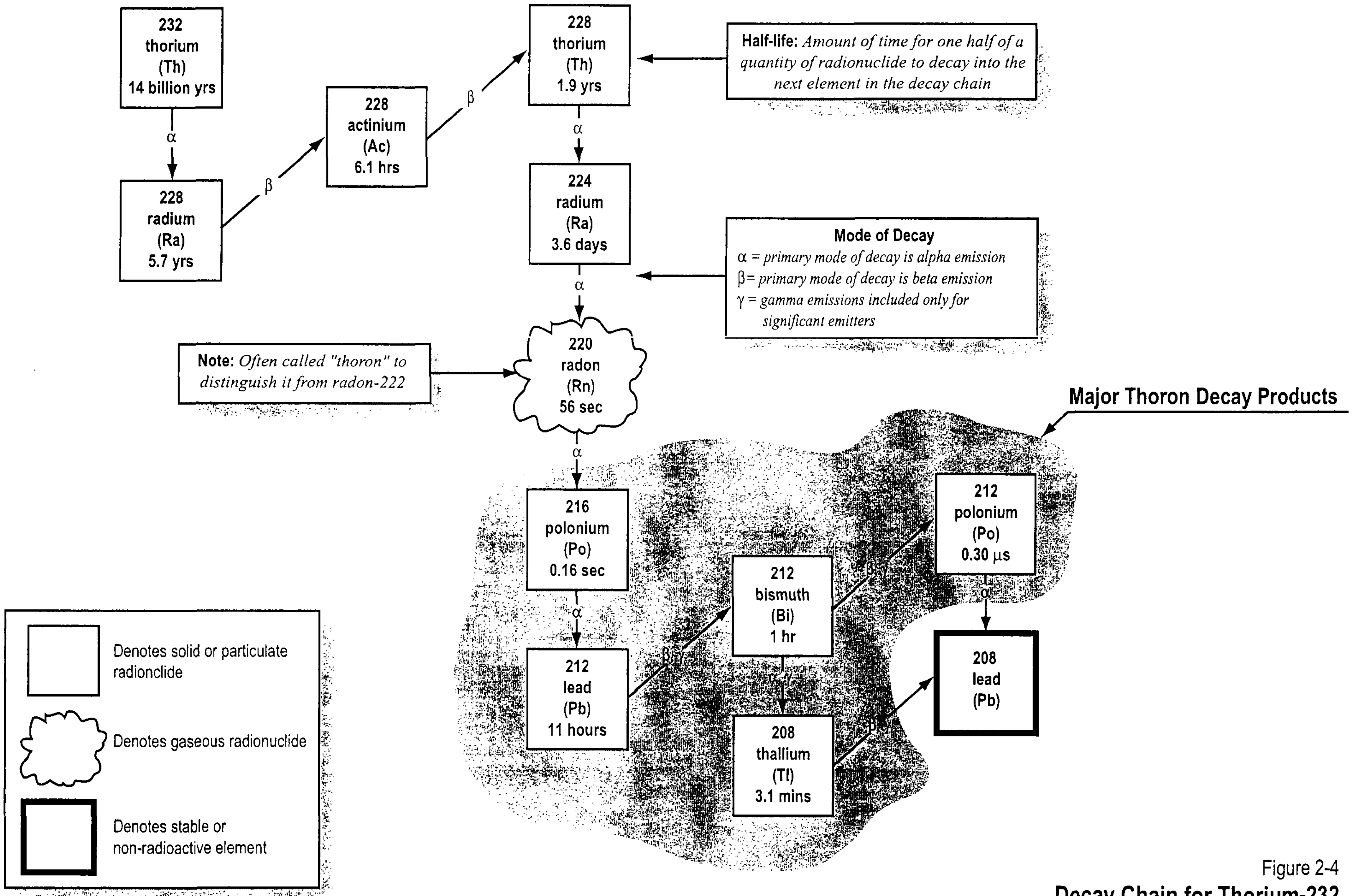


Figure 2-4
Decay Chain for Thorium-232
Kerr-McGee West Chicago

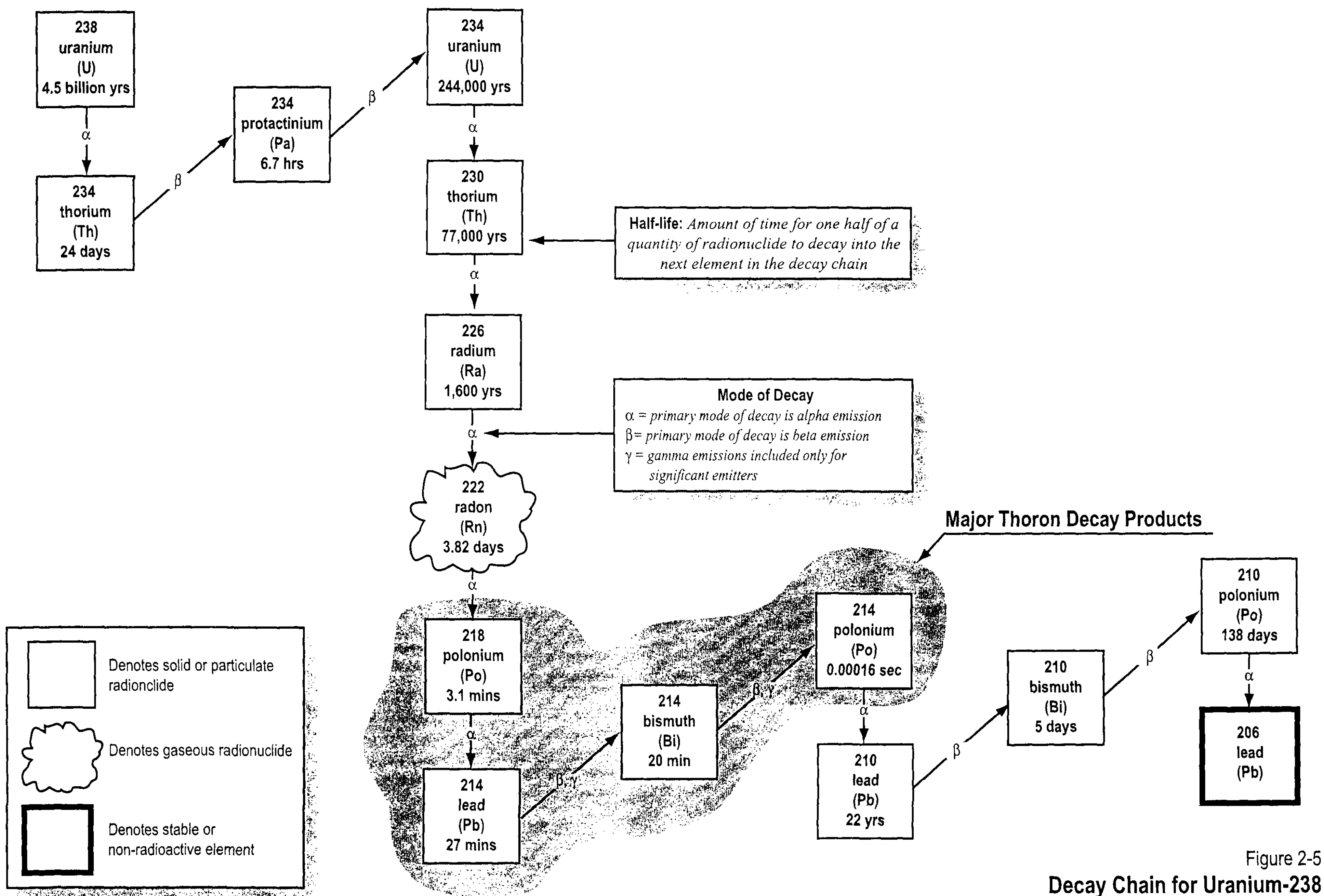


Figure 2-5
Decay Chain for Uranium-238
Kerr-McGee West Chicago

2.9.1 Radiation Exposure

Typical background gamma radiation exposure rates for the West Chicago area vary from about 5 μR/hr to 13 μR/hr (Frigerio et al. 1978; Frame 1984; Booth et al. 1982; IDNS 1993).

2.9.2 Radioactivity in Soil

The natural activity of Th-232 in background soil in the West Chicago area has been reported as ranging from approximately 0.85 pCi/g (IDNS 1993) to 1.6 pCi/g (Frame 1984). Under natural conditions, Ra-228, an alpha decay product of Th-232, is in secular equilibrium with Th-232. This means that the background Ra-228 level is also about 0.85 to 1.6 pCi/g. Booth et al. (1982) reported that an estimated background concentration for Ra-226 is approximately 1.4 pCi/g. IDNS did not report a Ra-226 value.

For this study, CH2M HILL estimated the background concentration of total RE from a set of 29 samples. These samples were composited from 0- to 6-inch grab samples collected from 60 designated background properties based on gamma surveys. The total RE concentration measured between 1.62 and 3.55 pCi/g; the mean concentration was 2.18 pCi/g. Section 3.2 contains a more detailed description of this study.

2.9.3 Radon and Thoron

Rn-222 (radon) and Rn-220 (thoron) are noble gas decay products from the U-238 and Th-232 decay chains, respectively, and are present under ambient conditions. These gases diffuse or migrate from soil and rock that contain the parent radionuclides. Because uranium and thorium are found naturally in soil, radon and thoron can be detected both outdoors and indoors. The average radon and thoron level (combined) in outside air is 0.4 pCi/L; the average indoor radon and thoron level (combined) is 1.55 pCi/L. Levels of radon in excess of 4 pCi/L in indoor air are considered elevated according to USEPA guidelines. The average outdoor thoron level has been estimated at 0.27 pCi/L (Li et al. 1992; Schery and Grumm 1992).

CH2M HILL measured radon and thoron in terms of WL. The derivation of the WL is described in Appendix A. 0.02 WL is roughly equivalent to 4 pCi/L.

2.9.4 Radioactivity in Groundwater

Illinois, specifically the West Chicago area, is unique because of generally high concentrations of Ra-226 in deep groundwater relative to naturally occurring uranium deposits. Private wells screened in the shallow Silurian Aquifer have been found to contain radium, thorium, and uranium levels near regional background levels as measured in samples taken from Lake Michigan. Ra-226 levels in municipal wells screened in the deep Ironton-Galesville formation, 1,350 to 1,465 feet below land surface, exceeded background levels for Lake Michigan by one or two orders of magnitude because of natural radium, not because of thorium wastes. The city diluted the water from the deep wells with water from shallow wells in an attempt to reduce the levels of radium to meet USEPA drinking water standards (Fermilab et al. 1981). In spite of dilution with water from shallow wells, the municipal water supply of West Chicago has continued to exceed the drinking water standard for radium. The city is developing a facility to remove radium from the municipal water supply, with completion of the facility expected in 2004 (U.S. Department of Health 2003).

SECTION 3

Study Area Investigation

This section describes the field activities conducted within the RAS study area during the RI and defines how results from those activities were used to characterize the properties or portions of properties that required remediation to achieve the USEPA's cleanup criteria. The field activities conducted at the RAS included outdoor and indoor studies. Section 3.1 describes the types of sampling performed outdoors and indoors with information on the data development and analysis activities for each type of sampling results.

Section 3.2 describes results from the pilot study conducted at representative properties within the RAS at the beginning of the field investigation (March through June 1994). Analytical results for these properties provided the basis of the decision rules for implementing USEPA action levels and for identifying whether a property required cleanup. Section 3.3 describes how field investigation results were processed and summarized to document cleanup recommendations made to the USEPA. Section 3.4 generically describes the implementation of the decision rules applied to the RAS field investigation results. Finally, Section 3.5 provides examples of the deliverable package for a prototypical DU and an individual property, as submitted to the USEPA for removal decisions.

3.1 Characterization Studies

This section describes the methods used by CH2M HILL to conduct the outdoor and indoor studies for the RAS study area. Table 3-1 summarizes the key characterization surveys and measurements.

TABLE 3-1
CH2M HILL Sample Collection Summaries

	Outdoor Gamma Surveys[a]	Indoor Measurements[b] and Samples	Soil Samples[c]	In Situ Gamma Spectroscopy M1 Measurements
Primary	2,018	2,124	2,427	307
Duplicate	122	211	245	29
Total	2,140	2,335	2,672	336

[a]Includes both the initial and expanded study areas.
[b]Each wall and floor surveyed within a property constitutes a single measurement. (See Table 3-3.)
[c]Includes 571 composite, 1,572 grab, and 353 Marinelli samples analyzed by IDNS for radiological parameters, and 176 CLP samples. Samples were collected from both the initial and expanded study areas. (See Table 3-2.)

3.1.1 Outdoor Studies

The outdoor studies associated with the RI that are summarized in this report were conducted from 1994 through 1996 and 1998 through 2000, in accordance with the Work Plan (USEPA 1994a) and the Quality Assurance Project Plan (QAPjP; USEPA 1994b). These studies, which were conducted at individual properties, included surface gamma scan (walkover) measurements, in situ gamma spectroscopy (M1) measurements, exposure rate measurements, and soil sampling activities. The activities are described in the following subsections.

Some or all of the methods described below were used on properties within the site study area. The methods used by staff from the USEPA's ORIA Las Vegas facility during the scan van surveys, which were performed to locate radiological anomalies outside the initial study area, are also described. Properties outside the initial study area that were identified as anomalies by the scan van surveys were then surveyed and sampled, as necessary, by the methods described in the following subsections. Data processing and analysis and interpretation of outdoor results are briefly described in Section 3.3. Section 4 contains the sitewide summary of the outdoor study data.

3.1.1.1 Gamma Surveys

Gamma scan (walkover) surveying was the primary tool for characterizing contamination on properties within the RAS. M1, exposure rate measurements, and soil sampling were performed, as needed, to obtain additional data for characterization and risk assessment purposes. As noted, scan van gamma surveying was conducted to help identify additional properties that needed walkover surveying.

Gamma Scan Surveys. Gamma scanning surveys provided data on the location, surface distribution, and relative amount (based on count rate) of surface soil radiological contamination. Radiation survey instrumentation coupled to a global positioning system (GPS) was used for the gamma scan survey at each property. As described in Section 1.2.1, properties targeted for characterization included (1) properties within the perimeter of the original "flyover footprint," (2) properties not within the footprint but within a DU partially within the original footprint (step-out surveys), (3) properties identified as "anomalous" by the scan van surveys performed throughout the area outside the flyover footprint, and (4) properties in the expanded site study area based on the USEPA's decision in 1998 to include more properties in the study area.

Gamma scans were conducted so that virtually 100 percent of the accessible surface of each property, including drives, walkways and ROWs, was covered by the survey. Property surveys covering the entire property consisted of parallel transects separated by 5 feet.

Gamma activity measurements, recorded as counts per minute (cpm), were taken using 2-inch-square sodium iodide (NaI) detectors coupled to Ludlum Model 2221 ratemeter/scalers. The probes were swung in a vertical arc with the lowest point about 6 inches above ground. Swinging the probes from left to right while walking along parallel transects effectively covered not only the transect lines but also the space between the transect lines. The count rate was recorded every 2 seconds and coupled with position coordinates from the GPS using a Trimble TDC-1 datalogger A NAVSTAR GPS was used to establish horizontal position for the continuous scan data obtained from the radiation walkover survey. Count rates and location coordinates for a property were recorded in an individual data file for that property. For a typical property, roughly 10,000 square feet, the survey resulted in about 1,100 point readings of northing, easting, and gamma activity.

Following the collection of data, the file was postprocessed to translate the coordinate locations from satellite readings recorded during the survey, using coincident readings collected at the base station, a known location. As described in Section 3.3, that file was uploaded into the primary database and accessed by ARC/INFO to generate a geographic information system (GIS) property map displaying the survey results.

Gamma Spectroscopy. M1 measurements were conducted during the initial stages of the RAS field investigations at about 10 percent of the background and slightly above background locations, as characterized by the gamma walkover surveys. The in situ measurements (336 samples) were taken to provide quality assurance/quality control (QA/QC) documentation that nuclide concentrations in soils characterized as uncontaminated were, in fact, less than the USEPA's action level (background plus 5 pCi/g total radium). M1 surveys were deemed no longer necessary and were discontinued after refinement of field methods developed following submittal of the decision rule technical memorandum for the characterization process. Surveys supplemented with grab soil sample collection and analyses replaced the M1 sampling.

The in situ system used for the M1 gamma spectroscopy measurements was an EG&G Ortec portable high-purity germanium (HPGe), GEM Model, detector. The system is made by Nomad and consisted of a multi-channel analyzer and spectrometer set about 1 meter above ground surface. In accordance with instrument calibration to known sources, the gamma spectrometer can accurately identify and quantify gamma-emitting radionuclides in environmental media. Gamma spectrometry was used to determine approximate soil concentrations or to determine the proportion of gamma radiation from background sources versus thorium tailings material.

Exposure or Dose Rate Surveys. Exposure rate measurements were taken with M1 measurements as part of the characterization process to determine the proportion of gamma radiation related to background sources versus thorium tailings material. This information was useful at locations showing elevated exposure rates caused by naturally occurring radionuclides (such as potassium-40 in fertilizer placed in a garden).

Exposure or dose rate measurements were taken at a height of 1 meter at selected properties using a tissue equivalent dose rate instrument pressurized ion chamber (PIC) or a gamma scintillation detector calibrated to exposure rate for the mixture of gamma energies of concern at this site. Initially, the PIC measurements were taken at each location where a gamma spectroscopy survey was conducted. Gamma exposure measurements were also taken at 10 percent of the properties determined to be uncontaminated based on gamma scan results.

Mobile Scanner Van Studies. The U.S. EPA recognized that the potential for contamination could exist and yet not be detected by the 1989 EG&G flyover survey taken from a helicopter flying overhead at 150 meters (500 feet). Therefore, in 1995 and 1996 the USEPA ORIA, Las Vegas, used the scan van to measure gamma activity in areas adjacent to and outside the original site study area.

The scan van (Mobile Scanner Van) is a modified commercial delivery truck equipped with a 4-inch × 4-inch × 16-inch NaI detector with a 3.5-inch photomultiplier tube and a PIC. Both instruments are displayed on the operator's console and are recorded on an analog strip chart recorder to identify elevated areas and to provide a permanent record of the measurements.

The instruments are capable of detecting very low levels of contamination and have the sensitivity to distinguish between background and measurements slightly above background.

For locations where elevated radiation levels were discovered outside the original study area with the Mobile Scanner Van, the same characterization protocols (gamma survey and soil collection) as those applied to properties inside the "footprint" were used to locate the source of gamma anomalies that had been detected by the scan van.

3.1.1.2 Soil Collection and Analysis

Soil samples from the RAS study area were collected for metals analysis during the pilot study and for radiological analyses throughout the RI. The type of soil sample, collection method for each, analytical protocols for metals, and radiological quantifications are described in the following subsections. Table 3-2 summarizes the numbers and types of soil samples collected and the analytical methods used for each. Section 4 presents the general results of the soil analyses.

TABLE 3-2
Breakdown of Soil Samples by Type

	All Soils	M1	IC	IG	IM	CC	CG	Interlab Comparison
Primary	2,734	307	517	1,419	327	149	15	–
Duplicate	274	29	54	153	26	12	0	–
Total	3,061	336	571	1,572	353	161	15	53

M1 = Samples collected from the in situ gamma spectroscopy 10-meter radius composite
IC = Composite sample submitted to IDNS for radiological analysis
IG = Grab sample submitted to IDNS for radiological analysis
IM = Marinelli sample submitted to IDNS for radiological analysis
CC = Composite sample submitted to the CLP Laboratory for metals analysis
CG = Grab sample submitted to the CLP laboratory for metals analysis

Soil Sample Collection Methods. Both composite and grab soil samples were collected for metals and radiological analyses. Composite samples were collected to identify representative contamination from a general area within a property. Grab samples were collected, in accordance with gamma surveys, from specific, biased (e.g., high or borderline radioactivity) locations. These methods are as follows.

Composite Samples. To collect a composite soil sample, five locations were randomly allocated within a circle with a radius of 10 meters around a point. Grab samples collected at the random locations were composited into zero- to 3-inch, zero- to 6-inch, and 6- to 12-inch samples from each location. Surface vegetation and roots were not included in the analysis of shallow samples. Soil samples were collected using two methods. Zero- to 3-inch and zero- to 6-inch samples were collected using a golf course hole or cup "plugger." Samples collected from 6 to 12 inches or greater were collected using a hand auger. The five fractions at each depth interval were composited into one sample for each depth. These samples were then sent to the respective laboratory (Contract Laboratory Program [CLP] or IDNS) for processing and analysis. Samples collected for metals analyses were placed in 8-ounce wide-mouth jars and cooled to 4 degrees Celsius (°C). Samples collected for radiological analyses were placed in 1-L wide-mouth glass or plastic jars. Radiological samples did not require cooling.

Grab Samples. Grab samples were collected from zero- to 6-inch, 6- to 12-inch, and 12- to 18-inch depths using a golf course cup plugger. The depths were based on downhole activity readings. Samples collected for metals analyses were placed in 8-ounce wide-mouth jars and cooled to 4 °C. Samples collected for radiological analyses were placed in 1-L wide-mouth glass or plastic jars. Radiological grab samples did not require cooling.

Laboratory Metals Analyses. Composited samples for metals analyses represented 50 general locations throughout the RAS study area. Samples covered the range of radiological readings in order to quantify metals levels in materials representative of thorium tailings that had originated from the REF. For the pilot study, 161 composited samples from 25 parcels, and 15 grab samples from 7 of the parcels, were collected for barium, lead, and chromium analyses. The samples were analyzed using the USEPA CLP's Statement of Work (SOW) ILM02.1. The results were sent to USEPA Region 5 for data validation. Of the 161 composited samples collected, 12 were duplicates. Table 3-2 presents a breakdown of the metals analyses. The results of these studies are presented in Section 3.2.

Laboratory Radiological Analyses. For radiological analyses, soil samples were taken to confirm gamma spectroscopy results on a frequency of 15 percent (roughly one set of three composite samples per day, assuming six to seven gamma spectroscopy measurements per day). Samples were also collected to determine soil activity levels at locations where the gamma spectroscopy system could not be used. The shallow soil sample (zero to 3 inches) provided an indication of potential windblown activity for risk assessment purposes at locations near the REF. The other depth intervals provided information for those properties contaminated by mechanisms other than windblown dust. A total of 571 composite samples were collected. These samples were then sent to the IDNS laboratory for processing (grinding and drying) and analysis for total radium (Ra-226 and Ra-228). The sampling and analyses of all composite samples were conducted according to the EE/CA and RI/FS Work Plan. A total of 54 duplicate composite samples (10 percent) were collected for radiological analyses.

In conjunction with a subset of composited samples, 327 primary samples were split into two aliquots. The first was handled as described above. The second was placed into a Marinelli beaker and submitted to the IDNS laboratory for analysis. The Marinelli samples were not processed and were analyzed for total radium (Ra-226 and Ra-228). Samples collected in Marinelli beakers were evaluated to determine the potential effects of processing on Ra-226 and Ra-228 quantification and its impact on the comparison of results with the in situ gamma measurements. The sampling and analysis of the Marinelli samples were conducted in accordance with a modified protocol developed during the pilot study. Twenty-six duplicate Marinelli samples were collected for radiological analysis.

Grab samples were collected to verify gamma survey results. These samples were collected and submitted to the IDNS laboratory for processing and analysis, and the samples were analyzed for total radium (Ra-226 and Ra-228). A total of 1,572 grab soil samples were collected and analyzed for radionuclides. Duplicates accounted for 153 of the grab samples.

The radiological samples were analyzed by IDNS using HPGe detectors in accordance with Appendix G of the QAPjP (USEPA 1994b).

Table 3-2 lists the numbers and types of soil samples collected and the analytical methods used for each. Section 4 presents general results for the composite, Marinelli, and grab samples.

3.1.2 Indoor Studies

The indoor study was divided into two phases. Phase I was used to evaluate the indoor gamma surveys and radon/thoron sampling as tools for locating contamination outside exterior walls and under the foundation of a structure and to examine the potential exposure to radon and thoron in the residences that results from contaminated soil on the property. Many of the Phase I properties were selected because they were known to be contaminated based on previous surveys performed by Kerr-McGee and IDNS. In accordance with the Phase I Indoor Radon/Thoron Decay Product Monitoring and Gamma Radiation Measurements Work Plan (USEPA 1994a), Phase I indoor studies, which included radon progeny integrating sampling unit (RPISU) samples and gamma surveys, were conducted between January 25 and April 1, 1994, at selected homes within the RAS (these measurements were taken just before the pilot study).

On the basis of the results from Phase I, indoor sampling for the remainder of the characterization work in the initial RAS study area (Phase II) was limited to gamma surveys along walls and floors of subsurface areas in buildings (basements and crawl spaces) and collection of radon/thoron RPISU samples from a small subset of properties. Selection of properties for radon/thoron sampling was based on the results of the indoor gamma surveys, and only properties with elevated indoor gamma readings were considered for radon/thoron sampling. Phase II surveys were conducted in 1995 and 1996 at properties in which indoor access was provided by the owner.

Based on the results of the combined Phase I and II indoor studies, USEPA decided not to conduct indoor studies at properties in the expanded site study area (1998 through 2000) because the indoor studies did not significantly aid in the discovery of contamination at properties.

Table 3-3 presents the numbers of the different types of measurements completed during Phases I and II (combined) of the indoor study.

TABLE 3-3
Breakdown of Indoor Samples by Type

	Total Indoor Measurements and Samples	Wall Scan Measurements*	Floor Scan Measurements*	Bicron (Dose Rate) Measurements	Number of RPISU Samples
Primary	2,124	701	672	664	86
Duplicate	211	67	68	65	11
Total	2,335	768	740	729	97

*Each wall and floor surveyed within a property constitutes a single measurement.

3.1.2.1 Indoor Gamma Survey

Gamma radiation measurements were taken using either NaI gamma scintillation detectors or portable exposure or dose rate instruments (Micro-R or Micro-Rem instruments). Gamma radiation measurements were taken for discovery purposes only and consisted of scanning the floors and walls in the lowest part of the house (basement or crawlspace, if possible). Gamma activity (count rate) and dose rate measurements at wall and floor locations were used to characterize each wall and floor area. The results of these studies are presented in Section 4.3.

3.1.2.2 Radon/Thoron

The survey meter RPISU was used to measure radon and thoron gas decay product concentrations. The USEPA chose this instrument because of its ability to discriminate between radon and thoron decay products.

This task included radon and thoron decay product monitoring during discovery operations to provide data on near worst-case, closed home conditions. To the extent possible, samples were placed in residences according to procedures specified in EPA 402-R-92-004, *Indoor Radon and Radon Decay Product Measurement Device Protocols*. However, to maximize the chance of locating properties with thorium tailings and to achieve conservative radon/thoron decay product measurements, the general practice was to place the devices in the lowest accessible area (crawlspace or basement). Properties that showed high radon/thoron decay product measurements under such conditions were candidates for additional measurements and further characterization to determine whether deposits of tailings were located outside near the walls or floors.

Further characterization decisions were based on the evaluation of the source of the elevated radon/thoron decay product concentrations. Background radon/thoron decay product measurements were taken inside residences at uncontaminated properties. Those measurements were used to determine the background of radon and thoron decay products and the relative concentration ratio of decay product concentrations. An evaluation was performed to determine the difference in the absolute concentrations and the ratios of radon/thoron progeny in homes in background areas to homes in contaminated areas. This evaluation included a simple geological assessment of soil types in background and contaminated areas. Based on this evaluation, design criteria were developed to trigger additional investigation at properties that showed elevated radon/thoron decay product concentrations. Residences that showed elevated radon/thoron decay product results attributed to natural conditions were not candidates for further characterization (unless contaminants were found at another part of the same property). Residences that showed elevated radon/thoron decay product concentrations determined to be related to thorium mill tailings were candidates for further characterization.

Radon/thoron decay product monitoring was performed in winter (when possible) under closed house conditions. Sampling was conducted in two phases. Phase I sampling was conducted during January through March 1994 and Phase II during 1995 and 1996. Section 4.3 describes the results of the radon/thoron sampling.

3.2 Pilot Study

To develop protocols for the appropriate and consistent characterization of potential contamination in the RAS, a pilot study was conducted during March and April 1994 to accomplish the following:

- Define background levels of radioactive concentration in soils.
- Quantify relationships among field measurements (gamma scan surveys and in situ and laboratory-quantified nuclide levels in soils).
- Evaluate relative contamination at different depths.

- Determine the level of metals contamination associated with the thorium mill tailings.

The USEPA's cleanup criterion for soils in the RAS study area is background plus 5 pCi/g of total RE, defined as the sum of the measures of Ra-226 and Ra-228. On the basis of this criterion, the USEPA developed decision rules to be applied in the field that would dictate action at the RAS study area. The following subsections briefly describe the background for developing the criteria that correspond to cleanup decisions. Detailed information on data interpolation and decision rule development and application is provided in *Decision Rule Development and Application, Kerr-McGee Residential Areas Site, West Chicago, Illinois, Technical Memorandum* (CH2M HILL 1995)[1].

3.2.1 Pilot Study Description

The 1994 pilot study consisted of extensive surveying and sampling at representative properties within the RAS study area. The surveys were performed using an unshielded Ludlum gamma detector coupled with a GPS. Approximately 284 acres, which included 409 properties, were surveyed. Ten of the properties were surveyed in duplicate to estimate uncertainty resulting from variability in the surveying method. Soil samples were collected from 175 locations (three depths at each location) for radionuclide analyses performed by IDNS. Roughly 200 M1 (in situ) readings were taken from 100 properties. Soil samples were collected from 50 locations and submitted to a CLP laboratory for metals analyses.

3.2.2 Results from the Pilot Study

3.2.2.1 Background Definition

Background levels of total RE were estimated from a set of 29 soil samples that had been composited from zero- to 6-inch grab samples collected from designated background properties. Total radium quantified in the 29 (zero- to 6-inch) samples ranged between 1.62 and 3.55 pCi/g. The mean was 2.18 pCi/g (or 2.2 pCi/g) with a standard deviation of 0.44.

3.2.2.2 Radionuclide Concentrations at Different Soil Depths

Comparisons of radionuclide levels at different sample depths from the same sample location indicated that while individual results exhibited some attenuation with depth, differences in radionuclide levels with depth were not statistically significant. Lack of statistically significant differences indicated that selection of data to be used in developing decision rules could be based on practical considerations with negligible effect on modeled estimates.

3.2.2.3 Metals

As noted, one objective of the pilot study was to evaluate metal levels in REF materials distributed on residential properties. Three issues were considered: (1) metals concentrations versus depth, (2) metals concentrations versus radiological activity, and (3) metals concentrations in comparison to available criteria.

[1] The use of the word *rule* in this context does not create a legal obligation, but instead simply describes the logic of the methodology used to conduct characterization.

Conclusions from the pilot study results included the following:

- Metals concentrations did not differ significantly with different depths at the same location.
- Metals concentrations were independent of total RE and, consequently, were not elevated as the result of the presence of thorium mill-tailing materials.
- Preliminary remediation goals (PRGs), established in the EE/CA, indicated that metals concentrations of potential concern were: 11,600 milligrams per kilogram (mg/kg) for barium, 832 mg/kg for chromium, and 400 mg/kg for lead. Maximum concentrations detected in the composite samples were 385 mg/kg for barium, 23 mg/kg for chromium, and 360 mg/kg for lead. Metals were therefore eliminated from further consideration in the development of decision criteria.

3.2.3 Decision Rule Development

Gamma surveys and M1 (in situ) measurements were conducted and soil samples collected to calibrate the specific gamma survey instrumentation used during RI field activities to corresponding EPA action levels of total radium in soils. The analytical solution of the decision rules required two quantities: background levels of total RE and regression estimates relating total RE to gamma activity. As described in Section 3.2.2.1, the mean concentration of total radium from background samples was 2.2 pCi/g, resulting in an action level of 7.2 pCi/g total radium in soils. Within the study area, 139 sets of gamma measurements were paired with total radium concentrations reported from zero- to 6-inch composited soil samples collected at the same location. The gamma measurement represented the average activity for all gamma survey readings recorded within the radius of the same circle from which the five grabs were composited. Distributions of gamma counts within the 10-meter radius of the sampled area in 76 of the 139 sets of paired observations were classified as homogeneous; 51 were classified as heterogeneous (where localized hot spots of gamma activity exist within the area); and 12 were classified as anomalous (isolated pockets of elevated gamma measurements).

To predict gamma levels from soil concentrations of total REs, the 76 homogeneous sets of paired gamma readings and associated soil sample results were used to estimate the relationship between the gamma survey results and soil concentrations, using regression analysis. Regression models were developed using SYSTAT, statistical software developed by L. Wilkinson et al. (Evanston, Illinois). The estimated regression model is described mathematically:

$$\text{Log 10 GAMMA (cpm)} = 3.851 + 0.609\ (\text{Log 10 Total RE})$$

As described earlier, the USEPA's cleanup criterion for the RAS study area is background plus 5 pCi/g of total radium equivalent (RE, defined as the sum of the measures of Ra-226 and Ra-228). Therefore 7.2 pCi/g [2.2 pCi/g (background) + 5.0 pCi/g] was identified as the cleanup criterion. The cleanup criterion, consisting of a best estimate and upper limits (UL) and lower limits (LL) of uncertainty, predicting gamma activity corresponding to the USEPA's action level was estimated from the regression equation:

Criterion: GAMMA associated with RE background + 5pCi/g = 23,700 cpm
UL: Upper Confidence Limit (UCL) associated with $RE_{background}$ + 5pCi/g = 25,500 cpm

LL: Lower Confidence Limit associated with $RE_{background}$ + 5pCi/g =21,800 cpm

The decision rule interval of 21,800 cpm and 25,500 cpm for the survey instruments used during the RI field work results in classification of gamma activity into three categories: (1) less than the cleanup criterion; (2) greater than the cleanup criterion; and (3) lying in the "gray area" between the UL and LL, evidence of enough uncertainty in predicting soil concentrations to warrant more detailed soil sampling and nuclide quantification.

The regression results were used to develop decision rules to be based upon survey results as follows.

- Gamma activity levels less than 21,800 cpm fall below the USEPA cleanup criterion of background plus 5 pCi/g total radium. Further action in such areas generally would be limited to 10 percent QA/QC confirmation samples, unless the USEPA directed further sampling.
- Gamma activity levels greater than 25,500 cpm exceed the USEPA's cleanup criterion of background plus 5 pCi/g total radium.
- Gamma activity levels falling within the interval either (1) required further sampling (if the areas were not contiguous with areas exceeding the USEPA's criterion) or (2) were targeted for QA/QC verification to define accurately the locations requiring cleanup.

Accuracy of results modeling of gamma surveys was tested using the 139 pairs of gamma-total radium pairs. The model correctly classified 85.3 percent of the 139 pairs tested. A single false negative (incorrectly classifying the soil as uncontaminated when total radium concentrations measured in the soil were, in fact, above the cleanup criterion), resulted in a false negative rate of less than 1 percent. The other the false classifications were false positives (incorrectly classifying the soil to be contaminated when concentrations in the soil were below the cleanup criterion), with a cumulative false positive rate of ~15 percent.

The USEPA also specified that levels of total RE in backfill imported from offsite during the restoration of properties in the RAS must be within normal background range for the RAS study area. For this purpose, background conditions were defined using results from 59 composite soil samples collected from the zero- to 6-inch and 6- to 12-inch intervals on uncontaminated properties within the study area. The mean total radium concentration is 2.2 pCi/g, the standard deviation is 0.52 pCi/g, and the standard error on the mean is 0.07pCi/g. For the purpose of backfill screening, the target total radium concentration is 3.7 pCi/g (2.2 pCi/g + 3 × 0.52 pCi/g). Acceptable backfill material must be below this target concentration.

3.3 Overview of the Data Processing Functions

This section describes the data processing required to implement the USEPA's decision rules in the interpretation of field investigation results. The section includes specification of the hardware and software (Sections 3.5.1 and 3.5.2) then follows with sample type-specific descriptions of how data were captured, tracked, preprocessed, validated, evaluated, and displayed in routine outputs.

3.3.1 System Specification

Figure 3-1 depicts the computer system hardware and software configuration for the RAS study area data processing and display. The specific components of the system were configured to handle the projected technical and analytical requirements of the project. The system is modeled after a client-server architecture with the following key features:

- The centralized database was stored in one location (the "server"). Access was limited and controlled.
- Users were permitted access to the central database located on the server using personal computer (PC) workstations. They were assigned access privileges appropriate to the database functions that they were to perform.

The database management system was based on two components: a tabular database that was used to store all analytical and radiological data, and a GIS to handle geographic features and their attributes.

The GIS software used was ARC/INFO, developed by Environmental Systems Research Institute (ESRI). ARC/INFO provides the analytical tools necessary to analyze and display the geographic data collected. Oracle 7 was the software used for the tabular database. This system is easily interfaced to a variety of PC-based software packages and is more flexible and easier to use than INFO, the database system provided with ARC/INFO. Queries of the database were run using the SQL PLUS software developed by Oracle. Data were loaded to the database, queried, and used in conventional reports through software applications developed by CH2M HILL.

Supplementary software to facilitate tracking activities in both the field and data validation offices was developed using Microsoft Access. Statistical analyses of the data were performed using SYSTAT or S+. Both programs are PC-based software applications.

3.3.2 Data Processing

Data processing functions for the RAS were specifically designed to correspond to the types of data collected during the field investigation, including GPS surveys, soil sample collection, and indoor surveys.

The functions in data processing were schematically displayed as a drop-down menu. While the data processing sequence varied depending on the source of data, the sequence started with specification of how data were captured. Data were next tracked through the steps of preprocessing, validation, evaluation, and loading into the data management system (DMS). The final function, which was the objective of the entire data processing structure, was the generation of outputs, including tables, statistical results, and graphical and mapping displays.

The following subsections describe the steps of data capture, tracking, preprocessing, validation, evaluation, loading, and outputs. These steps are briefly described for the GPS data, M1 data, and soil samples results for radiological and metals analyses, as appropriate.

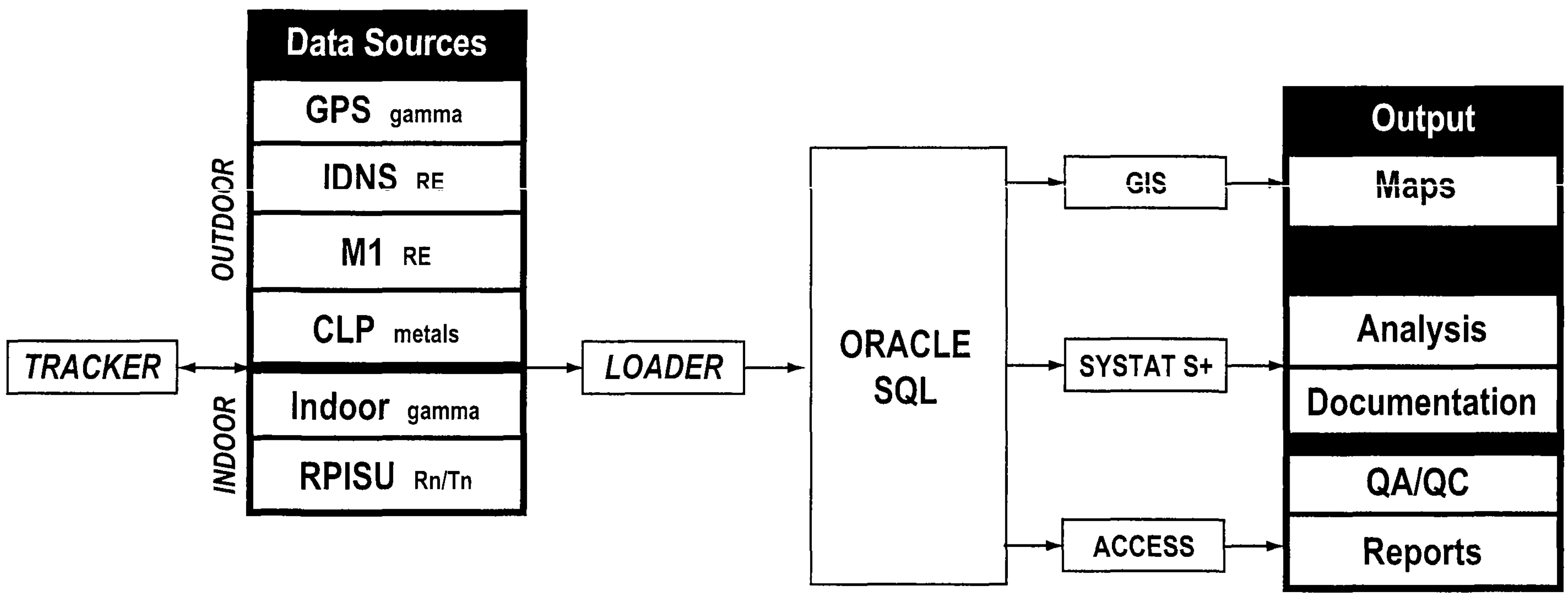


Figure 3-1
Data Management System Components
Kerr-McGee West Chicago

3.3.2.1 Capture

Data processing was initiated with data acquisition performed in accordance with the RAS Work Plans. Methods of data acquisition ranged from manual recording of field notes in logbooks through generation or receipt of electronic results files. Data captured included both QA/QC and characterization data.

GPS/Gamma Survey Data. Site characterization of parcels at the RAS began with a GPS/gamma survey. Prior to the survey, a hard copy file was assembled for each parcel. The field crew proceeded to the parcel (residence) and staked out parallel transects 5 feet apart. GPS/gamma survey data were captured using the NaI detector coupled with a ratemeter/scaler and a Trimble TDC-1 GPS datalogger (the rover). Gamma counts and position coordinates were recorded every 2 seconds during the property survey and stored into the datalogger until downloaded to an electronic file at the end of each day.

M1 Data. M1 data were collected with an EG&G (HPGe) coupled to a multichannel analyzer/portable computer system. The instrument records the number and energy level of gamma radiation decay events that occur within a 30-minute interval at a sample location. These data were stored in the form of an energy spectrum for the sample location.

Radiological Analysis of Soil Samples. Soil samples to be analyzed at the IDNS laboratory were collected in the field and analyzed following the procedures outlined in the QAPjP for the RAS. Composites were taken from five randomly assigned locations within the radius of the M1 samples. Additional composites were collected for characterization and validation of gamma readings. Marinelli samples (splits of composite samples) were collected during the pilot study and were not pre-processed. Grab samples were collected to validate gamma surveys. Sampling and analysis protocols for soil samples are described in Section 3.1.1.2. All preprocessing and analyses were performed by IDNS. Analytical results from the soil samples were provided by the laboratory in electronic and paper copy formats. The electronic files were transferred in comma-delimited American Standard Code of Information Interchange (ASCII) format directly from the IDNS computer using a modem and ProCom Plus communications software.

Metals Analysis of Soil Samples. During the pilot study, soil samples were collected in the field and analyzed for metals following procedures outlined in the QAPjP for the RAS. Analytical results from the soil samples were provided by the CLP laboratory in paper copy format.

3.3.2.2 Tracking

RAS data ranged from simple (e.g., parameter-specific radiological and chemical measurements from individual soil samples) to complex (e.g., a 2,500-record electronic file that represents the complete survey of a residential property). Regardless of source or data type, all data were documented and tracked using bar codes. The application of bar codes to all data sources facilitated tracking of all data, regardless of structure or source.

Bar codes were read using an Intermec wand attached to a base unit programmed with PQL, proprietary bar code programming software. Bar codes were generated using Quick Draw, which translates alphabetic or numeric characters into bar codes. Bar code labels for parcel identifiers (attached to parcel maps) were generated off ASCII files. Templates with appropriate codes for individual field entries into the bar code files were generated for each data source.

Gamma Survey. Each gamma survey at a property was assigned a unique sample identification number (ID) specific to the location and a duplicate number of the survey. A bar code template, specific to GPS survey tracking information, was developed. The parcel identifier was read into the reader from the bar code on the parcel file or on the plan view map generated from the DMS. The remaining information—type of survey, location, sample identifier, and duplicate information—was read directly from the bar code template. The GPS file was tracked by bar coding upon return to the field office. The bar coded tracking file was then loaded to the Oracle DMS following the verification of correct entries.

M1 Data. Each M1 sample location was assigned a unique sample ID that was coded into the bar code sample tracking file. A bar code template specific to M1 was developed for the M1 measurements. The parcel ID was read into the reader from the field map showing the sample location. The remaining tracking information—location, duplicate information, and depth of reading—was read from the bar code template. The bar coded tracking file was loaded to the Oracle tracking table as a precursor to loading M1 raw results.

Radiological Analysis of Soil Samples. A unique 6-digit sample ID was assigned to each composite, grab, or Marinelli sample shipped to IDNS. A bar code template, specific to soil samples, was developed. The parcel ID was read into the reader from the field map showing the sample location. The remaining tracking information—location, duplicate information, and depth of reading—was read from the bar code template. The final field sample ID was read from the sample container. The bar code file was loaded into the Oracle tracking table as a precursor to loading IDNS results.

Metals Analysis of Soil Samples. Like the radiological analyses, a unique 6-digit sample ID was assigned to each metal composite sample shipped to the contract laboratory. A bar code template was developed for the soil samples. The parcel ID was read into the reader from the field map showing the sample location. The remaining tracking information—location, duplicate information, and depth of reading—was read from the bar code template. The final field sample ID was read from the sample container. In addition to the CH2M HILL sample ID, each sample was assigned a USEPA sample ID following the protocol described in the QAPjP. The bar code file was loaded into the Oracle tracking table as a precursor to loading the metals results.

3.3.2.3 Preprocessing

Data files generated from the GPS surveys and the M1 measurements required preprocessing before being loaded into the database. Preprocessing takes the recorded responses and interprets the results into the format required for property characterization.

Gamma Survey. Following bar coding, the GPS/gamma survey file was downloaded from the rover. Position measurements as collected were adjusted using reference data recorded at the GPS base station, located at the West Chicago field office. This adjustment corrects for the position bias, which was built into the satellite transmission data for military purposes. In some instances, satellite signal was lost during a survey. In those cases, the start position for subsequent transect lines was measured from a known point (e.g., southwest corner of the residence on the property). Transects were completed, in straight lines, with identification of transect end position with respect to the same or another known point on the property. Gamma readings collected between start and end were interpolated along a uniform spacing of the transect line.

M1 Data. Isotope activity levels and minimum detectable activity (MDA) levels, along with the errors associated with each value, were calculated from the energy spectrum using ORTEC, a proprietary software program developed by EG&G, and compiled into an electronic file.

3.3.2.4 Validation

Data validation protocols were applied to radiological results from the in situ and IDNS gamma spectrometers and to the metals data received from CLP laboratories.

M1 Data. Unvalidated M1 results were loaded into the Oracle DMS using LOADER. Duplicates were stored in the Oracle ERROR tables where they were marked as unvalidated results. During the loading of the unvalidated results, values of Ra-226, Ra-228, and total RE were calculated. An ASCII file that includes the additional calculated values was generated and shipped to validators, trained in the evaluation of QA/QC procedures associated with radiological analyses.

Radiological Analyses for Soil Samples. The radiological analyses for soil samples were validated separately according to the QAPjP for the RAS. Following validation, validation flags were added to the DMS. The validation team provided paper copies and electronic files of the validated data for archiving. The fields included in the electronic files were sample ID, analyte, collection date/time, units, detection flag, activity, activity error, MDA, MDA error, preliminary qualifier flag, date/time validated, final qualifier flag, and duplicate information.

Metals Analyses for Soil Samples. The metals analyses data were validated by USEPA prior to distribution and input of the data into the DMS. Upon receipt of analytical results, the USEPA summaries were reviewed and validation flags were annotated on each of the analytical data sheets. Where appropriate, validated flags were amended following the procedures outlined in the USEPA's *National Functional Guidelines for Evaluating Inorganic Data* (1994).

3.3.2.5 Evaluation

Evaluation of collected data was an ongoing process. Informally, data evaluations were made routinely throughout the data collection process, even prior to loading data into the DMS. A formalized procedure of data evaluation relies upon results from duplicated samples that were entered into ERROR tables in the Oracle DMS. Prior to development of decision rules or preparation of packages summarizing results from characterization activities, sampling error estimates were calculated using the duplicate field sample results. In general, evaluations of internal consistency relied on relative percent difference (RPD).

Sampling errors reflect differences across samples rather than within samples (analytical measurement error). While no criteria exist for sample error, USEPA CLP protocols have established parameter-matrix specific criteria for measurement error. Sampling errors are expected to be greater than analytical measurement error. Therefore, sampling errors that approach measurement errors (matrix spike duplicate results) would be considered to indicate internally consistent sampling results. Sampling errors that exceed measurement errors are taken to indicate a variable process and/or spatial or temporal variations in the media being sampled, requiring an evaluation of the causes and resulting action was taken to correct or explain the issue.

Gamma Survey Data. Duplicated gamma scans were evaluated using graphical and statistical outputs. Maps were generated of the RPD for gamma values between the two surveys with the contour intervals from each survey overlaying the RPD values. Additionally, probability plots were prepared and evaluated of RPD values within each contour interval based on the contours generated from each gamma survey. Lastly, a tabulation of RPDs was generated and evaluated for the area between contour intervals estimated from each gamma survey.

M1 Data. Calibration points were read daily with the M1 at a background location in RKP to verify instrument consistency. A backlog of readings collected during the pilot study was used to establish control limits on the calibration readings. The readings were then compared with the limits to determine that the instrument was performing consistently. Additionally, duplicate samples collected with the M1 instrument were loaded into the Oracle ERROR table. The routing of samples into the ERROR table was based on the code for duplicate number specified in the sample tracking file. Evaluation of internal consistency then relied on the RPD.

Radiological Analyses for Soil Samples. Field duplicate samples were loaded into the Oracle ERROR table. RPD values were tabulated for each set of duplicated samples.

Metals Analyses for Soil Samples. The CLP metals data were tabulated for each sample location at a parcel and organized by analyte and depth. RPD values also were summarized for barium, chromium, and lead at each duplicate sample location and depth.

3.3.2.6 Loading

All data were loaded into the ARC/Oracle DMS using LOADER, which verified the existence of the sample identifier in the tracking file and routed data to the appropriate validated or unvalidated data tables. The specific fields entered into the DMS were unique to the measurement methods. In addition to loading data, LOADER included conventional queries and reports to document successful loading.

Gamma Survey Data. The data structure for the preprocessed files for the GPS equipment is proprietary to the software manufacturer of the Trimble GPS units. The final step of the preprocessing was creation of an ASCII comma-delimited file given the name of the parcel ID. The file included reference header information and data records for the scan. Header information included miscellaneous information (column names and formats) that was not loaded into the Oracle DMS. Detail data records in the body of the file were loaded into an Oracle file called SCAN_RES. Oracle converted the raw character fields to number fields during the loading process. The Oracle data loading process then generated specific record identifiers for each set of x and y coordinates and generated a link number for mapping.

M1 Data. The in situ gamma scan data structure of the M1 is proprietary to EG&G. Data were generated from the instrumentation in two formats. The first contained paper copies of the analytical output, containing raw data, analytical results, and associated QC information. The second was a comma-delimited electronic file that contained the following fields: header information on location and instrument settings as well as analyte, activity, activity error, MDA, detection flag, units, and MDA error. The file name was the sample ID. The M1 file was initially loaded into the Oracle RAW_RES file. The radium data were calculated during the loading according to energy lines identified in the RAS QAPjP. A file was generated for the data validation process, which included the RAW_RES with the calculated radium activities data. Final results were then entered into the RESULTS table following validation.

Radiological Analyses of Soil Samples. The data analysis file structure for the IDNS analytical results is proprietary to the analytical software company, Canberra. The semicolon-delimited ASCII file of the analytical data included the following fields: analyte, detection flag, activity, activity error, MDA, and MDA error. The file names for these files were the sample numbers. The IDNS data were loaded into the Oracle RAW_RES table, and time estimates for the radium components were then calculated. A semicolon-delimited ASCII file was then generated with the same data structure as described above, and including the estimated radium values, and sent to the data validation team. Following receipt of the validated data files, the Oracle database was updated with results that were loaded in the RESULTS tables.

Metals Analyses of Soil Samples. Metals data were provided in paper copy form as validated results, using standard USEPA CLP format. CH2M HILL validators completed a QC check, and the data were entered into a transitional Access database to format the data for upload to the Oracle database. The ASCII file generated for the upload to Oracle was a comma-delimited ASCII file with double quotes around text fields. The validated data were loaded to the Oracle RESULTS table, and the USEPA's tracking data were loaded into the Oracle SAMPLE TRACKING table. Duplicate data were loaded to the ERROR table on the basis of the duplicate specification in the SAMPLE TRACKING table for the sample.

3.3.2.7 Output

Each field measurement associated with the characterization of the RAS properties has specific outputs appropriate for display and interpretation of results. Linking the ARC, Oracle, and S+/SYSTAT software makes data interpretation of the characterization results and the DMS powerful and efficient. Virtually any display that can be designed can be created through the DMS. Examples include adjacent tabulation of indoor survey data opposite contoured gamma survey plan views.

Gamma Survey Data. The distribution of gamma values was presented in both statistical displays and in contoured maps. Gamma values were summarized using SYSTAT. Summary statistics were tabulated for gamma distributions. Probability plots, box plots, and histograms of the sample data at each parcel were generated and the parcel data were classified as background, background with elevated exposures from the REF, small bimodal, and large bimodal, as based on the gamma count distribution.

ARC GPS software generated report quality maps that summarized GPS surveys and included contours for individual properties and transects for continuous lines of observations that cross numerous properties. Specific options included differential shading to display specific gamma count intervals, highlighting individual points that exceed a prespecified count (e.g., > 20,000 cpm), and surface areas associated with specific contours.

M1 Data. The output of the M1 data generally consisted of statistical evaluation of in situ results versus radiological analysis results for composited samples. The M1 sample locations were identified on parcel maps and were delineated by a 10-meter-radius circle with the results of the composited sample inside.

Radiological Analyses of Soil Samples. Radiological results generally consist of statistical evaluation of the data. In addition, the radiological data were used to verify and provide decision criteria for specific parcel areas. Therefore, results can be integrated into parcel contour maps to identify criteria exceedances.

Metals Analyses of Soil Samples. The metals analysis results consist of tabulation of data and statistical evaluation and display.

Prototypes of complete deliverable packages submitted to the USEPA for DUs and individual parcels are provided in Section 3.5.

3.3.3 RI Data Quality Assurance / Quality Control

QA/QC of data collected in the RAS RI field investigation was performed on two different levels. The first level involved multiple cross references and verifications of data control procedures to maintain data quality throughout the steps from data collection through tracking, post-processing, validation, and loading into the database. The second level focused on the outputs from the data through the extensive QA/QC review of all information collected at each property before submittal to the USEPA in the form of a deliverable package. Each level of QC is described briefly below.

3.3.3.1 Data Controls

Transmission of data on the RAS included shipments of data from the field crews to the data management team, from the field crews to the laboratory, from the laboratory to the data management team, and between the data management team and the data validation team. Each of the above data transfers included both electronic and hardcopy versions. The process of uploading data into the RAS DMS was initiated only after verification that electronic files corresponded to paper copies, an activity completed prior to import of any results into the database. The following briefly summarizes procedures for tracking sample information, GPS survey data, and laboratory results.

Sample Tracking Controls. Data transmitted from the field to the data management team included sample tracking records for all samples collected during a given sampling period (typically 1 week), chain-of-custody records for all samples submitted for laboratory analysis, and records of field screening data collected at each discrete sampling location.

Upon receipt of data from the field the following QC steps were observed:

1. The sample tracking files were verified against the paper copies of the files sent by the field crew.

2. Soil sampling records were verified against copies of sample chain-of-custody forms sent by the field crew.

3. The sample tracking records were loaded into the database using the data loader program. Uniqueness in each sample tracking record was checked by the data loader program during the data loading process. If a record did not meet the uniqueness criteria, the record was rejected and could not be appended to the RAS DMS.

4. If a tracking record was rejected, the field crew was contacted to obtain clarification of the sample data, based on the sample data entered in the field log books. If changes to

data were required, a database change form was completed, filed, and the data were adjusted to reflect the corrected information.

Once a sample tracking record was loaded to the database, it provided a basis for loading all subsequent data associated with the record. No analytical data, survey coordinate data, field screening data, or gamma survey data could be loaded to the database without a sample tracking record.

GPS Survey Results Controls. The following QC steps were observed upon receipt of GPS survey data from the field office.

1. The list of GPS surface gamma surveys and discrete point coordinates, included in the transmittal letter for the sample delivery group, was compared with the list of files in the delivery group. In addition, the parcel IDs and locations listed for the data were compared with the sample tracking records for the samples.
2. Each surface gamma survey file was loaded into the database, using the data loading program.
3. The uniqueness of the sample number was verified by the sample loader program prior to insertion of the data to the Oracle results table (SCAN_RESULTS). If the sample number failed the uniqueness criteria, the loader program rejected the data.
4. If the sample data were rejected, the field crews were contacted to obtain clarification of the sample tracking data, based on the sample data recorded in the field notebooks. If changes to data were required, a database change form was completed and filed, and the data were adjusted to reflect the corrected information.

Laboratory Results Controls. Laboratory analytical data were transferred to the data management team in paper copy form through the mail and downloaded electronically through a modem connection with the laboratory computer. The following QC steps were observed for loading of laboratory analytical data.

1. Laboratory data, available electronically, were not loaded to the database prior to receipt of the paper copies of the data.
2. The sample numbers listed in the laboratory transmittal letter were verified against the sample tracking records in the database and the chain-of-custody forms.
3. The electronic files downloaded from the laboratory computer were compared against the paper copies for each respective sample.
4. Samples were loaded to the database using the loader program. Uniqueness of the sample information was verified by the loader program prior to insertion of the data into the analytical results table. If the sample data failed to meet the uniqueness criteria of the program, the data were rejected.
5. If the sample data were rejected, the field crews were contacted to obtain clarification of the sample tracking data, based on the sample data recorded in the field notebooks. Verification of sample identification was also obtained from the laboratory. If changes to data were required, a database change form was completed and filed, and the data were adjusted to reflect the corrected information.

Data transfers from the data management team to the data validation team followed analogous procedures.

In addition to ongoing data controls, RAS DMS database audits were conducted each year to verify the accuracy of the data in the database. Audits included verification that sample tracking records matched field notebooks and chain-of-custody records; that survey coordinates and point gamma measurements had been loaded for discrete sample locations; that electronic and paper copies of analytical data matched; and that data had been loaded for each appropriate sample record.

3.3.3.2 Deliverable Package Review

The deliverable packages, summarizing field investigation results, prepared for submittal to the USEPA are described in detail in Section 3.5. The packages include cross references in order to document internal consistency of reported results. For example, outputs include tables that record every sample collected on the property, regardless of type of sample. Results reported for each sample type (e.g., indoor and outdoor surveys and soil samples) include cross reference sample identifiers that correspond to the summary table.

Additionally, an integral part of the preparation and processing of deliverable packages included development of corresponding QA/QC forms for package review. Each piece of the DU and parcel-specific deliverable package has a detailed set of checks to verify internal consistency of the data package and reasonableness of data interpretation. Forms were completed at the time of package review and were included in each parcel-specific and DU-specific documentation file of packages delivered to the USEPA.

3.4 Decision Rule Implementation

As described in Section 1, the RAS non-time-critical removal action and RI investigation may be thought of as a real-time process of property characterization, excavation and remediation, verification, and restoration using the decision rules developed from the pilot study to achieve the USEPA's cleanup criteria. Each property within the RAS follows a sequence of events described in this section.

The detailed steps in the real-time process of characterization, excavation and remediation, and verification are schematically represented in Figure 3-2. The horizontal axis displays time and processing events, from left to right. The vertical axis identifies the various participants in the flow of data. The participants include, from top to bottom:

- Individuals owning property within the RAS study area
- USEPA
- CH2M HILL
- IDNS
- Kerr-McGee

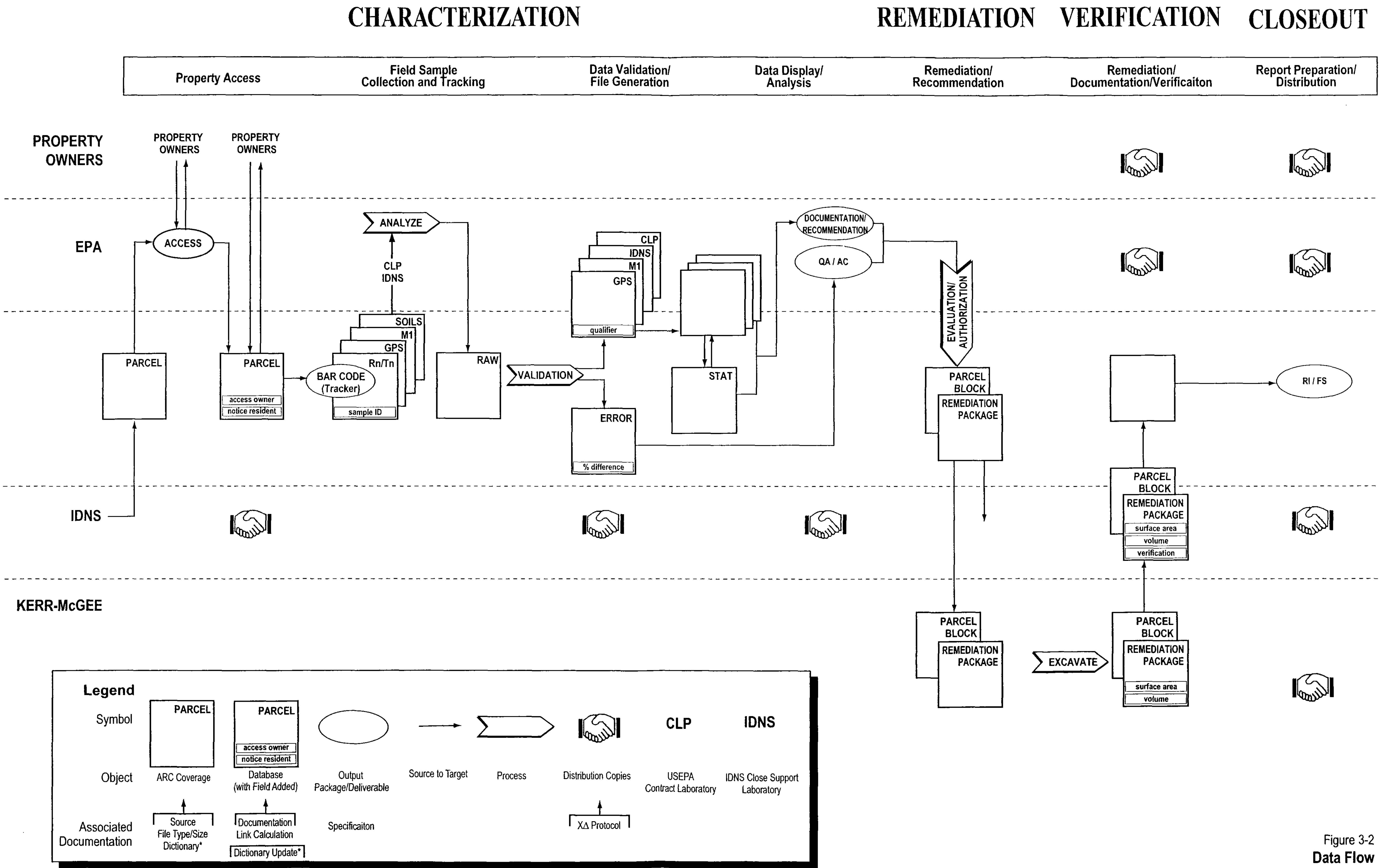


Figure 3-2
Data Flow
Kerr-McGee West Chicago

Data flow through the characterization, remediation, verification, and project closeout activities is represented by the icons. Icons represent ARC coverages, database files (with specific field annotations), and outputs (maps, hard copy tables, or electronic deliverables and distribution copies), as defined in the legend of the exhibit. Arrow lines have been used to indicate source-to-target directions of data exchange. Vectors are used to indicate data processes. The handshake icon is used to represent the exchange or distribution of results.

Characterization, which was performed by CH2M HILL, is the real-time evaluation of individual residential properties. Development of and specific steps in the characterization data flow for the RAS are briefly summarized below:

- IDNS provided the USEPA with ARC coverages and parcel-specific attribute files developed by DuPage County. Those files included property tax parcel identifiers and the names and addresses of owners and residents. These files were the foundation database to which all subsequent attribute data were linked.

- This foundation database was the source for the USEPA's property owner mailings that solicited access agreements for the characterization activities.

- Following receipt of the signed access forms, an attribute was added to the parcel file to reflect that access to the property was granted. Property access initiated a sequence of property characterization activities that are described in the following bullets.

- Characterization of a property started with a complete gamma survey. Coordinate locations and associated gamma radiation readings (cpm) were captured using the GPS and NaI detector. Coordinates and activity readings were merged into a single electronic file using field instrumentation and proprietary software developed by Trimble. The survey file was assigned a unique sample identifier and bar code label. The unique sample identifier functions as both the sample identifier entered into the data tracking file as well as the file name used during pre-processing and loading into the database.

- If deemed necessary at a property based on the gamma survey, CH2M HILL sampled soil and the IDNS laboratory conducted radiological analyses. The soil sampling supplemented the complete external gamma/GPS survey.

- Following uploading, validation, verification, and evaluation (including error estimates of uncertainty), a data package was developed for submittal to the USEPA. The data package included contour maps and statistical evaluations of the data, prototypes of which are provided in Section 3.5. The USEPA then either notified the owner that their property required no remediation or that their property required remediation. The USEPA then notified Kerr-McGee of the findings and notified IDNS of the need to conduct verification sampling post Kerr-McGee cleanup. Kerr-McGee and IDNS were provided with copies of the data packages for properties requiring remediation.

- For properties requiring remediation, Kerr-McGee conducted remediation/excavation activities, and IDNS conducted the verification sampling to ensure that the USEPA's cleanup criteria were met.

- Following successful remediation, Kerr-McGee restored the property as close as practicable to its original condition.

3.5 Results Prototype

During the RAS field investigations, all properties in the RAS study area for which access had been obtained were characterized. Outdoor gamma surveys were conducted at all of these properties. Supplemental sampling activities that were conducted at the RAS properties included indoor gamma surveys and RPISU samples, outdoor soil sampling for radiological or metals analysis, or M1 measurements.

The data collected were processed to produce DU and parcel-specific packages that documented all fieldwork performed at the properties within each DU. Prototypes of DU and parcel-specific deliverable packages are discussed below. The results presented in the DU and parcel-specific prototypes are real results. To maintain owner privacy, parcel identifiers included in the outputs shown here have been replaced with Xs or the designation "PROTOTYPE."

3.5.1 Deliverable Unit Prototype

As described in Section 1.2.1, parcels were aggregated geographically into DUs. In general, DUs are discrete plots of land within the RAS that are separated from other DUs by roadways, railroads, or water bodies and typically coincide with city blocks. Investigations and removal actions were identified by DUs and parcels. Deliverable package for DUs provided to the USEPA contained four reports, described below. (Note: *Italics* represent specific areas on the exhibits.) Figures 3-3 through 3-6 are all for the same DU.

A **DU Summary Report** (Figure 3-3) serves as a cover sheet for the data package. It lists the *DU* and each of the parcels (*PARCEL ID*) that have been assigned to this DU. The *PHASE* describes the time (Phase I or II) that the indoor survey was conducted (P0 indicates that no indoor sampling was conducted). *CONTAMINATION* is broken out by *PROPERTY* and *ROW*; a simple yes/no is given to indicate the existence of contamination on that particular parcel. The *COMMENT* field is used to clarify information about the property or to identify any anomalies noted during the internal review. The *QA/QC* is "initialed" and dated by the person conducting the technical review of that property's data package.

A **Missing Report** (Figure 3-4) identifies any samples collected for which no analytical results or data were received. It is used to identify and track missing sample information.

Figure 3-5 is a **RPD Report.** RPD is calculated for all duplicate samples collected. RPDs greater than 75 percent were commented on in the Summary Report.

The **DU map** (Figure 3-6) shows each parcel within the DU. The DU map identifies contamination areas and provides the description of isolated contamination, contamination that crosses property lines, or contamination that abuts property lines. A supplemental map with gamma contours was also provided to the USEPA. The USEPA uses these maps (in conjunction with the individual data packages from each property in the DU) to identify the need for additional sampling, clear the properties for no further action, or identify areas for remediation. The data for each property in the DU is provided as a separate parcel-specific data package. One parcel (labeled ***Parcel Prototype***) has been selected from this DU, and the data collected for this example property is reflected in the prototype parcel-specific data package as described in the following subsection.

Deliverable Unit Summary Report

PRODOTYPE DU

Parcel ID	PHASE	CONTAMINATION PROPERTY	ROW	COMMENT	QA/QC
xxxxxxxxxx	P2	Y	N	Single supplementary soil sample result was less than criterion.	AT 10/30/96
xxxxxxxxxx	P0	N	N	The area without GPS coverage is a house under construction.	MFP 3/6/96
xxxxxxxxxx	P2	Y	N		MFP 3/6/96
xxxxxxxxxx	P2	N	N	The shaded area shown on the parcel map is from the GPS survey performed on the adjacent parcel. That survey found elevated readings very near the parcel boundary.	MFP 3/6/96
xxxxxxxxxx	P0	N	N		MFP 3/6/96
xxxxxxxxxx	P2	Y	Y		MFP 3/6/96
xxxxxxxxxx	P2	Y	N		MFP 3/6/96
xxxxxxxxxx	P2	N	N		MFP 3/6/96
xxxxxxxxxx	P2	N	N		MFP 3/6/96
xxxxxxxxxx	P2	N	N		MFP 3/6/96
xxxxxxxxxx	P0	N	N		MFP 3/6/96
xxxxxxxxxx	P2	N	N		MFP 3/6/96
xxxxxxxxxx	P0	N	N		MFP 3/6/96
xxxxxxxxxx	P2	N	N		MFP 3/6/96
xxxxxxxxxx	P2	N	N		MFP 3/6/96
xxxxxxxxxx	N/A		N	This parcel is the ROW inside the block. The phase is "N/A" because there are no structures.	MFP 3/6/96

Phase = Indoor Survey
P0 = None
P1 = Gamma Survey w/RPISU
P2 = Gamma Survey w/Dose

Property
Y = Property Contains Areas > EPA's Action Levels
N = No Areas within Property Boundaries > EPA's Action Levels

ROW = Right Of Way
Y = ROW Contains Areas > EPA's Action Levels
N = No Areas within Parcel ROW > EPA's Action Levels

Figure 3-3
Deliverable Unit Summary Report

Missing Report

Missing Block: Deliverable Unit

Site ID	Parcel ID	Sample ID	Analysis	Location	Depth	Duplicate	Collection Date

No samples were listed as missing in this deliverable unit

Figure 3-4
Missing Report

RPD Report

RPD Total Radium: Deliverable Unit

Parcel ID	Location	Depth	Analysis	Total RE Dup 01	Total RE Dup 02	Total RE RPD
	No Duplicate Soil or M1 Samples were collected in this Deliverable Unit					

Figure 3-5
RPD Report

Kerr-McGee Residential Properties RI/FS
West Chicago, Illinois

0 50 ft

Survey Interpretation

- > 25.5 K CPM: 63 + 2 sq. yds.
- 21.8 - 25.5 K CPM: 19 + 1 sq. yds.
- < 21.8 K CPM: 13067 sq. yds.

Activity Isoline: 1000 Gamma Count/Min (K CPM)

Supplemental Data

- Potential Remedation Area
- No Remediation
- GPS/Gamma Survey Point
- Gamma Point > 25.5 K CPM
- (1) M1 Sample (5M Radius)

CH2MHILL EPA

Figure 3-6
Example DU Map
Kerr-McGee West Chicago

E052003006MKE 160587.RR.01 Example DU Map 6-24-03 tll

3.5.2 Parcel-Specific Prototype

The Parcel-Specific Deliverable Package consists of six reports, presented in Figures 3-7 through 3-12. All parcel deliverable packages included the summary report, the GPS gamma probability plot, and the property map. All probability plots, laboratory results and indoor results summary sheets were included if those sample types were collected at the property.

Figure 3-7 is an example **Parcel Summary Report.** The Parcel Summary Report lists all samples collected at that parcel. ANALYSIS indicates the type of sample collected as defined in the footer section of the figure. SAMPLE ID is the unique sample number assigned to each sample collected. Sample results are tracked throughout the data package by sample ID number. LOCATION provides further information regarding the sample type. For example:

Analysis	Location	
GP	G1	Indicates that GPS survey transects were on 1-foot spacing [micro-grid]
GP	NA	Indicates that GPS survey transects were on 5-foot spacings
M1	01	Indicates an M1 (in situ) sample taken at location 01 indicated on parcel map
IG	S1	Indicates radiological grab sample taken at location S1 indicated on parcel map
WL	NA	Indoor gamma wall scan, location not applicable (not shown on parcel map)
FL	NA	Indoor gamma floor scan, location not applicable (not shown on parcel map)
B1	NA	Indoor dose measurement, location not applicable (not shown on parcel map)

DEPTH indicates the depth at which the soil sample was collected. DUPLICATE gives the number of samples collected at a single location and depth. Duplicate results for all parcels are listed on the DU RPD Report (see Figure 3-5). COLLECTION DATE is the date that each sample was collected. DOSE MEASUREMENT is the date that the dose rate was collected, if one was taken. EASTING is the longitude and NORTHING is the latitude of that particular sample/measurement location.

An example **Gamma Probability Plot,** presented in Figure 3-8, displays the distribution of gamma activities recorded in the GPS walkover survey of the entire property. The gamma activities are displayed in three statistical views (clockwise from the upper left: a simple box plot, frequency distribution historigram, and probability plot). While each gives a different perspective of the data, they all display that most gamma activities are less than 40,000 cpm, with individual readings as high as 180,000 cpm.

An example **Gamma Probability Plot** of gamma activity from an M1 sample is shown in Figure 3-9. It shows the same type of information as Figure 3-8 but is limited to activity within a 10-meter radius of the M1 location.

An example **Radiological Results Table**, reporting results from M1 and soil samples collected, is given in Figure 3-10. RE data are presented in pCi/g by RAD TYPE (analysis type) and SAMPLE ID. These samples were analyzed for Ra-226 (*Re-226*) and Ra-228 (*Re-228*). TOTAL RE (total radium) is calculated and shown, as is the error calculation for each. The AVERAGE CPM taken at the sample location for each "Rad" sample is given under GAMMA RADIATION LEVELS. Although no metals samples were collected at this particular parcel, metal results are included in the results table when appropriate.

Summary of Sample Collection by Parcel

PROTOTYPE

Analysis	Sample Id	Location	Depth	Duplicate	Collection Date	Dose Measurement	Northing-Easting	Coordinates
GP	010379	G1	NA	01	95/10/20			
GP	002432	NA	NA	01	04/10/17			
GP	002520	NA	NA	02	94/11/07			
GP	010468	NA	NA	03	95/10/23			
MI	002222	01	00	01	94/11/17	94/11/17	1897182.63	1020134.25
IG	003926	S1	06	01	95/10/20	96/01/26	1897196.63	1020072.44
IG	003927	S2	06	01	95/10/20	96/01/26	1897180.00	1020087.94
IG	003928	S3	06	01	95/10/20	96/01/26	1897154.25	1020152.63
WL	006229	NA	NA	01	94/12/21			
FL	006230	NA	NA	01	94/12/21			
B1	006231	NA	NA	01	94/12/21			

GP: Gamma Walkover Survey

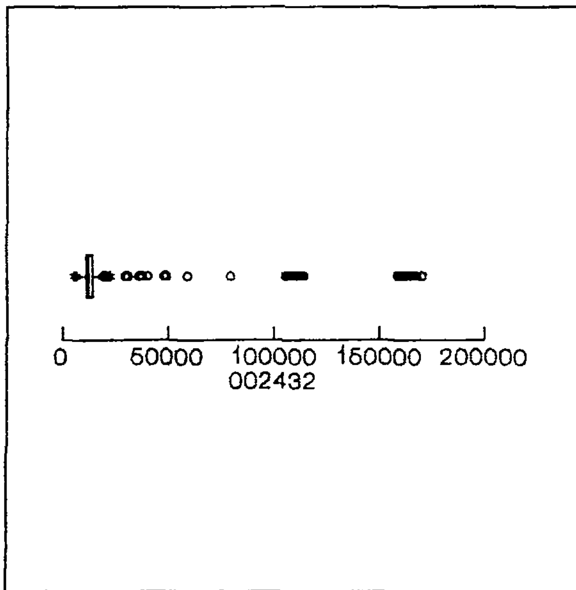
MI: In Situ Gamma Spectroscopy

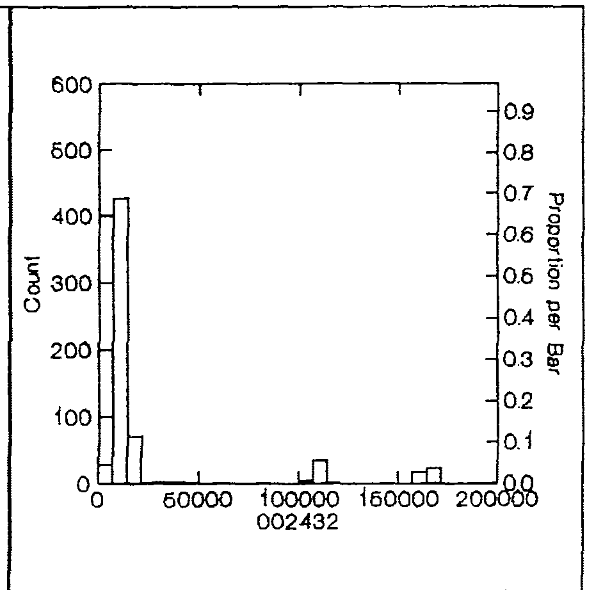
Radiological Soil Samples
- IC: Composite Soil Sample
- IG: Discrete (uncomposited) Soil Sample
- IM: Composite Soil Sample Packed in Marinelli in the Field

Metal Soil Samples
- CC: Composite Soil Samples
- CG: Discrete (Uncomposited) Soil Sample

WL: Indoor Gamma Wall Scan
FL: Indoor Gamma Flor Scan
BI: Indoor Dose Measurement
RP: Indoor Radon/Thoron Gas Measurement
SG: Supplemental Gamma Measurement

Figure 3-7
Summary of Sample Collection by Parcel





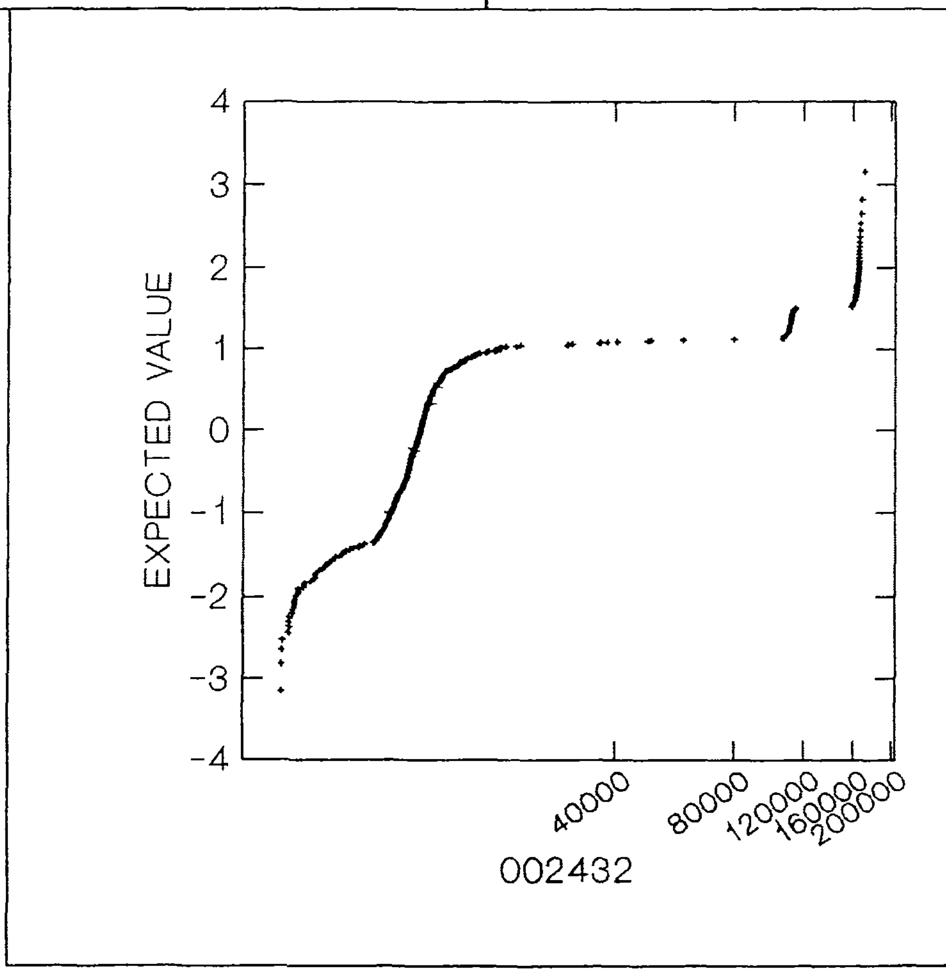


Figure 3-8

Gamma Summary Plots

Kerr-McGee West Chicago

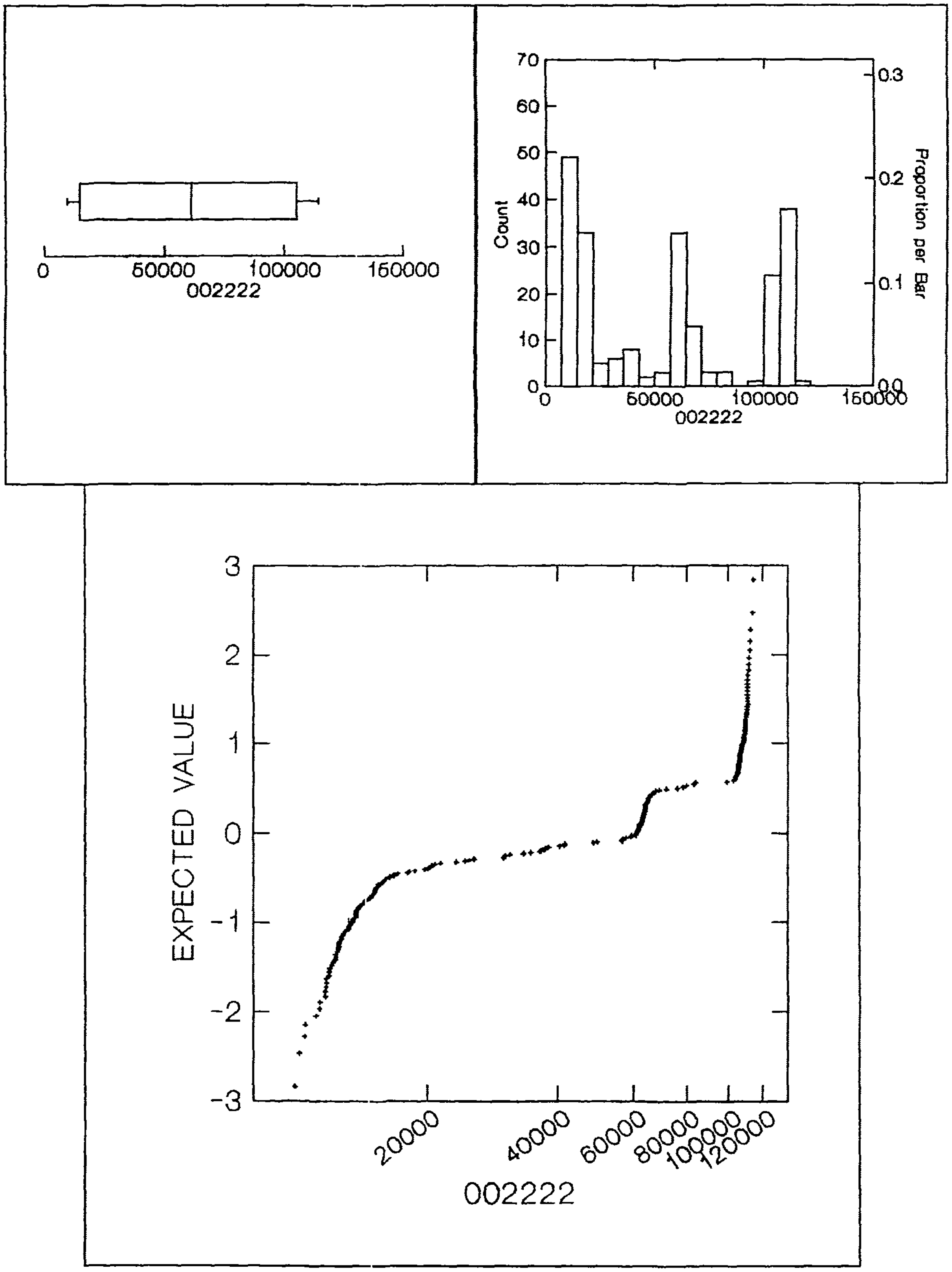


Figure 3-9
M1 Gamma Plots
Kerr-McGee West Chicago

Radiological Results Table

PROTOTYPE

Radium Equivalent data (pCi/g)

Sample ID	Location	Depth	Rad Type	Re-226	Error Re-226	Re-228	Error Re-228	Total Re	Error Total Re
002222	01	0	M1	1.72	0.09	14.10	0.20	15.82	0.21
003926	S1	06	IG	0.94	0.03	7.05	0.12	7.99	0.13
003927	S2	06	IG	0.97	0.08	6.75	0.23	7.72	0.24
003928	S3	06	IG	2.35	0.14	22.30	0.54	24.66	0.56

Gamma Radiation Levels:

Sample ID	Location	Average CPM
002222	01	68539
002222	01	57055
003926	S1	20517
003927	S2	20018
003928	S3	37741

Figure 3-10
Radiological Results Table

Figure 3-11 is an example **Indoor Report,** which summarizes gamma activities from walls and floors and dose readings collected. A corresponding floor plan sketch indicating wall and floor locations made by the surveying crew was also provided to the USEPA. Minimum (MIN CPM), maximum (MAX CPM), and average count rate (AVG CPM) are given for each floor and wall location, as well as the average dose rate reading (μREM/HR) and average cpm (GAMMA CPM) in selected locations. Radon/thoron RPISU samples were not collected from this structure.

Figure 3-12 is an example **Parcel Map**. Data are tracked by sample ID. The primary GPS sample identifier is displayed in the legend. Surrounding the building structure, each small plus (+) sign represents a gamma survey point. Points within an area of shading are indicative of elevated gamma readings. Soil sample locations S1 through S3 are indicated. Shaded sample locations indicate results that exceed the USEPA's action level criteria. The M1 (large circle) sample and the G1 (microgrid/dense) survey area near sample location S3 also are shown.

Indoor Report

PROTOTYPE

Floor Data

Sample ID	Floor	Count	Min CPM	Max CPM	Avg CPM
6230	1	44	5445	8206	6362
6230	2	10	6008	8416	7379

Wall Data

Sample ID	Wall	Count	Min CPM	Max CPM	Avg CPM
6229	1	7	5280	6751	6077
6229	2	13	5496	8369	6437
6229	3	28	5748	8599	7011
6229	4	25	6411	9403	7506
6229	5	11	6953	9151	7908
6229	6	8	7004	8801	7901
6229	7	14	5646	8847	7063
6229	8	17	6003	7437	6824

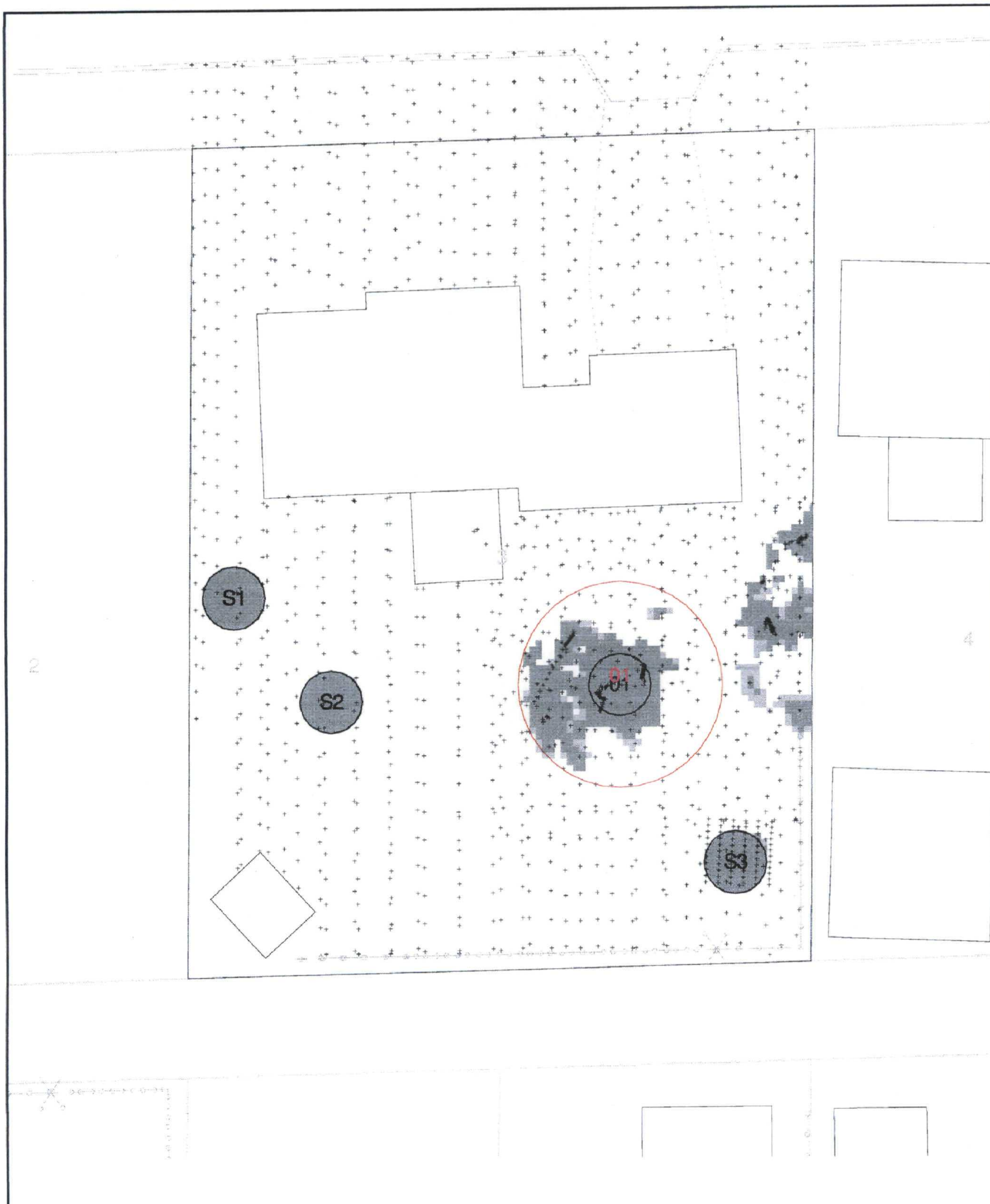
Dose Data

Sample ID	Location	microrem/hr	Gamma CPM
6231	2	4	5400
6231	3	4	6400

Radon/Thoron Data

NO RADON/THORON DATA AVAILABLE

Figure 3-11
Indoor Report



Kerr-McGee Residential Properties RI/FS
West Chicago, Illinois

N

0 — 50 ft

Potential Remediation Area
- 52 sq. yds. in property
- 11 sq. yds. in property

TOTAL SURVEY AREA: 0.246 Acres

(1) M1 Sample Location (5 Meter Radius)

\+ GPS/Gamma Survey Point

Sample #002432

Supplemental Data
- Potential Remedation Area
- No Remediation

CH2MHILL EPA

Figure 3-12
Example Parcel Map
Kerr-McGee West Chicago

E052003006MKE 160587.RR.01 GPS Gamma Survey_rev2 7-7-03 ül

SECTION 4

Nature and Extent of Contamination

This section presents the results of the investigation activities within the RAS study area. The information includes the results of outdoor radiation measurements and soil sampling activities and of indoor radiation and radon and thoron measurements. Although groundwater was not investigated as a part of this RI, groundwater studies performed by others have been summarized earlier in Sections 1 and 2.

4.1 Contamination Source

As described in Section 1, the ultimate source of the radioactive (not natural) contamination within the West Chicago area is the REF. Extraction activities at the REF produced (1) products that were sold to government and private industry and (2) diverse by-products called tailings that contained Th-232 and residual levels of radium (Ra-226 and Ra-228). The tailings were stored in large piles on the REF property, that for many years did not have physical containment.

From the REF, four transport mechanisms enabled radiation and radioactive material to come into contact with the West Chicago population:

1. **Tailings Material Used as Fill.** The largest contribution to radioactive contamination and radioactive exposure that resulted from the tailings material is by individuals, businesses, and municipalities that used the tailings as fill on their properties. Many properties within the West Chicago area used this material for gardens, to support sidewalks and driveways, and to level or landscape yards. Tailings were used in municipality work for infrastructure support (e.g., as fill around buried utilities) and fill for coverage, and building contractors used the tailings as fill when landscaping yards. These practices resulted in widespread surface and subsurface contamination.

2. **Airborne.** Tailings piles on the REF property were uncovered and exposed to outdoor air and wind. Radioactive particulates from the piles were subject to wind dispersal. The particulates could be spread in the general direction of the wind outside the REF and onto residential properties.

3. **Surface Water Runoff and Direct Discharges.** The tailings piles also were exposed to rainfall. Precipitation falling on the piles suspended particles in the water runoff and washed them into local drainage ditches. The drainage ditches discharged to Kress Creek through a storm sewer. The storm sewer also may have carried direct discharges of radioactive waste from the REF to Kress Creek. These mechanisms resulted in the KCK site being listed on the NPL.

4. **Direct Exposure.** During the time that radioactive materials were present on the REF, elevated levels of gamma radiation existed outside the REF due to the materials on the REF. Individuals in the immediate vicinity of the REF were subject to low levels of

direct radiation exposure. Radiation exposures within 200 feet of the REF were elevated. The direct exposure due to the REF was negligible at distances greater than 200 feet.

Outdoor and indoor studies were conducted throughout the residential area during the RAS RI. The studies described in Section 3 were used to investigate and characterize the effects of the above mechanisms 1, 2, and 4. The KCK site, affected by mechanism 3, is being investigated as part of the RI/FS activities associated with the KCK site.

4.2 Outdoor Studies

The outdoor surveys performed for the evaluation of contamination within the RAS study area include gamma GPS surveys, scan-van surveys, and soil sampling (see Section 3). Gamma GPS surveys were conducted to determine the radiation levels at properties throughout the RAS study area. The radiation levels were mapped on parcel property maps that identified radiation levels above and below the cleanup criterion. The results of the gamma surveys are described in the following subsections.

Soil samples were also collected during the characterization of the RAS study area as described in Section 3. The samples were collected to confirm radiation levels in soil and to characterize metal contamination in soil due to the tailings. The results of each of these studies are described in the following subsections.

4.2.1 Gamma GPS Surveys

Gamma GPS surveys were conducted at parcels throughout the RAS study area. Figure 1-5 shows the general areas where the surveys were conducted. The gamma surveys were conducted using handheld equipment. More than 1.71 million gamma survey points were measured by CH2M HILL using the handheld NaI detector and GPS system.

The surface area of DUs surveyed by CH2M HILL between 1994 and 2000 with GPS units covered 945 acres. Based on the decision rules discussed in Section 3.2.3, 35.2 acres were determined to exceed the USEPA action level (>25,500 cpm), 18.0 acres were found to be in the "gray area" (>21,800 cpm and <25,500 cpm), and 891.9 acres were below the action level (<21,800 cpm). The total surface areas above include only those areas actually tested by CH2M HILL and do not include roadways (except for roadways specifically designated by USEPA for testing), building footprints, water bodies, areas that could not be reached with the surveying equipment and properties tested later by IDNS.

The surveys conducted by CH2M HILL resulted in the collection of 1.71 million data points consisting of gamma activity (from the Ludlum) and northing and existing (from the GPS). The maximum gamma level measured during the outdoor GPS studies was 999,999 cpm (the maximum reading measurable on the detector). The average gamma level was 11,990 cpm. Table 4-1 summarizes the results of the CH2M HILL gamma surveys.

As previously noted, as USEPA gained access late in the characterization effort from property owners who previously had not granted access, IDNS performed gamma GPS surveys for USEPA. Table 4-1 does not include information from the property surveys conducted by IDNS.

TABLE 4-1
Summary of CH2M HILL Gamma Scan Data

	Areas Surveyed	Acres >25,500 cpm	Acres Between 21,800 and 25,500 cpm	Acres<21,000 cpm
Number of outdoor gamma surveys	2,018[a]	—	—	—
Maximum parcel size (acres)	84.6	—	—	—
Minimum parcel size (acres)	0.03	—	—	—
Average parcel size (acres)	0.54	—	—	—
Total area (acres)	945[b]	35.2[b]	18.0[b]	891.8[b]
Gamma counts on parcels				
Total readings	1,712,300			
Maximum reading	999,999 cpm			
Minimum reading	76 cpm			
Average reading	11,990 cpm			

[a]Number of outdoor gamma surveys excludes duplicate GPS surveys. (See Table 3-1.)
[b]Does not include properties surveyed by IDNS, the area occupied by roadways, building footprints, water bodies, and areas on properties inaccessible to equipment.

4.2.2 Scan-Van Surveys

The scan-van studies were conducted along roadways outside the original flyover footprint and gamma GPS study area. The scan-van surveys covered 17,056 acres (see Figure 1-4). As a result of the scan-van findings, USEPA identified 94 parcels outside the original flyover footprint that warranted additional gamma GPS surveys.

4.2.3 Soil Sampling

Grab and composite soil samples were collected and quantified for radioactive constituents as described in Section 3. Composite soil samples were analyzed for metals constituents. The results of CH2M HILL's sampling are described below. Table 4-2 summarizes the radiological soil sampling data and Table 4-3 the metals sampling data. Table 4-2 does not include information on the radiological soil samples collected from the properties tested by IDNS late during the characterization effort. (IDNS did not collect any metals samples at the RAS.)

TABLE 4-2
Summary of CH2M HILL Soil Sampling Data for Total RE

	No. of Samples or Measurements	Maximum (pCi/g)	Minimum (pCi/g)	Average (pCi/g)	Criteria (pCi/g)
Composite Soil for Radiological Analysis	571	165	0.53	7.4	7.2
Grab Soil for Radiological Analysis	1,572	966	1.3	12.0	7.2
Marinelli Samples for Radiological Analysis	353	85	0.4	6.8	7.2
M1 In Situ Gamma Spec Measurements	336	252	0.5	6.7	7.2

4.2.3.1 Grab Soil Samples—Radioactivity

A total of 1,572 grab samples were collected by CH2M HILL within the RAS study area and analyzed for radionuclides and total RE. Of those samples, 153 (9.7 percent) were duplicates. The maximum total RE level measured was 966.5 pCi/g, the minimum 1.3 pCi/g, and the average 12.0 pCi/g. The USEPA criterion is 7.2 pCi/g. Because the soil grab soil samples generally were collected in areas suspected of containing elevated radium concentrations, the results are biased high compared to the composite samples.

4.2.3.2 Composite Soil Samples—Radioactivity

Sample handling for radionuclide analysis of composite samples was performed in two ways. In most samples, soil material was ground and dried before a reading was taken using a high-purity germanium detector. A subset of samples, which were splits from composites preprocessed in the conventional way, were not preprocessed but put directly into the Marinelli beakers and then on the detector. A total of 571 composite, processed samples were collected and analyzed for total RE. Of the 571 composite samples, 54 (9.5 percent) were collected as duplicate samples. The maximum concentration was 165.2 pCi/g, the minimum 0.53 pCi/g, and the average 7.4 pCi/g. A total of 353 composite, unprocessed samples were collected in Marinelli beakers for total RE. The maximum concentration was 85.5 pCi/g, the minimum 0.4 pCi/g, and the average 6.8 pCi/g.

TABLE 4-3
Summary of CH2M HILL Soil Sampling Data for Metal Constituents

	Number of Samples	Maximum (mg/kg)	Minimum (mg/kg)	Average (mg/kg)	Criteria (mg/kg)
Composite Samples					
Barium	161	385	22	130	11,600
Total Chromium	161	23	2.9	15	832
Lead	161	360	6.5	98	400
Grab Samples					
Barium	15	288	107	179	11,600
Total chromium	15	51	10.6	18	832
Lead	15	543	18	154	400

4.2.3.3 Soil Sampling—Metals

As described in Section 3.2, CH2M HILL collected soil samples during the pilot study to determine whether the thorium tailings placed on properties contained metal contamination that exceeded respective soil standards. On the basis of this study, the USEPA determined that the RAS properties did not contain metal contamination at levels of concern. Maximum concentrations measured in composite soil samples were 385 mg/kg for barium, 23 mg/kg for chromium, and 360 mg/kg for lead. Fifteen grab samples were also collected for analysis of metals. The maximum concentrations were 288 mg/kg for barium, 51 mg/kg for chromium, and 543 mg/kg for lead. Although the maximum lead concentration exceeded the PRG established in the EE/CA (400 mg/kg), the data show this value to be an outlier since the other lead data are well below this level (the average grab sample for lead was 51 mg/kg). With the exception of one outlier, these concentrations are below the PRGs established by the USEPA. Table 4-3 summarizes the soil sampling results for metals quantification.

4.2.3.4 In Situ Gamma Spec Measurements (M1)

During the initial stage of the investigation, in situ gamma spec measurements were made with an EG&G Ortec portable HPGe, GEM Model detector which was set at a height of 1 meter above ground surface. This system was used to measure gamma-emitting radionuclides over a 5-meter radius. Soil samples randomly collected within this radius were used to correlate M1 readings in counts per minute to soil radiological results. After the Decision Rule document (CH2M HILL 1995) was finalized and field measurements were refined, the M1 sampling was discontinued. The M1 study was performed between April 1994 and November 1995. Of the 336 measurements, the maximum reading was 252 pCi/g, the minimum 0.5 pCi/g, and the average 6.7 pCi/g.

4.3 Indoor Studies

This section describes the results of the indoor studies. Further information on the indoor studies can be found in *Radon/Thoron Surveys, 1994-96, Kerr-McGee Residential Areas* (CH2M HILL 1997). Descriptions of the purpose and procedures for conducting the indoor studies are found in Section 3.1. As described in Section 3.1, the indoor studies were conducted during Phase I (early 1994) to: (1) evaluate the indoor gamma surveys and radon/thoron sampling as discovery tools for locating contamination outside exterior walls and under the foundation of a structure and (2) to examine the potential exposure to radon and thoron in the residences that results from contaminated soil on the property.

During Phase II (1995 and 1996), indoor gamma surveys were conducted at all properties for which indoor access was provided by the owner. RPISU samples for radon and thoron were collected from inside selected residences during Phase II based on the results of the indoor gamma surveys. Only properties with elevated indoor gamma readings (defined as exceeding the median value from an initial group of properties tested during 1994) were considered for radon/thoron sampling during Phase II. Indoor sampling was discontinued for the field characterization effort conducted from 1998 through 2000 for properties in the expanded RAS study area.

4.3.1 Indoor Radon and Thoron Studies

Table 4-4 summarizes the results of the Phase 1 and Phase II (combined) RPISU sampling effort. Eighty-six (86) primary RPISU samplers were placed in 82 residential properties. Duplicate samples were collected at 11 of the properties for a total of 97 samples at the 82 properties. The RPISU samples were collected and analyzed for radon and thoron gas decay products. The maximum WL (combined radon + thoron) for the RPISU samplers was 0.034 WL, the minimum level 0.002 WL, and the average 0.010 WL. Nine out of the 86 primary samples exceeded the screening criterion of 0.02 WL. For all of these samples, thoron was at background levels, and elevated radon accounted for the exceedance. Only 1 sample result (0.034 WL) exceeded (slightly) the 0.03 WL action level (maximum) for radon plus thoron. Because the exceedances were caused by elevated radon, and thoron was not elevated, the results are likely attributable to naturally-occurring radon and not thorium contamination.

TABLE 4-4
Summary of Indoor Survey Results

	Wall and Floor[a]	Bicron	RPISU
Number of measurements	1,508[b]	729[b]	97[b]
Maximum	87,963 cpm	11 µrem/hr	0.034 WL
Minimum	133 cpm	1 µrem/hr	0.002 WL
Average	6,783.9 cpm	3.95 µrem/hr	0.010 WL

[a] Each wall and floor surveyed within a property constitutes a single measurement.

[b] Includes duplicate measurements and samples. (See Table 3-3.)

4.3.2 Indoor Gamma Surveys

Gamma radiation measurements were taken using either NaI gamma scintillation detectors or portable exposure or dose rate instruments (Bicron, Micro-R, or Micro-Rem instruments). Indoor gamma measurements were conducted in all homes to which indoor access was permitted. The purpose of the gamma measures was (1) to determine the appropriate location for RPISU samplers; (2) to determine whether contaminated fill existed immediately outside the exterior walls or below the floor of the property; and (3) to determine estimated dose and associated risk using appropriate conversion factors. The gamma readings from walls and floors ranged from 133 cpm to a maximum of 87,963 cpm, with an average of 6,783.9 cpm. The maximum exposure rate from the Bicron was 11 µrem/hr, the minimum 1 µrem/hr, and the average 3.95 µrem/hr. Table 4-4 lists the results of the indoor gamma surveys.

4.3.3 Relationship of Indoor Surveys to Outdoor Surveys

Based on an evaluation of the Phase I and II indoor gamma and radon/thoron results from 71 properties that also had exterior gamma surveys, CH2M HILL made the following observations: (1) the utility of the indoor monitoring as a discovery tool is limited, and (2) the potential for exposure to indoor radon and thoron gases appears low. While 42 properties with indoor gamma exceeding median levels had contamination outside near the structure, there were 26 properties that had indoor gamma exceeding median levels but no outdoor contamination near the structure. The exterior gamma GPS surveys were found to be sufficient for identifying deposits of thorium material. Some exceedances of the radon/thoron screening criterion were observed at properties with no thorium contamination on the property, clearly due to naturally-occurring levels of radon. All exceedances of the radon/thoron screening criterion were due to elevated radon, not thoron, even at properties with thorium materials near the residence. CH2M HILL and USEPA therefore concluded that indoor monitoring was not a useful "finding tool" for identifying contaminated properties and the use of indoor surveys was discontinued after 1996.

4.4 Surface Water and Sediment Samples

The investigation of the RAS study area concentrated on residential, institutional, commercial, industrial, and municipal properties within the study area. Surface water and sediments were not a focus of the study and are not addressed in this report.

4.5 Ecological Impact

The RAS study area is predominantly residential and does not include significant wildlife or wetland areas. Ecological impacts therefore were not studied as part of the RAS RI and are not addressed in the baseline risk assessment for the RAS.

4.6 Overall Summary of Extent of Contamination

As a result of the extensive characterization fieldwork conducted by CH2M HILL and, late in the project, IDNS, all but 3 of the properties in the RAS study area had been tested as of the writing of this report. In all, 2,171 of the 2,174 properties in the study area have been evaluated to date, and USEPA will continue its efforts to gain access to and test the remaining 3 properties. Based on the CH2M HILL and IDNS testing to date, USEPA identified 676 properties as contaminated and requiring remediation. Table 4-5 summarizes these overall findings.

TABLE 4-5
Summary of Overall Findings at RAS

	In RAS Study Area	Tested *	Identified as Contaminated
Total Number of Properties	2,174	2,171	676

* Current as of the writing of this report. Includes properties tested by either CH2M HILL or IDNS.

SECTION 5

Fate and Transport

This section presents results from an evaluation of the fate and transport of the contaminants of concern for the RAS. The key components of that evaluation are as follows:

- Contaminants of concern for soil
- Contaminant characteristics including physical and chemical properties, chemical and biological transformations, and persistence
- Potential sources of contamination and release pathways in affected areas
- Potential routes of migration
- Transport of the constituents of concern for each medium.

5.1 Contaminants of Concern

According to the *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual* (Part A), EPA/540/1-89/002, contaminants of concern are those chemicals in a particular medium that, based on concentration and toxicity, are most likely to contribute significantly to risks calculated for exposure scenarios involving that medium.

The waste materials transported from the REF contained a wide range of constituents, including tailings from processed ores, possibly untreated ores, and other waste products from other process and manufacturing activities at the REF. Numerous sampling and analysis programs have been conducted for the original waste materials at the REF. The radiological residuals include thorium, uranium, and their radioactive decay products. The indicators of U-238 and Th-232 are Ra-226 and Ra-228, which are daughter products of U-238 and Th-232 and in equilibrium with their parents; in other words, the concentration of the activity for the various decay chain radionuclides is the same (Kerr-McGee 1981; Kerr-McGee 1985; NRC 1983). However, due to the higher radiotoxicity of Ra-226 and Ra-228, these are the contaminants of concern in soil for the RAS.

Section 3 of this report describes several metals—specifically, barium, chromium, and lead—that were believed to coexist with thorium tailings and could have been considered contaminants along with the radioactive tailings. However, as presented in the Decision Rule Technical Memorandum (CH2M HILL 1995), metal concentrations in samples collected during the pilot study were within metal-specific preliminary remediation goals (PRGs) developed for the RAS. Therefore, metals were eliminated as contaminants of concern.

Similarly, radon and thoron were investigated as potential contaminants of concern because of the existence of potentially high levels of U-238 and Th-232 near residential homes. However, because all exceedances of the indoor radon and thoron action criteria were due solely to elevated radon, and thoron was not elevated, the results were attributed to naturally-occurring radon and not thorium contamination. Therefore, radon and thoron were eliminated as contaminants of concern.

5.2 Contaminant Characteristics

Chemical and physical properties of contaminants provide information about their fate in the environment. Physical characteristics such as vapor pressure, solubility, and adsorptivity will determine the matrix (air, water, and solid) in which a compound resides and that affects the compound's mobility and persistence in the environment. Chemical and structural properties of compounds provide information on their resistance to chemical and biological transformations and determine their persistence in the environment. The toxicity and concentration of a constituent may have a significant effect on its biodegradability and the rate of biodegradation.

Because Ra-226 and Ra-228 have limited interaction characteristics (i.e., they do not volatilize or oxidize) and because they do not undergo biodegradation, this section addresses only those characteristics relevant to Ra-226 and Ra-228.

5.2.1 Physiochemical Properties

Volatility, solubility, and adsorption are the chemical properties that, coupled with groundwater flow velocity, determine an element's mobility. Ra-226 and Ra-228 are not volatile, and their solubility, similar to that of calcium, is dependent on metal speciation and pH. The radium ion (Ra^{2+}) is therefore controlled by adsorption onto sediment particles. Mobility by adsorption processes (ion exchange on clays; adsorption to iron, manganese, and aluminum oxyhydroxides; and absorption by organic matter) collectively is calculated from the distribution coefficient (K_d). The distribution coefficient is a partition coefficient that compares the amount of the element partitioned to the sediment or soil with the concentration dissolved in water (slope of the adsorption isotherm of a material at its origin). Therefore, a constituent with a high K_d will partition preferentially to soil and remain relatively immobile in groundwater. Ra^{2+} has a K_d value of 250 milliliters per gram (mL/g) for soils similar to those in West Chicago (Langmuir 1997; Oztunali and Roles 1984). Constituents with a K_d of 250 mL/g are considered highly immobile in soil. Table 5-1 presents the physical properties of Ra-226 and Ra-228.

TABLE 5-1
Characteristics of Ra-226 and Ra-228

Constituent Name	Radium 226	Radium 228
Symbol	Ra-226	Ra-228
Half Life	1,600 years	5.7 years
Nuclide Parent	Uranium 238	Thorium 232
Decay Mode	α, γ	β, γ
Aqueous Solubility* (mg/L)	—	—
Distribution Coefficient* (Kd)	250 mL/g	250 mL/g

Note: Radium 226 and Radium 228 has similar solubility characteristics as does calcium.
*O. Languir. *Aqueous Environmental Geochemistry*. Prentice Hall. New Jersey. 1997.

The parent of the radium species also significantly affects the distribution of each species. Ra-226 is a daughter product of uranium (K_d = 45 mL/g), which has a higher mobility than thorium (60,000 mL/g), the parent of the Ra-228 daughter product. Uranium-enriched materials typically contain higher Ra-226 than Ra-228, while thorium-enriched materials typically contain higher Ra-228 than Ra-226.

5.2.2 Constituent Transformation

Ra-226 and Ra-228 do not undergo chemical processes such as biotransformation and photolysis. Metallic radium is highly chemically reactive and decomposes in water. It combines directly with water to form the hydroxide. Radioactive decay is the only process that will affect concentrations of Ra-226 and Ra-228 in soils. The half-life of Ra-226 by alpha decay is 1,600 years. The half-life of Ra-228 is 5.7 years by beta decay. Therefore, Ra-226 and Ra-228 will decay by the following rate:

Ra-226: $C(t) = C(t_o) * e^{-((1/1600) * t)}$
Ra-228: $C(t) = C(t_o) * e^{-((1/5.7) * t)}$

where:

$C(t)$ = concentration at time (years)
$C(t_o)$ = concentration at some initial time
t = number of years

5.2.3 Constituent Persistence

The mobility of constituents and their resistance to chemical or biological transformations determine their persistence at a property. As described in this section, radium is very immobile in soil and, except for radiological decay, does not undergo biological or chemical transformation. Therefore, radium will persist in soil but will decay at the rates described in Subsection 5.2.2.

5.3 Affected Areas

This study focuses on the RAS, which consists of mainly residential, but also commercial and public properties. The contaminants of concern are located predominantly on residential properties, where radioactive tailings were used as fill. The affected areas are primarily yards, gardens, and driveways of residential properties, but affected areas also include areas of other nonresidential properties, plus alleys, areas under streets and sidewalks, and around buried utilities. Contamination also was found under some structures (e.g., garages and room additions), where thorium residuals were used as fill under the structure or where the structure was built upon already existing areas of contamination.

5.4 Potential Routes of Migration

From the standpoint of human health or environmental risk, the migration pathway for any constituent is composed of four elements: (1) an affected area or "source," (2) a transport medium such as air, surface water, groundwater, or soil, (3) an exposure point where exposure may occur, and (4) an exposure route into the body. All four elements must occur before the migration pathway is considered complete. The migration pathway will be considered incomplete if one or more of the four elements does not occur.

The risk assessment (Section 6 of this report) addresses exposure points and exposure routes for the RAS. The other two elements—affected areas and transport medium—are addressed in this section.

Surface and subsurface soils located on the RAS properties are the only media in which the contaminants of concern are being considered in this investigation. The primary release mechanisms for the contaminants of concern from soil that will lead to the spread of the contaminants of concern to other areas are the following:

- Airborne dust containing the contaminants of concern
- Leachate of contaminants of concern to groundwater and groundwater transport
- Stormwater surface runoff of contaminants of concern to other properties or to Kress Creek and the West Branch DuPage River

5.4.1 Airborne

Most airborne dust transport occurred from the REF onto nearby properties. Airborne transport from property to property is minimal. However, for properties subject to airborne transport, the characterization would have detected the extent.

5.4.2 Leachate of Soil to Groundwater

As noted, the distribution coefficient for radium is approximately 250 mL/g, and so radium particles are retained in soil. Because the soils in the affected areas tend to be clayey and to contain relatively elevated organic material, it is unlikely that radium will transport through the soil and underlying sediments to the groundwater. Several groundwater studies conducted within the West Chicago area support this conclusion. As described in Sections 1 and 2, the contaminants of concern (and also thorium and uranium) were not detected in groundwater at levels above natural concentrations. Thus, the contaminants of concern at the RAS will not transport to groundwater through the leaching mechanism.

5.4.3 Stormwater Surface Runoff

This study does not address Kress Creek or the West Branch DuPage River because these two water bodies are being addressed as part of the KCK and STP sites.

5.5 Contaminant Transport

The calculation of horizontal migration by groundwater flow using the K_d of 250 mL/g is provided in the following. Using the K_d of 250 mL/g for Ra, a retardation coefficient of 2,418 (unitless) is calculated using the following equation:

$$R = 1 + [(r/n)K_d]$$

where:

r = 1.45 (g/mL, estimated in accordance with subsurface characteristics)
n = 0.15 (assumed)

Therefore:

R = 2,418 (unitless)

The horizontal migration flow can then be calculated using the horizontal groundwater transport equation

$$Vc = (K \times I)/(n \times R) \text{ (ft/day)} \qquad \text{(Freeze 1979)}$$

where:

K = hydraulic conductivity (28 ft/day) (CH2M HILL 1997)
i = hydraulic gradient (0.0077 ft/ft)
n = effective porosity (assumed to be ~0.15)

Therefore:

$Vc = 0.00057$ ft/day

Hydraulic conductivity was determined by a groundwater investigation at RKP.
The hydraulic gradient was obtained from the RKP investigation, and topography was estimated from the center of the footprint to KCK (CH2M HILL 1997).

The horizontal distance traveled in a specified time period is then calculated using the equation

$$d = Vc \times 365 \text{ days/year (ft/year)}$$

Therefore:

$d = 0.22$ ft/year

On the basis of these data assumptions, the clayey soil and sediment with variable organic material within the West Chicago area would allow radium to migrate an estimated 0.22 foot (about 2.5 inches) per year. Because the vertical hydraulic conductivity is commonly about one-tenth the horizontal hydraulic conductivity, the vertical mobility would be approximately 0.022 foot (0.25 inch) per year. These calculations clearly indicate it is unlikely that radium and its parent elements will migrate any significant distance vertically in soil (to groundwater) or laterally in the groundwater from their original source.

SECTION 6

Baseline Risk Assessment

This section addresses the requirement for a baseline risk assessment in an RI/FS, as specified by the NCP [Section 300.430 (d)(1)]. The purpose of the baseline risk assessment is to provide risk managers with an understanding of the actual and potential risks to human health and the environment posed by a site and to describe and evaluate uncertainties associated with the assessment of risks. The baseline risk assessment presented in this section is specific to the RAS, and, consequently, differs from conventional risk assessments in several important respects. These are briefly summarized, as follows:

- The USEPA performed a preliminary, focused risk assessment (USEPA 1993a), results of which supported the decision to conduct non-time-critical removal actions at the RAS.
- Contaminants of concern at the RAS are radiological constituents. Quantification of health risks associated with potential exposure to radiologically contaminated materials requires conversion from radionuclide concentrations (as quantified in samples analyzed) to radiological dose levels corresponding to those concentrations for the specific nuclide. For the RAS baseline risk assessment, a standard model developed by ANL, Residual Radioactive Material Guidelines Model (RESRAD) (named for DOE's *Residual Radioactive Material Guidelines,* which the model was designed to implement) was used to convert concentrations to dose. Input to the RESRAD model requires radionuclide-specific concentration data and surface area estimates for the specific levels of contamination.
- Results from the pilot study (presented in Section 3.2) generated a predictive relationship between gamma activity and total radium concentrations, providing an extensive set of data to be used to develop input parameters for RESRAD. The analysis consists of first estimating nuclide concentrations from GPS survey gamma activity results then using the RESRAD model to convert concentrations to dose.

Thus, the RAS baseline risk assessment presented in this section is an expansion of the focused RA and includes descriptions of both the RESRAD model as well as the site-specific method used to generate surface area point of contact concentration estimates for model input.

Section 6.1 describes the overall approach to the baseline risk assessment. Section 6.2 defines *contaminants of potential concern* (COPCs) at the RAS. Section 6.3 provides the exposure assessment, exclusive of the methods used to estimate point of contact concentrations, which is detailed in Section 6.4. Section 6.5 provides a toxicity assessment of the RAS COPCS, as defined in Section 6.2. Section 6.6 documents the actual risk characterization, including a summary of numerical risk estimates, comparisons of estimated risks to USEPA criteria, and a brief evaluation of uncertainties in the risk calculations.

6.1 Approach to the Risk Assessment

This section presents the objectives and focus of this baseline risk assessment. The RESRAD model used to convert concentrations to dose values is introduced.

6.1.1 Removal Action Objectives and Action Levels

The removal action objectives (RAOs) specified by the USEPA for the RAS serve as the basis for identifying and evaluating appropriate response actions and alternatives that manage the contaminated materials. The RAOs are intended to minimize potential health hazards to humans living or working on contaminated properties, to minimize potential environmental impacts from the soil contamination, to be cost-effective, to use permanent solutions to the maximum extent practicable, and to establish soil conditions that comply with all ARARs.

Specific removal goals to meet the above objectives for radionuclide contaminants were established by the USEPA in their *Action Criteria for Superfund Removal Actions at the Kerr-McGee Residential Areas Site: West Chicago, Illinois* (USEPA November 1993b). That document explains how the criteria were derived and quotes the ARARs that form the foundation of the criteria. Table 6-1 summarizes the USEPA's action criteria for the RAS.

TABLE 6-1
USEPA's Action Criteria for RAS

Radionuclide	Background	Criteria
Indoor thoron and radon decay product concentrations	0.002 WL[a]	Reasonable efforts must be made to achieve an annual average concentration (including background) in occupied buildings of no more than 0.02 WL; in any case, the concentration (including background) must not exceed 0.03 WL (40 CFR 192.12(b)(1) and 192.40(b).
Outdoor gamma exposure rate	5–13 μrem/hr[a]	After backfilling, the outdoor gamma exposure rates must not statistically exceed background at a distance of 100 cm from the surface (Illinois Administrative Code, Section 332.150(b)(2)).
Indoor gamma exposure rate	Data unavailable	Indoor gamma exposure rates must not statistically exceed background (Illinois Administrative Code, Section 332.150(b)(2)). Note: This criterion will be used as a "finding tool" during verification to help determine if additional removal is necessary.
Radionuclide activity (concentration) in soils	2.18 pCi/g dry soil[b]	Dry soil concentrations of total radium (Ra-226 plus Ra-228) must not exceed 5 pCi/g above background levels averaged over areas up to 100 m^2 in any 15-cm depth (based on relevant and appropriate portions of Illinois Administrative Code, Section 332.150(b)(1)).

[a] Background values shown are approximate and are based on current available data.
[b] This background value is for total radium.

6.1.2 Risk Assessment Strategy

The basic framework for the risk assessment has been derived from the USEPA and DOE guidance documents, which include *Risk Assessment Guidance for Superfund, Part A, Volume 1* (RAGS) (USEPA 1989); *Health Effects Assessment Summary Tables for Radionuclides*, issued by the ORIA (USEPA 1997); and *Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD* (ANL 1993), prepared by ANL for DOE.

The steps involved in preparing the risk assessment are described below:

1. **Identification of Contaminants of Potential Concern.** This step involves identifying and selecting for inclusion into the risk assessment those chemicals or, as in the case of the RAS, constituents, at the site that are of greatest potential health concern. This step is presented in Section 6.2.

2. **Exposure Assessment**. An exposure assessment is conducted to identify the pathways through which humans are potentially exposed to COPCs detected at the site and to estimate the magnitude of potential human exposures and the frequency and duration of these exposures. Estimates of exposure are developed for the most feasible current and future land uses. The exposure assessment involves evaluating contaminant releases from the site, identifying potentially exposed populations and pathways of exposure, estimating exposure point concentrations for specific pathways, and estimating contaminant intake rates in humans. The exposure assessment, exclusive of the point concentration estimates, is found in Section 6.3. Point concentration estimates are presented, with the methodology description, in Section 6.4.

3. **Toxicity Assessment**. Toxicity assessment involves the characterization of the toxicological properties and health effects of COPCs with special emphasis on defining their dose-response relationships. From these dose-response relationships, toxicity values are derived that can be used to evaluate the potential occurrence of adverse health effects at different levels of exposure. This step is presented in Section 6.5 of the risk assessment.

4. **Risk Characterization**. The risk characterization summarizes and combines the results of the exposure and toxicity assessments to characterize health risks, in both numerical expressions and qualitative statements. Section 6.6 presents the estimated risks associated with the RAS and discusses the uncertainties in the risk assessment process and how these uncertainties influence the characterization of health risks.

While more recent risk assessment approaches incorporate "multiple descriptors" of health risks (USEPA 1992), the standard guidance for Superfund, RAGS, relies on a single risk descriptor, the reasonable maximum estimate (RME). The RME is defined as the highest exposure that is reasonably expected to occur at a site and is generally considered as the 95 percent UCL of the average level of exposure associated with site contaminants. The USEPA's Science Advisory Board (SAB) recommends presentation of some type of "most reasonable" estimate of exposure along with the RME (USEPA 1993c). USEPA guidelines for risk assessors and risk managers (USEPA 1992) recommends presentation of health risks associated with "high-end" and central tendency portions of the statistical distribution of exposure estimates, allowing risk managers to interpret the relative uncertainty in resulting risk estimates and to incorporate this understanding into their decision making. Consequently, in developing factors for inclusion into the RAS risk calculations, RME and best estimate exposure parameter and point of contact concentration estimates were used to provide a range of estimated risks.

6.1.3 Focus of the Baseline Risk Assessment

This baseline risk assessment focuses on the protection of human health and associated uncertainties. Because the RAS consists predominantly of residential properties and does not include any significant wildlife or wetland areas, an ecological risk assessment to address potential risks to the environment has not been performed.

As stated by the National Academy of Sciences (NAS), "The principal potential impact of radioactive effluents on the biosphere is the induction of deleterious health effects in [people]. Comparable levels of impact undoubtedly exist in other biota, but there is no present evidence that there is any biological species whose sensitivity is sufficiently high to warrant a greater level of protection than that adequate of [people]" (USEPA 1993d). Similarly, the National Council on Radiation Protection and Measurements (NCRP) concluded that "if man is adequately protected then other living things are also likely to be sufficiently protected" (USEPA 1993d).

The conclusions reached by the NAS and the NCRP provide the technical rationale for focusing on human health risks in the development and implementation of the radiation site cleanup regulations.

6.1.4 RESRAD Model Description

Quantification of doses involves converting radionuclide concentrations (in pCi/g) in soil into dose rates (in millirem/year) using a dose assessment model. Use of the model requires an exposure scenario that specifies a hypothetical receptor (i.e., resident), pathways of exposure from radionuclides in soil to the receptor, and assumptions and parameters for estimating exposures and doses to the receptor from radionuclides in soil.

RESRAD, the model selected for the Kerr-McGee RAS, was developed by ANL for implementing DOE guidelines for residual radioactive material in soil (ANL 1993).

6.2 Contaminants of Potential Concern

COPCs are contaminants that potentially present the greatest human health concerns (i.e., those present in the highest concentrations, with the widest distribution over the site, or that exhibit the highest mobility or the highest toxicity). The purpose of identifying COPCs is to focus the risk assessment on the most important contaminants found at a site; while there are no criteria defining the "most important chemicals" or COPCs, USEPA guidance mentions that COPCs generally are those representing 99 percent of the total site risk (USEPA 1989). The COPCs at the RAS are radionuclides

The REF was operated as an extraction facility producing commercial thorium, radium, and other materials such as bastnasite (a rare earth ore), for various purposes. Production of thorium, mesothorium (commercial Ra-228), and rare earths yielded radioactive mill tailings primarily containing Th-232 and residual levels of radium (Ra-226 and Ra-228), radiological COPCs. The radioactive decay chains for Th-232 and U-238 (see Figures 2-4 and 2-5, respectively) display the progeny and half-lives for each isotope and principal particles (alpha or beta) emitted during the decay. Released gamma energy is also a significant component of some of decays. The decay chains for U-238 and Th-232 are briefly summarized as follows.

- Uranium-238 transforms by alpha and beta decay, after several intermediate transformations, to Ra-226, the parent of Rn-222, commonly known as radon. Rn-222 is a noble (chemically inert) gas that may diffuse or migrate through solids and be released to the atmosphere. The daughters of Rn-222, such as polonium-218 (Po-218) and lead-214 (Pb-214), are generally formed as ions that attach to particulates. The decay chain ends with stable lead-206 (Pb-206).
- Thorium-232 alpha-decays to Ra-228, which transforms to Ra-224 by alpha and beta decays. Radium-224 is the parent of a noble gas, Rn-220, often called thoron to distinguish it from Rn-222, produced from the U-238 decay chain. Rn-220 decays with a

56-second half-life to polonium-216 (Po-216), which transforms by several beta and alpha decays to stable lead-208 (Pb-208).

Potential metal contamination associated with tailings from the REF was identified at the time that the USEPA proposed listing the RAS on the NPL. Consequently, during the pilot study conducted at the beginning of the USEPA's characterization of the RAS study area, roughly 150 composite soil samples (excluding duplicates) were quantified for barium, chromium, and lead. Comparison with PRGs developed during preparation of the EE/CA indicated that all concentrations in the composite soil samples were below the USEPA criteria (CH2M HILL, March 1995). Metals therefore were precluded from further sampling and were eliminated as COPCs.

Radon and thoron originally were considered COPCs. As described in Section 4.3, extensive sampling documented that WLs of radon and thoron in residences where tailings were found adjacent to exterior structural walls were generally less than the USEPA's action levels for radon and thoron. The instances where the radon and thoron action level was exceeded were due solely to elevated radon, not thoron, and were not attributed to thorium contamination. Therefore, radon and thoron were removed from the list of COPCs.

Bastnasite, which was produced at the REF, was not analyzed for and does not have associated oral, inhalation, or dermal slope factors (SFs) or reference doses (RfDs).

Based on the comparatively high radiotoxicity of Ra-226 and Ra-228, these radionuclides are the RAS COPCs used in this baseline risk assessment.

6.3 Exposure Assessment

Exposure refers to the potential contact of an individual with a contaminant. Exposure assessment is the estimation of the magnitude, frequency, duration, and routes of exposure to a contaminant. Human exposure to contaminants is typically evaluated by estimating the amount of a contaminant that could come into contact with, for example, the lungs, gastrointestinal (GI) tract, or skin during a specified period of time.

The exposure assessment for this site is based on scenarios that define human populations potentially exposed to COPCs that originate from the RAS. The potential pathways of exposure, frequency and duration of potential exposures, rates of contact with air and soil, and the concentrations of contaminants in air or soil are evaluated in the assessment of human intake of COPCs. Contaminant intakes and associated risks have been quantified for all exposure pathways considered potentially complete.

This section describes the assumptions, data, and methods used to evaluate the potential for human exposure to COPCs that originate from the Kerr-McGee RAS, including:

- Description of COPC sources (6.3.1)
- Identification of potential receptor (6.3.2)
- Identification of exposure pathways (6.3.3)
- Development of exposure scenarios (6.3.4), based upon results from the fate and transport of COPCs described in 5.3 and 5.4, and the conceptual model of the site, as developed in the RAS Work Plan (CH2M HILL 1994c)

- Development of exposure factors associated with each exposure pathway (6.3.5).

The final component to the exposure assessment, that is, estimate of best and reasonable maximum concentrations of contaminants at points of contact, is described in Section 6.4.

6.3.1 Sources of COPCs

From 1932 to 1973, the REF was operated as a thorium extraction facility for various purposes. Production of thorium, mesothorium, and rare earths yielded radioactive tailings primarily containing Th-232 and residual levels of radium (Ra-226 and Ra-228). The tailings were stockpiled at the REF and were available for use as fill material at residential and other properties throughout the West Chicago area, resulting in widespread surface and subsurface contamination of soils (see Section 1.2.2). In addition, piles of the material were subject to wind dispersal, blowing the material off the facility. Therefore, the primary source of contamination at the RAS is a result of tailings used as backfill or from wind blowing material off the REF.

The other major dispersion mechanism, described in Section 5.4—lateral transport of materials off the REF with stormwater runoff—affects properties adjacent to the banks of the receiving water bodies, including Kress Creek and the West Branch DuPage River, areas that are part of the KCK site. Although characterization of the creekside areas of properties abutting the creek was completed at the same time as the rest of the property, remediation of the bank materials will be accomplished in conjunction with the KCK remedy.

6.3.2 Identification of Potential Receptors

Residents living at single-family dwellings (children and adults) are considered the most important receptors. These receptors have the greatest potential for daily exposure to the contaminants of concern as a result of normal activity patterns within the home and outside within the confines of their own property. An intermittent-type receptor, such as a trespasser or visitor or a construction worker coming into contact with site contaminants, is not considered a potential receptor because of the much lower integrated exposure time.

No future changes in receptors are anticipated because the study area is fully developed primarily with single-family residences. Because this land use is not likely to change in the future, current receptors may also describe future receptors.

6.3.3 Identification of Exposure Pathways

An exposure pathway describes the mechanism through which a contaminant comes into contact with a receptor. A complete exposure pathway must exist from the source of contaminants in the environment (i.e., in soil or air) to human receptors in order for contaminant intake to occur. In this section, the complete exposure pathways are chosen from all potential pathways and are further evaluated. A complete exposure pathway consists of the following four elements

- A source of contaminant release to the environment
- An environmental transport medium
- A point of contact (known as the exposure point) for receptors with the COPCs
- A route of intake for the contaminant into the receptor

If one of the four elements is missing, the exposure pathway is incomplete and no intake or health risk is associated with that pathway. The presence or absence of any of these elements depends on the specific conditions found at the site.

6.3.4 Exposure Scenarios

The conceptual site model developed during work planning for the RI (see Figure 6-1) is a framework that identifies and illustrates environmental pathways of concern by depicting the various media, transport pathways, and exposure pathways that could be affected as a result of the residential soil contamination. Although the model is representative of current conditions, future conditions under a no-action scenario are expected to be similar. Unrestricted future use of the RAS is assumed to be represented by a resident in a rural-residential setting.

Exposure scenarios describe the conditions under which exposures to COPCs at the RAS could occur. The scenarios identify receptor populations, pathways of exposure to receptors, and contaminant data used to estimate contaminant intake through each exposure pathway. The exposure pathways resulting from the presence of tailing materials or potential release mechanisms identified in the conceptual model include:

- Gamma radiation emitted from the soil through radioactive decay
- Uptake of radionuclides in vegetables grown in the contaminated soil
- The presence of contamination in residential soil allowing direct contact to the COPCs (independent of) any release mechanism, including particulate ingestion, inhalation or dermal contact to beta emitters

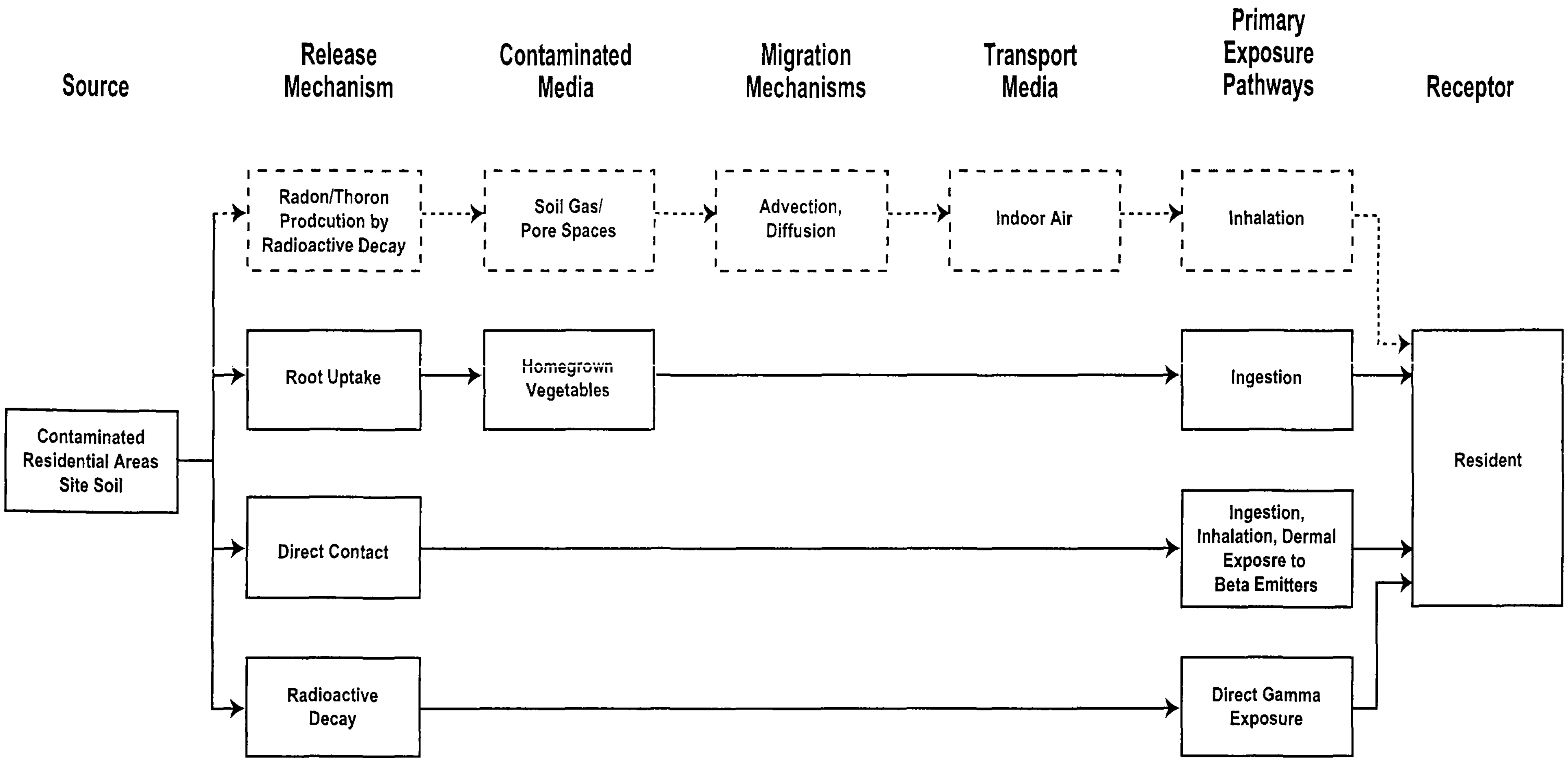
Although the original conceptual model included potential inhalation of radon or thoron within residences and buildings within the RAS, site-specific results from the indoor sampling of radon and thoron have resulted in elimination of inhalation of indoor gases as a potential exposure scenario.

Ingestion of groundwater, fish, and meat/milk were not considered potential exposure pathways at the RAS. A complete exposure pathway does not exist, and intake of the COPCs is not expected to occur. Ingestion of groundwater is not a complete pathway because of the low mobility of the contaminants.

For the radium COPCs in the RAS, external exposure and vegetable ingestion represent the dominant exposure pathways; i.e., other soil ingestion and dermal contact contribute little to total exposure. The three exposure pathways are consistent with default pathways used in the RESRAD model to evaluate a rural-residential exposure scenario, with the exception of drinking water exposure, ingestion of meat and milk, and ingestion of fish from surface water (ANL 1993). RESRAD calculates risks associated with each individual pathway, then totals estimated risks across all pathways to calculate aggregated risk for each scenario.

6.3.5 Exposure Factors

This subsection describes the exposure factors associated with each identified exposure pathway. The exposure pathways considered in this risk assessment include external exposure, inhalation, vegetable/fruit ingestion, and soil ingestion. In the first pathway, exposure is by external radiation from radionuclides outside the body. For the remaining pathways, exposure is by internal radiation from radionuclides that are inhaled or ingested.



Legend

——— Probable Pathways

- - - - - Potential Pathway Eliminated

Potential contaminants of concern: Th-232 and U-238 and daughters

Figure 6-1

Conceptual Site Model

Kerr-McGee West Chicago

6.3.5.1 External Gamma Exposure Pathway

Gamma radiation from radionuclides distributed throughout the RAS study area represents the dominant external radiation pathway. The dose due to external gamma radiation is first calculated for an individual exposed continuously to radiation from an infinite contaminated zone at a distance of 1 meter from the ground surface. Correction factors, such as shielding by a cover of uncontaminated soil, irregular shape, shielding by floors and walls of a house, and less-than-continuous occupancy, are then applied for the finite area and thickness of the contaminated zone (ANL 1993). Table 6-2 lists the parameters for estimating dose from external radiation, including assumed correction factors.

TABLE 6-2
Summary of Parameters Used for Estimating Dose

Description	Subsection	Default Value*	RME Value	Best Estimate Value	Units	Source
Area of contaminated zone	6.3.5.1	10,000	Property-specific	Property-specific	m^2	See Table 6-5
Thickness of contaminated zone	6.3.5.1	2	2	2	m	ANL 1993
Cover depth	6.3.5.1	0	0	0	m	ANL 1993
Density of cover material	6.3.5.1	1.5	Not used	Not used	g/cm^3	ANL 1993
Cover depth erosion rate	6.3.5.1	1.5	Not used	Not used	m/yr	ANL 1993
Evapotranspiration coefficient	6.3.5.1	0.5	0.5	0.5	Unitless	ANL 1993
Precipitation	6.3.5.1	1	1	1	m/yr	ANL 1993
Irrigation	6.3.5.1	0.2	0.2	0.2	m/yr	ANL 1993
Exposure duration	6.3.5.1	30	30	30	yr	ANL 1993
Shielding factor, external gamma	6.3.5.1	0.7	0.7	0.7	Unitless	ANL 1993
Fruits, vegetables, and grain consumption	6.3.5.2	160	160	29	kg/yr	EPA 1995
Leafy vegetable consumption	6.3.5.2	14	14	14	kg/yr	ANL 1993
Soil ingestion rate	6.3.5.2	36.5	36.5	18.3	g/yr	EPA 1995
Mass loading for foliar deposition	6.3.5.2	0.0001	0.0001	0.0001	g/m^3	ANL 1993
Depth of soil mixing layer	6.3.5.2	0.15	0.15	0.15	m	ANL 1993
Depth of roots	6.3.5.2	0.9	0.9	0.9	m	ANL 1993
Inhalation rate	6.3.5.3	5,110	8,400	5,110	m^3/yr	EPA 1995
Mass loading for inhalation	6.3.5.3	0.0002	0.00005	0.00005	g/m^3	ANL 1993
Dilution length for airborne dust, inhalation	6.3.5.3	3	3	3	m	ANL 1993
Shielding factor, inhalation	6.3.5.3	0.4	0.4	0.4	Unitless	ANL 1993
Fraction of time spent indoors	6.3.5.4 6.3.5.1	0.5	0.5	0.65	Unitless	ANL 1993
Fraction of time spent outdoors (onsite)	6.3.5.4 6.3.5.1	0.25	0.25	0.1	Unitless	ANL 1993

*Source: ANL 1993.

6.3.5.2 Vegetable/Fruit Ingestion Pathway

Uptake of radionuclides in vegetables grown in the contaminated soil is also considered a dominant exposure pathway. Exposure to radionuclides is through root uptake from crops grown in the contaminated area. This pathway contributes to dose as soon as a family establishes a residence and a garden on the site. The time dependence of these pathways is determined by the time dependence of the cover, contaminated zone thickness, and the radionuclide concentrations in the contaminated area.

Radionuclide transport through the food pathway is also determined by quantities of foods consumed (dietary factors), the fraction of the diet from foods contaminated by radionuclides from the contaminated area (determined by the fraction raised locally and the area of the contaminated zone), the cover depth and contaminated zone thickness relative to the root zone of the plants, and the various transfer factors from plant to plant (ANL 1993). Table 6-2 lists the parameters for estimating dose from vegetable ingestion.

6.3.5.3 Inhalation of Soil Particulates Pathway

For the purposes of this risk assessment, inhalation exposure results primarily from inhalation of contaminated dust. The inhalation exposure pathway is complete when an airborne radionuclide originating from the source (contaminated zone) comes into contact with the exposed individual. Inhalation exposure is characterized by an occupancy factor (equivalent fraction of time during which an individual inhales contaminated air) and a factor for the inhalation rate. It is also characterized by the air/soil concentration ratio, which is defined as the ratio of the airborne concentration of a radionuclide at a human exposure location to the concentration in the soil. This ratio is dependent upon the complex processes by which soil particles become airborne and are transported to an exposure location (ANL 1993). Table 6-2 lists the parameters for estimating dose from inhalation of soil particulates.

6.3.5.4 Soil Ingestion Pathway

The soil ingestion pathway corresponds to direct ingestion of soil. The dose due to ingestion of soil depends on the amount of soil ingested and the concentration of soil (ANL 1993). Table 6-2 lists the parameters for estimating dose from soil ingestion.

6.4 Point of Contact Estimates

The purpose of this section is to describe the RAS-specific best and reasonable maximum point of contact estimates used in RESRAD. Point of contact input for RESRAD requires estimates of radium concentrations and the surface areas corresponding to those concentrations. Radium levels were converted from gamma activity levels, based upon the regression analysis developed in the Decision Rule Technical Memorandum (CH2M HILL 1995). Associated surface areas were determined using contoured output from the GPS gamma surveys. Best and RME conditions were selected from radium-surface areas from site-specific parcels where at least part of the property exceeded the USEPA's action levels.

Subsections describe the source of analytical data (6.4.1), the method used to select RAS properties representative of best and RME estimates of gamma activity and surface areas (weighted sums) (6.4.2), and the conversion of gamma estimates to total radium concentrations (6.4.3). Subsection 6.4.4 explicitly defines the best and RME estimates used in the RESRAD model.

6.4.1 Source of Analytical Data

As described in Section 4.2, RAS gamma activity surveys conducted by CH2M HILL identified 35.2 acres of the RAS that exceeded the USEPA's action levels (>25,500 cpm). CH2M HILL identified these areas on 571 of the properties that CH2M HILL surveyed during two investigations: the initial investigation completed between March 1994 and November 1996, and the expanded study area investigation performed between November 1998 and May 2000. A baseline risk assessment for the RAS was performed in 1997 on the properties surveyed by CH2M HILL during the initial investigation, prior to USEPA's decision to expand the site study area. During the initial investigation CH2M HILL identified 28.9 acres on 487 properties that exceeded the USEPA's action levels. These data account for approximately 82 percent of the total acreage that CH2M HILL ultimately found to exceed the USEPA's action levels and 72 percent of the total number of properties that USEPA ultimately determined to be contaminated (based on all surveys conducted by CH2M HILL and IDNS). USEPA determined that it served no useful purpose to conduct another risk assessment after expansion of the site study area. This will be discussed further in Section 6.6.3 which discusses uncertainties associated with the risk assessment.

6.4.2 Methodology for Calculating Weighted-Sum Gamma Activities Times Surface Area

RESRAD input requires both contaminant concentrations and associated surface areas. Consequently, the best and "reasonable maximum" estimates were more appropriately selected among individual properties rather than as average or ULs of concentrations and surface areas over the entire RAS. Properties where no gamma activity exceeded USEPA's action levels were excluded from consideration. RAS properties for best and RMEs were limited to properties where one or more gamma readings from the outdoor survey exceeded the UL of gamma values used to trigger cleanup (25,500 cpm). Properties with radium concentrations and associated surface area that reflected best estimate or RME assumptions were selected as the mid-lying and upper 95th percentile of the 487 properties when they had been ranked by the weighted sum of gamma activity times surface area.

The total surface area and gamma activity for areas of properties exceeding gamma activity action levels were used to calculate the average gamma for the total contaminated surface area on the property, the required inputs into RESRAD. Surface areas for each of the following gamma intervals were multiplied by the average gamma for that interval, resulting in a weighted sum gamma activity for each property.

Table 6-3 summarizes the calculation of weighted sums and identifies the gamma intervals used to define cutpoints for areal estimates from the property survey and the average gamma for that interval.

TABLE 6-3
Calculation of Property-Specific Weighted Sum Gamma Activities

Interval	Gamma Interval	Average Gamma	Surface Area	Weighted Interval
1	>25,499 – 26,475	25,712	SA1	SA1*25,712
2	>26,475 – 28,326	27,363	SA2	SA2*27,363
3	>28,326 – 30,586	29,420	SA3	SA3*29,420
4	>30,586 – 33,265	31,879	SA4	SA4*31,879
5	>33,265 – 36,744	34,933	SA5	SA5*34,933
6	>36,744 – 41,328	38,893	SA6	SA6*38,893
7	>41,328 – 47,760	44,375	SA7	SA7*44,375
8	>47,760 – 58,205	52,598	SA8	SA8*52,598
9	>58,205 – 79,275	66,611	SA9	SA9*66,611
10	>79,275 – 999,999	171,092	SA10	SA10*171,092
	Total		**SA > 25.5K**	**Weighted Sum**

The method consisted of two steps, applied to all 487 properties where one or more gamma values exceeded the USEPA's action levels, but only to the portions of the property that exceeded the criterion. Steps are summarized as follows:

1. Gamma intervals 1 through 10 were based on the distribution of all gamma values from all surveys that exceeded 25,500 cpm (114,249 observations). Ten percent of the 114,249 gamma values lie within each of the intervals. The average gamma for each interval was generated from the approximately 11,425 records in each interval.
2. Surface areas for each interval for each property where at least one gamma value exceeded 25,500 cpm were found using GIS. Surface areas for intervals 1 through 10 were multiplied by the average gamma for that interval. The weighted sum for the parcel is the total of the 10 products, i.e., [(surface area1) × (25,712)] + [(surface area2) × (27,363)] + . . . + [(surface area10 × (171,092)].

Properties selected for use as best and RME estimates in the risk assessment were found by first ranking the weighted sum for the 487 properties. Five properties distributed around the 95th percentile (ranks 462 through 466) were then selected to represent the RME scenario and five distributed around the 50th percentile (ranks 242 through 246) to represent the best estimate scenario.

6.4.3 Conversion of Gamma Activities to Total Radium Concentrations

Average gamma activities for each property were converted to pCi/g total radium, using the regression relationship defined in the Decision Rule Technical Memorandum (CH2M HILL 1995):

$$Log_{10}\ GAMMA\,(cpm) = 3.851 + 0.609\,(Log_{10}\ Total\ RE)$$

The value for Ra-226 was taken as the average background level (1.1 pCi/g), in accordance with (1) the Decision Rule technical memorandum and (2) the distribution of Ra-226 from all properties surveyed. The property-specific average concentration of Ra-228 was then calculated as the difference between total radium and Ra-226.

The average background level of 1.1 pCi/g in soil was corroborated by comparing the Ra-226 results from all soil samples collected through 1996 during the initial investigation, including preprocessed composite soils analyzed by IDNS, unpreprocessed composite soils analyzed by IDNS (designated "Marinelli"), grab samples analyzed by IDNS, and M1 measurements from the field instrument. Table 6-4 summarizes the minimum, mean, and maximum Ra-226 concentrations from each type of soil analysis. The selected value of 1.1 pCi/g for Ra-226, originally estimated in the Decision Rule technical memorandum, corresponds to the means of both the preprocessed and unpreprocessed composite soil samples. The decision to use this value for Ra-226 will be discussed further in Section 6.6.3 which discusses uncertainties associated with the risk assessment.

TABLE 6-4
Summary of Ra-226 Concentrations in Soil

Sample Type	Count	Minimum Ra-226 (pCi/g)	Mean Ra-226 (pCi/g)	Maximum Ra-226 (pCi/g)
IDNS Composite	543	0.23	1.07	3.81
IDNS Marinelli	329	0.52	1.07	3.17
IDNS Grabs	1189	0.58	1.55	109.57
In Situ M1	296	0.31	1.01	30.91

Notes: The selected value of 1.1 pCi/g for Ra-226 presented in the Decision Rule Technical Memorandum corresponds to the means of both preprocessed and unpreprocessed composite soil samples.

6.4.4 Exposure Point Concentrations

Table 6-5 summarizes the property surface area, average gamma, converted total radium, default Ra-226 and Ra-228 (the difference between total radium and Ra-226) for each of the five properties representing best case and RME conditions in the RAS.

6.5 Toxicity Assessment

The toxicity assessment describes the relationship between the magnitude of exposure to a chemical and adverse health effects. This section briefly describes the adverse effects and toxicity values used to characterize health risks for the COPCs detected at the site.

6.5.1 Assessment of Radionuclide Risks

The COPCs are radionuclides. There are five major studies of the adverse effects in humans associated with exposure to radionuclides and upon which quantitative estimates have been developed for the health risks from radionuclide exposure. The basic studies upon which the quantitative calculations are based include occupational exposure to radium in the early 20th century, the atom bomb survivors, miners exposed to radon, patients irradiated with x-rays for ankylosing spondylitis, and children irradiated with x-rays for inea capitis (ringworm) (Harley 1991).

TABLE 6-5
Summary of Exposure Point Concentrations for RME and Best Estimate Exposure Scenarios

Case	Surface Area (m^2)	Average Gamma (cpm)	Ra-228 (pCi/g)	Ra-226 (pCi/g)	Total Re (pCi/g)
Reasonable Maximum Exposure					
1	678	100,309	76.6	1.1	77.7
2	1,923	39,244	15.5	1.1	16.6
3	1,114	68,223	40.2	1.1	41.3
4	958	65,603	37.6	1.1	38.7
5	1,622	45,078	19.8	1.1	20.9
Best Estimate Exposure					
1	31	41,191	16.9	1.1	18.0
2	43	29,675	9.42	1.1	10.5
3	45	27,360	8.11	1.1	9.21
4	44	26,659	7.72	1.1	8.82
5	35	38,143	14.8	1.1	15.9

Ionizing radiation has been shown to be a carcinogen, a mutagen, and a teratogen. Radiation can induce cancers in nearly any tissue or organ in both humans and animals, and the probability of cancer induction increases with increasing radiation dose. Cancer induction is a delayed response that has been documented extensively in epidemiological studies of Japanese atomic bomb survivors, uranium miners, radium dial painters, and patients subjected to a variety of radiation treatments. Laboratory animal research and mammalian tissue culture studies have provided additional, corroborative data.

Data are also available from both human and animal studies on the teratogenic effects of radiation. These data show that the fetus is most sensitive to radiation injury during the early stages of organ development (between 8 and 15 weeks for the human fetus). Resultant radiation-induced malformations depend on which cells are most actively differentiating at the time of exposure.

The USEPA classifies all radionuclides as known human carcinogens, based on their property of emitting ionizing radiation and on the extensive weight of evidence provided by epidemiological studies of radiogenic cancers in humans. Evaluation of the health risks consider the carcinogenic effects of radionuclides only. In most cases, cancer risks are limiting, exceeding both mutagenic and teratogenic risks (USEPA 1997).

6.5.2 Radionuclide Profiles

This section presents the profiles for the COPCs (radium) for the Kerr-McGee RAS.

6.5.2.1 Radium

Radium is a naturally occurring radioactive metal that can exist in several forms called isotopes. It is formed when uranium and thorium decay in the environment. There are four naturally occurring radium isotopes (Ra-223, Ra-224, Ra-226, and Ra-228), but discussion of radium will be limited to the isotopes Ra-226 and Ra-228. The radioactive half-life of Ra-226 is 1,600 years and the radioactive half-life of Ra-228 is 5.7 years. The decay mode for Ra-226 is through alpha emission and the decay mode for Ra-228 is through beta emission. The thorium and uranium decay chains are presented in Figures 2-4 and 2-5, respectively.

Studies of various significant human exposures to radium (e.g., ingestion of radium by dial painters) form the basis for estimates of risk from internal deposition of radium isotopes (ICRP 1981). Radium acts similarly to its chemical analog calcium, whereupon entry into the body through ingestion or inhalation radium becomes deposited almost exclusively in the skeletal tissues. Observed skeletal cancers in humans from radium include bone sarcomas and head sinus carcinomas. The primary radioisotope involved in radium doses has been Ra-226 with a smaller contribution from Ra-228. Inhalation exposure studies of humans exposed to Ra-228 detected this radioisotope in the lungs and skeleton only.

- Radium dial painters ingested radium by licking radium self-luminous compound from the fine brushes with which they painted numerals on watches, clocks, and instruments. It is estimated that the lowest total intake level of radium associated with malignancy was 60 μCi (2.2 kilo Becquerel [kBq]) over an exposure period of roughly 2 years. In accordance with findings from ANL, bone sarcomas, carcinomas of the perinasal sinuses and mastoid air cells (head cancers), and the deterioration of skeletal tissue are considered to be the only effects that are unequivocally attributable to internal radium.
- A 52-year-old man reportedly ingested a rejuvenating tonic that contained radium. The total dose over a 5-year period was approximately 2,800 μCi. Symptoms resulting from radium ingestion included necrosis of the jaw, abscess of the brain, secondary anemia, and terminal bronchopneumonia (Agency for Toxic Substances and Disease Registry [ATSDR] 1990).
- Based on the results from one inhalation exposure, humans were accidentally exposed to Ra-226 (the sulfate), with radium primarily depositing in the lungs. Radium was eliminated from the lungs by systemic circulation to the skeleton, soft tissue, and excretory system. Additionally, some of the radium salt may have been coughed up and swallowed during the exposure episode (ATSDR 1990).

6.5.3 Derivation of Cancer Slope Factors

Unless evidence to the contrary exists, if a carcinogenic response occurs at the exposure levels studied (typically high doses), it is assumed that responses will occur at all lower doses. Exposure to any level of a carcinogen is then considered to have a finite risk of inducing cancer. Because risks at low levels of exposure cannot be quantified directly by either animal or epidemiological studies, mathematical models are used to extrapolate from high to low doses. The models provide numerical estimates of cancer potency referred to as slope factors (SFs). Under an assumption of dose-response linearity at low doses, the SF defines the cancer risk due to continuous constant lifetime exposure to one unit of carcinogen (in units of risk per mg/kg-day). Individual cancer risk was calculated as the product of exposure to a chemical (in pCi) and the SF for that chemical (in $pCi)^{-1}$ as follows:

$$Risk = Intake \times SF$$

The USEPA's ORIA calculates radionuclide SF values using health effects data and dose and risk models from a number of national and international scientific advisory commissions and organizations, including the NAS, the NCRP, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the International

Commission on Radiological Protection (ICRP). A detailed discussion of ORIA's approach and assumptions is provided in Estimating Radiogenic Cancer Risks (EPA 402-R-93-076).

Radionuclide SFs are calculated for each radionuclide individually, in accordance with its unique chemical, metabolic, and radioactive properties. The calculation uses dose estimates from USEPA's computer code RADRISK, vital statistics from the U.S. Decennial Life Tables for 1979 through 1981 (described in EPA 402-R-93-076), and cancer risk estimates based largely on the results of the NAS Biological Effects of Ionizing Radiation (BEIR) V report, ICRP Publication 60, and NRC analyses. Ingestion and inhalation SFs for radionuclides account for the following:

- The amount of radionuclide transported into the bloodstream from either the GI tract following ingestion or from the lungs following inhalation
- The ingrowth and decay of radioactive progeny produced in the body after intake
- The distribution and retention of each radionuclide (and its associated progeny, if appropriate) in body tissues and organs
- The radiation dose delivered to body tissues and organs from the radionuclide (and its associated progeny, if appropriate)
- The sex, age, and organ-specific risk factors over the lifetime of exposure

The SFs are the average risk per unit intake or exposure for an individual in a stationary population with vital statistics (mortality rates) of the U.S. in 1980. (The expected lifetime for an individual in this population is about 74 years.) Consequently, radionuclide ingestion and inhalation SFs are not expressed as a function of body weight and time and do not require corrections for GI absorption or lung transfer efficiencies (USEPA 1997). Table 6-6 lists the SFs for the radioactive COPCs.

TABLE 6-6
Summary of Slope Factors of Chemicals of Potential Concern

	Slope Factor Lifetime Excess Total Cancer Risk per Unit Intake or Exposure		
Isotope	**Ingestion (Risk/pCi)**	**Inhalation (Risk/pCi)**	**External Exposure (Risk/yr per pCi/g soil)**
Ra-226 + Decay Products	2.96E-10	2.75E-09	6.74E-06
Ra-228 + Decay Products	2.48E-10	9.94E-10	3.28E-06

Because of the radiation risk models employed for both internal and external exposures, SFs for radionuclides are characterized as central estimates in a linear model of the age-averaged lifetime total radiation cancer incidence risk per unit intake or exposure.

Selected radionuclides and radioactive decay chain products are designated in Health Effects Assessment Summary Tables (HEAST) with the suffix "+D" (e.g., U-238+D, Ra-226+D, cesium-137 [Cs-137] +D) to indicate that cancer risk estimates for these radionuclides include the contributions from their short-lived decay products, assuming equal activity concentrations (i.e., secular equilibrium) with the principal or parent nuclide in the environment.

6.5.4 Dose Conversion Factors

Human health impacts from exposure to radionuclides typically are represented by radiation dose or increased lifetime cancer risk (ILCR). As noted, individual cancer risk was calculated as the product of exposure to a chemical (in pCi) and the SF for that chemical. Radiation dose is calculated by the RESRAD model using dose factors published in Federal Guidance Reports Nos. 11 and 12 (Eckerman et al. 1988; 1993).

Dose for the external pathway is calculated using the formula

$$Dose\left(mrem / yr\right) = Concentration\left(pCi / g\right) \times DCF\left(mrem / yr / pCi / cm^3\right) \times \rho\left(g / cm^3\right)$$

where:

DCF = dose conversion factor
ρ = soil density

Dose for the internal pathways (ingestion and inhalation) is calculated using the formula

$$Dose\left(mrem / yr\right) = Intake\left(pCi / yr\right) \times DCF\left(mrem / pCi\right)$$

6.6 Risk Characterization

Risk characterization involves estimating the magnitude of the potential adverse health effects under study by combining the results of the dose-response and exposure assessments to provide numerical estimates of potential health effects. These values represent comparisons of exposure levels with appropriate cancer SFs and estimates of excess cancer risk. Risk characterization also considers the nature and weight of evidence supporting these estimates as well as the magnitude of uncertainty surrounding such estimates.

6.6.1 Summary of Numerical Risk Estimates

Table 6-7 presents estimated ranges of health risks potentially associated with the RME and best estimate residential exposure scenarios at the RAS. Estimated ranges of health risks are presented for each weighted sum RME and best estimated case. RESRAD calculations are presented in terms of dose (millirem/year) as well as in terms of ILCRs. The percent of total dose contributed by each radionuclide (Ra-226 or Ra-228) is also provided.

The ILCR was calculated for each radium isotope (Ra-226 and Ra-228) by RESRAD using the formula

$$Risk = Intake \times Slope\ Factor$$

where:

Intake = pCi
Slope = Risk/pCi

TABLE 6-7
Summary of Dose and Increased Lifetime Cancer R sks for the Best Estimate and Reasonable Maximum Exposure Scenarios

Case	Dose (millirem/year)					Increased Lifetime Cancer Risk		
	Ra-226	% of Dose*	Ra-228	% of Dose*	Total RE	Ra-226	Ra-228	Total RE
Weighted Sum Ranks: Best Estimate Exposure Scenario								
1	4E+00	11	4E+01	89	4E+01	8E-05	6E-04	7E-04
2	5E+00	18	2E+01	82	2E+01	9E-05	4E-04	4E-04
3	5E+00	18	2E+01	82	2E+01	4E-04	4E-04	4E-04
4	5E+00	21	2E+01	79	2E+01	9E-05	3E-04	4E-04
5	5E+00	12	4E+01	88	4E+01	9E-05	6E-04	7E-04
Weighted Sum Ranks: Reasonable Maximum Exposure Scenario								
1	1E+01	2	5E+02	98	5E+02	1E-04	5E-03	6E-03
2	1E+01	8	1E+02	92	1E+02	2E-04	1E-03	1E-03
3	1E+01	3	3E+02	97	3E+02	2E-04	3E-03	7E-03
4	1E+01	4	3E+02	96	3E+02	2E-04	3E-03	3E-03
5	1E+01	7	2E+02	93	2E+02	2E-04	2E-03	2E-03

*Percent of total dose contributed by each radionuclide (Ra-226 and Ra-228).

Pathways of exposure include external gamma radiation, vegetable/fruit consumption, incidental soil ingestion, and inhalation of dust particles by residents. The ILCR for residential properties that reflect an RME scenario is estimated to range between 1×10^{-3} and 7×10^{-3}. The ILCR for the residential properties that reflects a best estimate exposure scenario is estimated to range from 4×10^{-4} to 7×10^{-4}.

Exposure through external gamma radiation and consumption of fruits and vegetables accounts for most of the relative contribution to total dose/ILCR. The contribution of the external gamma radiation pathway to total dose/risk was approximately 99 percent for the best estimate scenario but 68 to 75 percent for the RME scenario. The contribution of the fruit/vegetable consumption pathway to total dose/risk was approximately 0.5 percent for the best estimate scenario but 25 to 32 percent for the RME scenario.

Exposure through the incidental ingestion and inhalation of soil provides negligible contributions of total dose/risk. The ingestion and inhalation pathways contribute less than 0.01 percent for both the RME and best estimate exposure scenarios.

6.6.2 Comparison to Criteria

Generally, the USEPA considers action to be warranted at a site when cancer risks exceed 1×10^{-4} based on an RME scenario. The USEPA can take action at a site when risks exceed 1×10^{-6}, but this is judged on a case-by-case basis. Risks less than 1×10^{-6} generally are not of concern to regulatory agencies. (USEPA 1991).

The ILCR for the RME scenario at the RAS is estimated to range from 1×10^{-3} to 7×10^{-3}. The ILCR for the best estimate exposure scenario is estimated to range from 4×10^{-4} to 7×10^{-4}. The ILCR for residential properties that reflect an RME scenario differs approximately 10- to 100-fold when compared to the ILCR for the best estimate exposure scenario. Risks calculated under either scenario exceed 1×10^{-4}, supporting the need for action at these sites.

6.6.3 Uncertainties

Several uncertainties are associated with estimating health risks from exposure to radionuclides from the RAS. Health risks were estimated using assumptions for a best estimate and an RME scenario. The method used to calculate weighted sum gamma activities, exposure scenarios, and exposure assumptions are parameters that could introduce uncertainty. The parameters for the RME scenario provide upper bound risk estimates while the parameters for the best estimate scenario provide average risk estimates. While it is possible and even probable that some assumptions have resulted in underestimating the health risks for contamination at each property, it is more likely that the reported health risks are conservative.

The risk assessment was conducted only for properties with gamma counts >25,500 cpm. Since some contaminated properties were identified by soil samples and not by gamma counts exceeding this criterion, they were not included in the risk assessment weighted-sum ranking.

The value for Ra-226 was assumed to be 1.1 pCi/g, which is the average background. The property-specific average concentration of Ra-228 was calculated as the difference between total radium (from the regression equation found in Section 6.4.3) and the assumed Ra-226 value of 1.1 pCi/g. Because the cancer SFs for Ra-226 are higher than those for Ra-228 (see Table 6-6), risks could be higher than estimated in this risk assessment if actual Ra-226 levels are greater than 1.1 pCi/g.

As noted earlier, the initial risk assessment was performed in 1997 (in an earlier draft version of this RI report), prior to expansion of the site study area. The draft document, which incorporated the risk assessment approach chosen for site characterization, was reviewed and commented on by USEPA and state agencies. The risk assessment, which utilized processes defined by accepted and valid guidance and methods, was retained for this final version of the RI report. However, because a new risk assessment was not performed, the following uncertainties are introduced:

- The SFs for Ra-226 and Ra-228 (and decay products) have been updated since the draft RI report was issued. The current SFs are more conservative than those presented in Table 6-6, which means that if a new risk assessment were performed today using the same data inputs, the risks would be greater than those shown. Since risk levels in the current risk assessment already exceed the USEPA's acceptable risk range, there would be little benefit to performing a new risk assessment with the new SFs.
- Risk methodologies, models, and other elements that go into risk assessment evolve with time, and changes may occur. These evolutionary changes are not a correction of faulty or imprudent practices and procedures but rather a "fine tuning" based on additional knowledge and information. In the absence of a new risk assessment, the exact impacts these changes would have are unknown.

- The risk assessment was performed in 1997 on what is now a subset of information used to represent the entire site. After the risk assessment was completed, USEPA expanded the site study area and additional data was acquired from investigation of the new properties added to the study area. This additional data, although an extension of the original study area, are not included in the risk assessment. The contaminated properties in the expanded study area generally had smaller areas of contamination, with lower activity concentrations, than the contaminated properties in the initial study area. USEPA believes that if a new risk assessment were performed that included the data from the new properties, it is likely that the risks for the RME scenario would not change significantly and that the risks from the best estimate (average) scenario would be somewhat lower than presented.

Pathways that contribute significantly to total risk are external gamma exposure and ingestion of homegrown fruits and vegetables. Doses calculated for these pathways by the RESRAD model are proportional to the surface area of the property. A sensitivity analysis was performed using the RESRAD model to determine the sensitivity of doses through these pathways to different assumptions for surface area. A range of concentrations was examined to verify the effects of surface area on doses for the external gamma exposure, and fruit/vegetable ingestion pathways were linear with increased concentration. Table 6-8 presents the results of the sensitivity analysis.

TABLE 6-8
Sensitivity Analysis: Relation of Dose to Surface Area in RESRAD

Concentration of Ra-228 in Soil (pCi/g)	Calculated Doses with Different Surface Area Assumptions (millirem/year)							
	1,000 ft^2 (92.9 m^2)		5,000 ft^2 (464.5 m^2)		15,000 ft^2 (1,394 m^2)		25,000 ft^2 (2,323 m^2)	
	External Exposure	Fruit/Veg Ingestion	External Exposure	Fruit/Veg Ingestion	External Exposure	Fruit/Veg Ingestion	External Exposure	Fruit/Veg Ingestion
1	2.81	0.46	3.14	2.32	3.23	4.99	3.26	4.99
7.2	20.2	3.34	22.6	16.7	23.3	35.9	23.5	35.9
30	84.2	13.9	94.1	69.5	96.9	149.7	97.9	149.7

The sensitivity analysis shows that doses calculated for the external gamma exposure pathway are not sensitive to changes in surface area. However, doses increase with increases in surface area up to approximately 1,000 m^2 for the fruit/vegetable ingestion pathway. For the fruit/vegetable ingestion pathway, the RESRAD model assumes that for properties with larger surface areas, an increase in gardening activities also occurs. According to the RESRAD user's manual, the calculation of doses through the fruit/vegetable pathway includes an area factor used to account for the fraction of consumption that is produced on the contaminated site. This fraction is never greater than 0.5 and, unless user-specified, is assigned by the model as follows:

Surface Area (m^2)	Factor
$0 < A < 1{,}000$ m^2	A/2,000
$A > 1{,}000$ m^2	0.5

SECTION 7

Removal Action

This section summarizes the non-time-critical removal action activities conducted at the RAS between April 1995 and 2003. Although the removal action was ongoing as this RI report was prepared, the USEPA anticipates that it will be completed during the 2003 construction season.

During the removal action, contaminated soils and other materials were removed to achieve the cleanup criteria specified in the Action Criteria Document for the RAS issued by the USEPA in November 1993 and in the Action Memorandum for the RAS issued in November 1994. A full summary of the removal action will be provided in the Final Removal Action Report for the Residential Areas Removal Site, which Kerr-McGee will prepare following completion of the removal action.

7.1 Summary of Site Cleanup Activities

Prior to site cleanup, the USEPA issued an action memorandum stating that the radiological contamination at the RAS had to be removed to achieve its criterion of 5 pCi/g above background. The USEPA simultaneously issued a UAO to Kerr-McGee ordering Kerr-McGee to conduct the non-time-critical removal action at the site by remediating contaminated properties to meet the cleanup criterion and restoring those properties. As noted, a background level of 2.2 pCi/g for the RAS was established during the pilot study, resulting in a cleanup criterion of 7.2 pCi/g.

Excavation activities at the RAS commenced in April 1995 and continue as of publication of this RI report. Excavation and restoration activities are expected to be completed during the 2003 construction season. As of June 30, 2003, 670 of the 676 contaminated properties identified by the USEPA had been cleaned up and restored by Kerr-McGee, and more than 110,000 cubic yards of contaminated material had been removed from the site. As of the writing of this report, only six known contaminated properties remain to be remediated.

The USEPA conducted the initial characterization work at the RAS, through the methods described in detail in earlier sections of this report, to identify properties in the site study area where the cleanup standard of 7.2 pCi/g was exceeded. As contaminated properties were identified, the USEPA provided that information to Kerr-McGee for cleanup work under the UAO. Kerr-McGee then performed additional characterization work at each contaminated property to further delineate the areal extent and depth of contamination, and then conducted excavation work to remove the contaminated soils. During and following the excavation work at each property, Kerr-McGee conducted "preverification" testing to determine if excavation work could cease. When Kerr-McGee believed it had met the cleanup standard at a property (based on preverification testing), it notified the USEPA and requested that the property be verified. The USEPA then contacted IDNS, and IDNS performed verification fieldwork, in accordance with IDNS procedures that were approved by USEPA, to confirm that Kerr-McGee achieved the cleanup standard.

The IDNS field work consisted first of surface gamma walkover surveys of the excavated areas. If the surface gamma readings indicated that the cleanup standard had not been achieved, Kerr-McGee was contacted to conduct additional cleanup work. When the surface gamma readings indicated that the cleanup standard had been achieved, IDNS conducted soil sampling within grids 100 square meters in size, compositing soil from five locations within each grid into one sample. (In cases where the excavated area was smaller than 100 square meters, the number of locations sampled within the grid was reduced proportionally.) The IDNS laboratory in West Chicago analyzed the samples, and IDNS provided all verification results (gamma readings and soil sample results) to the USEPA. When the USEPA and IDNS verified that the 7.2 pCi/g cleanup standard was met, the USEPA authorized Kerr-McGee to backfill and restore the property. Kerr-McGee then filled the excavated areas with clean fill and restored the property as close as practicable to its original condition (or to such other condition as agreed to by the property owner and Kerr-McGee).

For more detailed information on the non-time-critical removal action at the RAS, refer to the *Final Removal Action Report for the Residential Areas Removal Site*, to be prepared by Kerr-McGee following completion of the removal action at the site.

7.2 Risks from Exposure to Soil

An assigned cleanup criterion of 7.2 pCi/g, based on existing federal and state standards designed to protect human health, replaced the risk assessment process in supporting a response action at the RAS. As noted, IDNS conducted verification testing at each property undergoing remediation to confirm that the 7.2 pCi/g cleanup standard was met. Each of the 670 properties cleaned up as of June 30, 2003, had verification results below 7.2 pCi/g, and in most cases, the results were well below the standard. For those 670 properties, IDNS analyzed samples from 2604 verification grids as part of its verification work. Overall, the analytical results ranged from 0.61 to 7.10 pCi/g, with a mean of 2.87 pCi/g, which is well below the cleanup criterion. Table 7-1 summarizes the range of activities. The range of activities for each of the 670 individual properties is shown in Appendix B. Unique property identifiers have been removed from the table in Appendix B for privacy reasons.

TABLE 7-1
Range of Cleanup Verification Results for the 670 Properties Remediated as of June 2003

Minimum (pCi/g)	Maximum (pCi/g)	Mean (pCi/g)	Verification Grids
0.61	7.10	2.87	2,604

The thorium-contaminated materials exceeding the cleanup criterion have been removed from the 670 properties remediated to date and replaced with clean backfill. As a result, with the exception of 6 known contaminated properties that remain to be remediated (as of the writing of this report), there are no known residual risks remaining at the site.

SECTION 8

Conclusions

The conclusions presented in this section are based on the physical characteristics of the RAS, the nature and extent of contamination, the fate and transport of the contaminants of concern, the baseline risk assessment, and the removal action.

- The USEPA chose to apply the SACM to the RAS. The SACM encourages early actions, such as non-time-critical removal actions, to be taken at sites. This allows focused actions that reduce risk to be taken sooner at sites that already have been characterized and for which remedial alternatives are limited.
- The participants in the SACM process included the USEPA, IDNS, CH2M HILL, Kerr-McGee, and the property owners. A real-time process was used to characterize, remediate, verify, and close out contaminated parcels.
- The contaminants of concern for the RAS are Ra-226 and Ra-228. The soil cleanup criterion developed by the USEPA for total radium equivalents is 7.2 pCi/g.
- Parcel properties were characterized, and CH2M HILL identified elevated contamination within soils around the RAS study area.
- The affected areas include the outdoor soils. CH2M HILL determined that indoor gamma levels and radon and thoron within homes generally were not a concern. CH2M HILL also determined that metals in soils were not a concern.
- The Ra^{2+} ion is highly immobile in soil. It is very unlikely that radium migrates vertically toward the groundwater table. The estimated vertical migration rate is 0.022 foot per year.
- For the RAS baseline risk assessment, a standard model developed by ANL, RESRAD, was used to convert radium concentrations to dose. ILCRs were calculated for the Best Estimate Exposure and the RME scenarios.
- Elevated ILCRs were determined for total RE under the best estimate exposure scenario. The calculated risks ranged from 4×10^{-4} to 7×10^{-4}.
- Elevated ILCRs were determined for total RE under the RME scenario. The calculated risks ranged from 1×10^{-3} to 7×10^{-3}.
- The thorium-contaminated materials exceeding the cleanup criterion have been removed from the 670 properties remediated to date and replaced with clean backfill. As a result, with the exception of 6 known contaminated properties that remain to be remediated (as of the writing of this report), there are no known residual risks remaining at the site.

SECTION 9

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Appendix A
Definitions, Conversions, and Terms

APPENDIX A

Definitions, Conversions, and Terms

Alpha Particle (α)

A positively charged particle ejected spontaneously from the nuclei during radioactive decay. It is identical to a helium nucleus that has a mass number of 4 and an electric charge of +2. An alpha particle can be shielded by a piece of paper.

Beta Particle (β)

A negatively charged particle emitted from a nucleus during radioactive decay.
A negatively charged beta particle is an electron. A positively charged particle is a positron.
A beta particle can be shielded by a thin sheet of metal or plastic.

Bicron

A device that measures dose equivalent in rems during indoor radiation exposure surveys.

Counting Error

Error is defined in this application as the estimated uncertainty of the measured quantity. The relative counting error of a count n is $\sqrt{n}$.

cpm

The nomenclature used to signify gross pulses received on a radiation detection device when measuring a radiation field. Using a calibration factor that is specific to that detection device, cpm can be converted to dps. During the pilot studies, a conversion factor was derived for the gamma surveys using the scintillation detector (see "Scintillation Detector"). A calibration factor was derived to convert cpm to pCi/g for total RE (total radium) in dry soil. This calibration factor is instrument-specific.

Gamma Ray (photon) (γ)

High-energy, short wavelength electromagnetic radiation. Often considered a packet of energy. Gamma rays are emitted from the nucleus during radioactive decay. They are very penetrating and are best shielded by dense materials, such as lead.

Decision Rule

Refers to the processes and criteria used to evaluate data as provided in the Decision Rule Development and Application Technical Memorandum (CH2M HILL March 1995). The use of the word *rule* in this context does not create a legal obligation, but instead simply describes the logic of the methodology used to conduct characterization.

Half-Life

The time period over which the amount of radioactivity or activity of a radioactive material is reduced by a factor of two.

High Purity Germanium Detector

A device used to measure speciated gamma activity during the M1 surveys.

Marinelli Beaker

A relatively large plastic jar or beaker with an annular bottom that can slide over a NaI detector.

mrem

See "Roentgen Exposed Man (rem)."

Parent

Uranium and thorium are naturally occurring elements. They are the parent elements from which their decay products (progeny) are formed. The progeny of uranium and thorium include radium-226 and radium-228, respectively.

pCi/g

See "Radioactivity."

Pressurized Ionization Chamber (PIC)

A tissue equivalent dose rate instrument that is used to measure dose rates in μR/hr during indoor and outdoor exposure surveys.

Rad

A unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram or 0.01 J/kg.

Radiation (ionizing radiation)

Alpha particles, beta particles, gamma rays (photons), x-rays, neutrons, etc. that are capable of producing ions from a gas through which they pass. The use of radiation in this report does not refer to nonionizing radiation.

Radiation Detection

Radiation can be detected and measured using a material or device that is sensitive to radiation and can produce a response signal suitable for measurement or analysis.

Radioactivity

Measured amount of radioactive substance. The basic unit is radioactive decays (disintegrations) per second (dps). This may be stated in the derived unit of curies (Ci). A prefix, such as pico- (p), is used in this report to indicate 1×10^{-12} of a unit. In this case, the picocurie (pCi) is 10^{-12} of a curie, or 0.037 decays/second.

Radiological Slope Factors

Slope factors are estimates of the probability of a response per unit of intake or exposure averaged over a lifetime. They are used to estimate lifetime cancer risks to members of the general population due to radionuclide exposure.

- Ingestion and inhalation slope factors are central estimates in a linear model of the age-average, lifetime attributable radiation cancer incidence (fatal and nonfatal) risk per unit of activity as inhaled or ingested, expressed as risk per pCi.
- External exposure slope factors are central estimates of the lifetime attributable radiation cancer incidence risk for each year of exposure to external radiation from photon-emitting radionuclides uniformly distributed in a thick layer of soil, expressed as risk per year per pCi/g of soil.

Roentgen (R)

The amount of gamma radiation in air near a source of radiation can be expressed as roentgens (R). A roentgen is the amount of gamma or x-rays required to produce ions carrying 1 electrostatic unit of electrical charge in 1 cubic centimeter of dry air under standard conditions.

Roentgen Exposed Man (rem)

The unit of radiation dose equivalent. The dose equivalent (in rems) is equal to the absorbed dose in rad multiplied by the quality factor (1 for gamma rays). For the purposes of this report, 1 μrem = 1 μR.

Scintillation Detector (NaI)

A detector used to record the cpm of radiation during gamma surveys. A calibration factor was derived to convert cpm to pCi/g for total RE (total radium) in dry soil. This calibration factor is instrument-specific.

Working Level (WL)

Radon-222 (radon) and radon-220 (thoron) are gaseous decay products from the U-238 and Th-232 decay chains. The exposure to radiation from inhalation of the decay products of radon and thoron is generally treated differently than other sources of radiation exposure. Since it is difficult to make a measurement of the specific concentration of each of the decay products, a measure of the combined effective concentration was developed, i.e., the working level (WL). The WL is a unit for the total alpha energy from the complete decay of all the decay products of radon and thoron in a liter of air. The instrument used for this project to measure the WL of radon and thoron is the radon progeny integrating sampling unit (RPISU).

The concentration of radon and thoron decay products in air has historically been measured as WL. Also, the estimates of health risks from this exposure, i.e., lung cancer, are correlated to the exposures in WLs. Since there is considerable uncertainty in calculating the radiation dose in rem from inhalation of the radon and thoron decay products, the USEPA has used the practice of assessing exposures in WL. The health effects are then directly estimated from the WL units, instead of by performing an intermediate calculation of radiation exposure in rem.

Appendix B
Range of Cleanup Verification Results for 670 Properties

Summary of IDNS Verification Data
for 670 Properties Remediated as of May 2003

Property	n # samples	MIN (pCi/g)	MAX (pCi/g)	MEAN (pCi/g)
1	3	1.89	2.65	2.24
2	1	4.27	4.27	4.27
3	3	2.37	2.93	2.58
4	1	5.14	5.14	5.14
5	1	2.79	2.79	2.79
6	7	2.03	2.63	2.28
7	10	3.26	4.58	3.97
8	1	2.24	2.24	2.24
9	2	2.17	2.75	2.46
10	4	2.46	4.46	3.33
11	2	1.92	3.93	2.93
12	1	2.73	2.73	2.73
13	3	2.37	2.75	2.53
14	1	4.24	4.24	4.24
15	1	2.95	2.95	2.95
16	2	2.40	2.47	2.44
17	2	2.04	2.12	2.08
18	7	2.14	3.68	3.02
19	1	4.87	4.87	4.87
20	1	5.67	5.67	5.67
21	1	2.57	2.57	2.57
22	1	1.76	1.76	1.76
23	6	1.90	3.21	2.35
24	2	2.75	2.79	2.77
25	2	2.19	2.81	2.50
26	1	1.18	1.18	1.18
27	1	2.39	2.39	2.39
28	1	2.40	2.40	2.40
29	6	2.43	3.57	3.08
30	1	1.63	1.63	1.63
31	14	2.55	6.50	4.37
32	7	2.00	5.00	3.32
33	2	2.14	2.82	2.48
34	3	2.71	4.35	3.74
35	3	2.23	3.06	2.65
36	1	2.09	2.09	2.09
37	1	3.72	3.72	3.72
38	2	2.13	2.20	2.17
39	1	3.28	3.28	3.28
40	1	2.82	2.82	2.82
41	2	3.88	4.46	4.17
42	1	2.44	2.44	2.44
43	6	2.34	3.00	2.69
44	1	2.04	2.04	2.04
45	1	6.14	6.14	6.14
46	2	2.13	2.88	2.51
47	1	3.19	3.19	3.19
48	2	2.31	2.68	2.50
49	4	1.96	3.11	2.43
50	1	2.76	2.76	2.76

Property	n # samples	MIN (pCi/g)	MAX (pCi/g)	MEAN (pCi/g)
51	1	3.36	3.36	3.36
52	1	4.06	4.06	4.06
53	4	2.11	3.42	2.89
54	1	4.14	4.14	4.14
55	1	2.82	2.82	2.82
56	6	2.51	5.03	3.43
57	1	2.74	2.74	2.74
58	1	3.44	3.44	3.44
59	4	2.06	4.58	3.30
60	2	4.00	4.45	4.23
61	1	3.58	3.58	3.58
62	1	3.82	3.82	3.82
63	2	2.71	3.06	2.89
64	1	3.46	3.46	3.46
65	1	2.65	2.65	2.65
66	2	3.45	4.29	3.87
67	1	4.61	4.61	4.61
68	1	2.03	2.03	2.03
69	1	2.18	2.18	2.18
70	1	2.64	2.64	2.64
71	1	3.33	3.33	3.33
72	3	1.93	3.35	2.81
73	1	2.04	2.04	2.04
74	1	3.50	3.50	3.50
75	1	1.94	1.94	1.94
76	1	2.18	2.18	2.18
77	2	2.13	2.53	2.33
78	1	3.35	3.35	3.35
79	1	3.31	3.31	3.31
80	1	2.74	2.74	2.74
81	3	2.16	5.92	3.51
82	1	3.87	3.87	3.87
83	1	2.24	2.24	2.24
84	2	2.17	2.27	2.22
85	1	2.37	2.37	2.37
86	2	2.42	3.58	3.00
87	1	3.05	3.05	3.05
88	1	2.83	2.83	2.83
89	1	4.56	4.56	4.56
90	1	2.76	2.76	2.76
91	2	2.51	3.70	3.11
92	3	2.38	3.06	2.62
93	1	2.62	2.62	2.62
94	1	2.57	2.57	2.57
95	1	2.44	2.44	2.44
96	2	2.19	2.59	2.39
97	2	2.51	4.26	3.39
98	1	2.17	2.17	2.17
99	3	2.03	3.15	2.47
100	1	1.78	1.78	1.78

Summary of IDNS Verification Data
for 670 Properties Remediated as of May 2003

Property	n # samples	MIN (pCi/g)	MAX (pCi/g)	MEAN (pCi/g)
101	1	5.55	5.55	5.55
102	1	2.67	2.67	2.67
103	1	2.03	2.03	2.03
104	4	1.60	2.30	1.92
105	1	3.30	3.30	3.30
106	1	2.32	2.32	2.32
107	1	2.42	2.42	2.42
108	2	3.07	5.87	4.47
109	2	3.06	6.23	4.65
110	1	3.63	3.63	3.63
111	1	2.64	2.64	2.64
112	1	3.84	3.84	3.84
113	1	2.12	2.12	2.12
114	2	3.22	4.13	3.68
115	1	2.33	2.33	2.33
116	1	2.13	2.13	2.13
117	1	1.97	1.97	1.97
118	1	3.81	3.81	3.81
119	1	2.87	2.87	2.87
120	3	2.21	4.77	3.21
121	1	2.25	2.25	2.25
122	1	2.34	2.34	2.34
123	3	2.16	3.53	3.03
124	2	2.93	3.27	3.10
125	1	2.55	2.55	2.55
126	3	2.49	3.92	3.43
127	3	2.71	3.37	2.94
128	2	2.85	3.22	3.04
129	3	1.93	2.77	2.31
130	3	2.75	4.60	3.48
131	5	2.90	5.05	3.77
132	3	1.99	2.06	2.02
133	1	2.75	2.75	2.75
134	1	2.35	2.35	2.35
135	1	4.57	4.57	4.57
136	1	2.03	2.03	2.03
137	3	2.00	5.43	3.57
138	2	1.95	5.14	3.55
139	2	1.83	2.63	2.23
140	1	3.89	3.89	3.89
141	2	1.90	2.18	2.04
142	1	1.68	1.68	1.68
143	2	0.73	2.26	1.50
144	3	1.85	2.73	2.20
145	2	2.48	2.81	2.65
146	3	2.71	6.85	4.18
147	23	0.61	6.00	3.32
148	5	2.04	3.60	2.92
149	2	1.93	2.53	2.23
150	4	2.42	4.30	3.39

Property	n # samples	MIN (pCi/g)	MAX (pCi/g)	MEAN (pCi/g)
151	2	2.34	4.65	3.50
152	1	1.94	1.94	1.94
153	3	1.85	2.71	2.26
154	2	1.94	2.10	2.02
155	9	1.68	5.01	2.64
156	7	1.93	3.67	2.62
157	1	4.34	4.34	4.34
158	1	2.94	2.94	2.94
159	2	1.60	3.13	2.37
160	2	3.24	4.02	3.63
161	2	2.40	2.50	2.45
162	2	5.50	5.72	5.61
163	2	2.13	5.14	3.64
164	3	2.54	3.73	3.01
165	1	2.17	2.17	2.17
166	1	1.94	1.94	1.94
167	1	2.55	2.55	2.55
168	1	3.06	3.06	3.06
169	2	4.18	4.29	4.24
170	2	1.82	1.96	1.89
171	1	1.21	1.21	1.21
172	1	2.78	2.78	2.78
173	2	3.15	3.64	3.40
174	0			
175	2	2.04	2.05	2.05
176	2	1.86	2.99	2.43
177	2	2.25	2.26	2.26
178	1	1.77	1.77	1.77
179	1	3.35	3.35	3.35
180	1	1.84	1.84	1.84
181	1	2.16	2.16	2.16
182	1	3.00	3.00	3.00
183	2	2.06	4.10	3.08
184	1	3.26	3.26	3.26
185	4	2.05	3.45	2.68
186	3	2.32	4.63	3.22
187	2	1.92	2.58	2.25
188	2	1.99	2.36	2.18
189	2	2.23	2.76	2.50
190	2	2.11	2.58	2.35
191	3	1.93	4.24	2.78
192	2	1.82	2.11	1.97
193	2	2.10	2.45	2.28
194	1	1.99	1.99	1.99
195	1	2.36	2.36	2.36
196	1	2.27	2.27	2.27
197	1	4.83	4.83	4.83
198	2	2.69	2.75	2.72
199	3	2.78	4.91	3.75
200	2	2.43	3.26	2.85

Summary of IDNS Verification Data
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Property	n # samples	MIN (pCi/g)	MAX (pCi/g)	MEAN (pCi/g)
201	1	2.21	2.21	2.21
202	1	2.37	2.37	2.37
203	1	2.43	2.43	2.43
204	1	2.02	2.02	2.02
205	2	2.39	3.38	2.89
206	2	2.01	2.30	2.16
207	1	3.04	3.04	3.04
208	1	4.35	4.35	4.35
209	3	2.45	3.24	2.78
210	2	1.89	3.58	2.74
211	2	2.15	3.51	2.83
212	1	2.75	2.75	2.75
213	3	1.87	3.38	2.43
214	2	2.82	2.95	2.89
215	1	5.24	5.24	5.24
216	1	5.59	5.59	5.59
217	2	1.78	2.73	2.26
218	4	1.74	3.50	2.52
219	4	1.95	5.10	3.73
220	2	2.00	2.22	2.11
221	1	2.48	2.48	2.48
222	1	3.49	3.49	3.49
223	1	3.40	3.40	3.40
224	1	2.41	2.41	2.41
225	3	2.42	3.11	2.67
226	5	2.32	4.86	2.97
227	5	2.38	3.70	3.20
228	3	1.99	3.99	2.94
229	13	2.29	4.65	3.42
230	2	2.56	2.83	2.70
231	5	2.10	3.18	2.65
232	5	2.21	3.07	2.57
233	3	2.25	4.14	2.91
234	1	2.94	2.94	2.94
235	8	1.87	3.26	2.39
236	6	2.11	3.01	2.59
237	4	1.86	3.13	2.45
238	7	1.42	2.60	2.08
239	9	1.91	2.99	2.28
240	7	2.33	4.63	3.22
241	3	2.01	2.92	2.62
242	3	1.78	2.22	2.03
243	8	1.86	3.43	2.57
244	2	2.03	2.80	2.42
245	4	2.63	3.80	3.07
246	7	2.16	3.15	2.82
247	7	1.97	3.29	2.52
248	10	2.10	3.27	2.66
249	8	2.42	3.99	2.96
250	7	2.10	2.40	2.21

Property	n # samples	MIN (pCi/g)	MAX (pCi/g)	MEAN (pCi/g)
251	30	1.72	6.62	4.14
252	4	2.42	4.02	3.09
253	2	2.98	3.04	3.01
254	1	4.42	4.42	4.42
255	2	2.49	2.74	2.62
256	1	3.13	3.13	3.13
257	1	2.18	2.18	2.18
258	6	2.13	2.94	2.57
259	2	1.96	3.47	2.72
260	1	3.28	3.28	3.28
261	2	2.12	2.40	2.26
262	1	2.14	2.14	2.14
263	2	2.26	4.48	3.37
264	2	2.13	2.37	2.25
265	1	2.40	2.40	2.40
266	6	2.68	3.32	3.08
267	2	1.99	2.00	2.00
268	1	3.07	3.07	3.07
269	3	2.81	4.20	3.42
270	2	3.73	4.06	3.90
271	1	3.59	3.59	3.59
272	5	2.25	3.99	2.97
273	6	2.15	3.73	3.11
274	3	3.57	3.84	3.74
275	5	2.21	4.39	3.11
276	6	1.76	2.83	2.37
277	6	2.04	3.01	2.46
278	4	2.55	3.60	3.01
279	5	2.26	4.09	3.00
280	7	2.26	3.80	3.30
281	6	2.05	3.66	2.44
282	9	1.98	3.31	2.43
283	5	1.97	3.07	2.42
284	5	2.17	3.20	2.46
285	6	1.82	2.53	2.12
286	7	1.83	2.65	2.16
287	6	1.89	3.37	2.43
288	6	2.01	3.42	2.53
289	2	1.55	1.86	1.71
290	4	2.57	3.17	2.91
291	6	1.79	3.14	2.63
292	7	1.68	3.40	2.29
293	7	1.89	2.53	2.23
294	7	1.90	3.98	2.61
295	4	2.15	3.27	2.82
296	3	1.89	2.36	2.10
297	18	1.95	3.79	2.72
298	7	2.51	4.62	3.44
299	2	2.08	2.83	2.46
300	7	1.86	2.89	2.49

Summary of IDNS Verification Data
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Property	n # samples	MIN (pCi/g)	MAX (pCi/g)	MEAN (pCi/g)
301	7	2.12	4.07	2.86
302	3	3.03	3.68	3.34
303	14	2.77	6.96	3.80
304	3	2.36	4.42	3.53
305	6	2.33	3.15	2.72
306	7	1.77	3.60	2.70
307	8	2.14	3.13	2.43
308	9	1.84	3.72	2.32
309	2	1.99	2.06	2.03
310	5	1.88	3.99	2.66
311	3	2.13	3.09	2.68
312	3	1.98	2.85	2.49
313	9	1.64	3.69	2.38
314	8	2.13	3.07	2.40
315	8	1.55	4.81	2.49
316	6	2.19	2.87	2.46
317	1	2.54	2.54	2.54
318	7	2.50	4.49	3.06
319	3	1.91	2.18	2.01
320	3	1.77	2.50	2.17
321	32	1.51	4.97	2.37
322	10	1.92	2.73	2.24
323	9	1.82	4.30	2.77
324	1	2.03	2.03	2.03
325	8	2.01	3.47	2.61
326	9	1.68	3.83	2.38
327	14	2.09	4.66	2.82
328	6	2.21	4.56	3.05
329	8	1.71	3.55	2.14
330	8	2.13	3.72	2.52
331	6	1.74	3.39	2.47
332	8	2.14	2.95	2.54
333	6	1.98	3.51	2.71
334	5	2.10	3.37	2.65
335	4	2.48	3.92	2.91
336	4	1.78	2.91	2.50
337	8	2.04	4.53	3.15
338	13	2.12	3.30	2.54
339	15	2.18	3.88	2.89
340	3	1.92	2.08	1.98
341	8	2.03	3.57	2.54
342	6	2.21	3.85	2.89
343	7	2.32	2.97	2.57
344	6	2.08	3.14	2.45
345	7	2.92	4.65	3.69
346	8	2.13	5.29	3.35
347	8	2.28	3.38	2.59
348	5	2.26	3.05	2.53
349	6	2.06	2.84	2.46
350	8	2.60	4.08	3.28

Property	n # samples	MIN (pCi/g)	MAX (pCi/g)	MEAN (pCi/g)
351	7	2.16	2.84	2.36
352	7	2.03	3.19	2.49
353	6	2.78	4.47	3.38
354	5	1.90	3.82	2.93
355	3	1.97	2.55	2.20
356	4	2.55	3.84	3.19
357	7	2.13	3.43	2.47
358	6	1.71	3.21	2.53
359	5	2.14	3.16	2.63
360	3	2.43	3.25	2.86
361	5	2.76	4.90	3.65
362	3	2.09	3.97	2.74
363	7	2.43	4.69	3.38
364	5	3.19	5.69	4.49
365	5	3.27	5.33	4.20
366	5	3.44	6.14	4.19
367	5	3.29	5.10	4.07
368	12	1.99	3.67	2.69
369	4	3.03	4.01	3.35
370	6	3.85	6.39	4.70
371	7	2.10	4.18	2.91
372	3	1.48	2.76	2.10
373	5	1.99	3.19	2.56
374	6	2.19	4.15	3.31
375	4	1.94	3.68	2.82
376	3	2.08	2.69	2.37
377	10	2.01	2.86	2.31
378	6	1.47	3.92	2.19
379	3	1.95	3.10	2.38
380	2	2.70	3.18	2.94
381	4	1.22	2.79	1.98
382	2	2.02	2.60	2.31
383	3	3.49	3.89	3.71
384	6	1.71	3.84	2.66
385	4	2.34	5.93	3.48
386	4	2.09	3.11	2.61
387	3	1.89	3.08	2.39
388	2	3.26	4.16	3.71
389	4	1.09	3.04	2.28
390	1	1.95	1.95	1.95
391	1	4.42	4.42	4.42
392	9	2.48	5.61	3.49
393	2	2.59	2.94	2.77
394	7	2.41	4.66	3.66
395	3	3.10	3.76	3.38
396	2	2.32	3.52	2.92
397	6	2.24	4.32	3.18
398	5	1.92	3.85	2.68
399	1	2.02	2.02	2.02
400	12	2.24	4.89	3.14

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Property	n # samples	MIN (pCi/g)	MAX (pCi/g)	MEAN (pCi/g)
401	2	2.64	3.54	3.09
402	3	2.71	5.17	3.69
403	1	4.15	4.15	4.15
404	6	2.40	4.85	3.47
405	2	2.89	3.34	3.12
406	1	3.80	3.80	3.80
407	2	1.35	5.50	3.43
408	1	3.41	3.41	3.41
409	2	2.91	4.01	3.46
410	6	1.95	3.10	2.73
411	3	2.15	3.05	2.70
412	1	1.26	1.26	1.26
413	4	2.56	3.16	2.96
414	3	1.76	3.71	2.54
415	2	2.15	3.13	2.64
416	1	5.02	5.02	5.02
417	1	2.92	2.92	2.92
418	8	2.51	4.76	3.53
419	8	2.08	3.57	2.84
420	5	1.99	2.84	2.52
421	4	2.96	5.39	3.76
422	7	1.99	4.75	2.88
423	3	2.47	3.48	2.97
424	1	3.15	3.15	3.15
425	4	1.83	3.70	3.13
426	1	4.19	4.19	4.19
427	2	2.55	3.49	3.02
428	1	2.84	2.84	2.84
429	2	1.96	2.40	2.18
430	1	2.55	2.55	2.55
431	3	1.74	5.83	3.11
432	6	2.30	6.02	3.27
433	1	2.05	2.05	2.05
434	4	2.15	3.98	2.90
435	2	1.80	2.34	2.07
436	2	4.03	5.68	4.86
437	1	2.51	2.51	2.51
438	1	2.09	2.09	2.09
439	1	2.72	2.72	2.72
440	2	1.75	3.19	2.47
441	1	2.07	2.07	2.07
442	4	1.65	3.71	2.47
443	3	1.72	1.94	1.85
444	3	3.12	3.17	3.15
445	2	2.05	3.10	2.58
446	6	1.91	5.86	2.80
447	9	1.66	4.77	2.62
448	7	1.21	2.51	2.08
449	3	1.94	2.06	1.99
450	8	1.87	4.22	3.07

Property	n # samples	MIN (pCi/g)	MAX (pCi/g)	MEAN (pCi/g)
451	10	1.78	2.85	2.27
452	5	1.82	2.53	2.30
453	1	2.65	2.65	2.65
454	4	2.13	2.65	2.44
455	7	2.51	3.76	3.38
456	4	1.96	2.87	2.26
457	1	4.19	4.19	4.19
458	1	1.92	1.92	1.92
459	1	3.58	3.58	3.58
460	2	2.12	2.51	2.32
461	1	2.33	2.33	2.33
462	1	5.89	5.89	5.89
463	1	2.84	2.84	2.84
464	3	2.57	3.79	3.36
465	1	3.87	3.87	3.87
466	3	2.26	3.53	3.05
467	1	2.67	2.67	2.67
468	1	2.93	2.93	2.93
469	7	2.46	5.69	3.23
470	1	2.69	2.69	2.69
471	1	3.88	3.88	3.88
472	2	2.33	4.04	3.19
473	1	3.71	3.71	3.71
474	1	2.53	2.53	2.53
475	6	2.01	3.96	2.57
476	4	2.82	3.88	3.36
477	2	1.71	3.49	2.60
478	1	3.25	3.25	3.25
479	1	3.05	3.05	3.05
480	1	4.23	4.23	4.23
481	1	3.12	3.12	3.12
482	1	2.06	2.06	2.06
483	47	1.76	5.83	2.94
484	1	5.09	5.09	5.09
485	2	2.22	2.35	2.29
486	3	1.93	3.64	2.74
487	3	2.35	2.91	2.55
488	4	2.28	2.73	2.52
489	5	2.13	3.52	2.77
490	16	2.46	5.77	3.36
491	4	2.13	3.09	2.47
492	2	2.81	3.22	3.02
493	2	2.14	3.05	2.60
494	2	2.79	2.83	2.81
495	1	2.38	2.38	2.38
496	1	4.81	4.81	4.81
497	1	2.04	2.04	2.04
498	5	2.02	3.00	2.55
499	1	2.33	2.33	2.33
500	1	2.54	2.54	2.54

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Property	n # samples	MIN (pCi/g)	MAX (pCi/g)	MEAN (pCi/g)
501	1	2.93	2.93	2.93
502	1	3.53	3.53	3.53
503	1	2.19	2.19	2.19
504	1	2.75	2.75	2.75
505	1	3.68	3.68	3.68
506	1	5.11	5.11	5.11
507	1	2.21	2.21	2.21
508	1	2.95	2.95	2.95
509	1	2.69	2.69	2.69
510	3	2.36	4.60	3.56
511	1	2.69	2.69	2.69
512	1	2.72	2.72	2.72
513	3	2.79	3.14	2.94
514	1	2.50	2.50	2.50
515	1	4.13	4.13	4.13
516	1	3.29	3.29	3.29
517	1	3.42	3.42	3.42
518	2	2.65	3.78	3.22
519	4	3.06	7.05	4.23
520	1	3.72	3.72	3.72
521	1	3.54	3.54	3.54
522	1	2.25	2.25	2.25
523	1	3.39	3.39	3.39
524	4	2.34	3.70	3.14
525	3	2.56	3.09	2.87
526	1	1.57	1.57	1.57
527	1	2.04	2.04	2.04
528	2	2.42	2.80	2.61
529	1	3.15	3.15	3.15
530	4	2.33	4.88	3.19
531	1	6.09	6.09	6.09
532	1	2.16	2.16	2.16
533	2	2.15	2.82	2.49
534	1	3.33	3.33	3.33
535	1	4.19	4.19	4.19
536	1	2.65	2.65	2.65
537	2	2.86	3.99	3.43
538	1	3.41	3.41	3.41
539	2	2.03	2.11	2.07
540	1	1.98	1.98	1.98
541	1	2.56	2.56	2.56
542	1	2.79	2.79	2.79
543	1	3.19	3.19	3.19
544	1	2.42	2.42	2.42
545	2	2.42	2.67	2.55
546	2	2.22	3.18	2.70
547	3	2.44	4.84	3.54
548	8	2.31	3.31	2.75
549	2	2.15	2.98	2.57
550	2	2.02	2.61	2.32

Property	n # samples	MIN (pCi/g)	MAX (pCi/g)	MEAN (pCi/g)
551	1	2.87	2.87	2.87
552	4	2.37	3.73	2.82
553	2	3.77	4.05	3.91
554	1	2.83	2.83	2.83
555	5	2.14	5.15	3.00
556	4	2.14	2.67	2.41
557	6	1.76	2.44	2.09
558	3	2.94	4.80	3.91
559	23	1.81	4.54	3.08
560	5	2.05	4.91	3.25
561	3	2.16	2.38	2.24
562	1	3.11	3.11	3.11
563	7	1.91	2.67	2.19
564	6	1.85	3.64	2.59
565	2	2.05	2.76	2.41
566	12	1.79	5.77	3.46
567	11	1.38	6.34	4.21
568	6	2.56	3.66	3.28
569	2	2.14	2.55	2.35
570	21	1.60	3.27	2.37
571	1	3.27	3.27	3.27
572	1	1.22	1.22	1.22
573	8	1.81	3.36	2.28
574	20	1.95	5.16	2.71
575	7	1.94	4.52	2.52
576	16	1.61	4.76	2.24
577	2	1.90	2.20	2.05
578	1	2.90	2.90	2.90
579	2	2.80	3.67	3.24
580	8	1.96	4.33	2.51
581	6	1.85	3.49	2.70
582	12	1.98	5.17	2.58
583	9	1.84	3.69	2.60
584	7	2.01	3.06	2.50
585	7	1.87	2.25	2.02
586	4	1.68	3.54	2.39
587	10	2.01	4.74	3.33
588	6	2.14	6.65	4.50
589	4	1.97	3.79	2.90
590	4	2.43	4.56	3.40
591	6	3.27	4.93	3.90
592	3	2.23	3.41	2.71
593	2	3.23	5.07	4.15
594	1	4.52	4.52	4.52
595	1	5.45	5.45	5.45
596	7	2.99	6.62	4.04
597	13	2.12	3.80	2.91
598	8	3.15	4.74	4.16
599	6	2.49	4.72	3.40
600	1	2.19	2.19	2.19

Summary of IDNS Verification Data
for 670 Properties Remediated as of May 2003

Property	n # samples	MIN (pCi/g)	MAX (pCi/g)	MEAN (pCi/g)
601	2	2.62	3.12	2.87
602	3	2.19	3.05	2.73
603	5	3.05	4.37	3.81
604	2	1.92	5.64	3.78
605	1	4.47	4.47	4.47
606	7	2.13	4.51	3.16
607	4	3.52	4.90	3.96
608	4	2.76	2.92	2.84
609	9	1.87	4.83	2.93
610	2	2.72	3.77	3.25
611	2	2.63	4.86	3.75
612	1	6.38	6.38	6.38
613	5	2.04	6.38	4.05
614	2	2.89	3.54	3.22
615	2	2.18	6.10	4.14
616	6	1.29	3.68	2.22
617	10	2.40	5.72	3.48
618	11	1.69	4.61	3.25
619	10	2.04	5.12	3.28
620	1	2.38	2.38	2.38
621	12	2.20	6.66	3.28
622	18	1.92	5.18	2.83
623	1	2.97	2.97	2.97
624	1	3.20	3.20	3.20
625	1	2.47	2.47	2.47
626	4	1.84	3.02	2.44
627	1	1.78	1.78	1.78
628	2	1.83	1.87	1.85
629	1	1.78	1.78	1.78
630	15	1.08	3.67	2.42
631	40	1.91	3.40	2.45
632	8	1.90	3.59	2.66
633	4	2.14	5.00	3.05
634	1	2.43	2.43	2.43
635	1	3.68	3.68	3.68
636	10	1.40	3.24	2.17
637	1	1.93	1.93	1.93
638	1	2.70	2.70	2.70
639	1	2.05	2.05	2.05
640	5	1.69	4.04	2.65
641	1	4.26	4.26	4.26
642	1	2.16	2.16	2.16
643	1	1.06	1.06	1.06
644	4	2.07	3.24	2.70
645	1	5.11	5.11	5.11
646	4	2.01	4.98	3.27
647	8	1.91	6.57	3.06
648	1	2.16	2.16	2.16
649	12	2.28	4.57	2.87
650	1	3.36	3.36	3.36

Property	n # samples	MIN (pCi/g)	MAX (pCi/g)	MEAN (pCi/g)
651	15	1.78	3.72	2.41
652	2	2.30	2.41	2.36
653	18	1.32	2.99	2.09
654	4	2.40	2.84	2.72
655	18	1.72	3.94	2.37
656	9	2.22	6.90	3.34
657	22	2.10	7.10	3.75
658	11	1.27	4.53	2.66
659	5	2.12	3.68	2.87
660	2	2.93	3.11	3.02
661	1	1.48	1.48	1.48
662	13	1.38	3.28	2.37
663	17	1.51	2.85	2.07
664	1	2.22	2.22	2.22
665	1	3.09	3.09	3.09
666	6	2.03	2.92	2.52
667	4	0.85	4.25	2.24
668	1	3.01	3.01	3.01
669	4	1.61	2.44	1.97
670	16	2.26	4.42	2.68

Summary Statistics

Total number samples	**2604**			
Overall MIN result		0.61		
Overall MAX result			7.10	
Overall mean result				2.87