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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

RELATED CORRESPONDENCE

July 3, 1985

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OFFICE OF SECRETARY
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Mr. Jack Russell
Environmental Protection Agency
401 M Street, S.W.
Mail Stop ANR-461
Washington, D.C. 20460

In the Matter of
KERR-MCGEE CHEMICAL CORPORATION
(Kress Creek Decontamination)
Docket No. 40-2061; ASLBP No. 84-502-01-SC
SC

Dear Mr. Russell:

As I indicated to you in our telephone conversation the following enclosed documents will be useful to you and other EPA personnel:

1. Order to Show Cause, dated March 2, 1984;

2. Memorandum and Order (Ruling on Kerr-McGee's Motion for Reconsideration), dated March 22, 1985 (see particularly page 5); and

3. Comprehensive Radiological Survey of Kress Creek, West Chicago Area, Illinois, prepared by Oak Ridge Associated Universities, dated February 1984.

If these documents raise any questions which you would like to discuss, please feel free to call me.

Sincerely,

Stephen H. Lewis

Stephen H. Lewis
Deputy Assistant Chief Hearing Counsel

Enclosures: As stated

cc w/o enclosures: Babette J. Neuberger, Esq.

D507

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

In the Matter of

Kerr-McGee Chemical Corporation (Kress Creek Decontamination)	)	Docket No. 40-2061 Source Material License No. STA 583

ORDER TO SHOW CAUSE

I

Kerr-McGee Chemical Corporation ("the licensee") is the holder of Source Material License No. STA 583 issued by the Nuclear Regulatory Commission (NRC) ("the Commission"). The license authorizes the possession of an unlimited quantity of thorium at the Rare Earths Facility, West Chicago, Illinois. Production operations under the license ceased in December, 1973.

II

Over the years, a portion of the wastes from the plant site have been disposed of by being discharged into Kress Creek, a tributary of the DuPage River, either via a storm sewer or a drainage ditch. The wastes entered the creek at a point about 0.7 Km south of the Kerr-McGee site. The creek flows in a southeasterly direction for about 2 Km to its confluence with the West Branch of the DuPage River.

Radioactive contamination along Kress Creek and the DuPage River was detected as a result of an aerial survey in 1977 and later verified by extensive surveys of the West Chicago area undertaken by Argonne National Laboratory in 1977 and 1978 under contract to the NRC. The results of these surveys, which were limited to measurements of surface exposures and dose rates, were reported in NUREG/CR-0413 published in September 1978. Additional surveys of the creek and river were made by the United States Environmental Protection Agency (EPA) (1980) and Oak Ridge Associated Universities (ORAU) under NRC Contract (1981). Based on these surveys, the NRC staff, in a letter dated December 18, 1981, requested that the licensee submit a plan for the decontamination of Kress Creek and for storage or disposal of the contaminated soil. After discussions with the licensee, further review of existing data on contamination along the creek and consideration of potential changes in EPA and NRC cleanup actions, the staff decided to further assess the radiological contamination in Kress Creek and informed the licensee, in a letter dated June 4, 1982, it was not necessary to take further action in regard to the December 18, 1981, letter and that the staff would further advise Kerr-McGee upon completion of the assessment.

III

A comprehensive, radiological survey of Kress Creek has now been performed by ORAU under contract to NRC. The comprehensive radiological survey was specifically designed to determine not only current direct radiation levels, but also the depth distribution of contamination in the creek and river beds and in bank soils along the creek and river. This survey indicated that lands adjacent to Kress Creek and the West Branch of the DuPage River are contaminated with thorium and with daughter products of the thorium decay chain essentially in secular equilibrium. Soil contamination levels and direct levels of radiation were found to be relatively constant throughout the length of Kress Creek, and to extend downstream along the West Branch of the DuPage River.

The average concentrations of total thorium (Th-232 + Th-228) at 1 meter from the edge of the creek at various depths were: 26.1 pCi/g (picocuries per gram) at the surface; 40.2 pCi/g at 15 cm depth; 38.9 pCi/g at 30 cm depth; 28.9 pCi/g at 60 cm depth; and 18.7 pCi/g between 60 and 90 cm. The soil concentrations decreased with increasing distance from the creek. The highest level of total thorium measured in a sample was 555 pCi/g, with a number of other samples exceeding 200 pCi/g. Many of the highest levels were detected in areas near the storm sewer outfall, and hence constitute a potential source of continuing contamination for locations further downstream.

Direct levels of radiation measured at 1, 5, 10, and 25 meters from the edge of the creek and 1 meter above ground surface averaged 28, 25, 21 and 14 uR/hr (microroentgen per hour) respectively. However, radiation levels greater than 100 uR/hr were detected in several locations. Normal background radiation levels in this area averaged 8.6 uR/hr.

The contamination levels found along the creek exceed the environmental standards promulgated by EPA under authority of the Atomic Energy Act of 1954, as amended, for unrestricted use of areas on which thorium processing wastes have been disposed. See 40 CFR 192.41 (48 FR 45947). The NRC is charged with implementation and enforcement of these standards. See Section 275d of the Atomic Energy Act of 1954, as amended. The contamination levels also exceed the identical standards established for cleanup of vicinity properties under Title I of the Uranium Mill Tailings Radiation Control Act of 1978, as amended, and published in 40 CFR 192, Subpart B. The EPA has stated that these standards are appropriate for cleanup of offsite vicinity properties.[1] In each case, the EPA standards were established under a statutory directive to establish standards of general application for the protection of public health, safety, and the environment from the radiological hazards associated with processing of thorium processing waste.

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[1] United States Environmental Protection Agency "Final Environmental Impact Standards for the Control of Byproduct Material from Uranium Ore Processing (40 CFR 192)", EPA 520/1-83-008-2, September 1983, Page A.1-3, Comment 6. Also, Federal Register notice, published October 7, 1983 (48 CFR 45940).

Accordingly, the NRC staff concludes that cleanup of the offsite vicinity properties along Kress Creek and the DuPage River is required and that the following levels of contamination specified in EPA standards are to be used as criteria for the offsite properties:

1. 5 picocuries of radium per gram of soil (pCi/g), averaged over the first 15 centimeters (cm) below the surface, and

2. 15 pCi/g averaged over 15 cm thick layers more than 15 cm below the surface.

The specified levels of contamination may be averaged over areas of 100 square meters.

IV

In view of the foregoing and pursuant to Sections 62, 63, 81, 83, 84, 161b, and 275d of the Atomic Energy Act of 1954, as amended, and the regulations in 10 CFR Parts 2 and 40, the licensee is HEREBY ORDERED TO SHOW CAUSE WHY IT SHOULD NOT BE REQUIRED TO TAKE THE FOLLOWING ACTIONS:

1. Prepare a remedial action plan for the cleanup of radiologically contaminated areas in and along Kress Creek and the West Branch of the DuPage River and for the subsequent safe storage or disposal of contaminated soil.

2. By July 2, 1984, submit the plan to the Office of Nuclear Material Safety and Safeguards, United States Nuclear Regulatory Commission, for review and approval.

3. After approval by the Office of Nuclear Material Safety and Safeguards, execute the cleanup plan in an expeditious manner.

4. In both the planning and execution of remedial actions, priorities shall be established based on the extent of public exposure resulting from the contamination and the timing of projected disposal or safe storage capacity.

The licensee may show cause why the actions described in Section IV should not be ordered by filing a written answer under oath or affirmation that sets forth the matters of fact and law on which the licensee relies. As provided in

10 CFR 2.202(c), the licensee may answer by consenting to the order proposed in Section IV. Upon the licensee's consent or the licensee's failure to answer this order, the terms of Section IV of this order shall be effective. Alternatively, the licensee may demand a hearing on this order.

Any request for a hearing or answer to this order must be filed within 20 days of the date of this order and shall be submitted to the Director, Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, Washington, D. C. 20555. A copy of the request for hearing or answer shall also be sent to the Executive Legal Director at the same address.

If the licensee demands a hearing, the issue to be considered at a hearing is:

- Whether on the basis of the matters stated in Sections II and III, the licensee should be ordered to take the actions stated in Section IV.

FOR THE NUCLEAR REGULATORY COMMISSION

(Signed) John G. Davis

John G. Davis, Director
Office of Nuclear Material Safety
and Safeguards

Dated at Silver Spring, Maryland,
this 2nd day of March, 1984.

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before Administrative Judges:
John H Frye, III, Chairman
Dr. James H. Carpenter
Dr. Peter A. Morris

In the Matter of	)	Docket No. 40-2061-SC
KERR-McGEE CHEMICAL CORPORATION	)	ASLBP No. 84-502-01-SC
(Kress Creek Decontamination)	)	March 22, 1985

MEMORANDUM AND ORDER
(Ruling on Kerr-McGee's Motion for Reconsideration)

On February 22, Kerr-McGee moved for reconsideration of our Second Prehearing Conference Memorandum and Order of February 7, 1985, in which we held that Kerr-McGee bears the burden of going forward with evidence on the averments stated in ¶¶ 10 through 13 of its amended answer. On March 15, the proponents of the Order to Show Cause at issue herein, Staff, the Nichiren Shoshu Temple, and the People of the State of Illinois, filed an answer in opposition. We deny Kerr-McGee's motion. However, because it appears that our Second Prehearing Conference Memorandum and Order was not fully understood, we clarify it in this Memorandum and Order.[1]

Kerr-McGee moves for reconsideration on three grounds:

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[1] In their opposition, the proponents take the position that Kerr-McGee has not been harmed by the Prehearing Conference Memorandum and Order and hence has no standing to complain. We do not respond to this argument; while it may be that Kerr-MGee is not injured by the Order, its motion nonetheless raises matters which we believe important to address. This is the first proceeding of its kind. It is important that all parties clearly understand the procedural ground rules for this proceeding and our rulings.

1. That we erred, or were at least premature, in concluding that authority exists in the Atomic Energy Act (AEA) independently of the Uranium Mill Tailings and Radiation Control Act (UMTRCA or Tailings Act) which would support any offsite cleanup order, let alone an order to clean up wastes which were not shown to present significant risks;

2. That we have erroneously accepted the proponents' view that the Tailings Act can provide guidance with respect to the levels of contamination which require cleanup when the Tailings Act is not itself applicable; and

3. That, even assuming that the proponents may proceed under the AEA independently of the Tailings Act, they still must comply with the mandate of the Tailings Act that risks, costs, and benefits of any proposed cleanup must be considered.

The proponents take issue with Kerr-McGee's first argument - that we erred in concluding that the AEA alone furnishes sufficient authority to support a cleanup order. Like Kerr-McGee, the proponents have read our Memorandum and Order as reaching that conclusion.

We reached no such conclusion. Rather, we found no indication in the Commission's decisions that a specific, significant risk, something more than a hazardous condition, to the health and safety of the public or to the environment must be found if the Order is to be enforced. (Order, at 9.) Consequently, we concluded that Kerr-McGee must bear the burden of going forward with evidence on that issue. This conclusion does not presuppose the conclusion that the AEA provides the authority

necessary to support enforcement of the Order to Show Cause in this instance.

Indeed, the conclusion that the AEA will support the enforcement of the Order to Show Cause in this instance requires consideration of more than simply the nature of the risk or hazard to be cleaned up. Staff has conceded that Kerr-McGee's position that the Tailings Act may not be retroactively applied in this proceeding is essentially correct, and that the EPA regulations promulgated under it do not fit this situation. (Tr. 70-71, 95, January 25, 1985.) The Tailings Act added thorium and uranium mill tailings to the definition of byproduct material. Prior to the enactment of the Tailings Act, the AEA provided little authority over mill tailings. Petition of Sunflower Coalition, CLI-82-34, 16 NRC 1502 (1982). Thus Staff must show that the contamination which it wishes cleaned up is properly classified as source material under 10 CFR § 40.4(h) if it is to be successful. That section presently provides

> (h) "Source Material" means: (1) Uranium or thorium, or any combination thereof, in any physical or chemical form or (2) ores which contain by weight one-twentieth of one percent (0.05%) or more of: (i) Uranium, (ii) thorium or (iii) any combination thereof. Source material does not include special nuclear material.

An evidentiary presentation is necessary as a basis for determining whether the alleged contamination in and along Kress Creek and the West Branch of the DuPage River meets this definition. Thus, we may not decide this question, nor the question raised by Kerr-McGee's averment,

on the basis of briefs alone.[2]

The proponents responded to Kerr-McGee's second and third points by asserting that issues of costs and benefits are unnecessary considerations in deciding whether to enforce the Order to Show Cause. The Proponents assert that EPA's standards issued under the Tailings Act, which are identified in the Order to Show Cause, are appropriate for use in determining whether a hazard exists. Again the parties have at least partially misunderstood our rulings. As we did with respect to Kerr-McGee's risk averment, we concluded only that Kerr-McGee must bear the burden of going forward with the evidence on its averments concerning costs and benefits, there being no apparent basis for them in the AEA.

We have already noted Staff's concession that the Tailings Act may not be applied in this proceeding. Thus EPA's standards issued under it are not legally binding, and the proponents may advocate them only as guidance. In our February 7 Memorandum and Order we did not conclude

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2 The People have filed a supplemental response to Kerr-McGee's motion in which they urge that the latter has again raised the question of subject matter jurisdiction. The People seem to view Kerr-McGee's motion as asserting that no jurisdiction under the AEA exists to raise the question of the company's responsibility for the Kress Creek wastes and go on to argue that the AEA clearly applies to this situation. We do not view Kerr-McGee's motion as challenging the Staff's authority to issue the Show Cause Order or our jurisdiction to preside under the AEA. Indeed, Kerr-McGee indicated in its response to the joint motion for disposition of averments of December 21, 1984, that it did not challenge Staff's authority to issue the Order to Show Cause. Insofar as the People

(Footnote Continued)

that the Tailings Act and EPA's standards issued under it are appropriate guidance. Indeed, we believe the proponents have a substantial burden to meet in this regard. Because the EPA standards identified in the Order to Show Cause are not legally applicable, they are not to be accorded the status of regulations under 10 CFR § 2.758 and therefore are not immune to attack by way of discovery, proof, argument, or other means. Consequently we expect the proponents to justify the application of these standards to the single, unique situation at Kress Creek and the West Branch of the DuPage River, as opposed to the application of other standards (for example, the standards found in 10 CFR Part 20).[3] We also anticipate that we may well pose questions on this point for the parties to address at the evidentiary hearing.

We view Kerr-McGee's averment that the proponents must show a specific, significant risk as also relevant to this issue. And because we can find no apparent basis in the AEA - under which the proponents are proceeding - for Kerr-McGee's cost-benefit averments, Kerr-McGee

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(Footnote Continued)
argue that the AEA clearly applies to the Kress Creek contamination and will support enforcement of the Order, they raise mixed questions of law and fact.

3 This answers the People's request for a ruling from us on the question whether proof that the Kress Creek contamination exceeds the EPA standards will satisfy the potential hazard standard of 10 CFR § 2.202. In their supplemental response, the People take the position that there is no legal or other justification for going behind the EPA standards. However, because those standards are not to be given the force of regulations in this proceeding, they are open to challenge and the proponents will have to demonstrate that they should be applied.

must bear the burden of presenting evidence on those issues. Kerr-McGee must also show that its averments here in issue are legally correct.[4]

As the proponents stated in their January 10 Memorandum (page 2), they must show that the Order to Show Cause was issued in accord with the AEA, that the contamination exists, that Kerr-McGee is responsible

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4 The proponents indicated in their opposition to Kerr-McGee's motion that they view our ruling on Kerr-McGee's averments as indicating that these would be appropriately considered in the second phase of this proceeding when the scope of the remedial action plan is at issue. We leave it to Kerr-McGee to decide when and how to present these matters. In addition, in their supplemental response the People urge that we dismiss the averment stated in ¶ 10 and limit the averments stated in ¶¶ 11 through 13 to the second phase of this proceeding. The People overlook the fact Kerr-McGee asserts that the averments raise mixed questions of law and fact (see Kerr-McGee's Memorandum of October 26, 1984). While the Rules of Practice provide a vehicle for the People to test Kerr-McGee's assertion and to eliminate or limit the averments, neither the People specifically nor the proponents generally have seen fit to employ it. The People's request is not authorized by the Rules of Practice and is denied.

In their supplemental response (p.2), the People also ask that we address the question of who bears the ultimate burden of persuasion because ". . . unless the parties know who has the burden of persuasion, they do not know how much evidence to put on at hearing . . . ." We decline to do so. We expect that all parties will present their best case and remind them that, under 10 CFR § 2.743(c), "[o]nly relevant, material and reliable evidence which is not unduly repetitious will be admitted." (The Board intends to follow the Federal Rules of Evidence in enforcing this standard.)

The People also request that we certify or refer the matters raised in their supplemental response should we not decide them, or decide them adversely to the People's position. We decline to do so. While we agree that this proceeding presents complex questions of first impression, we see nothing to be gained but delay if they are certified or referred for interlocutory review. In our view these questions cannot be decided in the abstract. They demand an evidentiary record if they are to be properly resolved.

for the contamination, and that the remedy proposed by the Order to Show Cause is necessary to abate the hazard thus presented. Assuming, but not deciding, that the proponents can prevail in showing that the contamination exists and was caused by Kerr-McGee, they must then show that:

First, the contamination is source material under the AEA;

Second, the EPA standards set forth in the Order to Show Cause are appropriate criteria by which to judge to what extent remedial action is necessary to protect health under § 161(b) of the AEA; and

Third, the contamination exceeds these criteria and the AEA will support enforcement of the Order to Show Cause.

In consideration of the foregoing, it is this 22nd day of March, 1985, ORDERED that Kerr-McGee's motion for reconsideration of our Second Prehearing Conference is denied.

It is so ORDERED.

THE ATOMIC SAFETY AND
LICENSING BOARD

Peter A. Morris
ADMINISTRATIVE JUDGE

James H. Carpenter
ADMINISTRATIVE JUDGE

John H. Frye, III, Chairman
ADMINISTRATIVE JUDGE

Bethesda, Maryland
March 22, 1984

Prepared by
Oak Ridge Associated
Universities

Prepared for
Division of Fuel
Cycle and
Material Safety

U.S. Nuclear
Regulatory
Commission

COMPREHENSIVE

RADIOLOGICAL SURVEY

OF

KRESS CREEK

WEST CHICAGO AREA, ILLINOIS

P. W. FRAME

Radiological Site Assessment Program
Manpower Education, Research, and Training Division

FINAL REPORT

February 1984

COMPREHENSIVE RADIOLOGICAL SURVEY OF KRESS CREEK WEST CHICAGO AREA, ILLINOIS

Prepared for

Division of Fuel Cycle and Material Safety
U.S. Nuclear Regulatory Commission

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FINAL REPORT

February 1984

This report is based on work performed under Interagency Agreement DOE No. 40-770-80, NRC Fin. No. A-9093 between the U.S. Nuclear Regulatory Commission and the U.S. Department of Energy. Oak Ridge Associated Universities performs complementary work under contract number DE-AC05-760R00033 with the U.S. Department of Energy.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

FOREWORD

A comprehensive radiological survey of Kress Creek has been performed by the Oak Ridge Associated Universities (ORAU) under contract to the United States Nuclear Regulatory Commission (NRC). Results of the survey are given in this report. This work is a continuation of effort by NRC to define the extent of radioactive contamination in Kress Creek and the West Branch of the DuPage River, downstream of the Kerr-McGee Rare Earths Facility in West Chicago, Illinois.

Radioactive contamination along Kress Creek and the West Branch of the DuPage River was first detected as a result of an aerial survey in 1977 and later verified by extensive surveys of the West Chicago area undertaken by Argonne National Laboratory in 1977 and 1978, and funded by the NRC. The results of these surveys, which were limited to measurements of surface exposures and dose rates, were reported in NUREG/CR-0413, published in September 1978. Additional surveys of the creek and river were made by the United States Environmental Protection Agency (EPA) (1980) and ORAU under NRC contract (1981). These surveys added to the overall information about the levels of contamination, but did not define the spatial distribution (i.e., depth in soil) of the contamination.

The comprehensive radiological survey reported in this document was specifically designed to determine not only current direct radiation levels, but also the depth distribution of contamination in the creek and river beds and in bank soil along the creek and river. This survey indicates that lands adjacent to the Kress Creek and West Branch of the DuPage River are contaminated with thorium and with daughter products of the thorium decay chain essentially in secular equilibrium. Soil contamination levels and direct levels of radiation were found to be relatively constant throughout the length of Kress Creek and to extend downstream along the West Branch of the DuPage River.

The average concentrations of total thorium (Th-232 + Th-228) at 1 meter from the edge of the creek at various depths were: 26.1 pCi/g (picocuries per gram) surface; and 18.7 pCi/g between 60 and 90 cm. The soil concentrations

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COMPREHENSIVE RADIOLOGICAL SURVEY OF KRESS CREEK WEST CHICAGO AREA, ILLINOIS

INTRODUCTION

Between 1931 and 1973 a thorium ore processing facility was operated in West Chicago, IL, by Lindsay Light and Chemical Co., and successor owners. Initially, the principal activity at this site was extraction of thorium for use in the manufacture of gas mantles. Later operations included the recovery of rare earths also present in the ores. The resulting solid wastes were accumulated in two large piles on the plant site. Over the years, waste material was transported from these piles into a nearby storm sewer and drainage ditch and then to Kress Creek; this resulted in most of the contamination along the creek.

In 1974, the present owner of the facility, Kerr-McGee Corp., began cleanup activities to decommission the facility. At the request of the Nuclear Regulatory Commission (NRC), Argonne National Laboratory (ANL) conducted a radiological evaluation of thorium residues in the West Chicago area.[1] This study of the Kress Creek region consisted primarily of direct radiation measurements between the outfall of the sewer runoff and the juncture of Kress Creek with the DuPage River (West Branch). Radiation levels up to 150 μrem/h were reported for several locations up to 1 km downstream from the outfall. The ANL study estimated that at least 80% of the thorium waste in the creek was deposited in the upper one-third of its course between the sewer outfall and the DuPage River. A 1977 aerial radiological survey by EG&G confirmed the presence of thorium residues along the creek.[2] Soil and sediment samples collected in 1980 by Region V of the Environmental Protection Agency (EPA) indicated that distribution of the radioactive material was "much more extensive" than indicated by the ANL study.[3] EPA also identified the primary radionuclides in the waste as Th-232 and Th-228 in essentially secular equilibrium.

In July 1981 the Radiological Site Assessment Program of Oak Ridge Associated Universities, Oak Ridge, TN, conducted additional sampling and monitoring of Kress Creek. This survey was limited to the creek bed and the surface soils within several meters of the edge of the creek. The results generally confirmed the findings of earlier surveys.

At the request of the NRC Division of Fuel Cycle and Material Safety, a comprehensive radiological survey of Kress Creek was conducted December 6-20, 1982 and April 4-22, 1983 by the Radiological Site Assessment Program of Oak Ridge Associated Universities (ORAU), Oak Ridge, Tennessee. This report presents the findings of the survey.

A glossary of technical and nuclear terms and schematic representations of the naturally-occurring thorium and uranium radioactive decay series have been provided in Appendices A and B, respectively, to aid the reader in interpreting this report.

SITE DESCRIPTION

Kress Creek in West Chicago, DuPage County, Illinois (see Figures 1, 2, and 3) originates on or near the Fermi National Accelerator Laboratory site. After leaving the Fermi site, the creek flows east under the Elgin, Joliet, and Eastern Railroad approximately 300 m south of Roosevelt Road. Immediately east of the railroad, the storm sewer from the Kerr-McGee facility, north of Roosevelt Road, empties into the creek. At this point Kress Creek changes direction, flowing toward the southeast until it joins the west branch of the DuPage River approximately 2 km downstream.

For the first 100 m south of the storm sewer outfall, Kress Creek flows through undeveloped property consisting mostly of trees and brush. The creek then passes through a subdivision between May and Joy Streets. Along its course through the subdivision, the creek expands to form Gunness Lake. South of Joy Street it flows through mostly open field until reaching Wilson Road. The banks along the 200 m of the creek immediately south of Wilson Road are covered with dense brush and trees. Beyond this, and until the creek reaches Illinois Route 59, the terrain is primarily open field although scattered

brush and trees are found on the west bank. Further downstream, between Route 59 and the DuPage River, a forest preserve forms the east bank of the creek, and the back yards of several private residences form the west bank. The east bank of the south-flowing DuPage River is forest preserve, as is its west bank upstream of Kress Creek. The west bank of the river downstream of Kress Creek consists of scattered trees and vegetation, some marshy areas, and the back yards of a few residences.

The creek width varies from a typical 3 m up to 15 m in the case of Gunness Lake. The width of the DuPage River is a nearly constant 15 m. Under normal conditions the depth of the creek is approximately 30 cm, rarely becoming deeper than 60 cm. The DuPage River is only slightly deeper. Flooding of Kress Creek and the DuPage River is not uncommon. During the course of the survey, heavy rains caused the creek to overflow its banks by as much as 30 m. Flooding primarily, although not exclusively, occurs over the western banks of the creek and river.

SURVEY PROCEDURES

Objectives

The primary objectives of this survey were to determine the following along Kress Creek and properties adjacent to the creek:

1. the direct radiation levels, and
2. the radionuclide concentrations in soil and sediment.

Plan

The survey plan included the following activities:

1. Systematic exposure rate measurements 1 m above the surface at specified intervals along the banks of Kress Creek and the DuPage River.
2. Dose rate and exposure rate measurements at the surface for each of the locations where measurements at 1 m were taken.

3. Monitoring surface gamma radiation levels along the banks of Kress Creek and the DuPage River.
4. Measurement of radiation levels in boreholes drilled at the locations of the systematic direct radiation measurements, and at locations of elevated direct radiation levels.
5. Collection of soil samples from various depths in approximately 15% of the boreholes.
6. Collection of sediment core samples at specified intervals along Kress Creek and the DuPage River.
7. Collection of several residential well water samples from the vicinity of the creek.
8. Sampling and measurements at off-site locations to provide baseline and background data for comparison.

Measurement of Direct Radiation

Kress Creek was divided into 50 m intervals between the DuPage River and a point approximately 100 m south of the Kerr-McGee storm sewer outfall. Permission could not be obtained from property owners to survey the area further north, i.e. immediately upstream and downstream of the outfall, or to survey two residential properties bordering Gunness Lake. One of these residential properties was immediately north of Joy Road on the east bank and the other was the second property north of Joy Road on the west bank. Fifty meter intervals were also established along the DuPage River, 200 m upstream and downstream of its juncture with Kress Creek.

At each interval, exposure rates were systematically measured both at the surface and 1 m above the surface, 1, 5, 10, and 25 m from the edge of the creek or river (measurement locations are identified in Figures 4, 5, 6, and 7). Exceptions were those areas for which permission was not granted by the property owners and those areas extending onto public roads. NaI(Tl) scintillation ratemeters, field-calibrated using a pressurized ionization chamber, were used to measure exposure rates.

Beta-gamma dose rates at 1 cm above the surface were measured at each location where the systematic exposure rates were measured. These

measurements were performed using G-M detectors and scaler/ratemeters. To evalute contributions from both penetrating and nonpenetrating radiations, the measurements were made with the probes in both the open- and closed-shield configurations.

Using NaI(Tl) gamma scintillation ratemeters, walkover surface scans were performed to a minimum distance of 25 m on either side of Kress Creek and the DuPage River. General radiation levels and locations of significantly elevated levels were noted.

Borehole Logging

Boreholes (15 cm diameter) were drilled with a portable motorized auger at locations of systematic direct radiation measurements. Boreholes were also drilled at selected areas of elevated direct radiation levels identified in the walkover surface scans. The former are referred to as systematic boreholes and the latter as biased boreholes. Figures 8, 9, 10, and 11 indicate the locations of both the systematic and biased boreholes. Whenever possible, boreholes were drilled to a depth of 1 m. A layer of rock, which prevented further drilling, was encountered at a depth of 60-90 cm in many of the boreholes.

Radiation profiles in the boreholes were determined by measuring gamma radiation levels at 15-30 cm intervals between the surface and the hole bottom. A collimated gamma scintillation detector and portable scaler were used for these measurements.

A calibration curve for converting direct radiation levels in the boreholes into thorium concentrations in soil was generated by plotting the gamma radiation level versus the thorium concentration in selected soil samples collected for this purpose.

Soil Sampling

Soil samples (approximately 1 kg each) were collected from various depths in approximately 15% of the boreholes. Subsurface samples were obtained by

scraping soil from the side of the boreholes with a specially constructed sampler from which residual soil was cleaned between samples. Surface samples (0-15 cm) were collected using a garden trowel.

Sediment Sampling

Sediment samples were collected at 100 m intervals along Kress Creek and the DuPage River. Samples were obtained with a split spoon sampler which was driven into the creek or river bed to a depth of at least 30 cm. Each core was then divided into 10 cm sections. Sampling locations are identified in Figure 12.

Water Sampling

Six well water samples of approximately 3.5 liters each were obtained from local residences.

Baseline and Background Measurements

Nine surface soil samples were collected at locations 1-7 km from Kress Creek; direct radiation levels were measured at these locations. Figure 13 indicates the locations of baseline samples and background measurements.

Equipment and Analytical Procedures

Appendix C contains a list of the major equipment and instrumentation used for this survey. Analytical procedures are described in Appendix D.

RESULTS

Background Radiation and Baseline Concentrations

Background radiation levels and baseline radionuclide concentrations are presented in Table 1.

Background exposure rates in the West Chicago, Illinois, area ranged from 6-11 μR/h at 1 m (8.6 μR/h average) and from 7-12 μR/h at the surface (9.6 μR/h average).

Baseline radionuclide concentrations in soil were: Th-232, 0.53-1.12 pCi/g (picocuries per gram); Th-228, 0.50-1.12 pCi/g; total thorium, 1.03-2.10 pCi/g; Ra-226, 0.68-1.38 pCi/g; and U-238, 0.15-1.10 pCi/g. These concentrations are typical of those normally encountered in soil.

Direct Radiation Levels

Exposure Rates

Exposure rates measured systematically along the banks of Kress Creek and the DuPage River are presented in Tables 2 and 3.

Exposure rates 1 m above the surface at 1 m from the edge of the creek ranged from 8 to 96 μR/h averaging 28 μR/h. At 5 m from the edge, the exposure rates ranged from 7 to 72 μR/h (25 μR/h average); at 10 m, 8 to 120 μR/h (21 μR/h average); and, at 25 m, 8 to 32 μR/h (14 μR/h average).

Exposure rates along the banks of the DuPage River, upstream of its juncture with Kress Creek were: 10 to 19 μR/h (14 μR/h average) at 1 m from the edge of the river; 9 to 22 μR/h (15 μR/h average) at 5 m; 10 to 17 μR/h (13 μR/h average) at 10 m; and 10-14 μR/h (12 μR/h average) at 25 m. Downstream of the juncture with Kress Creek, exposure rates along the banks of the DuPage River were significantly higher. At 1 m from the river's edge exposure rates 1 m above the surface ranged from 14 to 104 μR/h (36 μR/h average). Exposure rates ranged from 11 to 64 μR/h (31 μR/h average) at 5 m; from 11 to 30 μR/h (18 μR/h average) at 10 m; and from 11 to 64 μR/h (20 μR/h average) at 25 m.

Exposure rates measured systematically at surface contact along the banks of the creek and river were generally about 20% higher than the levels measured at 1 m above the ground.

At 1, 5, 10, and 25 m from the edge of Kress Creek these levels ranged from 7-172 μR/h (36 μR/h average); 8-80 μR/h (27 μR/h average); 8-250 μR/h (24 μR/h average); and 8-38 μR/h (14 μR/h average), respectively. Along the DuPage River upstream of Kress Creek, the surface exposure rates were 10-22 μR/h (16 μR/h average) at 1 m from the river edge; 9-22 μR/h (16 μR/h average) at 5 m; 10-17 μR/h (14 μR/h average) at 10 m; and 11-16 μR/h (13 μR/h average) at 25 m. Downstream of the confluence with Kress Creek, the surface exposure rates along the banks of the DuPage River were 16-136 μR/h (45 μR/h average) at 1 m from the river edge; 13-88 μR/h (37 μR/h average) at 5 m; 11-32 μR/h (19 μR/h average) at 10 m; and 13-68 μR/h (21 μR/h average) at 25 m.

Several generalizations can be made regarding the systematic exposure rate measurements. Overall, exposure rates decrease with increasing distance from the edge of the creek, averaging 4 times background at the creek edge and decreasing to approximately 1.5 times background at 25 m. Although a similar decrease in exposure rate might be expected with increasing downstream distance, the same general levels of direct radiation are maintained throughout the length of the creek. One exception is that portion of the creek located 800 m to 1150 m downstream, north of Wilson Road. Here the exposure rates are somewhat below average, possibly due to the decreased tendency of the creek to overflow its banks in this region. Along the banks of the DuPage River upstream of its juncture with Kress Creek, the overall radiation levels are slightly above background. Downstream of Kress Creek, the exposure rates are substantially higher with average values exceeding those along Kress Creek itself. The highest exposure rates are found on the western bank of the river. Two possible explanations for this are that Kress Creek merges with the west side of the river and that the western bank is low-lying and more susceptable to flooding.

Beta-Gamma Surface Dose Rates

The systematically measured surface dose rates (μrad/h) typically ranged from 1-2 times the measured surface exposure rates (μR/h). Differences between the open- and closed-shield measurements averaged 26% indicating a small contribution from beta and low-energy photon radiations. Because of the

close relative agreement between the surface dose rates and surface exposure rates, the dose rate values have not been individually included in this report.

Walkover Surface Scan

The walkover surface scan, in addition to providing more detail, confirmed the general patterns identified by the systematic measurements. Numerous isolated regions were located in which the radiation levels were substantially elevated above those in adjacent areas. Exposure rates at several of these locations (also corresponding to the biased borehole locations) are presented in Table 4. These ranged up to 820 μR/h at the surface and 210 μR/h at 1 m above the surface. This highest level was noted 15 m east of the creek bank and 197 m downstream. Direct radiation levels at these isolated areas were generally higher upstream (closer to the sewer outfall) even though the overall radiation levels were reasonably constant along the length of the creek. Most of these locations were within 1-2 m of the edge of the creek and could be attributed to deposition during flooding. There were some areas of elevated exposure rates where the distance from the creek and/or the bank elevations would have precluded such deposition. One such area is on the east bank between 50 and 100 m downstream. In this example, elevated exposure rates were found near the end of a driveway, approximately 30 m from the creek and up a relatively steep incline.

Although the portion of the creek upstream of 0 m and downstream of the outfall could not be included in the survey, certain tentative assumptions can be drawn. Typical exposure rates along these banks are likely to be in the 20-50 μR/h range, slightly lower than earlier reports indicated. Since the banks are relatively low and the area prone to flooding, there may be more isolated areas of elevated direct radiation levels and these areas may be distributed further from the creek than was noted downstream.

Along the DuPage River elevated direct radiation levels on the west bank likely continue to at least 0.5 km downstream of the juncture with Kress Creek with a slight rise in the levels on the east bank possible. Beyond that

point, the west bank becomes steeper and less subject to flooding so that elevated radiation levels would be expected to be limited to the river edge.

Radionuclide Concentrations in Soil

A review of the analyses for 70 soil samples indicated that thorium is the radioactive material of concern at this site. Lower levels of Ra-226 and U-238 are present, at approximately 2.5% and 5% of the total thorium (Th-232 and Th-228) concentration respectively. Thorium-232 and thorium-228 were nearly always in secular equilibrium.

Total thorium concentrations determined for the systematic boreholes along Kress Creek and the DuPage River are presented in Tables 5 and 6, respectively. Total thorium concentrations for the biased boreholes are presented in Table 7.

Thorium concentrations in soil follow the same general pattern as the direct radiation levels - decreasing with distance from the edge of the creek. At 1 m from the edge, average concentrations at the various depths were: 26.1 pCi/g, surface; 40.2 pCi/g, 15 cm; 38.9 pCi/g, 30 cm; 28.9 pCi/g, 60 cm; and, 18.7 pCi/g, between 60 and 90 cm. These average values decrease by approximately 50% at 5 m from the edge of the creek, remain unchanged at 10 m, and at 25 m decrease to approximately 17% of the original concentration. At 25 m the average concentrations were approximately 3 times the baseline levels; however, the true averages may be slightly lower since the computer-generated curve used to calculate the thorium concentrations slightly overestimates concentrations near baseline levels.

Along the DuPage River, upstream of Kress Creek, the average thorium levels at 1 m from the river edge were: 3.45 pCi/g, surface; 4.86 pCi/g, 15 cm; 7.95 pCi/g, 30 cm; 5.09 pCi/g, 60 cm; and, 3.08 pCi/g, from 60-90 cm. These values showed a gradual decrease with distance from the edge of the river. At 25 m the thorium concentrations were only slightly above the baseline levels. Downstream of Kress Creek, the average concentrations at 1 m from the river edge were: 12.5 pCi/g, surface; 18.1 pCi/g, 15 cm; 30.8 pCi/g, 30 cm; 15.8 pCi/g, 60 cm; and, 11.3 pCi/g from 60-90 cm.

As was true of the direct radiation levels, the thorium concentrations in soil did not indicate a significant overall decrease with increasing downstream distance along those parts of the creek and river included in the survey. Concentrations on the west bank of the DuPage River were only slightly lower than those on the creek banks nearest the Kerr-McGee outfall. The highest level of total thorium measured in a sample (555 pCi/g) was 60 cm deep in a systematic borehole 1750 m downstream and 1 m from the west side of the creek. Other high levels were in the three biased boreholes collected closest to the outfall: 197 m downstream, 15 m from the east edge of the creek - 489 pCi/g; 25 m downstream, 1 m from the east edge of the creek - 432 pCi/g; and, 205 m downstream, 12 m from the east edge of the creek - 417 pCi/g. While the overall concentrations decrease very little along the length of the creek, the highest levels are at isolated upstream locations nearest the outfall.

The average concentrations along Kress Creek and the DuPage River do not reflect the localized distribution of the contamination however. In order to provide such information, the thorium concentrations in soil from Tables 5, 6, and 7 were evaluated in combination with the results of the walkover surface scan. Estimates were made of the locations in which thorium concentrations in soil ranged from 10-20 pCi/g, 20-50 pCi/g, and >50 pCi/g. These estimates are presented in Figures 14, 15, 16, and 17. The figures indicate maximum concentrations at a given location, regardless of the depth of the contamination. Except for a few areas - most notably around Gunness Lake - the contamination is predominantly on one bank or the other. Frequently, this bank is on the inside of a curve or bend in the creek and prone to flooding. As a result, along much of the creek the thorium concentrations on one bank will be well below 10 pCi/g even though the average value may be higher.

Maximum thorium concentrations were typically 15-30 cm deep along the banks of both Kress Creek and the DuPage River. The greatest depth at which a maximum thorium concentration was encountered in a borehole was at 110 cm in the systematic borehole 50 m downstream and 10 m from the east edge of the creek (226 pCi/g). This was a unique situation and not easily attributed to deposition brought about by a periodic flooding of the creek. The depth of the material, together with the steepness of the bank and the pattern of the

surface exposure rates observed in the walkover scan, suggest that contaminated fill may have been used during landscaping of the property.

The maximum depths to which thorium concentrations of 10-20 pCi/g, 20-50 pCi/g, and >50 pCi/g are present, average between 30-60 cm. Conservative estimates of these depths are 60, 55, and 50 cm respectively. There is also a general tendency for the depth of the contamination to decrease with distance from the edge of the creek or river.

Radionuclide Concentrations in Sediment

Radionuclide concentrations in sediment samples along Kress Creek and the DuPage River are presented in Tables 8 and 9, respectively. In almost all cases, secular equilibrium was observed between Th-232 and Th-228. Along Kress Creek the total thorium concentrations ranged from <0.34 to 131 pCi/g. Contrary to what might be expected, there was no overall decrease in the thorium concentrations with increasing downstream distance. Instead, the thorium levels appeared to fluctuate randomly; the highest concentration was observed at the 1850 m downstream distance while the sample immediately downstream (1950 m) had one of the lowest concentrations. There are several factors which may explain the fluctuations. To some degree, the small samples obtained with the split spoon sampler may not have been representative of the sediment at any given location. More likely, the observations reflect differential deposition of thorium resulting from changing conditions of the stream bed and changes in the direction and rate of stream flow, i.e. placer deposition. Both the fluctuations in thorium levels and the general range of these levels are consistent with the results of the initial survey of Kress Creek performed by Oak Ridge Associated Universities.[4]

Along the DuPage River, as expected, the downstream sediments had considerably higher thorium concentrations (up to 27.2 pCi/g) than the samples collected upstream of the juncture with Kress Creek (up to 2.24 pCi/g).

Thorium concentrations decreased with depth. In almost all cases, the concentrations reached what could be considered baseline levels at a depth of 20-30 cm; however, in the sediment collected at 0 m (the sampling location

closest to the outfall), they remained essentially constant down to 40 cm (at approximately 50 pCi/g).

These findings suggest that thorium levels in the creek sediment between 0 m and the storm sewer outfall will exceed 50 pCi/g and that the depth of the contamination will be greater than that observed along the rest of the creek.

The uniform nature of the DuPage River indicates that the progressive decrease in thorium concentration observed in the river sediment between Kress Creek and 200 m downstream would likely continue.

Radionuclide Concentrations in Water Samples

Gross alpha and beta concentrations in the residential well water samples are presented in Table 10.

The gross alpha concentrations ranged from <1.33 to 1.48 pCi/l, and gross beta concentrations ranged from <2.26 to 4.98 pCi/l. Because of these low levels, no further isotopic analyses were necessary.

SUMMARY

At the request of the Nuclear Regulatory Commission, the ORAU Radiological Site Assessment Program conducted a radiological survey of portions of Kress Creek and the DuPage River in the West Chicago Area, Illinois. The survey findings indicated thorium contamination in soil and sediment along certain sections of the creek and river. Radionuclides of the uranium decay series, i.e. uranium-238 and radium-226, are also present, but in quantities so low in comparison with the thorium as to be inconsequential.

The contamination originated on property originally owned by Lindsay Light and Chemical Company and now owned by Kerr-McGee Corporation. Contaminated residues from two waste piles on the property were carried by precipitation-induced runoff into a nearby storm sewer which subsequently emptied into Kress Creek. From there it was transported down the remaining 2 km of Kress Creek and into the west branch of the DuPage River.

The thorium contaminated residues were deposited along the streambed and banks, primarily at locations where the creek flow abruptly changed speed or direction. In many areas flooding deposited the material well beyond the immediate banks of the creek. In at least one area, elevated thorium levels, which appear to have resulted from the use of contaminated backfill, were observed. Overall contamination levels decreased slightly along the length of the creek and downstream along that portion of the DuPage River included in the survey. The contamination is primarily limited to the upper 60-90 cm of soil with the maximum levels located at depths of 15-30 cm. Low gross alpha and beta concentrations in the residential well water samples are consistent with the low solubility of the material. It is likely that the primary mode for the exposure of the local population is external gamma radiation. In a couple of cases, vegetable gardens located in moderately contaminated areas offer an additional, although probably not major, pathway for exposure.

The levels of direct radiation and radionuclide concentations in soil and sediment at many locations along Kress Creek and the DuPage River exceed target criteria proposed by the EPA and NRC for uncontrolled use by the general public. These criteria were developed to implement the philosophy of these agencies that unnecessary exposures to radiation should be reduced or eliminated to the extent practicable.

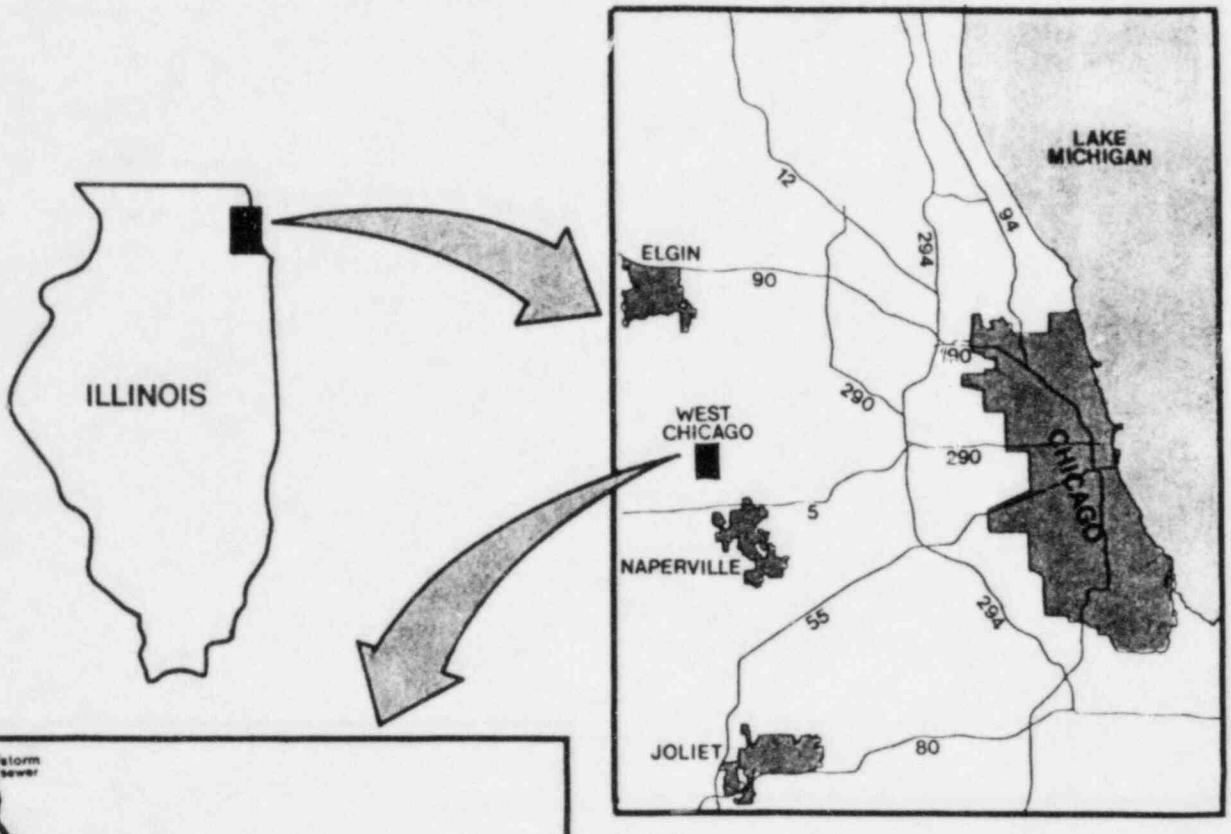

FIGURE 1. Map of Chicago, Illinois, and Vicinity Indicating the Location of Kress Creek.

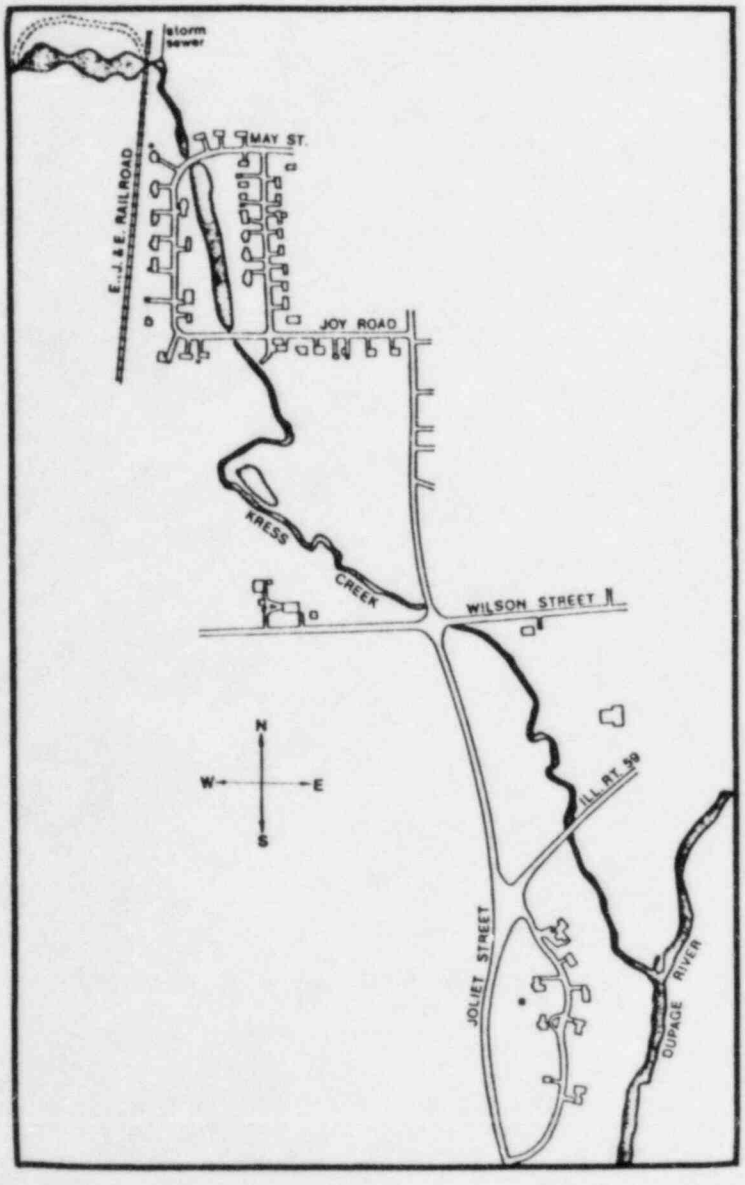

FIGURE 2. Portion of West Chicago, Illinois, Indicating Sections of Kress Creek and the DuPage River.

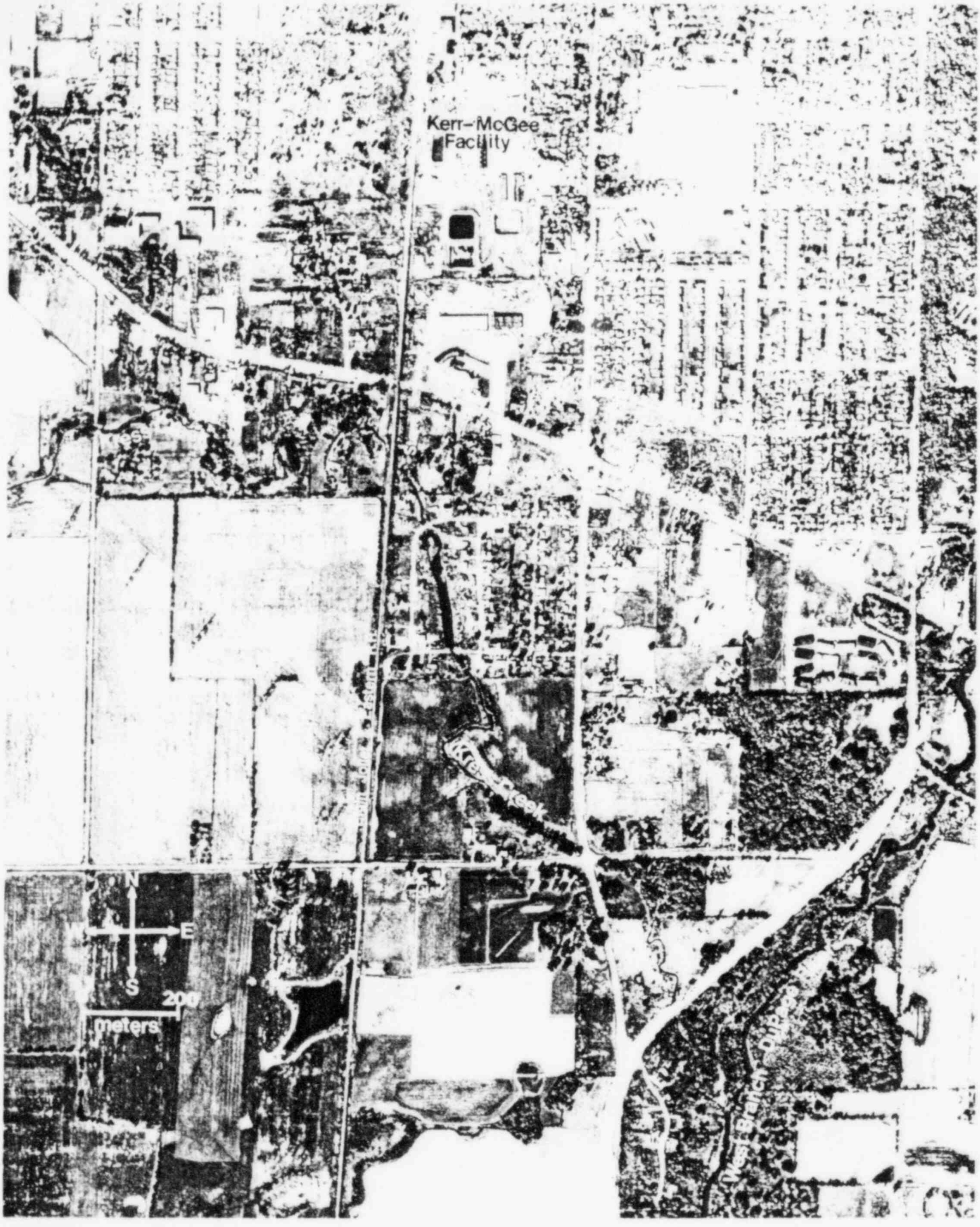

FIGURE 3. Aerial Photograph of West Chicago, Illinois, Indicating Sections of Kress Creek and the Dupage River.

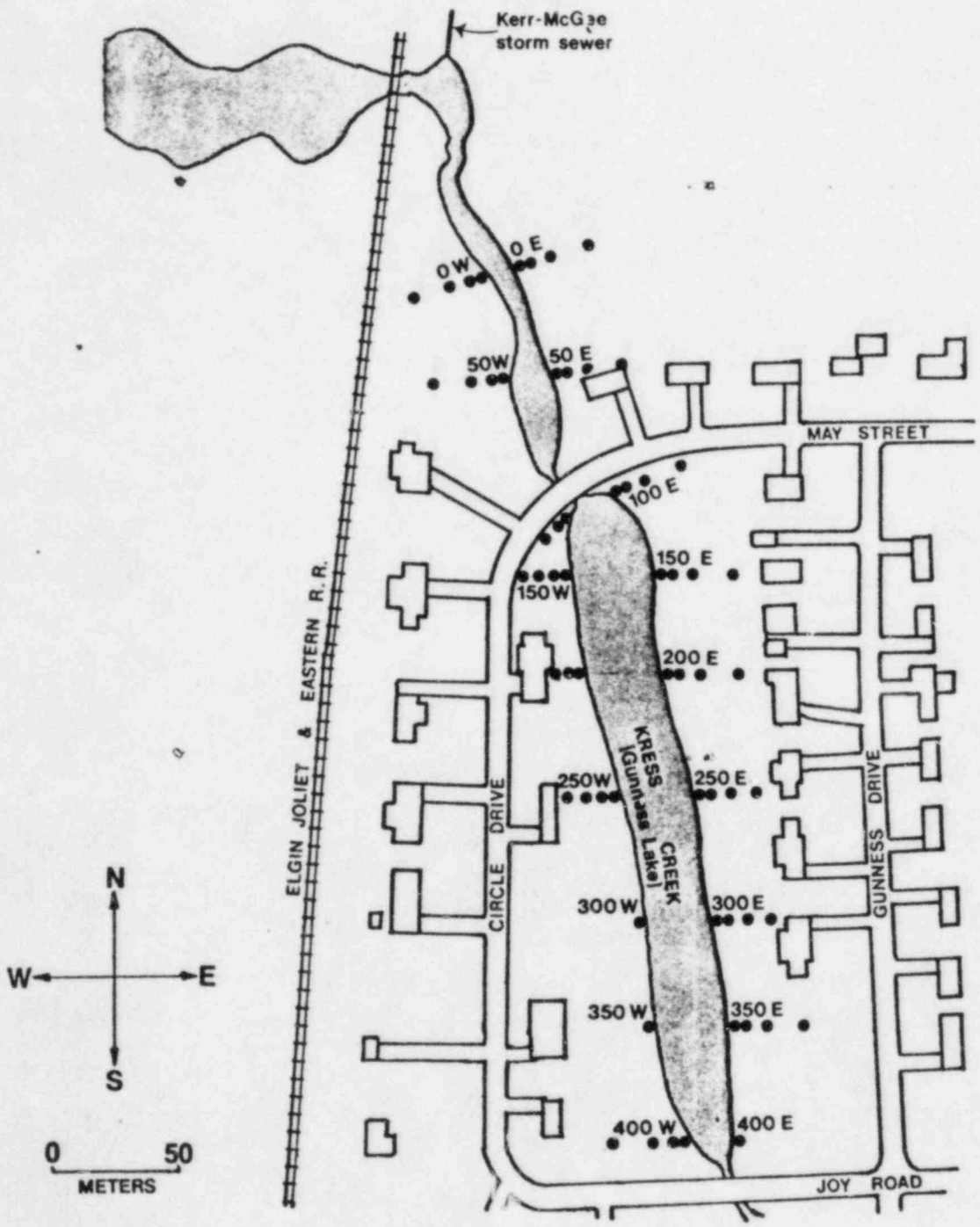

FIGURE 4. Map of Kress Creek Between the Storm Sewer Outfall and Joy Road Indicating Locations of the Systematic Direct Radiation Measurements.

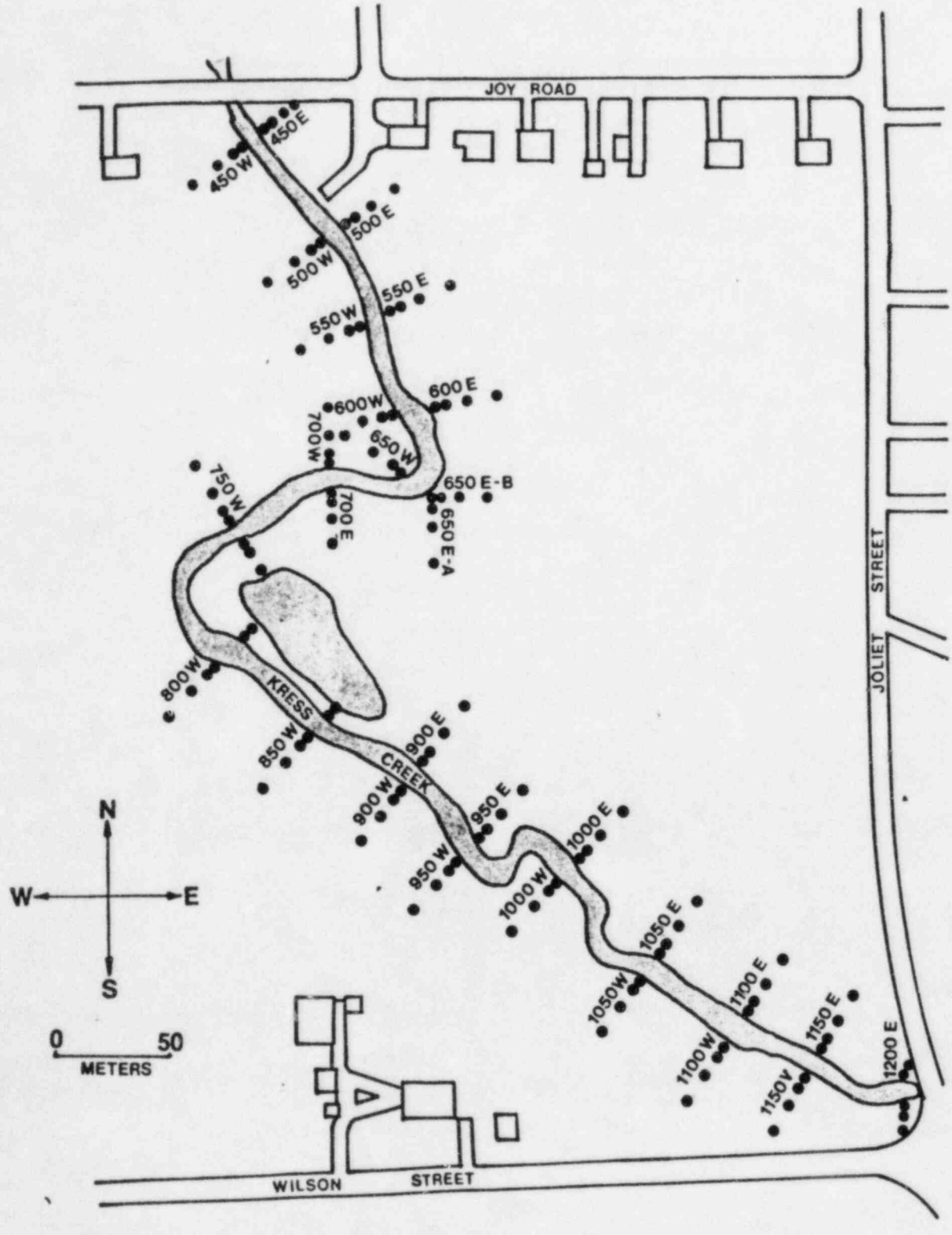

FIGURE 5. Map of Kress Creek Between Joy Road and Wilson Street Indicating Locations of the Systematic Direct Radiation Measurements.

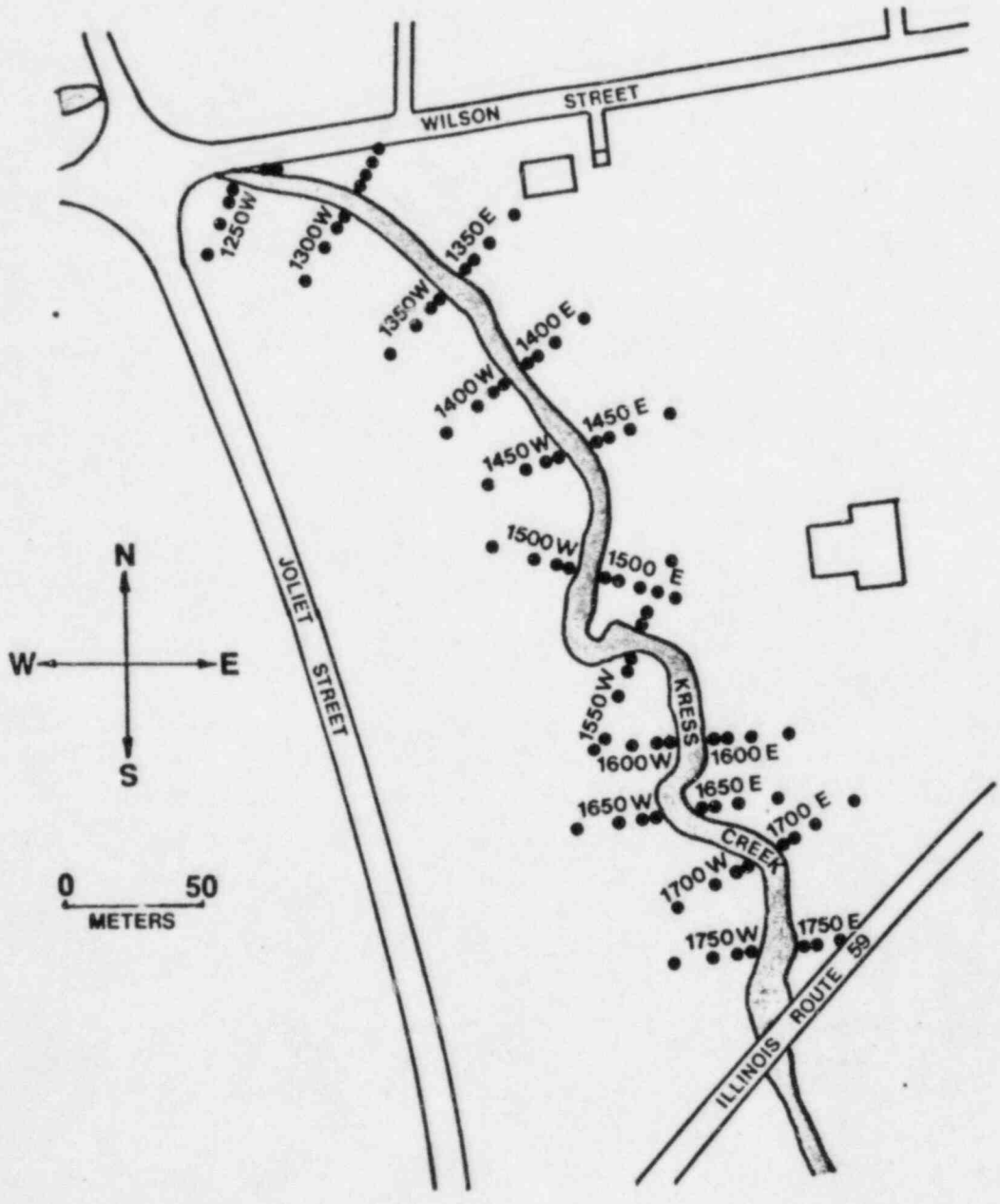

FIGURE 6. Map of Kress Creek Between Wilson Street and Illinois Route 59 Indicating Locations of the Systematic Direct Radiation Measurements.

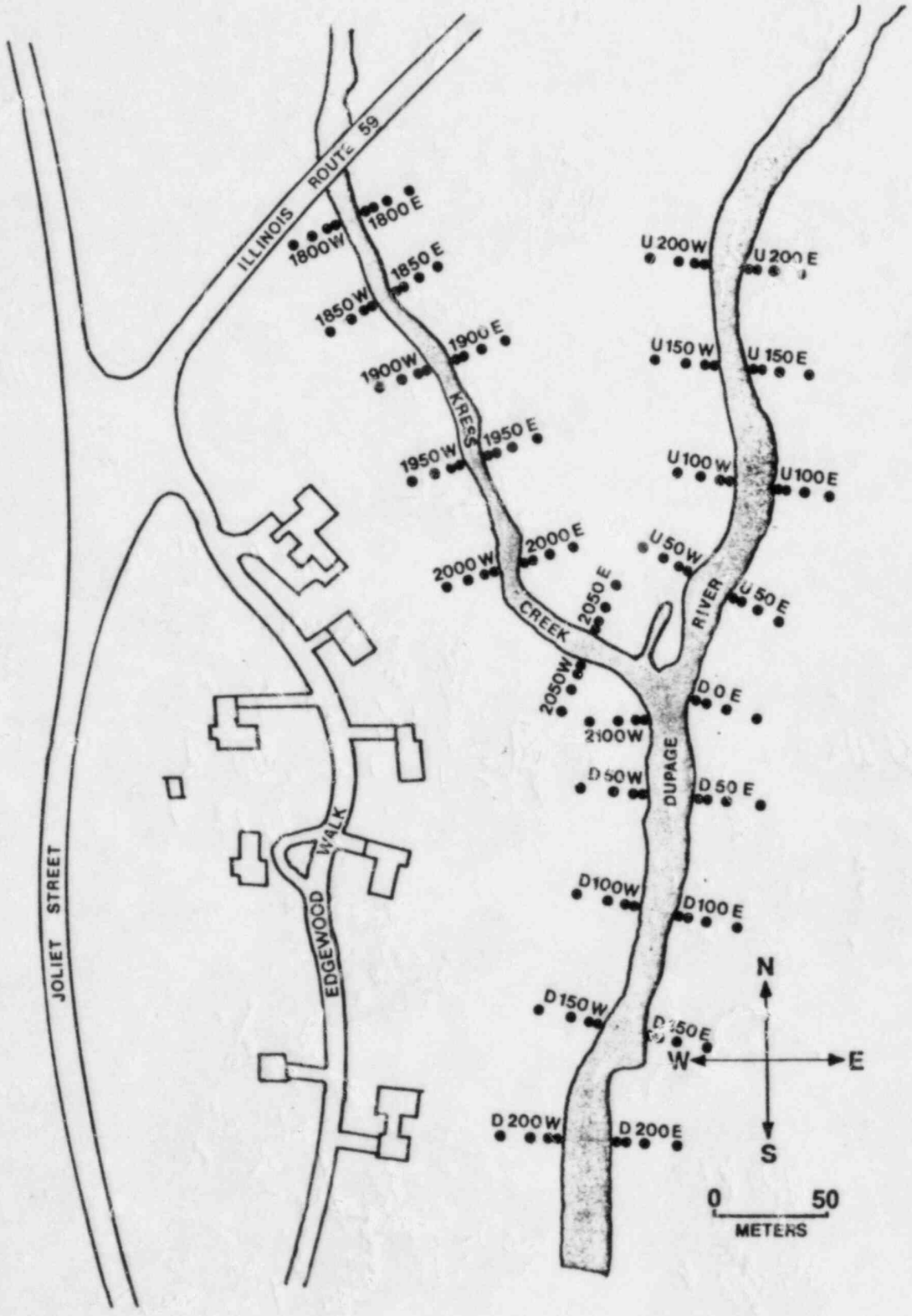

FIGURE 7. Map of Kress Creek Between Illinois Route 59 and the DuPage River Indicating Locations of the Systematic Direct Radiation Measurements.

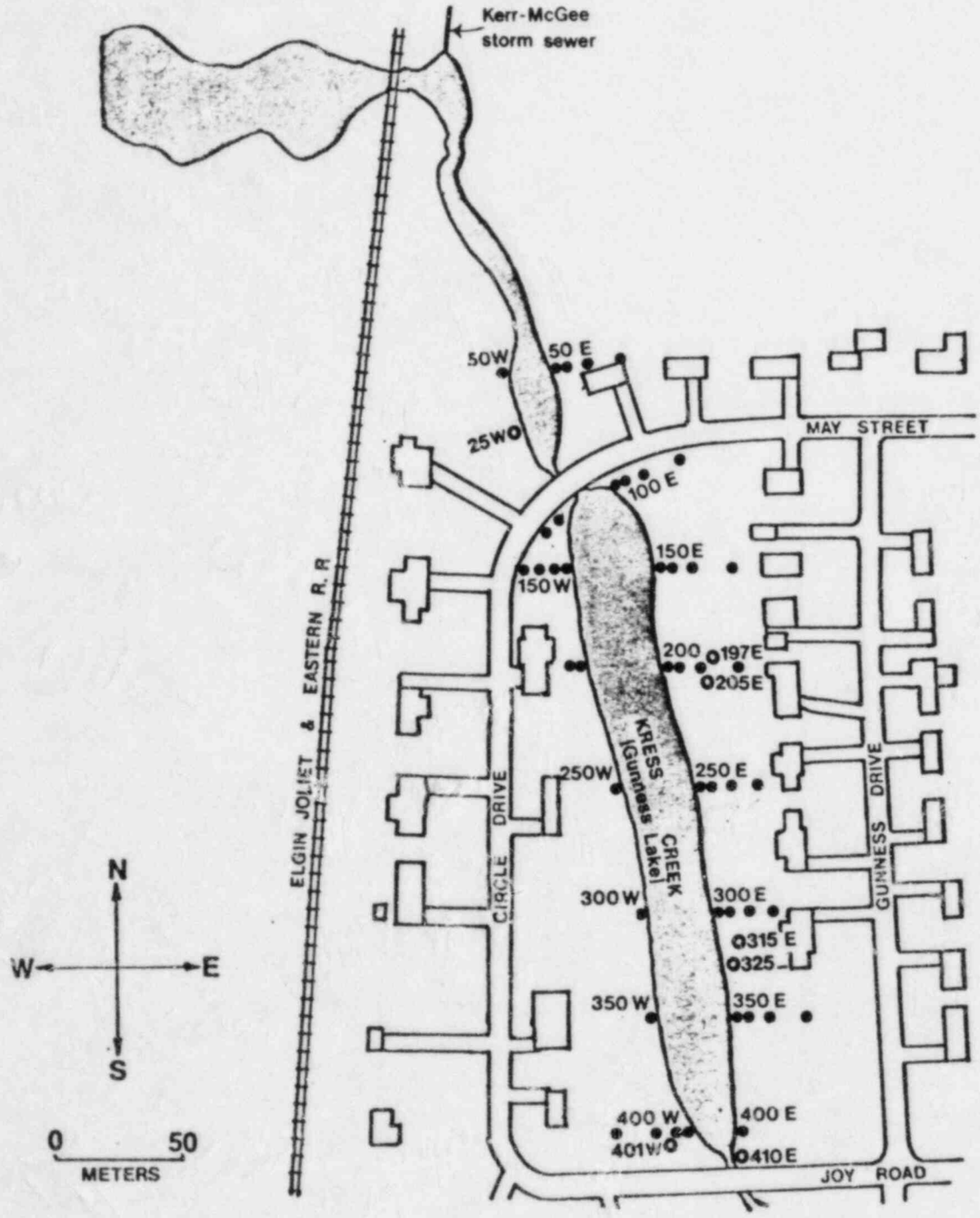

FIGURE 8. Map of Kress Creek Between the Storm Sewer Outfall and Joy Road Indicating Borehole Locations. (Systematic and biased boreholes are indicated by closed and open circles respectively.)

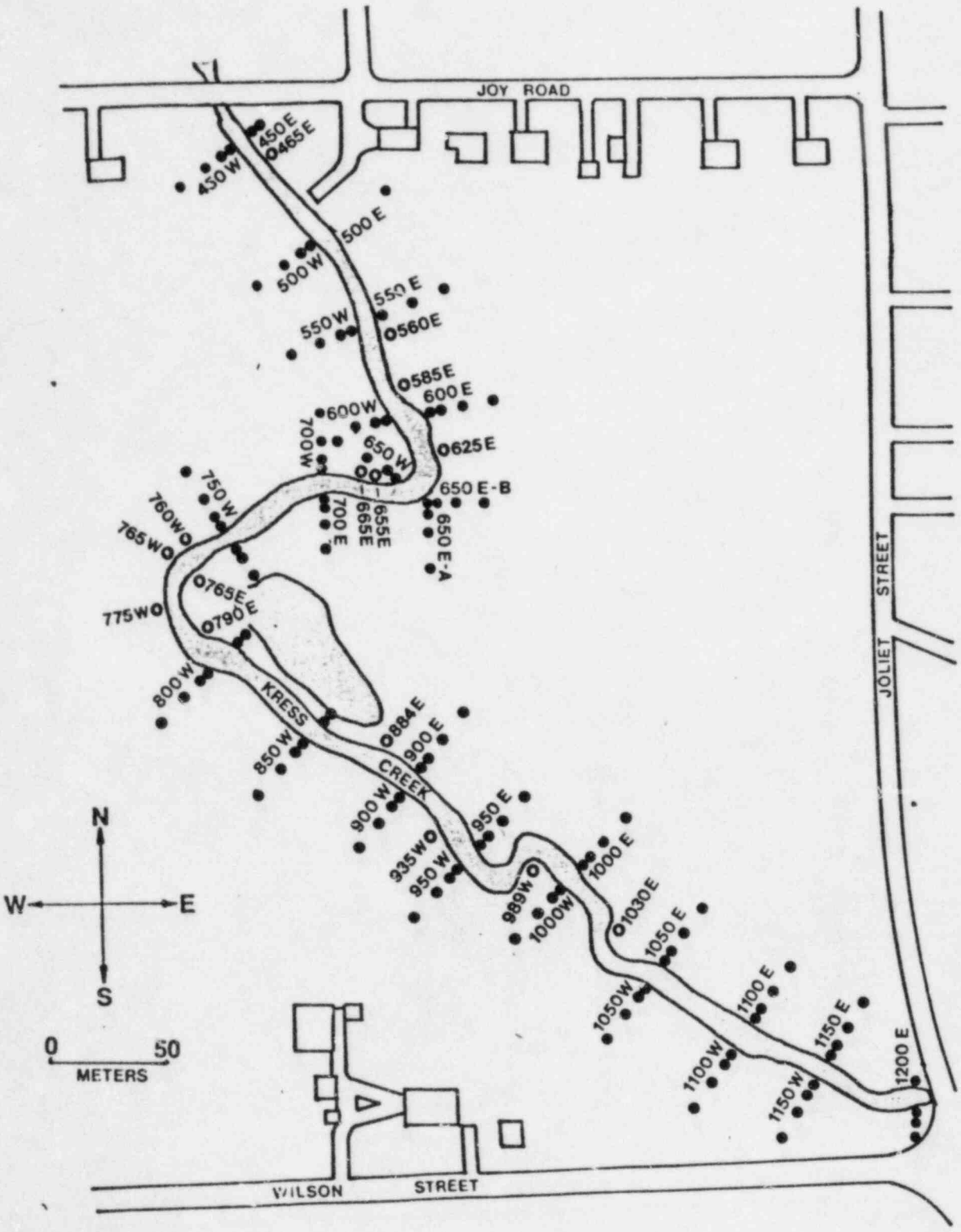

FIGURE 9. Map of Kress Creek Between Joy Road and Wilson Street Indicating Borehole Locations. (Systematic and biased boreholes are indicated by closed and open circles respectively.)

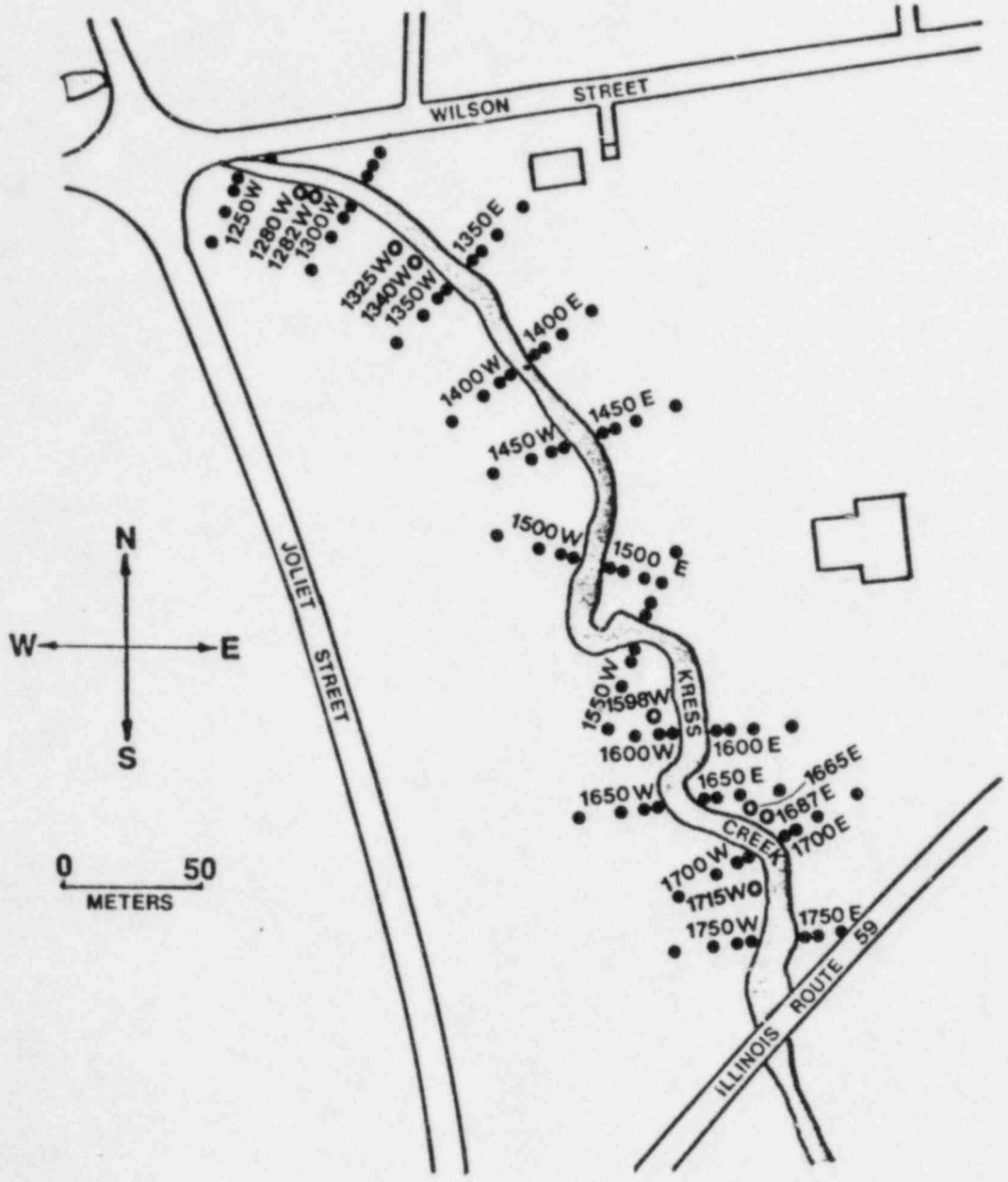

FIGURE 10. Map of Kress Creek Between Wilson Street and Illinois Route 59 Indicating Borehole Locations. (Systematic and biased boreholes are indicated by closed and open circles respectively.)

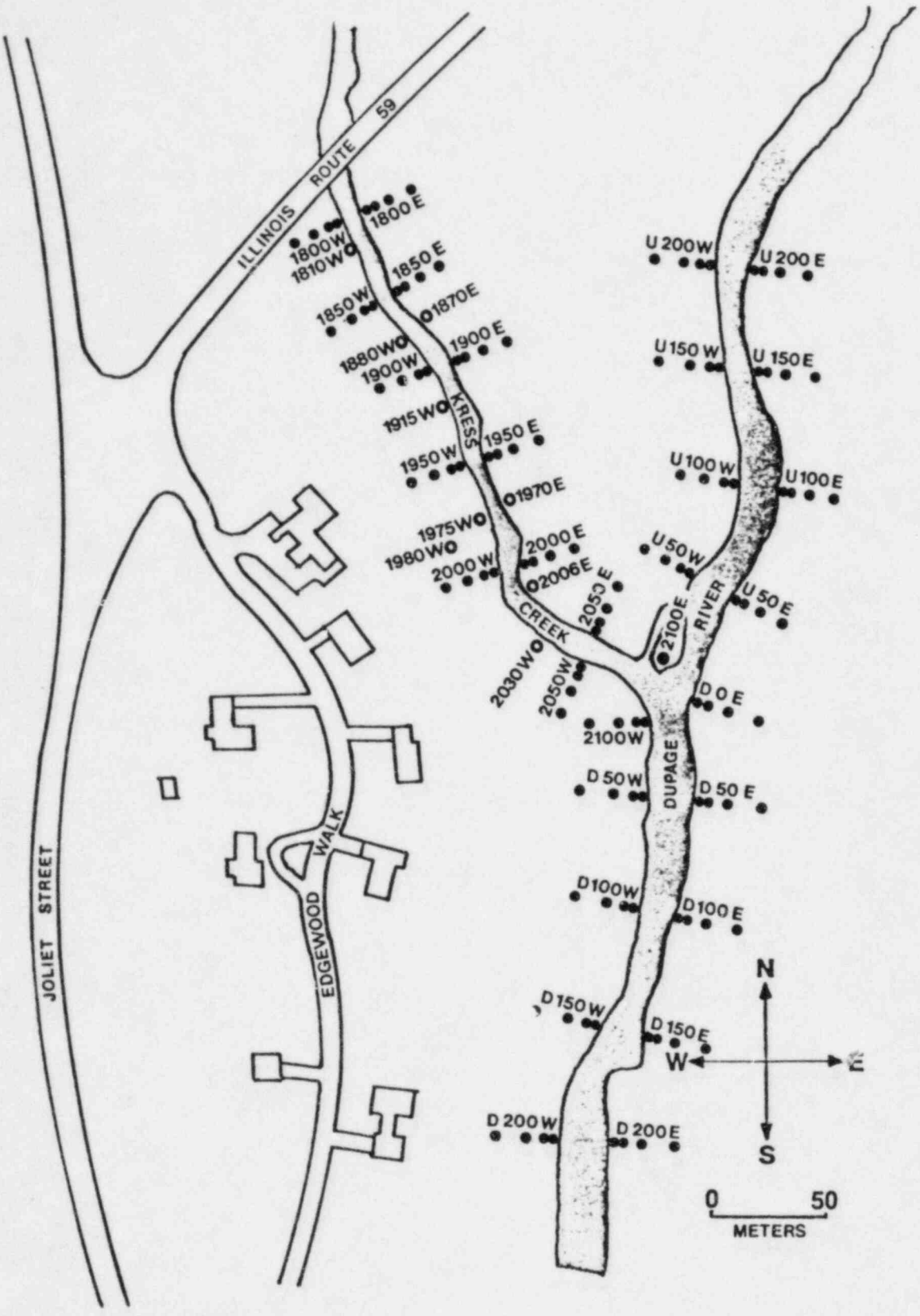

FIGURE 11. Map of Kress Creek Between Illinois Route 59 and the DuPage River Indicating Borehole Locations. (Systematic and biased boreholes are indicated by closed and open circles, respectively.)

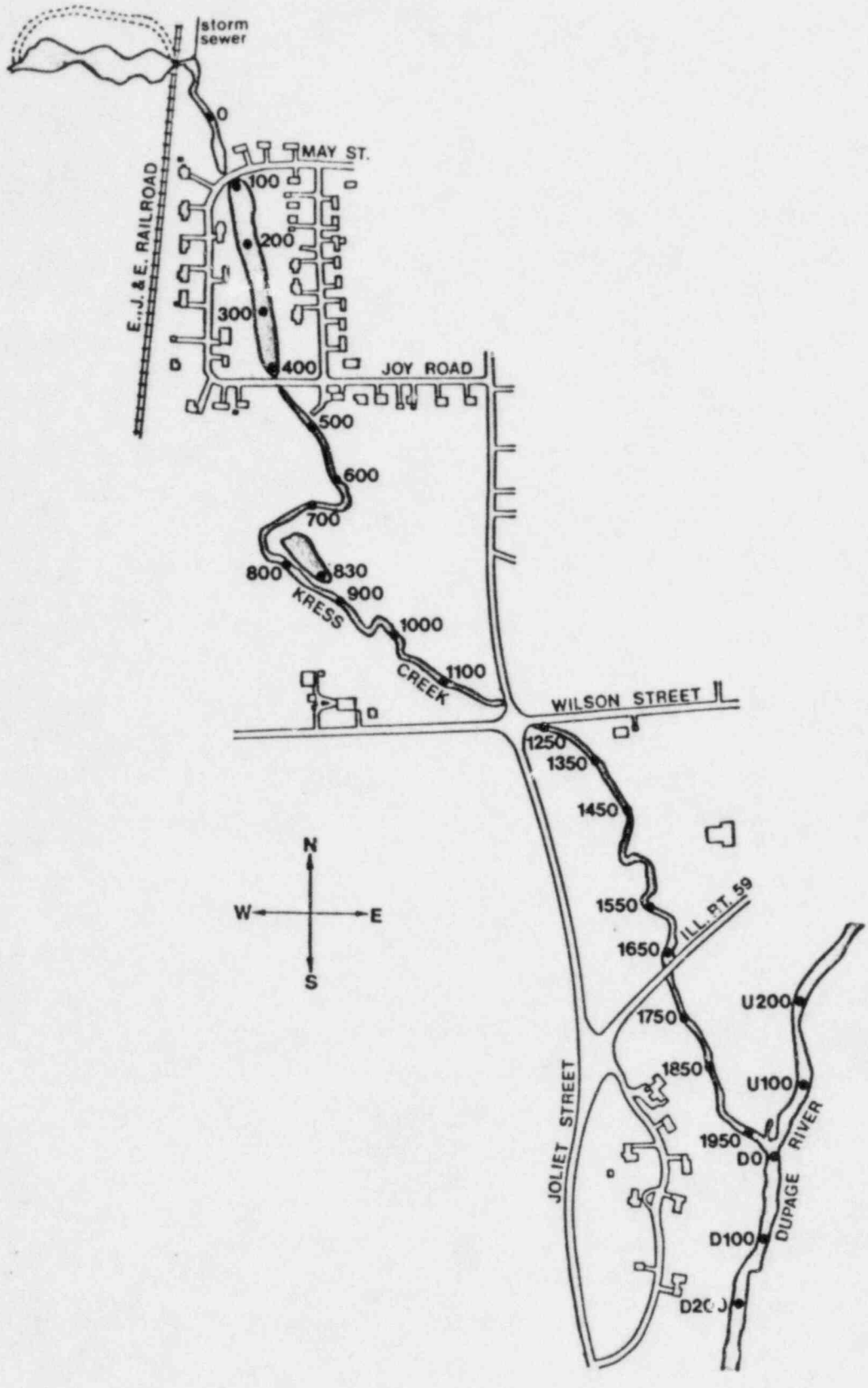

FIGURE 12. Map of Kress Creek Indicating Sediment Sampling Locations.

FIGURE 13. Map of West Chicago and Vicinity Indicating Locations of the Background Measurements and Baseline Samples.

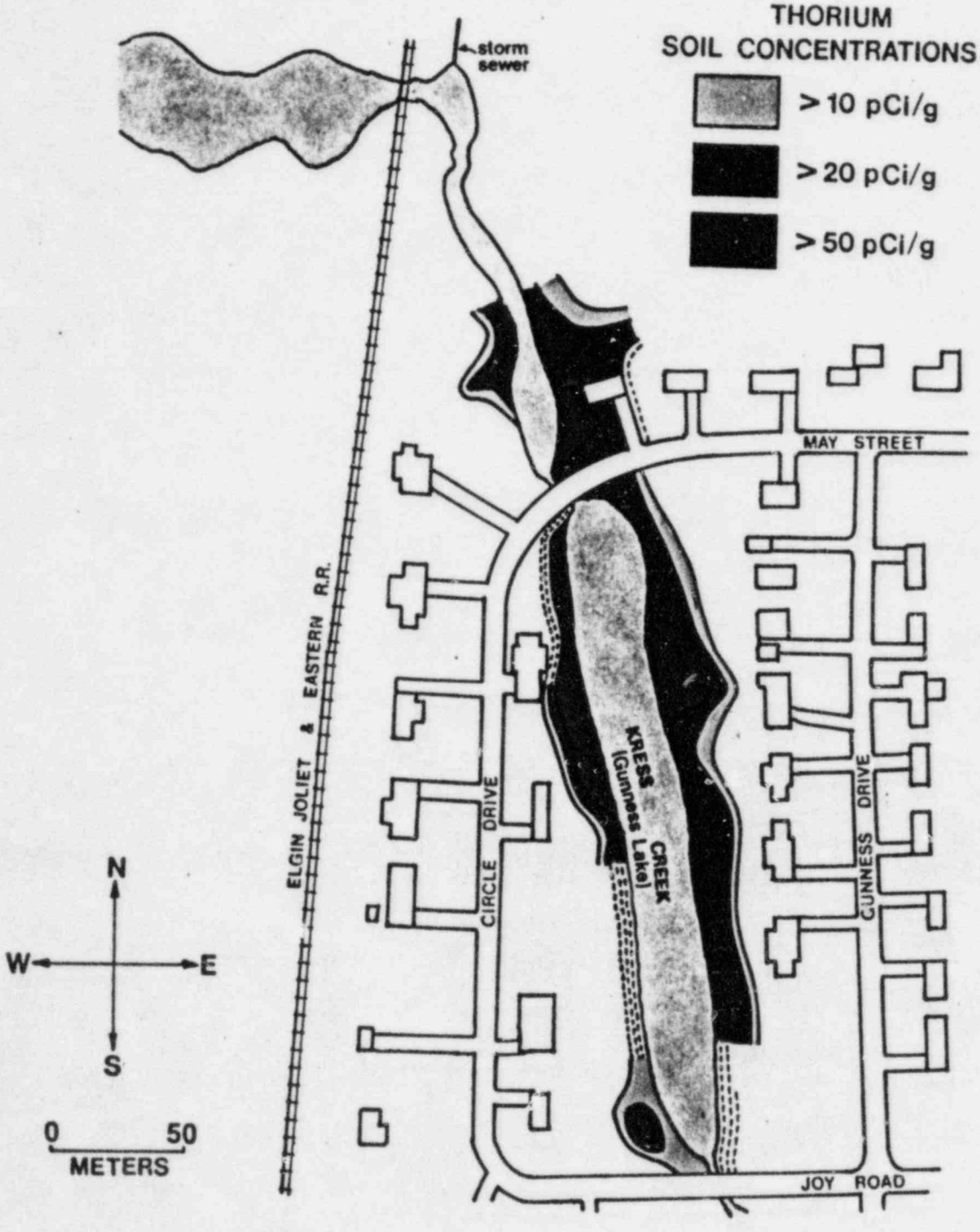

FIGURE 14. Map of Kress Creek Between the Storm Sewer Outfall and Joy Road Indicating Total Thorium Concentrations in Soil.

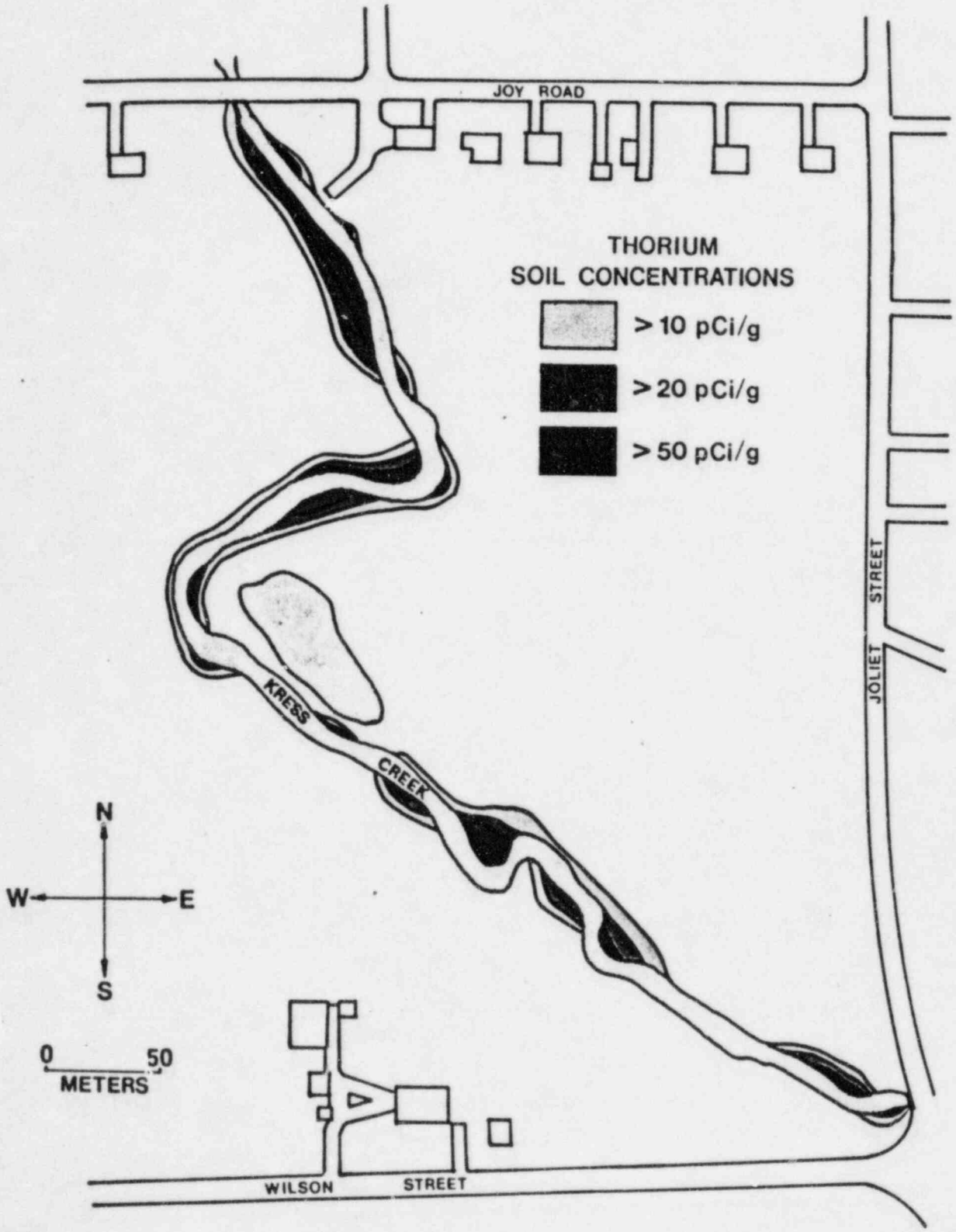

FIGURE 15. Map of Kress Creek Between Joy Road and Wilson Street Indicating Total Thorium Concentrations in Soil.

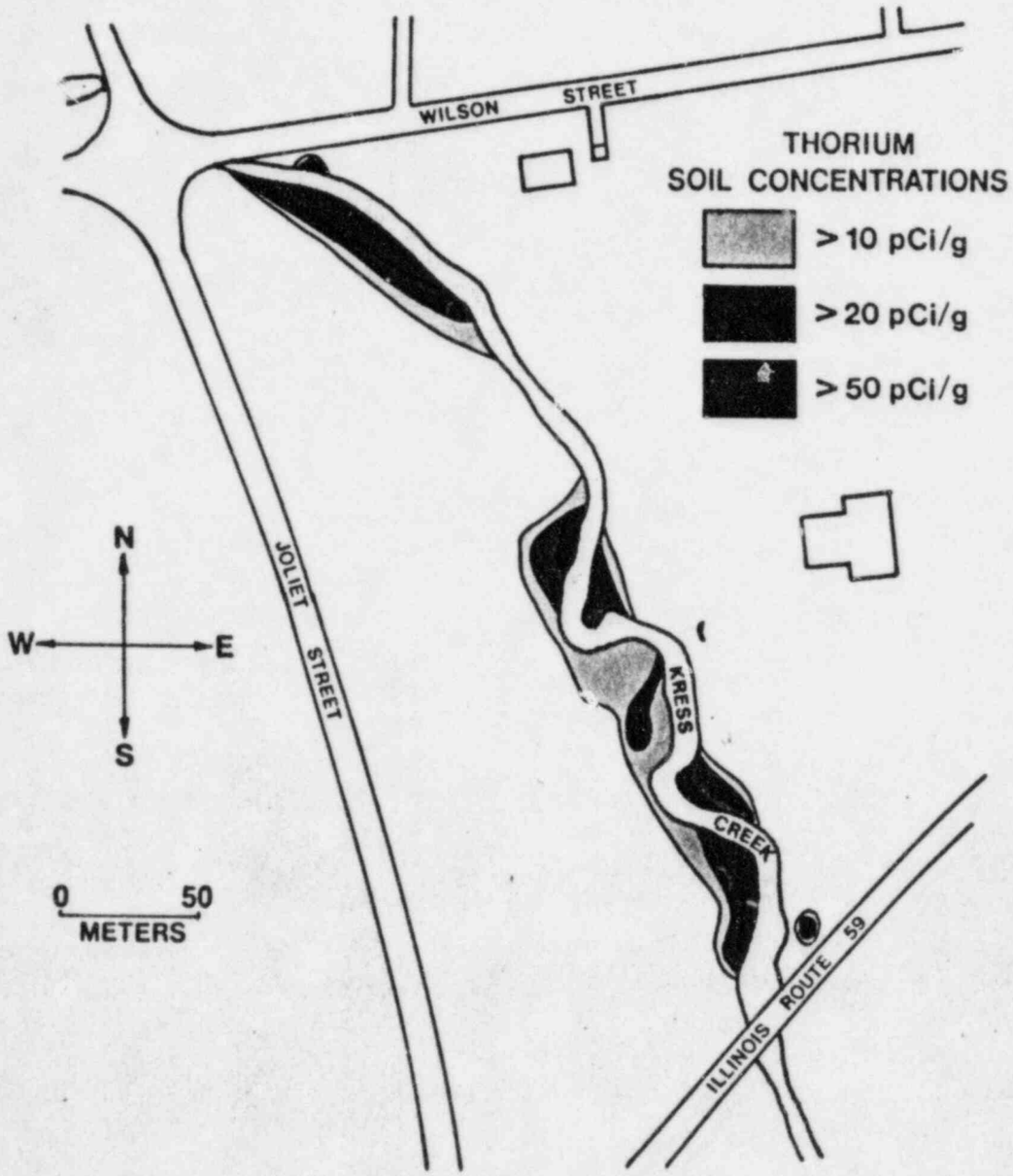

FIGURE 16. Map of Kress Creek Between Wilson Street and Illinois Route 59 Indicating Total Thorium Concentrations in Soil.

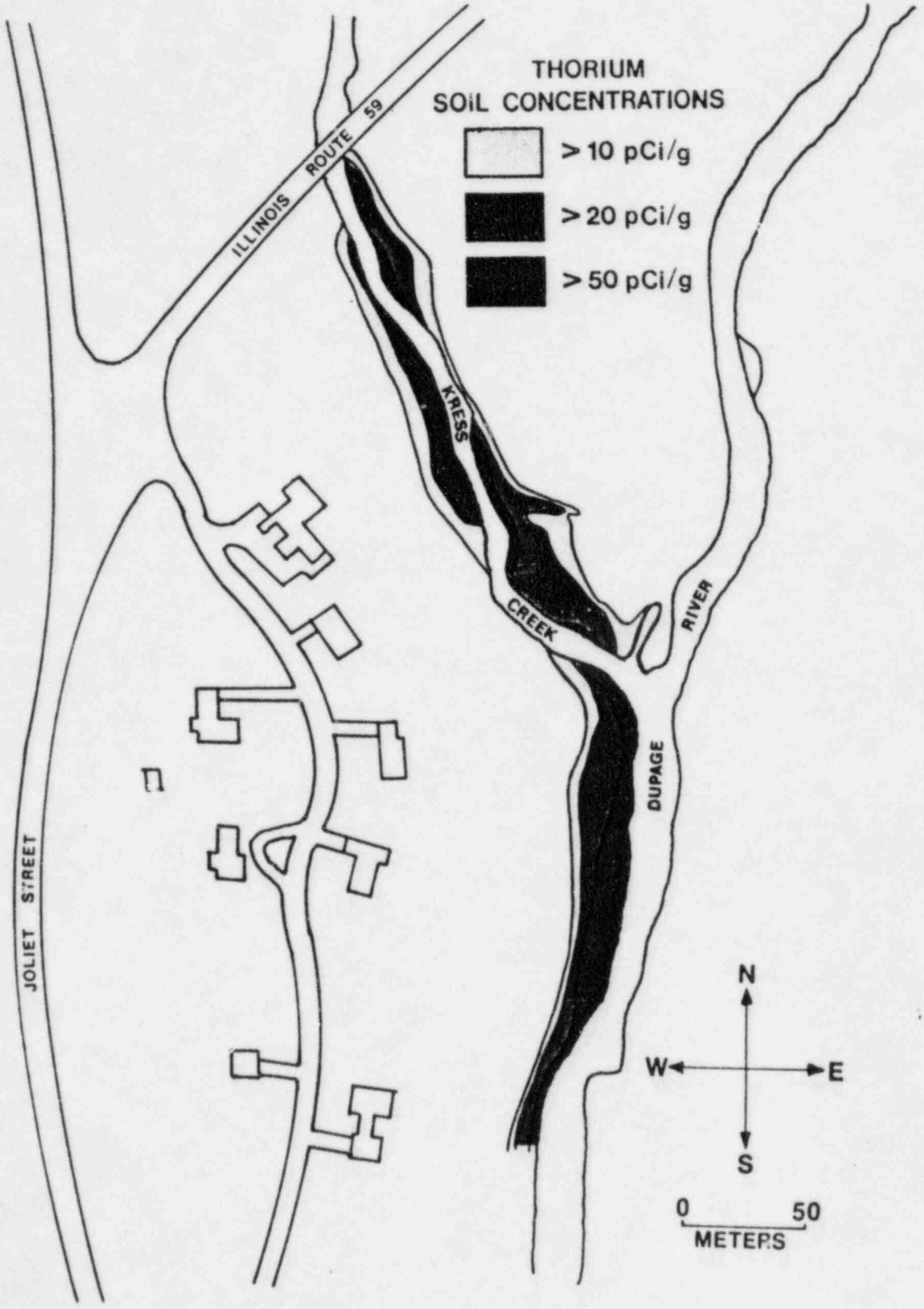

FIGURE 17. Map of Kress Creek Between Illinois Route 59 and the DuPage River Indicating Total Thorium Concentrations in Soil.

TABLE 1

BACKGROUND DIRECT RADIATION LEVELS AND
RADIONUCLIDE CONCENTRATIONS IN BASELINE SOIL SAMPLES

Location[a]	Exposure Rate (μR/h)		Radionuclide Concentration (pCi/g)				
	1 m	Surface	Th-232	Th-228	Total Thorium (Th-232 & Th-228)	Ra-226	U-238
1	6	7	0.59 ± 0.26[b]	0.82 ± 0.24	1.41	0.73 ± 0.17	0.35 ± 0.74
2	9	10	0.65 ± 0.37	1.12 ± 0.28	1.77	1.18 ± 0.31	0.63 ± 1.54
3	8	10	0.61 ± 0.25	0.59 ± 0.17	1.20	0.80 ± 0.21	0.56 ± 0.54
4	8	9	0.92 ± 0.40	0.94 ± 0.38	1.86	1.35 ± 0.31	1.10 ± 0.89
5	11	12	0.85 ± 0.27	0.72 ± 0.19	1.57	0.82 ± 0.21	0.15 ± 0.28
6	11	11	0.75 ± 0.46	1.10 ± 0.36	1.85	1.38 ± 0.29	0.59 ± 1.22
7	7	8	0.53 ± 0.21	0.50 ± 0.21	1.03	0.68 ± 0.21	0.22 ± 0.52
8	9	10	1.12 ± 0.37	0.98 ± 0.33	2.10	1.12 ± 0.33	0.82 ± 0.52
Range	6-11	7-12	0.53 - 1.12	0.50 - 1.12	1.03 - 2.10	0.68 - 1.38	0.15 - 1.10
Average	8.6	9.6	0.75	0.85	1.60	1.01	0.57

[a] Refer to Figure 13.
[b] Errors are 2σ based on counting statistics.

TABLE 2

DIRECT RADIATION LEVELS SYSTEMATICALLY
MEASURED ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)[a]	Measurement	Exposure Rate (μR/h)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
0	1 m	12	16	19	19	24	22	17	11
	Surface	13	19	22	28	26	24	19	13
50	1 m	13	13	26	26	30	26	22	22
	Surface	17	13	28	22	32	28	22	24
100	1 m	—[b]	11	16	28	22	28	18	10
	Surface	—	11	12	28	38	24	17	11
150	1 m	8	15	13	14	13	22	19	8
	Surface	10	16	13	16	11	24	22	8
200	1 m	—	17	30	28	34	48	120	24
	Surface	—	16	34	32	44	44	250	24
250	1 m	16	24	36	50	16	18	22	13
	Surface	17	26	50	100	17	17	22	14
300	1 m	—	—	26	24	16	19	24	12
	Surface	—	—	26	30	17	19	24	13
350	1 m	—	—	—	50	17	16	22	10
	Surface	—	—	—	56	18	30	22	11
400	1 m	11	32	36	22	30	26	22	19
	Surface	11	40	44	22	48	28	22	19

TABLE 2, cont.

DIRECT RADIATION LEVELS SYSTEMATICALLY
MEASURED ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Measurement	Exposure Rate (μR/h)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
450	1 m	10	11	13	34	20	11	9	8
	Surface	10	10	12	50	24	12	8	9
500	1 m	10	16	52	88	16	13	10	9
	Surface	10	13	54	172	17	13	9	9
550	1 m	9	19	40	58	11	10	10	10
	Surface	10	16	48	76	11	10	10	9
600	1 m	--	13	16	16	12	10	8	8
	Surface	--	12	17	17	11	10	8	10
650A	1 m	12	19	36	68	18	22	11	9
	Surface	12	19	36	88	19	22	11	10
650B	1 m	--	--	--	--	18	14	13	10
	Surface	--	--	--	--	19	19	15	10
700	1 m	10	11	13	24	68	52	24	11
	Surface	10	11	12	36	104	54	22	11
750	1 m	10	10	10	14	8	9	19	--
	Surface	10	10	11	14	9	10	24	--
800	1 m	9	10	12	19	8	9	--	--
	Surface	10	10	11	26	8	9	--	--

TABLE 2, cont.

DIRECT RADIATION LEVELS SYSTEMATICALLY
MEASURED ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Measurement	Exposure Rate (μR/h)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	15
800	1 m	9	10	12	19	8	9	--	--
	Surface	10	10	11	26	8	9	--	--
850	1 m	8	8	8	8	9	7	--	--
	Surface	9	8	9	8	10	9	--	--
900	1 m	10	11	19	26	19	9	8	8
	Surface	10	11	19	24	24	10	10	9
950	1 m	9	10	10	10	26	32	24	13
	Surface	8	11	10	11	38	38	28	14
1000	1 m	10	11	24	32	24	16	10	8
	Surface	10	13	22	48	24	18	9	8
1050	1 m	9	10	10	11	13	13	10	8
	Surface	8	12	11	11	13	14	10	8
1100	1 m	10	9	10	11	10	9	9	8
	Surface	10	9	9	10	14	10	10	9
1150	1 m	9	8	11	14	24	22	16	8
	Surface	8	8	10	16	28	17	13	9

TABLE 2, cont.

DIRECT RADIATION LEVELS SYSTEMATICALLY
MEASURED ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Measurement	Exposure Rate (μR/h)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
1200	1 m	--	8	9	22	8	8	--	--
	Surface	--	8	8	30	7	8	--	--
1250	1 m	12	13	16	19	40	26	22	17
	Surface	12	14	16	34	40	28	22	17
1300	1 m	16	19	24	92	96	68	64	22
	Surface	18	22	22	58	132	72	72	22
1350	1 m	16	32	44	40	48	42	24	22
	Surface	16	34	58	54	60	48	24	32
1400	1 m	13	19	19	19	11	12	12	12
	Surface	13	22	22	32	13	12	12	12
1450	1 m	13	16	17	28	18	13	13	12
	Surface	14	17	17	28	38	13	13	13
1500	1 m	16	44	58	38	28	34	30	16
	Surface	14	44	76	54	40	40	38	14
1550	1 m	24	26	28	24	22	24	24	17
	Surface	19	28	30	34	26	26	26	16

TABLE 2, cont.

DIRECT RADIATION LEVELS SYSTEMATICALLY
MEASURED ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Measurement	Exposure Rate (μR/h)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
1600	1 m	24	64	36	19	14	14	16	14
	Surface	32	76	28	22	18	14	16	14
1650	1 m	16	22	24	24	19	38	54	22
	Surface	17	24	26	30	28	42	68	28
1700	1 m	24	40	72	38	19	18	16	13
	Surface	26	44	80	48	28	19	16	13
1750	1 m	16	24	44	40	16	19	13	--
	Surface	16	26	52	64	18	24	13	--
1770	1 m	16	19	16	16	--	--	--	--
	Surface	16	24	14	19	--	--	--	--
1800	1 m	13	14	14	14	26	22	13	10
	Surface	12	14	16	17	40	30	13	12
1850	1 m	14	16	26	26	44	48	46	17
	Surface	14	16	30	36	44	54	52	16
1900	1 m	16	36	44	38	17	14	14	13
	Surface	16	40	48	60	24	15	13	13

TABLE 2, cont.

DIRECT RADIATION LEVELS SYSTEMATICALLY
MEASURED ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Measurement	Exposure Rate (μR/h)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
1950	1 m	16	38	44	34	50	40	19	14
	Surface	16	48	50	44	76	56	22	14
2000	1 m	13	15	16	24	44	46	44	32
	Surface	14	16	16	30	58	54	46	38
2050	1 m	14	16	28	32	40	46	30	19
	Surface	14	16	24	40	60	48	--	--
2100	1 m	15	34	42	48	--	--	--	--
	Surface	15	44	46	76	--	--	--	--

[a] Refer to Figures 4, 5, 6, and 7.
[b] Dashes indicate inaccessible location.

TABLE 3

DIRECT RADIATION LEVELS SYSTEMATICALLY
MEASURED ALONG THE BANKS OF THE DUPAGE RIVER

Upstream or Downstream Distance (m)[a]	Measurement	Exposure Rate (μR/h)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
Upstream:									
200	1 m	11	13	14	13	14	17	16	13
	Surface	12	13	16	14	16	22	17	13
150	1 m	13	10	11	10	19	22	17	14
	Surface	13	10	13	10	22	22	17	16
100	1 m	13	14	16	14	10	9	12	11
	Surface	13	16	16	17	10	9	12	11
50	1 m	14	14	16	18	14	12	10	10
	Surface	16	16	16	22	17	13	11	11
0	1 m	—[b]	—	—	—	13	13	13	8
	Surface	—	—	—	—	64	17	13	8
Downstream:									
50	1 m	16	30	52	42	16	11	11	12
	Surface	17	32	54	52	16	13	11	13
100	1 m	64	17	36	32	14	14	12	13
	Surface	68	17	40	40	16	14	13	14
150	1 m	16	24	64	104	14	12	11	12
	Surface	16	24	88	136	17	13	13	13
200	1 m	16	22	40	44	19	22	19	11
	Surface	13	22	48	64	22	26	22	13

[a] Refer to Figure 7.
[b] Inaccessible location.

TABLE 4

DIRECT RADIATION LEVELS AT LOCATIONS
IDENTIFIED BY THE WALKOVER SURFACE SCAN

Downstream Distance (m)[a]	Distance from East(E) or West (W) Bank (m)	Exposure Rate (μR/h)	
		Surface	1 Meter
25	1 W	720	170
197	15 E	820	210
205	12 E	410	130
315	8 E	33	35
325	5 E	63	49
401	7 W	210	84
410	1 E	185	76
465	1 E	84	43
585	2 E	210	155
620	0.5 E	170	80
760	1 W	18	18
765	1 W	145	31
765	3 E	190	105
775	1 W	105	61
790	2 E	125	63
889	2 E	70	31
1030	3 E	115	59
1280	1 W	105	74
1325	4 W	93	76
1340	1 W	240	110
1598	6 W	93	74
1665	5 E	135	120
1687	1 E	210	135
1715	1 W	190	140
1810	1 W	130	84
1870	1 E	130	85
1970	1 E	130	53
1975	4 W	105	88
1980	20 W	130	72
2006	1 E	210	95
2030	1 W	80	63

[a] Refer to Figures 8, 9, 10, and 11.

TABLE 5

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC BOREHOLES ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m) [a]	Depth (cm)	Total Thorium (pCi/g)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
50	Surface	—[b]	—	—	46.6	28.4	13.4	19.9	29.1
	15	—	—	—	121	38.9	12.2	24.0	9.14
	30	—	—	—	101	23.3	9.98	27.7	3.34
	45	—	—	—	—	—	11.1	—	—
	60	—	—	—	20.0	7.33	—	76.6	—
	70	—	—	—	13.6	7.89	—	—	—
	90	—	—	—	—	—	—	169	—
	110	—	—	—	—	—	—	226	—
	130	—	—	—	—	—	—	176	—
	150	—	—	—	—	—	—	46.8	—
	170	—	—	—	—	—	—	23.5	—
100	Surface	—	11.6	7.07	—	30.0	41.8	45.2	3.17
	15	—	28.5	9.26	—	14.8	38.8	32.9	5.38
	30	—	30.0	7.39	—	8.90	17.5	18.2	4.83
	60	—	—	8.99	—	5.65	6.38	7.22	5.49
	70	—	—	—	—	6.10	—	—	—
	75	—	—	—	—	—	—	8.10	—
	80	—	—	—	—	—	6.99	—	—
150	Surface	—	8.01	9.47	8.66	3.32	23.1	16.8	—
	15	—	12.9	25.6	14.6	2.50	42.4	24.6	—
	30	—	9.50	46.7	25.2	3.56	41.8	25.6	—
	50	—	—	—	—	5.25	—	—	—
	60	—	20.3	41.1	66.5	—	33.5	27.7	—
	80	—	—	—	—	—	—	35.8	—
	90	—	63.7	41.6	68.5	—	—	—	—
	100	—	—	—	51.4	—	—	—	—

TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Depth (cm)	Total Thorium (pCi/g)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
200	Surface	—	—	25.5	39.9	37.9	51.5	166	22.7
	15	—	—	44.6	51.1	44.2	40.4	261	37.4
	30	—	—	54.5	23.5	35.4	32.3	296	23.0
	60	—	—	24.1	17.3	13.0	15.0	193	9.68
	70	—	—	—	—	—	7.42	—	9.32
	80	—	—	—	11.1	—	—	—	—
	90	—	—	11.3	—	—	—	51.7	—
	100	—	—	—	—	—	—	25.4	—
250	Surface	—	—	—	49.5	8.01	5.63	21.1	9.20
	15	—	—	—	32.8	5.99	10.3	33.3	16.9
	30	—	—	—	14.7	2.34	15.1	44.3	24.8
	40	—	—	—	9.17	—	—	—	—
	45	—	—	—	—	2.34	—	—	—
	60	—	—	—	—	—	—	12.2	14.2
	70	—	—	—	—	—	3.22	—	—
	75	—	—	—	—	—	—	9.74	—
	80	—	—	—	—	—	—	—	9.14
300	Surface	—	—	—	25.7	5.16	22.4	19.6	5.02
	15	—	—	—	49.5	10.9	28.3	21.4	5.10
	30	—	—	—	66.1	12.0	20.2	21.0	6.13
	60	—	—	—	71.3	5.32	7.54	7.1	6.99
	75	—	—	—	—	—	3.89	—	6.38
	80	—	—	—	55.0	—	—	—	—
	90	—	—	—	—	2.59	—	—	—

TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC BOREHOLES ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Depth (cm)	Total Thorium (pCi/g)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
350	Surface	—	—	—	76.2	9.17	—	—	—
	15	—	—	—	116	8.63	—	—	—
	30	—	—	—	93.5	4.10	—	—	—
	50	—	—	—	34.4	2.68	—	—	—
400	Surface	4.65	55.1	32.8	11.8	74.2	—	—	—
	15	5.65	125	27.6	8.72	74.8	—	—	—
	30	7.10	163	24.2	5.13	29.8	—	—	—
	60	7.36	21.9	14.2	1.86	10.1	—	—	—
	80	9.95	—	8.04	—	—	—	—	—
	90	—	12.1	—	—	—	—	—	—
	100	—	10.0	—	—	—	—	—	—
450	Surface	4.20	3.51	3.05	64.7	18.4	5.05	—	—
	15	6.07	6.16	4.36	102	31.2	6.44	—	—
	30	6.33	7.89	3.74	79.7	28.4	5.30	—	—
	40	6.84	—	—	—	—	—	—	—
	45	—	—	3.32	30.2	—	—	—	—
	60	4.81	5.96	—	—	2.68	15.8	—	—
	70	—	—	—	—	—	18.6	—	—
	80	—	4.59	—	—	—	—	—	—
500	Surface	3.37	3.97	69.8	156	—	—	—	3.76
	15	4.86	4.97	111	251	—	—	—	4.75
	30	4.97	2.79	106	150	—	—	—	4.25
	60	6.16	1.41	14.5	14.5	—	—	—	3.74
	80	6.84	—	3.64	5.57	—	—	—	—
	90	—	—	—	—	—	—	—	4.28

TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Depth (cm)	Total Thorium (pCi/g)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
550	Surface	3.17	8.54	46.2	118	5.30	—	3.47	3.34
	15	3.84	11.1	3.65	222	4.20	—	—	—
	30	4.78	5.02	43.5	354	3.94	—	4.94	4.83
	50	—	1.27	—	—	—	—	—	—
	60	4.38	—	8.21	35.5	1.90	—	2.15	4.75
	70	4.49	—	—	—	2.04	—	—	—
	80	—	—	2.61	—	—	—	—	—
600	Surface	—	4.05	5.38	5.65	4.89	3.05	3.17	2.61
	15	—	4.41	5.54	8.57	—	—	—	—
	30	—	4.44	1.43	6.3	4.30	3.34	3.51	5.41
	60	—	4.86	2.70	2.45	4.28	1.77	1.45	6.47
	75	—	—	1.45	1.36	—	—	—	—
650 (W & Ea)	Surface	2.41	9.77	25.8	102	26.3	13.7	5.43	4.05
	15	4.20	11.6	34.5	173	25.7	—	—	—
	30	4.62	6.16	12.5	220				
	60	4.46	2.00	2.30	45.9	3.61	2.08	4.41	5.24
	70	—	—	—	29.7	2.45	—	2.33	—
	75	—	1.70	—	—	—	1.41	—	—
	90	4.30	—	—	—	—	—	—	—
650 (Eb)	Surface	—	—	—	—	26.3	7.51	7.45	2.96
	15	—	—	—	—	25.7	—	—	—
	30					8.33	11.7	5.71	6.47
	60	—	—	—	—	3.61	3.51	4.73	4.02
	70	—	—	—	—	2.45	—	2.54	3.34
700	Surface	1.36	2.68	2.91	38.4	133	47.1	8.15	3.05
	15	2.41	3.71	2.86	75.3	186	79.4	—	—

TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC BOREHOLES ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Depth (cm)	Total Thorium (pCi/g)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
	30	1.60	2.98	47.5	133	79.6	47.4	5.05	7.28
	45	--	--	0.57	--	--	--	--	--
	50	--	--	--	--	--			
	60	0.49	--	--	31.3	--	--	1.30	5.46
	70	0.60	--	--	--	--	--	--	--
	80	--	--	--	--	--	--	--	3.82
750	Surface	2.54	2.15	3.12	13.2	20.8	2.45	3.42	--
	15	4.46	4.54	4.15	18.1	12.5	--	5.90	--
	30	4.73	5.99	5.65	52.4	6.16	2.15	7.48	--
	40	--	--	--	--	5.32	--	--	--
	60	1.73	4.73	2.41	22.8	--	--	7.39	--
	70	0.73	3.10	--	5.88	--	--	5.99	--
800	Surface	3.29	3.03	6.61	25.5	4.38	3.42	--	--
	15	3.94	4.57	8.39	35.0	--	--	--	--
	30	6.61	5.65	10.1	35.3	9.62	4.62	--	--
	45	4.89	--	--	--	--	--	--	--
	60	--	4.97	1.06	10.4	3.42	2.98	--	--
	70	--	--	1.00	--	--	2.15	--	--
	75	--	5.54	--	--	2.23	--	--	--
850	Surface	3.07	4.53	2.30	3.51	7.57	3.64	--	--
	15	6.73	5.00	4.44	4.70	12.0	--	--	--
	30	6.58	6.49	6.16	4.97	22.0	5.60	--	--
	60	7.44	7.85	6.73	5.71	59.0	5.02	--	--
	70	--	--	--	--	--	2.79	--	--
	90	6.25	6.54	6.13	3.71	95.6	--	--	--
	110	--	--	--	--	26.6	--	--	--
	120	--	--	--	--	7.95	--	--	--

TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Depth (cm)	Total Thorium (pCi/g)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
	130	--	--	--	--	6.67	--	--	--
900	Surface	3.64	2.96	5.35	48.3	18.6	3.51	1.72	2.98
	15	--	--	--	83.4	40.9	4.81	--	--
	30	5.82	2.70	7.36	10.9	32.2	4.83	2.45	4.86
	60	6.44	2.59	1.34	26.2	5.13	4.92	3.82	5.08
	70	--	--	1.41	--	--	3.87	6.70	5.05
	90	6.50	--	--	--	--	--	--	--
950	Surface	4.10	4.41	3.97	4.23	44.3	30.2	19.3	5.27
	15	--	--	--	--	77.9	59.1	27.9	--
	30	9.86	7.51	6.76	6.27	41.6	24.6	12.7	2.93
	60	6.07	9.65	7.30	6.47	8.99	5.49	2.43	1.08
	70	--	--	--	5.63	--	3.76	--	--
	75	--	--	5.96	--	--	--	--	--
	90	--	9.44	--	--	--	--	--	--
1000	Surface	2.54	4.20	14.0	59.1	19.6	6.70	3.54	4.23
	15	--	--	17.7	78.2	--	--	--	--
	30	5.21	4.12	7.98	53.0	14.7	4.94	3.56	5.46
	50	--	--	--	--	--	--	1.54	---
	60	6.02	1.24	1.94	6.24	3.03	1.27	--	3.64
	65	--	--	1.68	--	--	--	--	--
	70	--	1.16	--	--	--	--	--	--
	75	--	--	--	--	--	--	--	3.15
	90	5.46	--	--	--	--	--	--	--
1050	Surface	2.82	2.56	4.10	4.62	14.1	6.70	2.47	2.15
	30	6.33	7.57	7.22	4.30	18.8	11.8	5.74	3.69
	60	7.07	7.74	8.21	8.10	3.39	3.00	4.15	2.32

TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Depth (cm)	Total Thorium (pCi/g)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
	70	—	—	7.95	6.81	—	—	—	—
	75	7.85	—	—	—	3.89	—	—	—
	80	—	7.01	—	—	—	—	—	—
1100	Surface	3.59	3.44	3.47	5.00	7.39	2.25	2.41	1.68
	30	7.36	8.96	4.36	5.41	5.02	1.94	4.78	3.32
	40	—	—	4.10	—	—	—	—	—
	60	8.69	9.05	—	4.38	1.54	0.94	3.37	1.32
	75	—	—	—	—	—	—	0.91	—
	90	7.63	—	—	—	—	—	—	1.04
1150	Surface	3.59	1.41	3.89	10.2	61.1	20.4	4.46	1.84
	30	7.10	3.99	3.07	6.38	78.9	13.3	4.70	3.59
	60	8.75	2.61	3.29	1.72	13.1	6.19	1.79	1.58
	70	10.2	—	—	1.06	—	5.49	—	—
	75	—	—	3.71	—	—	—	0.98	1.37
	80	—	—	—	—	9.29	—	—	—
1200	Surface	—	2.39	2.10	4.94	7.60	—	—	—
	30	—	5.32	2.93	6.56	11.1	—	—	—
	60	—	2.32	3.24	8.10	14.7	—	—	—
	75	—	—	4.59	7.80	—	—	—	—
	90	—	—	—	—	16.0	—	—	—
1250	Surface	4.75	2.98	2.71	11.2	2.23	—	—	—
	15	6.01	3.75	3.68	16.6	2.79	—	—	—
	30	4.84	3.91	4.36	30.3	2.36	—	—	—
	60	3.18	2.35	4.10	21.5	2.07	—	—	—

TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC BOREHOLES ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Depth (cm)	Total Thorium (pCi/g)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
1300	Surface	2.95	12.2	3.69	46.2	7.08	2.22	1.85	--
	15	5.03	7.42	3.77	77.4	9.35	3.09	3.04	--
	30	3.27	17.8	2.93	69.7	7.34	3.25	3.65	--
	60	1.46	80.3	1.58	9.07	2.08	2.13	3.49	--
	70	--	--	--	--	2.24	--	--	--
	90	1.45	9.88	1.38	--	--	--	3.39	--
1350	Surface	3.17	9.31	20.5	30.1	2.16	2.17	2.36	2.07
	15	3.71	12.9	27.3	38.0	2.37	2.58	2.92	2.78
	30	3.46	10.6	24.3	93.3	2.97	4.00	4.45	3.86
	60	1.64	3.51	4.86	52.3	2.75	4.50	5.76	4.47
	65	--	--	--	30.0	--	--	--	--
	80	--	--	3.37	--	--	--	--	--
	90	--	1.95	--	--	2.83	4.07	5.16	3.04
1400	Surface	2.13	5.30	5.24	8.88	1.88	2.24	2.16	--
	15	2.39	5.89	5.11	11.8	1.72	2.41	3.63	--
	30	1.34	5.65	4.20	11.0	1.42	3.81	4.74	--
	60	1.31	1.36	1.84	3.01	14.3	3.15	5.00	--
	70	--	1.38	--	--	--	--	--	--
	80	--	--	1.74	1.61	--	--	--	--
	90	--	--	--	--	2.46	2.37	2.57	--
1450	Surface	2.86	3.90	3.54	6.44	2.87	1.31	1.67	2.12
	15	2.87	4.55	3.89	7.93	2.63	1.60	1.77	2.95
	30	3.31	5.57	3.99	6.54	3.30	1.72	2.82	4.06
	60	2.03	2.30	1.09	1.69	1.69	1.39	3.20	4.96
	75	--	--	--	--	2.62	--	--	--
	80	--	--	--	1.15	--	--	--	--
	90	1.29	1.31	--	--	--	1.48	2.93	4.57

TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC BOREHOLES ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Depth (cm)	Total Thorium (pCi/g)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
1500	Surface	2.58	22.8	30.9	34.3	14.6	14.9	15.8	--
	15	2.84	33.1	42.2	50.9	21.3	17.7	19.4	--
	30	2.70	32.5	46.9	104	25.4	15.3	13.5	--
	60	1.31	5.83	5.16	39.6	4.70	4.57	2.65	--
	70	--	--	--	13.6	--	--	--	--
	75	--	2.69	3.45	--	--	--	--	--
	80	1.33	--	--	--	1.50	2.45	--	--
1550	Surface	6.98	7.36	6.91	10.9	8.31	10.5	7.52	1.72
	15	11.6	8.38	11.0	16.4	10.4	15.8	10.3	4.92
	30	9.63	7.63	12.6	14.9	7.96	16.9	13.4	3.30
	60	2.53	2.33	2.44	3.07	1.84	6.18	2.18	4.20
	75	--	--	--	--	--	--	1.48	--
	80	--	--	--	--	--	3.03	--	--
	90	2.14	1.89	--	--	--	--	--	4.43
1600	Surface	6.98	38.3	11.8	5.29	1.74	1.79	1.64	4.17
	15	11.6	56.3	16.2	7.75	2.16	2.19	4.91	1.77
	30	9.63	79.3	27.0	5.92	2.93	2.87	4.13	2.34
	60	2.53	7.92	48.9	3.35	3.04	3.20	4.17	3.25
	90	2.14	3.42	7.09	--	2.84	3.01	--	3.67
1650	Surface	3.47	5.35	5.89	8.29	5.26	18.0	29.1	3.38
	15	3.64	6.98	6.57	11.7	6.96	25.0	45.4	4.95
	30	4.17	5.82	5.2	10.1	8.31	42.9	86.1	3.64
	60	3.51	3.73	2.59	3.10	3.54	53.9	23.8	2.70
	80	--	--	--	--	--	50.5	--	--
	90	2.88	2.57	2.42	1.91	3.00	--	4.11	2.61

TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC BOREHOLES ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Depth (cm)	Total Thorium (pCi/g)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
1700	Surface	6.23	15.8	40.6	46.6	6.17	2.12	1.43	1.22
	15	7.62	22.8	64.1	21.4	8.52	3.13	2.33	1.97
	30	6.64	19.8	90.2	12.7	6.85	2.74	2.68	2.33
	60	2.80	4.04	19.9	3.7	5.21	2.78	2.82	2.86
	90	1.92	2.47	4.36	20.5	4.50	2.6	2.59	3.12
1750	Surface	3.11	5.75	20.2	43.7	3.71	5.15	1.27	—
	15	3.85	7.04	30.1	82.2	4.88	9.58	1.53	—
	30	3.51	5.36	21.0	140	3.72	21.7	1.93	—
	60	3.24	3.14	3.79	555	4.11	59.4	1.41	—
	90	3.03	2.92	2.50	357	3.15	9.26	2.06	—
1770	Surface	2.70	8.31	3.17	5.91	—	—	—	—
	15	3.76	9.75	3.67	8.79	—	—	—	—
	30	3.87	12.7	4.27	9.64	—	—	—	—
	60	3.44	20.6	5.71	9.62	—	—	—	—
	90	2.85	4.10	—	—	—	—	—	—
1800	Surface	2.47	2.14	3.09	4.55	14.6	8.40	2.75	2.18
	15	2.53	2.71	3.84	6.26	19.0	12.5	3.04	2.27
	30	3.22	2.78	5.52	5.98	31.1	17.2	3.42	2.78
	60	3.30	2.48	5.48	3.09	10.7	19.1	2.97	1.91
	75	3.59	—	5.92	2.94	7.59	—	—	—
	80	—	—	—	—	—	9.59	—	—
	90	—	—	—	—	—	—	—	1.88

TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC BOREHOLES ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Depth (cm)	Total Thorium (pCi/g)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
1850	Surface	2.45	2.33	8.82	9.21	41.9	34.5	21.7	3.34
	15	3.14	3.35	11.2	14.0	60.4	36.1	26.3	3.69
	30	3.78	2.96	9.21	15.6	107	40.2	18.1	3.19
	60	3.25	2.62	3.26	4.33	32.7	6.23	4.99	2.85
	80	—	—	—	—	10.0	—	—	—
	85	—	—	—	—	—	2.92	—	—
	90	—	1.82	3.18	2.69	—	—	—	2.47
1900	Surface	2.62	13.8	19.5	40.3	4.63	2.09	2.22	2.54
	15	3.46	19.7	30.4	58.4	4.96	2.76	2.42	3.19
	30	5.75	18.2	32.3	107	4.25	3.27	2.60	3.47
	60	3.82	5.49	5.80	62.7	4.26	3.49	3.34	2.98
	70	—	—	—	—	3.55	—	—	—
	85	—	—	—	—	—	3.16	3.60	—
	90	2.58	2.55	3.97	17.7	—	—	—	—
1950	Surface	2.35	20.0	20.6	14.0	60.5	17.1	5.44	2.25
	15	2.78	29.6	29.2	24.6	93.1	24.7	6.11	2.91
	30	3.81	31.2	24.5	23.8	154	22.9	5.02	3.99
	60	3.12	5.93	4.40	5.81	20.2	4.69	4.49	4.10
	75	—	—	—	—	11.0	—	—	—
	80	—	—	—	3.12	—	—	—	—
	90	2.33	3.12	2.75	—	—	2.39	2.85	3.73
2000	Surface	—	2.51	2.79	10.1	28.7	21.1	18.5	13.3
	15	3.44	3.17	3.00	15.2	42.5	29.4	26.6	17.5
	30	4.45	3.70	4.28	23.6	89.4	31.5	38.0	15.1

TABLE 5, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC BOREHOLES ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Depth (cm)	Total Thorium (pCi/g) Distance from West Bank (m) 25	10	5	1	Distance from East Bank (m) 1	5	10	25
	60	4.53	4.20	4.15	9.16	33.2	6.58	11.0	4.06
	65	—	—	3.65	—	—	—	—	—
	70	—	—	—	5.26	—	—	—	—
2050	Surface	2.67	3.05	6.08	31.1	44.6	21.2	14.1	4.14
	15	3.31	3.01	7.29	41.3	58.6	29.8	20.2	5.78
	30	4.37	3.47	5.89	94.8	59.0	28.1	16.3	7.13
	40	—	—	3.35	—	—	—	—	—
	60	3.72	3.39	—	139	8.44	4.68	4.50	2.07
	75	—	—	—	—	4.62	—	—	—
	80	—	—	—	—	—	3.40	—	—
	85	—	—	—	30.2	—	—	—	—
	90	2.51	2.13	—	—	—	—	3.71	—
2100	Surface	2.32	19.0	26.0	28.5	5.4	—	—	—
	15	3.21	29.3	41.5	43.2	7.46	—	—	—
	30	4.30	30.0	101	71.4	11.5	—	—	—
	60	3.92	5.91	17.3	27.3	7.40	—	—	—
	85	—	—	8.72	—	3.14	—	—	—
	90	2.09	2.70	—	9.15	—	—	—	—

[a] Refer to Figures 8, 9, 10, and 11.
[b] Dash indicates inaccessible location, impenetrable rocks, etc.

TABLE 6

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC BOREHOLES ALONG THE BANKS OF THE DUPAGE RIVER

Upstream or Downstream Distance (m)[a]	Depth (cm)	Total Thorium (pCi/g)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
Upstream:									
200	Surface	1.74	2.92	3.07	2.87	3.60	6.23	3.31	2.31
	15	2.87	3.50	3.79	3.87	4.71	0.71	4.55	2.92
	30	3.36	7.49	4.28	4.67	7.16	11.9	5.59	3.00
	60	2.71	2.65	2.86	3.52	9.61	7.11	2.88	2.78
	90	2.04	1.88	1.96	2.84	5.51	2.39	1.5	2.09
150	Surface	2.21	1.64	2.00	1.51	6.80	7.11	3.73	1.58
	15	2.33	2.33	2.61	2.5	11.2	12.6	6.33	1.98
	30	2.91	2.51	3.15	2.55	24.8	25.4	2.55	2.00
	60	3.48	3.21	3.37	2.79	13.4	5.84	2.48	1.72
	75	—[b]	—	—	—	—	—	—	—
	90	2.92	3.42	3.74	3.29	4.80	2.09	—	1.37
100	Surface	2.06	2.63	3.12	3.59	2.20	1.35	2.15	1.92
	15	2.34	3.23	4.00	4.42	2.34	1.45	2.87	3.13
	30	2.86	3.73	4.67	5.39	2.28	1.74	3.68	3.83
	60	3.06	3.18	3.15	3.84	1.50	1.87	1.84	3.91
	70	—	—	—	—	1.60	—	—	—
	80	—	—	—	—	—	2.19	—	3.00
	90	3.19	2.27	2.95	2.55	—	—	—	—
50	Surface	1.97	2.25	2.50	5.00	3.46	1.84	1.55	1.83
	15	2.53	2.85	2.96	7.55	4.62	2.18	1.92	1.84
	30	3.32	3.28	3.70	11.9	7.61	2.80	1.97	2.05
	40	—	—	—	—	—	—	—	—
	60	2.84	3.34	3.04	4.80	3.91	1.60	1.65	—

TABLE 6, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF THE DUPAGE RIVER

Upstream or Downstream Distance (m)	Depth (cm)	Total Thorium (pCi/g)							
		Distance from West Bank (m)				Distance from East Bank (m)			
		25	10	5	1	1	5	10	25
Upstream cont.:									
50	80	1.69	--	--	--	--	--	--	--
	85	--	--	--	1.95	--	--	--	--
	90	--	2.72	3.84	--	2.08	1.55	1.42	--
0	Surface	--	--	--	--	2.03	2.56	2.33	2.68
	15	--	--	--	--	2.42	2.99	2.86	3.80
	30	--	--	--	--	5.19	2.99	4.87	3.00
	60	--	--	--	--	2.41	3.69	3.05	2.42
	80	--	--	--	--	--	--	--	1.78
	90	--	--	--	--	--	3.53	1.74	--
Downstream:									
50	Surface	33.8	33.0	7.51	2.85	2.71	1.66	1.64	2.01
	15	47.1	48.9	9.35	3.34	3.71	2.23	1.53	3.13
	30	91.8	93.8	7.89	3.67	6.47	2.85	1.52	3.71
	60	249	133	4.16	3.83	3.42	1.71	1.83	2.89
	70	--	--	--	--	--	--	--	2.41
	85	85.3	--	--	--	--	--	--	--
	90	--	15.0	3.31	4.02	1.71	1.50	--	--
100	Surface	2.32	60.8	17.3	14.5	2.66	1.86	1.87	2.19
	15	2.96	14.4	22.4	18.7	3.51	1.84	2.20	[illegible]5
	30	3.69	49.7	33.9	31.4	2.71	2.27	2.89	3.21
	60	4.23	18.3	111	55.1	1.54	1.44	2.31	3.30
	80	--	--	--	--	--	--	1.45	2.12

TABLE 6, cont.

TOTAL THORIUM CONCENTRATIONS IN SYSTEMATIC
BOREHOLES ALONG THE BANKS OF THE DUPAGE RIVER

Upstream or Downstream Distance (m)	Depth (cm)	Total Thorium (pCi/g) Distance from West Bank (m) 25	10	5	1	Distance from East Bank (m) 1	5	10	25
Downstream cont.:									
100	85	--	2.32	29.7	--	--	--	--	--
	90	2.82	--	--	52.6	--	1.65	--	--
150	Surface	2.68	6.15	17.0	28.1	4.61	7.73	3.81	2.49
	15	2.75	7.56	23.1	63.3	3.47	2.61	2.98	2.55
	30	3.39	7.89	17.3	96.7	3.32	3.43	3.90	3.59
	60	3.86	2.52	7.82	12.6	1.79	3.65	4.29	3.96
	85	3.83	--	--	3.27	--	--	3.06	--
	90	--	--	4.01	--	--	3.34	--	3.09
200	Surface	2.39	4.57	14.7	28.1	4.61	7.73	3.81	2.49
	15	2.91	5.49	24.1	41.8	7.13	12.5	6.08	2.75
	30	3.68	5.42	37.3	90.7	11.0	20.3	8.36	3.55
	60	4.47	4.42	6.87	34.4	13.8	11.4	4.41	4.10
	70	--	--	--	--	--	--	--	3.03
	80	--	--	--	--	--	3.37	--	--
	85	4.17	--	--	--	2.51	--	2.20	--
	90	--	3.89	2.73	3.91	--	--	--	--

[a] Refer to Figure 11.
[b] Dash indicates inaccessible location, impenetrable rocks, etc.

TABLE 7

TOTAL THORIUM CONCENTRATIONS IN BIASED BOREHOLES
ALONG THE BANKS OF KRESS CREEK

Downstream Distance[a] (m)	Distance from East (E) or West (W) Bank (m)	Depth (cm)	Total Thorium (Th-232 & Th-228) (pCi/g)
25	1W	Surface	428
		15	432
		30	364
		60	158
		70	126
197	15E	Surface	489
		15	428
		30	155
		60	26.3
		90	27.3
205	12E	Surface	303
		15	417
		30	372
		60	77.7
		90	18.3
315	8E	Surface	31.5
		15	32.5
		30	37.4
		60	23.9
		80	12.4
325	5E	Surface	171
		15	232
		30	109
		60	19.2
		90	16.9
401	7W	Surface	136
		15	140
		30	56.9
		45	20.2
410	1E	Surface	131
		15	179
		30	196
		60	72.7
		70	61.6

TABLE 7, cont.

TOTAL THORIUM CONCENTRATIONS IN BIASED BOREHOLES
ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Distance from East (E) or West (W) Bank (m)	Depth (cm)	Total Thorium (Th-232 & Th-228) (pCi/g)
465	1E	Surface	92.8
		15	91.8
		30	47.8
		60	7.13
560	0E	Surface	135
		15	243
		30	221
		60	33.2
585	2E	Surface	138
		15	247
		25	351
		30	322
		60	103
620	0.5E	Surface	123
		15	201
		30	121
		60	25.0
		70	12.2
655	2W	Surface	165
		15	259
		30	216
		60	44.9
665	2W	Surface	135
		15	224
		30	205
		60	26.8
760	1W	Surface	5.24
		15	8.30
		30	16.7
		60	3.87
		70	1.54
765	3E	Surface	150
		15	232
		30	395
		60	200
		90	49.0

TABLE 7, cont.

TOTAL THORIUM CONCENTRATIONS IN BIASED BOREHOLES
ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Distance from East (E) or West (W) Bank (m)	Depth (cm)	Total Thorium (Th-232 & Th-228) (pCi/g)
765	1W	Surface	64.9
		15	120
		30	135
		50	106
775	1W	Surface	68.1
		15	106
		30	101
		60	20.0
790	2E	Surface	119
		15	140
		30	53.6
		60	20.0
		70	13.8
889	2E	Surface	53.9
		15	101
		30	204
		60	75.5
935	4W	Surface	95.9
		15	141
		30	76.5
		60	11.0
		70	7.42
989	1W	Surface	94.9
		15	191
		30	218
		60	67.3
1030	3E	Surface	106
		30	285
		60	66.5
		70	39.8
1280	1W	Surface	41.1
		15	42.9
		30	18.5
		60	4.22

TABLE 7, cont.

TOTAL THORIUM CONCENTRATIONS IN BIASED BOREHOLES
ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Distance from East (E) or West (W) Bank (m)	Depth (cm)	Total Thorium (Th-232 & Th-228) (pCi/g)
1282	1W	Surface	30.3
		15	37.6
		30	45.3
		60	3.13
		90	2.30
1325	4W	Surface	15.5
		15	19.7
		30	13.1
		60	3.64
1340	1W	Surface	38.0
		15	64.2
		30	128
		60	47.0
1598	6W	Surface	80.4
		15	122
		30	299
		60	117
		90	7.00
1665	5E	Surface	83.3
		15	145
		30	109
		60	76.8
		90	12.3
1687	1E	Surface	75.8
		15	107
		30	181
		60	64.3
		90	17.5
1715	1W	Surface	107
		15	151
		30	301
		60	37.2
		90	6.67

TABLE 7, cont.

TOTAL THORIUM CONCENTRATIONS IN BIASED BOREHOLES
ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Distance from East (E) or West (W) Bank (m)	Depth (cm)	Total Thorium (Th-232 & Th-228) (pCi/g)
1810	1W	Surface	53.3
		15	49.4
		30	30.6
		60	4.49
1870	1E	Surface	53.9
		15	87.3
		30	80.9
		60	10.1
		70	6.35
1880	1W	Surface	27.0
		15	34.0
		30	9.40
		60	9.11
		75	6.89
1915	1.5W	Surface	44.1
		15	58.3
		30	54.5
		60	13.0
1970	1E	Surface	46.3
		15	63.2
		30	54.7
		60	12.7
		65	10.6
1975	4W	Surface	51.4
		15	81.5
		30	148
		60	25.2
		80	6.35
1980	20W	Surface	89.8
		15	137
		30	253
		60	117
		80	45.0

TABLE 7, cont.

TOTAL THORIUM CONCENTRATIONS IN BIASED BOREHOLES
ALONG THE BANKS OF KRESS CREEK

Downstream Distance (m)	Distance from East (E) or West (W) Bank (m)	Depth (cm)	Total Thorium (Th-232 & Th-228) (pCi/g)
2006	1E	Surface	109
		15	138
		30	205
		60	103
		75	54.3
2030	1W	Surface	46.7
		15	63.7
		30	33.7
		60	3.86
		65	3.57

[a] Refer to Figures 8, 9, 10, and 11.

TABLE 8

RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES
FROM KRESS CREEK

Downstream Distance (m)[a]	Depth (cm)	Radionuclide Concentration (pCi/g)			
		Th-232	Th-228	Total Thorium (Th-232 & Th-228)	Ra-226
0	0-10	27.9 ± 1.5[b]	30.0 ± 1.4	57.9	2.31 ± 0.58
	10-20	26.2 ± 1.4	24.8 ± 1.3	51.0	1.69 ± 0.50
	20-30	6.51 ± 0.68	6.12 ± 0.64	12.6	1.16 ± 0.37
	30-40	24.0 ± 1.3	25.8 ± 1.2	49.8	1.99 ± 0.50
100	0-10	4.09 ± 1.11	4.08 ± 1.33	8.17	7.46 ± 0.77
	10-20	0.99 ± 0.62	1.49 ± 0.62	2.48	0.71 ± 0.36
	20-30	0.96 ± 1.26	0.51 ± 0.44	1.47	1.45 ± 0.69
200	0-10	29.4 ± 4.5	29.0 ± 3.7	58.4	2.98 ± 1.70
	10-20	23.3 ± 4.9	22.7 ± 3.6	46.0	1.84 ± 1.39
	20-30	7.69 ± 1.86	6.54 ± 2.05	14.23	1.58 ± 0.96
	30-40	2.95 ± 1.40	2.35 ± 1.31	5.30	1.80 ± 0.81
	40-50	0.76 ± 1.24	1.08 ± 0.74	1.84	1.02 ± 0.50
	50-60	1.64 ± 0.95	0.65 ± 0.92	2.29	1.39 ± 0.73
300	0-10	4.38 ± 1.81	3.21 ± 1.79	7.59	1.64 ± 0.94
	10-20	1.01 ± 0.67	0.83 ± 0.46	1.84	0.64 ± 0.23
	20-30	0.58 ± 0.31	0.65 ± 0.55	1.23	1.31 ± 0.32
400	0-10	1.29 ± 0.93	1.40 ± 1.05	2.69	0.80 ± 0.87
	10-20	<0.33	0.75 ± 0.74	<1.08	1.12 ± 5.73
	20-30	<0.23	0.15 ± 0.23	<0.38	0.59 ± 0.40
500	0-10	2.33 ± 0.74	2.55 ± 0.75	4.88	0.89 ± 0.51
	10-20	24.2 ± 2.3	19.0 ± 2.0	43.2	1.83 ± 0.83
	20-30	<.33	0.57 ± 0.47	<0.90	0.76 ± 0.54

TABLE 8, cont.

RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES
FROM KRESS CREEK

Downstream Distance (m)	Depth (cm)	Radionuclide Concentration (pCi/g)			
		Th-232	Th-228	Total Thorium (Th-232 & Th-228)	Ra-226
600	0-10	44.4 ± 3.5	39.6 ± 3.1	84.0	1.45 ± 1.21
	10-20	9.96 ± 1.52	8.13 ± 1.50	18.1	0.70 ± 0.61
700	0-10	1.56 ± 0.71	1.47 ± 0.55	3.03	0.68 ± 0.50
	10-20	0.53 ± 0.68	0.51 ± 0.34	1.04	0.46 ± 0.35
	20-30	<1.81	1.59 ± 0.64	<3.40	0.61 ± 0.27
800	0-10	12.2 ± 2.5	13.8 ± 1.9	26.0	1.43 ± 0.80
	10-20	11.1 ± 1.7	9.99 ± 1.14	21.1	1.16 ± 0.53
	20-30	1.80 ± 0.77	2.83 ± 0.81	4.63	0.87 ± 0.49
900	0-10	1.60 ± 0.63	1.49 ± 0.57	3.09	1.09 ± 0.60
	10-20	0.21 ± 0.30	0.84 ± 0.49	1.05	0.67 ± 0.28
	20-30	0.57 ± 0.41	0.44 ± 0.45	1.01	0.59 ± 0.24
1000	0-10	1.18 ± 1.36	1.78 ± 1.14	2.96	2.08 ± 0.86
	10-20	5.29 ± 1.69	4.38 ± 1.54	9.67	1.68 ± 1.50
	20-30	1.16 ± 0.61	1.29 ± 0.41	2.45	0.65 ± 0.34
1100	0-10	6.38 ± 1.54	6.18 ± 1.40	12.6	1.06 ± 0.54
	10-20	1.33 ± 0.56	1.15 ± 0.47	2.48	0.90 ± 0.30
	20-30	0.87 ± 0.36	0.52 ± 0.43	1.39	0.64 ± 0.29
1250	0-10	21.5 ± 2.1	18.1 ± 1.8	39.6	1.34 ± 0.76
	10-20	11.9 ± 1.9	10.0 ± 1.7	21.9	1.41 ± 0.86
	20-30	2.29 ± 0.91	2.19 ± 0.72	4.48	0.68 ± 0.38

TABLE 8, cont.

RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES
FROM KRESS CREEK

Downstream Distance (m)	Depth (cm)	Radionuclide Concentration (pCi/g)			
		Th-232	Th-228	Total Thorium (Th-232 & Th-228)	Ra-226
1350	0-10	5.96 ± 1.42	5.04 ± 0.88	11.0	0.56 ± 0.55
	10-20	5.32 ± 1.43	4.29 ± 1.29	9.61	1.28 ± 0.78
	20-30	5.09 ± 3.18	4.71 ± 1.52	9.80	0.75 ± 1.75
1450	0-10	<0.45	0.95 ± 0.37	<1.40	0.84 ± 0.72
	10-20	0.85 ± 0.91	1.01 ± 0.55	1.86	1.73 ± 0.64
	20-30	0.46 ± 0.68	0.54 ± 0.64	1.00	1.13 ± 0.61
1650	0-10	3.77 ± 0.76	3.27 ± 0.6	7.04	1.05 ± 0.29
	10-20	0.60 ± 0.34	0.27 ± 0.34	0.87	0.62 ± 0.21
	20-30	0.65 ± 0.52	1.48 ± 0.48	2.13	0.64 ± 0.38
1750	0-10	2.39 ± 0.87	1.91 ± 0.54	4.30	0.89 ± 0.55
	10-20	1.28 ± 0.57	0.66 ± 0.49	1.94	1.17 ± 0.37
	20-30	1.00 ± 0.49	0.98 ± 0.52	1.98	0.94 ± 0.50
1850	0-10	66.0 ± 4.2	49.8 ± 3.7	116	2.60 ± 1.44
	10-20	71.7 ± 4.2	59.1 ± 3.8	131	2.66 ± 1.69
	20-30	4.13 ± 0.94	3.06 ± 0.62	7.19	0.77 ± 0.32
1950	0-10	0.64 ± 0.40	0.67 ± 0.48	1.31	0.39 ± 0.27
	10-20	0.43 ± 0.42	<0.07	<0.50	0.70 ± 0.44
	20-30	0.44 ± 0.65	0.33 ± 0.56	0.77	0.37 ± 0.25
2050	0-10	4.40 ± 1.04	3.69 ± 0.91	8.09	0.92 ± 0.61
	10-20	1.13 ± 0.83	1.17 ± 0.51	2.30	0.75 ± 0.36
	20-30	0.69 ± 0.46	0.50 ± 0.62	1.19	0.53 ± 0.28

[a] Refer to Figure 12.
[b] Errors are 2σ based on counting statistics.

TABLE 9

RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES
FROM THE DUPAGE RIVER

Upstream or Downstream Distance (m)[a]	Depth (cm)	Radionuclide Concentrations (pCi/g)			
		Th-232	Th-228	Total Thorium (Th-232 & Th-228)	Ra-226
Upstream:					
200	0-10	0.51 ± 0.31[b]	0.70 ± 0.33	1.21	0.57 ± 0.36
	10-20	1.06 ± 0.50	1.18 ± 0.43	2.24	0.40 ± 0.26
	20-30	<0.18	<0.16	<0.34	0.54 ± 0.27
100	0-10	<0.45	0.70 ± 0.47	<1.15	<0.39
	10-20	0.58 ± 0.49	0.40 ± 0.42	0.98	0.63 ± 0.36
	20-30	<0.31	1.16 ± 0.20	<1.47	0.72 ± 0.37
0	0-10	1.23 ± 0.50	0.71 ± 0.43	1.94	0.50 ± 0.28
	10-20	0.71 ± 0.49	0.53 ± 0.42	1.24	0.83 ± 0.29
	20-30	0.58 ± 0.36	0.81 ± 0.35	1.39	0.36 ± 0.24
Downstream:					
100	0-10	15.2 ± 1.9	12.0 ± 1.60	27.2	1.39 ± 0.84
	10-20	0.38 ± 0.37	0.65 ± 0.29	1.03	0.67 ± 0.32
	20-30	0.41 ± 0.61	<0.08	<0.49	0.29 ± 0.51
200	0-10	1.83 ± 0.94	2.84 ± 0.82	4.67	0.48 ± 0.27
	10-20	1.22 ± 0.46	1.07 ± 0.35	1.29	0.57 ± 0.26
	20-30	0.33 ± 0.36	0.26 ± 0.42	0.59	0.38 ± 0.18

[a] Refer to Figure 12.
[b] Errors are 2σ based on counting statistics.

TABLE 10

RADIONUCLIDE CONCENTRATIONS IN WELL WATER SAMPLES

Sample Location[a]	Radionuclide Concentration (pCi/l)	
	Gross Alpha	Gross Beta
1	<1.42	<2.25
2	<1.35	4.29 ± 3.37[b]
3	<1.37	2.58 ± 3.29
4	<1.44	<2.26
5	1.48 ± 2.13	4.98 ± 3.41
6	<1.33	4.62 ± 3.38

[a] All samples were collected from Edgewood Walk. Locations are not identified on a figure.

[b] Errors are 2σ based on counting statistics.

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APPENDIX A

GLOSSARY OF TERMS

Glossary

Activation: The process of making a material radioactive by bombardment with neutrons, protons, or other nuclear particles.

Activity: Radioactivity, the spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the nuclei of an unstable nuclide. As a result of this emission, the radioactive material is converted (or decays) into a different nuclide (daughter), which may or may not be radioactive. Ultimately, as a result of one or more stages of radioactive decay, a stable (nonradioactive) nuclide is formed.

Aerial survey: A search for sources of radiation by means of sensitive instruments mounted in a helicopter or airplane. Generally, the instrumentation records the intensity, location, and spectral analysis of the radiation.

Alpha particle: A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons bound together, and hence is identical with the nucleus of a helium atom. It is the least penetrating of the three common types of radiation (alpha, beta, gamma) emitted by radioactive material, and can be stopped by a sheet of paper.

Background radiation: The radiation in man's natural environment, including cosmic rays and radiation from the naturally radioactive elements. It is also called natural radiation. The term may also mean radiation that is unrelated to a specific experiment. Levels vary, depending on location.

Baseline concentration: The concentration of a given substance typically encountered in the area under consideration, i.e. the normal or naturally occurring level.

Beta particle: An elementary particle emitted from a nucleus during radioactive decay, with a single electrical charge and a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron.

Contamination: Undesired radioactive materials that have been deposited on surfaces, are internally ingrained into structures or equipment, or that have been mixed with another material.

Curie: A special unit of activity. One curie equals 3.7×10^{10} nuclear disintegrations per second. Several fractions of the curie are in common usage:

-- Millicurie - one thousandth of a curie. Abbreviated as mCi.

-- Microcurie - one millionth of a curie. Abbreviated as μCi.

-- Nanocurie - one billionth of a curie. Abbreviated as nCi.

-- Picocurie - one trillionth of a curie. Abbreviated as pCi.

Daughter: The product of radioactive decay of a nuclide. (also see Parent).

Decay, radioactive: The spontaneous transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide. The process results in a decrease, with time, of the number of original radioactive nuclides in a sample. It involves the emission from the nucleus of alpha particles, beta particles, or gamma rays; or the nuclear capture or ejection of orbital electrons; or fission. Also called radioactive disintegration.

Decontamination: Those activities employed to reduce the levels of contamination.

Dose: A measure of the quantity of radiation absorbed in a unit mass of a medium. The unit of dose is the rad.

Dose rate: The radiation dose delivered per unit time and measured, for example, in rads per hours.

Exposure: A measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of the air in the volume element. The special unit of exposure is the roentgen.

Exposure rate: The radiation exposure per unit time. Measured, for example, in roentgens per hour.

Gamma radiation: High-energy, short-wave length electromagnetic radiation of nuclear origin (radioactive decay). Gamma rays are

the most penetrating of the three common types of radiation.

Half-life: The time in which half the atoms of a particular radioactive sustance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billions of years.

Microrad (μrad): A submultiple of the rad, equal to one-millionth of a rad. (see rad).

Microroentgen (μR): A submultiple of the roentgen, equal to one-millionth of a roentgen. (see roentgen).

Millirem (mrem): A submultiple of the rem, equal to one-thousandth of a rem. (see rem).

Natural uranium: Uranium as found in nature, containing 0.7 percent of uranium-235, 99.3 percent of uranium-238. It is also called normal uranium.

Natural thorium: Thorium as found in nature. Natural thorium contains equal activity level of thorium-232 and thorium-228.

Parent: A radionuclide which disintegrates or decays to produce another nuclide which is also radioactive. This second radionuclide is known as the daughter product.

Picocurie (pCi): One-trillionth (10^{-12}) of a curie.

Rad: The unit of absorbed dose. The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. One rad equals 0.01 joules/kilogram of absorbing material.

Radiation: Energetic nuclear particles including neutrons, alpha particles, beta particles, x-rays, and gamma rays (nuclear physics). Also includes electromagnetic waves (radiation) of any origin.

Radioactivity: The property of certain nuclides of spontaneously emitting particles, or gamma radiation. Often shortened to "activity."

Radionuclide: A general term applicable to any radioactive form of the elements, a radioactive nuclide.

Radium (Ra): A radioactive metallic element with atomic number 88. As found in nature, the most common isotope has an atomic weight of 226. It occurs in minute quantities associated with uranium in pitchblende, carnotite, and other minerals; the uranium decays to radium in a series

of alpha and beta emissions. By virtue of being an alpha- and gamma-emitter, radium is used as a source of illuminescence and as a radiation source in medicine and radiography. The isotope of radium with an atomic weight of 228 is found in the thorium decay series.

Radon (Rn): The heaviest element of the noble gases, produced as a gaseous emanation from the radioactive decay of radium. Its atomic number is 86. All isotopes are radioactive. Rn-222 is an isotope with a half-life of 3.82 days.

Rare earths: A group of 15 chemically similar metallic elements, including elements 57 through 71 on the Periodic Table of the Elements, also known as the Lanthanide Series.

Rem: The unit of ionizing radiation that produces the same biological damage to man as a unit of absorbed dose (1 roentgen) of high voltage x-rays.

Roentgen (R): A unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce ions carrying one electrostatic unit of electrical charge (either positive or negative) in one cubic centimeter of dry air under standard conditions.

Secular Equilibrium: The state which prevails when the rate of formation of a radioactive material equals the material's rate of decay. Although, by theory, this condition is never completely achieved, it is essentially established in the thorium decay series as it occurs in nature.

Survey: An evaluation of the radiation hazards incidental to the production, use, or existence of radioactive materials or other sources of radiation under a specific set of conditions.

Thorium (Th): A naturally occurring radioactive element with atomic number 90 and, as found in nature, an atomic weight of approximately 232.

Thorium series: The series (sequence) of nuclides resulting from the radioactive decay of thorium-232. Many man-made nuclides decay into this sequence. The end product of the sequence in nature is lead-208.

Uranium (U): A radioactive element with the atomic number 92 and, as found in natural ores, an average atomic weight of approximately 238. The two principal natural isotopes are uranium-235 (0.7 percent of natual uranium) and uranium-238 (99.3 percent of natural uranium). Natural uranium also includes a minute amount of uranium-234.

Uranium series: The series (sequence) of nuclides resulting from the radioactive decay of uranium-238. The end product of the series is lead-206.

EXPLANATION OF SYMBOLS AND UNITS

Symbols	Unit	English Equivalents
cm	centimeter (x 10^{-2} meters)	0.394 inches
g	gram	0.032 ounces
h	hour	-----
kg	kilogram (x 10^{3} grams)	2.2 pounds
km	kilometer (x 10^{3} meters)	0.622 miles
l	liter	0.264 gallons
m	meter	3.28 feet
ml	milliliter (x 10^{-3} liters)	0.061 cubic in.
mrem	millirem (x 10^{-3} rem)	-----
pCi	picocurie (x 10^{-12} curies)	-----
Ra	Radium	-----
U	Uranium	-----
Th	Thorium	-----
µCi	microcurie (x 10^{-6} curies)	-----
µrad	microrad (x 10^{-6} rads)	-----
µR	microroentgen (x 10^{-6} roentgens)	-----

APPENDIX B

THORIUM AND URANIUM DECAY TABLES

Thorium Decay Series

Parent	Half-Life	Major Decay Products	Daughter
Thorium-232	14 billion years	alpha	Radium-228
Radium-228	5.8 years	beta	Actinium-228
Actinium-228	6.13 hours	beta, gamma	Thorium-228
Thorium-228	1.91 years	alpha	Radium-224
Radium-224	3.64 days	alpha	Radon-220
Radon-220	55 seconds	alpha	Polonium-216
Polonium-216	0.15 seconds	alpha	Lead-212
Lead-212	10.6 hours	beta, gamma	Bismuth-212
Bismuth-212	60.6 minutes	alpha (1/3)* beta (2/3)*	Thallium-208 Polonium-212
Thallium-208	3.1 minutes	beta, gamma	Lead-208
Polonium-212	0.0000003 seconds	alpha	Lead-208
Lead-208	stable	none	none

* Two decay modes are possible for Bismuth-212.

Uranium Decay Series

Parent	Half-Life	Major Decay Products	Daughter
Uranium-238	4.5 billion years	alpha	Thorium-234
Thorium-234	24 days	beta, gamma	Protactinium-234
Protactinium-234	1.2 minutes	beta, gamma	Uranium-234
Uranium-234	250,000 years	alpha	Thorium-230
Thorium-230	80,000 years	alpha	Radium-226
Radium-226	1,600 years	alpha	Radon-222
Radon-222	3.8 days	alpha	Polonium-218
Polonium-218	3 minutes	alpha	Lead-214
Lead-214	27 minutes	beta, gamma	Bismuth-214
Bismuth-214	20 minutes	beta, gamma	Polonium-214
Polonium-214	0.0002 seconds	alpha	Lead-210
Lead-210	22 years	beta	Bismuth-210
Bismuth-210	5 days	beta	Polonium-210
Polonium-210	140 days	alpha	Lead-206
Lead-206	stable	none	none

APPENDIX C

MAJOR ANALYTICAL EQUIPMENT

APPENDIX C

Major Analytical Equipment

The display or description of a specific product is not to be construed as an endorsement of that product or its manufacturer by the authors or their employer.

A. Direct Radiation Measurements

Eberline "RASCAL"
Portable Ratemeter
Model PRS-1
Beta-Gamma "Pancake" Probe, Model HP-260
(Eberline Instrument, Santa Fe, NM)

Eberline PRM-6
Portable Ratemeter
Scintillation Probe, Model 489-55
(Victoreen, Inc., Cleveland, OH)

Pressurized Ionization Chamber (PIC)
Model RSS-111
(Reuter Stokes, Cleveland, OH)

Ludlum Ratemeter-Scaler
Model 2200
(Ludlum Measurements Inc., Sweetwater, TX)

B. Laboratory Analysis

Ge(Li) Detector
Model LGCC2220SD, 23% efficiency
(Princeton Gamma-Tech, Princeton, NJ)

Used in conjunction with:
Lead Shield, SPG-16
(Applied Physical Technology, Smyrna, GA)

High-Purity Germanium Detector
Model GMX-23195-S, 23% efficiency
(EG&G ORTEC, Oak Ridge, TN)

Used in conjunction with:
Lead Shield, G-16
(Gamma Products Inc., Palos Hills, IL)

Pulse Height Analyzer, ND680
Model 88-0629
(Nuclear Data, Inc., Schaumburg, IL)

Low Background Alpha-Beta Counter
Model LB5100-2080
(Tennelec, Inc., Oak Ridge, TN)

25 mg Californium-252 Source with Flexo-Rabbit
Pneumatic Transfer System
(Reactor Experiments, Inc., San Carlos, CA)

Multichannel Analyzer
Model TN-7200
(Tracor Northern, Middleton, WI)

APPENDIX D

ANALYTICAL PROCEDURES

APPENDIX D

Analytical Procedures

Gamma Scintillation Measurements

Walkover surface scans and measurements of gamma exposure rates were performed using an Eberline PRM-6 portable ratemeter with a Victoreen Model 489-55 gamma scintillation probe containing a 3.2 cm x 3.8 cm NaI(Tl) scintillation crystal. A graph of count rate (cpm) vs. exposure rate (μR/h) was developed by comparing the response of the scintillation detector with that of a Reuter Stokes Model RSS-111 pressurized ionization chamber at several locations along Kress Creek. This plot was used to convert the meter readings to exposure rates.

Beta-Gamma Dose Rate Measurements

Measurements were performed using Eberline "Rascal" Model PRS-1 portable ratemeters with Model HP-260 G-M probes. Dose rates (μrad/h) were determined by comparison of the response of a Victoreen Model 440 ionization chamber survey meter to that of the G-M probes for a natural thorium source.

Soil and Sediment Sample Analysis

Soil samples were sifted to remove rocks (the fraction removed constituted <5% of the total), dried at 120° C, finely ground, mixed, and a portion placed in a 0.5 liter Marinelli beaker. The quantity placed in each beaker was chosen to reproduce the calibrated counting geometry and typically ranged from 500 to 800 g of soil. Sediment samples were treated identically except that they were placed in 0.2 liter jars and typically weighed 100 g. Net weights were determined and the samples counted using either a Ge(Li) detector (Princeton Gamma Tech) or a high purity germanium detector (EG&G ORTEC) coupled to a Nuclear Data model ND 680 pulse height analyzer. The following energy peaks were used for determination of the radionuclides of concern:

Th-232 - 0.911 MeV from Ac-228 (secular equilibrium assumed)
Th-228 - 0.583 MeV from Tl-208 " " "
Ra-226 - 0.609 MeV from Bi-214 (corrected for equilibrium conditions)
U-238 - 1.001 MeV from Pa-234m " " "
or 0.093 MeV from Th-234 " " "

Peak identification and concentration calculations were provided by computer analyses.

Selected samples for which gamma spectrometry indicated detectable levels of uranium were subsequently analyzed for U-238 by neutron activation. Approximately 15-20 g of soil were irradiated for 15 minutes in a neutron flux of 10^8 n/cm^2/sec. After a one minute wait time, the U-239 peak (74.6 keV) was counted for 10 minutes and the U-238 concentration calculated.

Borehole Logging and Calculation of Thorium Concentrations

Borehole gamma radiation measurements were made using a Victoreen Model 489-55 gamma scintillation probe connected to a Ludlum Model 2200 portable scaler. The scintillation probe was shielded by a 1.25 cm thick lead shield with four 2.5 cm x 7 mm holes evenly spaced around the shield in the region of the scintillation detector. Measurements were typically performed at depths of 0, 15, 30, 60, and 90 cm.

The thorium, uranium, and radium ratios were sufficiently constant to allow the estimation of the total thorium concentrations in soil from the borehole logging data. Soil samples were taken from approximately 15% of the boreholes and analyzed for total thorium (Th-228 and Th-232) by gamma spectrometry. The total thorium concentrations and the gamma radiation levels measured at the points of sampling were used to generate a third order logarithmic polynomial equation. This equation was then used to convert gamma levels in the boreholes into pCi/g of thorium in soil.

The data points and the curve generated are presented in the accompanying graph. It should be noted that the curve has a tendency to overestimate the

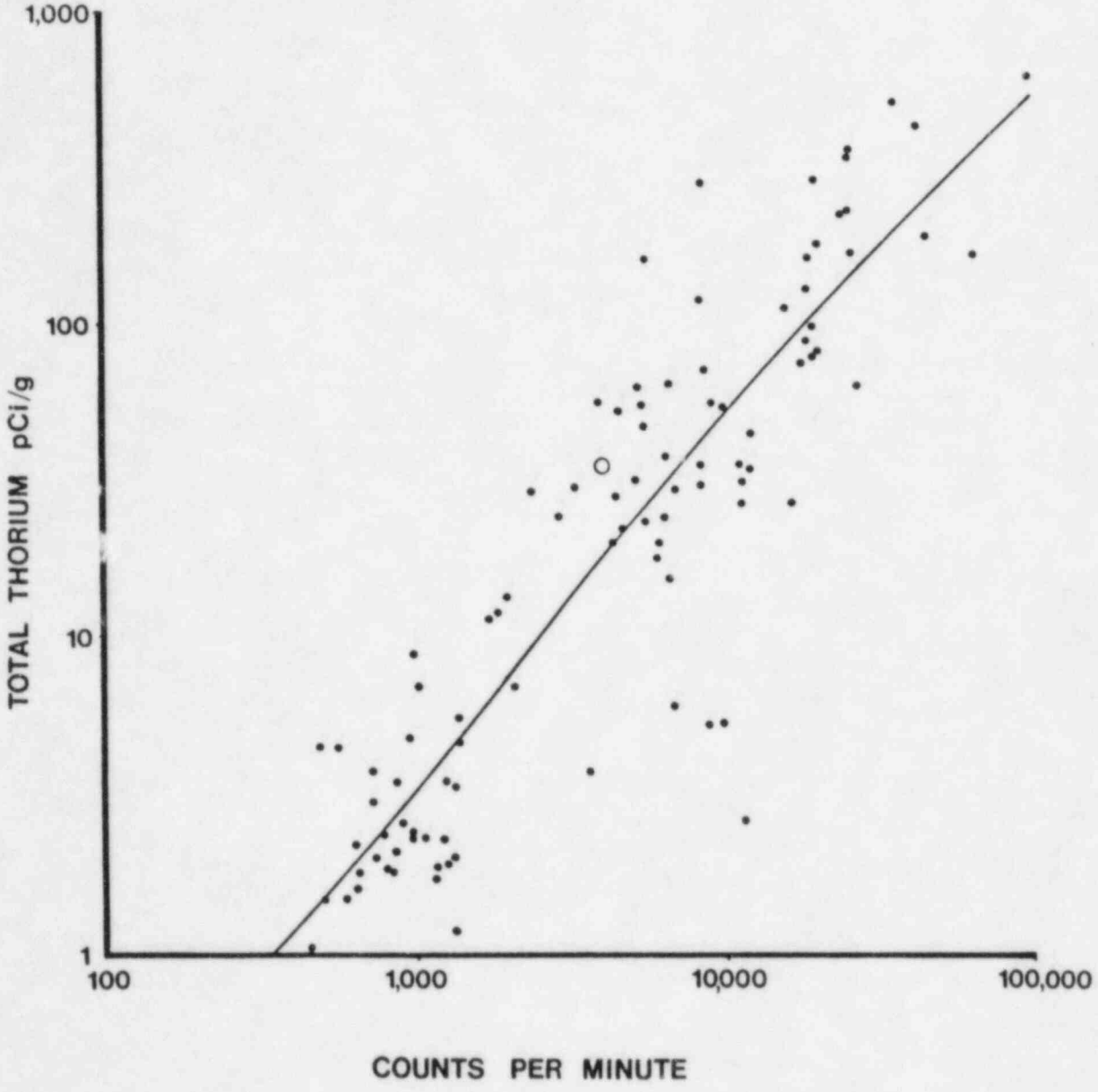

FIGURE 1. Direct Radiation Levels in Boreholes (CPM) Versus Total Thorium Concentration (pCi/g) in Soil.

thorium concentrations at the low end. The open circle in the figure indicates a measurement in a monazite sand standard.

Water Samples

Water samples were rough filtered through Whatman No. 2 filter paper. Remaining suspended solids were removed by filtration through 0.45 μm pore size membrane filters. The filters, together with attached solids, were discarded, and the filtrate was acidified by the addition of 20 ml of concentrated nitric acid.

Gross Alpha and Gross Beta Analysis

Fifty milliliters of each sample was evaporated to dryness and counted on a Tennelec Model LB5100 low background proportional counter.

Errors and Detection Limits

The errors associated with the analytical data presented in the tables of this report, represent the 95% (2σ) confidence levels for that data. These errors were calculated, based on both the gross sample count levels and the associated background count levels. When the net sample count was less than the 2σ statistical deviation of the background count, the sample concentration was reported as less than the minimum detectable activity (<MDA). This means that the radionuclide was not present, to the best of our ability to measure it, utilizing the analytical techniques described in this appendix. Because of variations in background levels, caused by other constituants in the samples, the MDAs for specific radionuclides differ from sample to sample.

Calibration and Quality Assurance

Laboratory and analytical instruments are calibrated using NBS-traceable standards. Portable survey instruments for exposure rate and dose rate measurements are calibrated by comparison of their responses to those of other instruments having NBS-traceable calibration. Field comparisons or comparisons using samples typical of the area are used to develop these calibrations.

Quality control procedures on all instruments included daily background and check-source measurements to confirm lack of malfunctions and nonstatistical deviations in equipment. The ORAU laboratory participates in the EPA Quality Assurance Program.