NATURAL BACKGROUND RADIATION IN THE PROPOSED ILLINOIS SSC SITING AREA

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EXECUTIVE SUMMARY

The major source of radiation exposure to man is from natural radioactivity in the environment. A rigorous characterization of these natural radiation sources is important for siting the Superconducting Super Collider (SSC). Man interacts with the natural environment in different ways as a function of occupation and life style. Therefore, an accurate understanding of the radiation dose delivered to man requires both broad and discrete characterization of the components of the total radioactivity environment.

This document addresses section 2.2.3.3.6.1 in the DOE Invitation for the Site Proposals for the SSC which states:

> **Volume 5 shall provide information on available data pertaining to soil/rock and groundwater radioactivity levels in the region of the proposed site.**

A large set of data exists to establish a baseline for background radioactivity in the siting area. The major terrestrial sources of background radioactivity are radioactive elements that are members of the decay series of the two primordial radioactive elements, uranium-238 and thorium-232, and the primordial radioactive element, potassium-40. These radioactive elements are distributed in soils (principally unlithified glacial sediments), bedrock, and groundwaters of the proposed study area for the Superconducting Super Collider (SSC).

The surficial soils (glacial sediments) are the source for one significant component of the natural radioactivity environment - gamma radiation at land surface. An airborne total gamma radiation survey flown over the Chicago region (including the proposed siting area) determined a mean value for the terrestrial absorbed dose rate in air of 42 mrad/yr. For comparison, the average for all gamma radiometric surveys in the middle United States is 46 mrad/yr with a range of 35 to 75 mrad/yr.

A national airborne gamma-ray spectrometer survey was conducted by the ~~United States~~ U.S. Department of Energy (DOE). The data set from the survey can be interpreted to calculate equivalent concentrations of potassium (K), uranium (eU), and thorium (eTh) for surficial materials in the proposed siting area. K ranges from 0.6 to 1.4 percent, eU ranges from 0.6 to 3.0 ppm, and eTh ranges from 5.5 to 7.0 ppm. These concentrations are low when compared to average values measured in surficial materials around the world.

The surficial glacial sediments are the major source for radon concentrations in indoor atmospheres. Concentrations of radon in groundwater resources in the proposed siting area are low and of no environmental concern. United States Environmental Protection Agency (U.S. EPA) has issued an action guideline of 4 pCi/L for radon in indoor atmospheres. National surveys are underway to characterize regional variations in indoor radon concentrations. Analysis of data for the eight-county region of northeastern Illinois (including the SSC siting area) determined an arithmetic mean of 2.3 pCi/L; a value that is significantly lower than either the national mean of 3.64 pCi/L or the U.S. EPA action guideline.

The average radioactive element concentrations for the major lithologic groups as measured by two separate techniques fall below the state and national levels. Clean sandstones and dolomites have very low concentrations of radioactive elements. The tunnel is to be constructed in Galena and Platteville dolomite. Even the highest concentrations of radioactive elements, which occur in shales and shaly sandstones, are relatively low and of no environmental concern. Bedrock in the proposed siting area does not contain materials of high radioactivity such as coal measures or uraniferous deposits. Rock debris generated during construction of shafts or the tunnel does not pose a radioactivity hazard that requires special handling or disposal.

Underground structures require monitoring to assure that atmospheric radon concentrations do not exceed occupational levels. The low concentrations of uranium and thorium in the dolomite and the low concentrations of radon in groundwater from these rocks are evidence that atmospheric radon concentrations will be readily controlled; conventional ventilation required for other reasons will likely reduce radon concentrations to low values.

U.S. EPA is in the process of setting drinking water standards for radium, uranium and radon. Groundwater resources are important for domestic and public water supplies in the SSC siting area. The majority of domestic supplies and many public supplies are obtained from wells that are 100 to 300 feet deep finished in sand and gravel deposits or in dolomite bedrock. An abundant data base exhibits that groundwaters from these aquifers have low concentrations of radioactive elements and are in compliance with drinking water standards.

Wells more than 1000 feet deep that produce groundwater from confined sandstones in the Cambrian and Ordovician bedrock are an important source of public water supplies in the siting area. In the proposed siting area, this source of groundwater has low values of uranium and radon but commonly exceeds the U.S. EPA interim standard of 5.0 pCi/L for dissolved radium. Concentrations are less than 10 pCi/L over much of the siting area but do exceed 20 pCi/L locally. The U.S. EPA has received expert testimony that the standard is conservative and that concentrations present over the majority of the siting area are of no concern for public health. It is also well-established that conventional water treatment methods (such as lime-sludge softening and ion-exchange resins) efficiently reduce radium concentrations to levels below the Drinking Water Standard.

In conclusion, there is a large set of data on the natural radioactivity of soils/bedrock and groundwater in the proposed siting area. An evaluation of this data indicates that the total natural radioactivity environment in the proposed siting area has low background value and poses no problems for construction and operation of the Superconducting Super Collider in Illinois.

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INTRODUCTION

The major source of radiation exposure to man is radiation from natural sources in the environment. A rigorous characterization of these natural radiation sources is important for siting the Superconducting Super Collider (SSC). Issues to be addressed include the pre-operational natural background radiation dosage to the public in the siting region, the identification of any changes in the natural radioactivity background that may result from construction of the SSC, and the assessment of the dosage that natural radioactive elements present to workers during construction and operation of the facility. To accurately assess dosage, the natural radioactivity environment must be evaluated in a variety of ways. This is because man interacts with the natural environment in different ways as a function of occupation and life style. Therefore, a complete understanding of the radiation dosage delivered to man requires both broad and discrete characterization of the components of the total natural radioactivity environment.

The natural radiation environment can be classified as terrestrial and extraterrestrial (cosmic) sources. A broad treatment of extraterrestrial radiation is adequate for characterization of dose in the siting region. This is because extraterrestrial radiation varies as a function of elevation. However, the terrestrial sources must be characterized both collectively and discretely because of the different ways in which man interacts with terrestrial sources of radiation. The terrestrial and extraterrestrial source terms are described separately. The natural source terms will be brought together in a later report (EIS) to provide an assessment of the total dose equivalent to man. (Note that the assessment does not include technologically enhanced sources of radiation such as the nuclear fuel cycle.)

EXTRATERRESTRIAL RADIATION

The cosmic radiation dose consists of primary particles of extraterrestrial origin as well as secondary particles generated by interactions of the primary particles with the atmosphere. The secondary particles are referred to as cosmogenic radionuclides. The cosmic radiation dose typically contributes about 30 to 50 percent of the total whole-body dose from all external environmental radiation (NCRP, 1975).

The assessment of the cosmic radiation dose requires knowledge of the composition, energy spectrum and angular distribution of the cosmic-ray particle flux, the spatial and temporal variations of the cosmic-ray intensity, and the distribution of the population with altitude and latitude. Existing information in these areas is sufficient to permit a reasonable estimate of the average population exposure to cosmic radiation. The estimate can therefore be based on the average elevation of the proposed SSC siting area.

Using data of cosmic-ray particle flux densities and absorbed dose rates in air, an altitude profile of the long-term average cosmic-ray dose in the lower atmosphere may be inferred (NCRP, 1975). The ground-level elevation in the proposed SSC siting area varies from 600 - 950 feet above mean sealevel.

Using an average elevation of 775 feet (325 m), the whole-body (gonadal) dose is calculated to be 28 mrem/yr. The dose has been calculated for a depth of 5 cm in a 30-cm cross section of tissue, and a 10 percent reduction has been applied to account for the effect of structural shielding. The average annual cosmic radiation dose to the entire population of the United States has been estimated to be 28 mrem/yr (Oakley and Goldin, 1975), while the average annual dose at sea level and in Denver, CO (elevation 1600 m) are estimated to be 26 mrem/yr and 50 mrem/yr, respectively.

The major production of cosmogenic radionuclides is through the interaction of cosmic rays with atmospheric gases. The four cosmogenic radionuclides that contribute a measurable dose are carbon-14, hydrogen-3 (tritium), sodium-22, and beryllium-7. The geographic and vertical production rates of these nuclides in the atmosphere have been measured (Young et. al, 1970a) or can be estimated from cosmic-ray data (Young et. al, 1970b).

Very little of the population dose from natural background radiation is contributed by cosmogenic radionuclides. The average dose equivalent rate to the whole body from cosmogenic radionuclides for a standard adult in the United States is estimated to be 0.7 mrem/yr, with essentially all the dose arising from carbon-14 (NCRP, 1975).

TERRESTRIAL RADIATION

The exposure of man to terrestrial radiation arises from radionuclides that are distributed in the geologic materials of the earth or have been transferred from the earth to the atmosphere or hydrosphere. Water (as groundwater or soil moisture) plays an important role in the transport of radionuclides in geologic materials. The significant natural sources are potassium-40 (^{40}K) and the decay series of the two primordial radionuclides, thorium-232 (^{232}Th) and uranium-238 (^{238}U). A third primordial radionuclide, uranium-235 (^{235}U), has a mass abundance ratio to uranium-238 of only 0.0073. Therefore, the uranium-235 (actinium) decay series is not significant for natural radiation exposure (NCRP, 1975).

Potassium-40, with a half-life of 1.26×10^9 years, decays directly to the stable element, calcium-40. Both beta and gamma radiation are produced in the disintegration. The isotopic abundance of potassium-40 is 0.0118 percent of total potassium.

The radioactive decay series of ^{238}U and ^{232}Th are shown in Figures 1 and 2, which present the half-life and the mode of disintegration (alpha, beta, or gamma) for series nuclides.

Gamma Radiation at Ground Surface

The naturally occurring radionuclides in near-surface geologic materials collectively supply a significant component of the background radiation exposure to the population. At ground surface, the significant exposure to man comes from the two terrestrial sources of gamma radiation, radionuclides in the shallow geologic materials and radon daughters present in the atmosphere (NCRP, 1975). The external radiation from alpha and beta emitters in the ground or in

the air does not contribute a significant absorbed dose (NCRP, 1975).

Two total gamma radiometric surveys have been flown over the SSC study area. The purpose of these areal radiological measuring system (ARMS) surveys was to provide information on the natural background radiation in the region surrounding nuclear facilities. A discrete analysis of the gamma radiation spectrum was not performed in the ARMS survey. Instruments measured the total flux of gamma radiation with energies greater than 50 keV (Burson, 1974). Despite the lack of discrete analysis of the gamma radiation, the data gathered in these surveys are valuable in assessing the total natural gamma background radiation from terrestrial sources.

The first radiometric survey was flown in 1959 over the Chicago region as one of several surveys (ARMS 1) performed by the U.S. Geological Survey. The second survey was flown over the Dresden nuclear plant in 1971 and was one of several surveys flown in the vicinity of nuclear power plants by the consulting firm E.G. and G., Inc. Most surveys were done before the plants were operating; and, in the others, no reactor-produced radionuclides were detected (NCRP, 1975). The surveys were flown at a height of approximately 500 ft on flight lines that were spaced 1 mi apart. Oakley (1972) analyzed the radiometric data from ARMS to calculate a whole-body absorbed dose rate for the Chicago region (fig. 3). The mean value for the region was 4.8 μrad/hr (42 mrad/yr). For comparison, Figure 3 shows the calculated absorbed dose rates in other ARMS 1 areas.

Data from radiometric surveys flown over nuclear plants were correlated by Burson (1974). The results for the Dresden area (53 mrad/yr) are compared to dose rates calculated for other surveys over reactor areas in Figure 4. The majority of these surveys were pre-operational. Applying a housing factor of 0.80 (Oakley, 1972) and a gonadal and bone marrow screening factor of 0.80 (Bennett, 1970), and assuming a quality factor of unity, the calculated gonadal or bone marrow dose equivalent rate for the Dresden area measurements are 0.8 x 0.8 x 53 x 1 μrad/yr = 34 mrem/yr.

Natural Radioactivity of Geologic Materials in the Proposed Siting Region

An accurate assessment of the radioactive content in the subsurface geologic materials in the SSC siting area is essential to the determination of possible health hazards due to exposure to these materials. Information on the natural radioactivity of surficial geologic materials is provided from a national airborne spectral gamma radiation survey conducted by the U.S. Department of Energy. Although the areal survey directly measured the natural radioactivity of material to a depth of only 30-60 cm, it is often interpreted to characterize the distribution of natural radioactivity in geologic materials to a depth of several meters. A measurement program was conducted to evaluate natural radioactivity in deep geological materials in the proposed siting area. This program included measurements with an in situ spectral gamma ray (SGR) geophysical tool in three boreholes and laboratory analysis of rock chips from the three boreholes by instrumental neutron activation analysis (INAA).

The airborne gamma ray spectrometer survey was flown over Illinois as part of the U.S. Department of Energy's (DOE) National Uranium Resource Evaluation

Program (NURE). The survey methods and results for the region of Illinois that includes the SSC study area are presented in a DOE report (1981a) for the Aurora Quadrangle. The location of the Aurora Quadrangle and the SSC study area are shown in Figure 5.

For the Aurora Quadrangle, gamma ray spectral data were gathered on east-west traverse lines flown at 6-mile intervals, and on north-south tie lines flown at 18-mile intervals. The mean flight altitude above land surface was 393 ft, and mean flight velocity was 96.6 mph. Altitude attenuation coefficients were used to correct measured count rates at any elevation to a reference elevation of 400 ft. The airborne detector measured gamma radiation from geologic materials and any other materials present on land surface or buried at shallow depth. Because of the strong attenuation of gamma rays in materials, the measurement recorded by the airborne spectrometer is generally from materials present to depths of only 1 to 2 ft below land surface.

In the airborne spectrometer survey, ^{40}K is directly measured by a single clear peak at 1.46 MeV (million electron volts). By contrast, ^{232}Th and ^{238}U do not have any clear distinct peaks. The concentrations of these isotopes are interpreted by measuring the activities of the daughter nuclides, bismuth-214 (for ^{238}U) and thallium-208 (for ^{232}Th). Because uranium and thorium concentrations are not measured directly, they are referenced as equivalent concentrations. A fundamental assumption in calculating the concentrations of uranium and thorium is that a state of equilibrium exists between parent and daughter nuclides. The ^{238}U and ^{232}Th decay series are shown in Figures 1 and 2.

The following interpretation maps of potassium, uranium and thorium variation in the SSC study area were taken from the NURE report. The maps are pseudo contour plots showing variation of total gamma radiation, total potassium (K), equivalent uranium (eU), and equivalent thorium (eTh). Table 1 presents scales for converting the numbers on pseudo contour plots into concentrations. The total potassium concentration was calculated from the isotopic abundance of ^{40}K (0.0118%). Uranium and thorium concentrations are expressed as equivalent uranium and equivalent thorium to indicate that measurements were on daughter isotopes with an assumption of equilibrium.

Table 1. Explanation of Pseudo contours

Pseudo contour no.	(fig.6) Total Gamma Radiation (counts/sec)	(fig. 7) K (percent)	(fig. 8) eTh(Tl-208) (ppm)	(fig. 9) eU(Bi-214) (ppm)
0	750-800	0	0	0
	800-850	0 - .1	0 - .5	0 - .2
1	850-900	.1 - .2	.5 - 1.0	.2 - .4
	900-1000	.2 - .3	1.0 - 1.5	.4 - .6
2	1000-1050	.3 - .4	1.5 - 2.0	.6 - .8
	1050-1100	.4 - .5	2.0 - 2.5	.8 - 1.0
3	1100-1150	.5 - .6	2.5 - 3.0	1.0 - 1.2
	1150-1200	.6 - .7	3.0 - 3.5	1.2 - 1.4
4	1200-1250	.7 - .8	3.5 - 4.0	1.4 - 1.6
	1250-1300	.8 - .9	4.0 - 4.5	1.6 - 1.8
5	1300-1350	.9 - 1.0	4.5 - 5.0	1.8 - 2.0
	1350-1400	1.0 - 1.1	5.0 - 5.5	2.0 - 2.2
6	1400-1450	1.1 - 1.2	5.5 - 6.0	2.2 - 2.4
	1450-1500	1.2 - 1.3	6.0 - 6.5	2.4 - 2.6
7	1500-1550	1.3 - 1.4	6.5 - 7.0	2.6 - 2.8
	1550-1600			2.8 - 3.0
8	1600-1650			

The total count rates of gamma radiation in the SSC study area (fig. 6) range from 750 to 1550 counts/s. Over most of the area, total gamma radiation ranges from 1100 to 1350 counts/s. The lowest counts (750 to 1100 counts/s) occur in an area along the Fox River Valley. Lower radioactivity values for all parameters were measured in the valley and probably are due to shielding of gamma radiation by water. The highest counts (1400 to 1550 counts/s) occur in a locality in the southwestern part of the study area.

Figures 7, 8, and 9 present pseudocontour maps for K, eTh, and eU. The concentrations of potassium-40, uranium, and thorium are derived by converting counts/s data using the detection efficiencies calculated for the measurement system and do not directly correspond to real geochemical data.

The range of potassium concentrations in the map area (fig. 7) is from 0.6 to 1.4%. Over much of the area, concentrations range uniformly from 0.9 to 1.2%. The lowest concentrations are in the region of the Fox River Valley; the highest (1.2 to 1.3%) are clustered in the southwestern, southeastern, northwestern, and northeastern parts of the study area.

The concentration of eTh in the surficial geologic materials in the SSC study area (fig. 8) are from 2.5 to 7.0 parts per million (ppm). Over most of the area, concentrations vary from 3.5 to 6.0 ppm. The lowest concentrations were measured along the Fox River Valley. Values are generally higher in the western part of the study area than in the eastern, with the highest concentrations (5.5 to 7.0 ppm) clustered in the southwest.

The NURE survey determined eU concentrations in the surficial geologic materials in the study area (fig. 9) to range from 0.6 to 3.0 ppm. Concentrations over most of the area vary from 1.0 to 2.0 ppm. A north-south zone of higher concentration occurs in the western half of the study area, with highest concentrations (2.2 to 3.0 ppm) present to the south. Relatively lower eU concentrations occur in the Fox River Valley.

Within the SSC study area, the concentrations of the three radioactive elements are relatively low. They are comparable to values that occur throughout the Aurora Quadrangle, and to concentrations measured by NURE surveys flown over the Rockford Quadrangle to the north and the Chicago Quadrangle to the east. For example, the average concentrations determined for the Chicago Quadrangle are 1.0% for potassium, 3.6 ppm for eTh, and 1.5 ppm for eU (DOE, 1981b). The average concentrations for radioactive elements in surface materials in northeastern Illinois are relatively low when compared to average values measured in surficial materials (soils) around the world (table 3).

The goal of the NURE program was regional reconnaissance to determine areas of anomalously high concentrations of uranium. However, the anomalies generated in the automatic reduction of data may be the product of many processes or conditions other than actual accumulations of radioactive minerals. Within the Aurora Quadrangle, the NURE program defined 23 anomalies. Only one of these anomalies is located within the SSC study area. The location of this anomaly is shown on the eU map (fig. 9). Superposition of the flight line that detected the anomaly over a topographic base map centered the anomaly at a rural cemetery located in the SW 1/4 of the SW 1/4 of Section 32, T 38 N, R 7 E, Kane County. The cemetery is at an elevation of 710 ft above mean sea level on a small knoll of anomalously high relief. The knoll is 35 to 50 ft higher than the surrounding landscape. The U.S. Department of Agriculture soil map for Kane County describes the surficial materials as well-drained loam over calcareous loam till. The relatively high eU (^{214}Bi) activities measured in the aircraft may reflect a combination of factors: the local relief, gamma radiation from uranium in granitic grave markers, and enhanced flux of gamma radiation due to the well-drained soils on the knoll in contrast to water-saturated soils lower on the landscape. Granitic markers have been documented as a source of anomalously high gamma radiation in cemeteries by environmental monitoring in the vicinity of Argonne National Laboratory (Golchert, Duffy, and Sedlet, 1983).

In situ measurements with a spectral gamma ray geophysical tool were taken in three boreholes drilled in the proposed siting area. The locations of the boreholes are shown in Figure 10. The holes were drilled with air rotary methods so that representative samples of the bedrock units could be collected for analysis by instrumental neutron activation in the lab.

The spectral gamma ray geophysical tool, run by Schlumberger Well Logging Co., Inc., uses a detection system consisting of a photomultiplier tube and a sodium iodide scintillation crystal mounted in a Dewar flask for maximum temperature stability. Due to limitations of the detector system and the degradation of gamma energies as they travel from their point of origin to the detector (primarily due to Compton Scattering) the discrete spectrum becomes

"smeared" and is referred to as the Potassium: Uranium: Thorium (KUT) spectrum.

The Schlumberger borehole system corrects for this smearing of spectral information by assigning individual spectral windows for ^{40}K, ^{238}U, and ^{232}Th. The spectral windows are centered at the following energy levels for each isotope:

ISOTOPE	ENERGY (MeV)
Potassium-40	1.46
Uranium-238 (Bi-214)	1.76
Thorium-232 (Tl-208)	2.62

Potassium-40 activities are measured directly, and the concentration of total potassium is calculated from the isotopic abundance of ^{40}K. However, ^{238}U and ^{232}Th do not have clear peaks with their disintegrations. Therefore, activities of these isotopes are determined by measurement of the activities of the daughter isotopes, ^{214}Bi and ^{208}Tl. Concentrations of the parent isotope are calculated from an assumption of radioactive equilibrium between parent and daughter nuclides. The terms equivalent uranium (eU) and equivalent thorium (eTh) are used in reference to the concentrations that are not measured directly. (Note that the determination of uranium and thorium concentration with the Schlumberger borehole spectral gamma radiation system is similar to the approach used to interpret the NURE Airborne data).

The Schlumberger SGR system operates by placing a detector in a borehole to count disintegration events occurring in the geologic materials. The information gathered as the detector is slowly retrieved from a borehole is transmitted to a digital computer on the surface where processing determines the concentrations of potassium, uranium, and thorium present in the geologic materials. The results are displayed as a continuous record of concentrations versus depth in the borehole.

The spectral gamma ray records for the three boreholes in the SSC siting area are presented in Figure 11, which presents the SGR logs for the boreholes in a general west to east perspective and correlates the major stratigraphic units in the bedrock. The correlation is based on study of the complete suite of geophysical records performed on the boreholes and study of rock chips collected during the drilling.

The concentrations of potassium, uranium (eU), and thorium (eTh) determined by the borehole method were compared to concentrations determined by Instrumental Neutron Activation Analysis (INAA) on discrete samples of rock chips collected in the drilling program. The INAA procedures are referenced in Harvey et al. (1983).

The laboratory analytical program initially focused on rock samples from borehole SSC-1. Two separate criteria were used to select samples for laboratory analysis. One criterion was to select samples from zones that displayed relatively high radioactivity on the spectral gamma ray log. A second criterion was to assure an accurate, unbiased comparison of the KUT concentration shown on the SGR log to concentrations measured analytically. To accomplish this criteria, rock samples from boring SSC-1 were analyzed on a 20-

foot spacing through the depth interval of 300 to 800 feet. The analytical results for boring SSC-1 are shown in Figures 12, 13 and 14. The three figures compare the INAA concentrations for potassium, uranium, and thorium to concentrations determined with the SGR method.

In contrast to the analytical program for boring SSC-1, only a limited number of zones from borings SSC-2 and SSC-3 were sampled for laboratory analysis. The comparison of INAA concentrations and SGR concentrations for the boreholes is presented in Figures 15 to 20.

The good correlation between the concentrations determined by the INAA and SGR methods is shown by the regression analyses in Figures 21, 22, and 23. There are two possible explanations to account for the few marked discrepancies that occur between the INAA and SGR data. First, rock fragments, which were collected during drilling at five-foot intervals, may not be rigorously representative of local variation in natural radioactivity detected by the SGR borehole sonde. Second, because the rock fragment samples are air-lifted hundreds of feet to the surface from the rotating drill bit, with a subsequent time lag there may be slight (1-3 ft) inaccuracies in determining the depths from which the samples were derived.

Table 2 shows the mean concentrations of potassium, uranium, and thorium in the major bedrock units present at the three boreholes from laboratory measurements with the INAA method. The exception is values for potassium, equivalent uranium, and equivalent thorium for the Silurian dolomite, which are calculated from the spectral gamma radiation record from borehole SSC-2.

Table 2. Mean Concentrations of Potassium, Uranium, and Thorium in Major Bedrock Units in the Proposed SSC Siting Area

	(n)*	K(%)	U(ppm)	Th(ppm)
Silurian dolomite	**	0.62	0.45	2.55
Maquoketa shale	7	3.02	2.45	7.2
(Range)		(0.02-4.74)	(0.30-4.60)	(0.30-11.5)
Galena dolomite	18	0.16	0.78	0.44
(Range)		(0.03-0.91)	(0.40-1.40)	(0.10-2.00)
Platteville dolomite	14	0.43	0.79	0.84
(Range)		(0.08-0.94)	(0.30-1.50)	(0.30-1.80)
Glenwood sandstone	11	1.11	1.25	0.65
(Range)		(0.15-2.16)	(0.20-4.10)	(0.24-1.90)
St. Peter sandstone	17	0.63	1.05	1.41
(Range)		(0.01-4.41)	(0.30-5.10)	(0.35-5.80)
Kress sandstone	4	1.47	2.03	4.90
(Range)		(0.05-2.74)	(0.60-3.90)	(0.10-16.00)

Note: Analysis by Instrumental Neutron Activation Analysis
(n)* Number of samples
** Concentrations of potassium, equivalent uranium, and equivalent thorium determined from borehole spectral gamma radiation measurements

The high concentrations of radioactive elements occur in the shale lithologies; the highest concentrations are present in the Maquoketa Shale Group. Shaly zones are also present in the Glenwood Formation and the Kress Member of the St. Peter Sandstone. Low concentrations of radioactive elements are present in the dolomites with the lowest concentrations measured in the Galena Group. Clean sandstones in the SSC study area have low concentrations of radioactive elements. The high values shown in the range for the sandstones represent finer grained rocks with a component of clay in the matrix. The finer grained shaly sandstones occur commonly in the Kress and the Glenwood, and very rarely in the St. Peter.

Table 3 presents a summary compilation of the concentrations of ^{40}K, ^{238}U and ^{232}Th in major rock types from measurements around the world (NCRP, 1975). Table 4 presents a summary of radioactive element data for samples collected over the entire state of Illinois. Comparison of table 2, table 3, and table 4 illustrates that average concentrations in the SSC study area are low compared to values determined in other regions of Illinois and around the world.

Table 3. Concentrations of major radionuclides in major rock types and soil

Materials	Radioactive Element (Concentration) K(%)	U(ppm)	Th(ppm)
Shale	2.7	3.7	12
Sandstone			
clean	<1	<1	<2
dirty Qtz	2	2-3	3-6
arkose	2-3	1-2	2
Carbonate	0.3	2	2
Soils	1.5	1.8	9

Source: National Council on Radiation Protection and Measurements Report No. 45 (1975)

Table 4. Summary of Uranium, Thorium, and Potassium Data for Major Illinois Rock Types

Rock type (n)	Radioactive Element (Concentration) K(%)	U(ppm)	Th(ppm)
Shale			
Blocher (24)	2.65	12	6.6
Selmier (79)	3.65	10	10
Grassy Creek(185)	3.73	26	10
Hannibal (60)	4.56	7	12
Anna (8)	2.52	31	12.5
Energy (4)	2.91	5	15
Various (11)			9
Recent Sediments			
Lake Michigan(286)	1.82	2.3	5.8
Illinois River(112)	2.00		13
Carbonates			
Limestones (4)	0.31	4.5	2.7
Various (10)		1.7	
Sandstones			
Various (14)		1.5	

Notes: Results are taken from Frost, Zierath and Shimp, 1985; Cahill, 1981; Cahill and Steele 1986; DeMaris et al., 1983; and Gilkeson et al., 1978.
(n) Number of samples analyzed.

The data gathered on the concentrations of radioactive elements in rocks of the SSC siting area demonstrate that the rocks have low concentrations of radioactive elements, and that rock debris generated during construction of

shafts or the tunnel does not pose a radioactivity hazard that requires special handling or disposal.

AIRBORNE RADON CONCENTRATIONS IN THE OUTDOORS, INDOORS, AND UNDERGROUND SHAFTS AND TUNNELS

Radon is a radioactive gas that is produced naturally in geologic materials by the normal decay of isotopes in the ^{238}U (fig. 1) and ^{232}Th decay series (fig. 2). The public health impact of radon-222 (^{222}Rn, half-life 3.82 days) in the ^{238}U decay series is an issue that is now receiving national attention. There is less health concern for ^{220}Rn in the ^{233}Th decay series because of its very short half-life (55 s). The health concern that is most significant for any population exposure, occupational or environmental, is the alpha dose deposited in the tracheobronchial region through inhalation of the short-lived ^{222}Rn daughters: polonium-218, lead-214, bismuth-214, and polonium-214.

Exposure to ^{222}Rn is defined in terms of the air concentration of radon daughters in units of the working level (WL). One WL is defined as that concentration of short-lived radon daughters that has a potential alpha energy release of 1.3×10^5 MeV per liter of air. Cumulative exposure is defined in working level months (WLM) which equals exposure in working level times exposure duration in multiples of the 170-hour occupational month. The occupational standard for radon daughter exposure in the United States is currently set at 4 WLM per year.

Secular equilibrium between radon and daughter nuclides is seldom found in ambient atmospheres. The daughter nuclides are chemically active solids that attach to surfaces such as walls, furniture, clothing, and also to airborne particles. The nuclides attached to airborne particles deliver the significant dose to the lungs. The ratio of the daughter nuclides in atmospheres to the radon concentration generally ranges from 0.3 to 0.5. Concentrations of radon in air are commonly expressed as pCi/L. The U.S. EPA has set 4.0 pCi/L as an action level guideline for indoor radon concentrations. For an equilibrium factor of 0.5, 4.0 pCi/L radon represents 0.02 working levels. Similarly, a radon concentration of 200 pCi/L would represent 1 working level.

Residential occupancy may differ significantly from the standard work-related occupational month of 170 hours. Cumulative exposure at a given concentration is more than 4 times that for occupational exposure (8766 hours versus 2000 hours on an annual basis).

Airborne concentrations of ^{222}Rn outdoors

The average outdoor ^{222}Rn concentration over continents is estimated to be 200 pCi/m^3 or (0.2 pCi/L) (NCRP, 1984). A survey of published measurements by (Gesell, 1983) found that the mean value for outdoor concentrations of ^{222}Rn for normal areas of the contiguous United States lies in the range of 100-400 pCi/m^3 and averages about 250 pCi/m^3 or (0.25 pCi/L). Measurements taken in the late spring and summer of 1960 at Argonne National Laboratory found an average ^{222}Rn concentration of 300 pCi/m^3 and 260 pCi/m^3 at heights of 1 and 4 m above ground surface, respectively (Pearson, 1967). A calculation applying the National Council on Radiation Protection (NCRP) model for predicting lung

cancer deaths from continuous environmental exposure to radon (NCRP, 1984) results in a lifetime risk of 0.06% for an average outdoor radon concentration of 300 pCi/m^3.

Airborne concentrations of ^{222}Rn indoors

There is a great national concern currently for the concentrations of ^{222}Rn that are present in indoor environments. Geologic materials immediately surrounding the substructure of a building are the principal source of indoor radon. For homes with groundwater supplies, radon released through water use may also supply a component to the indoor environment. (Radon concentrations in groundwater are discussed in a separate subsection of this report.)

Several programs have been initiated at national, state, and local, levels to measure and evaluate regional indoor radon concentrations. The Illinois Department of Nuclear Safety has initiated a program to evaluate indoor radon concentrations across the state of Illinois, but the survey for the region of the SSC study area is not yet complete.

The first measurements of indoor radon in homes in northeastern Illinois came from a study of 144 single family homes located in the vicinity of Argonne National Laboratory. The values shown in table 5 were provided by Dr. Richard Toohey (personal communication, 1986) of Argonne National Laboratory. Analysis was based on grab samples collected during brief visits to the homes. The samples may not be representative of the long-term average concentrations present in the indoor atmosphere.

Table 5. ^{222}Rn CONCENTRATIONS MEASURED IN 144 RESIDENCES

pCi/L	Basements (% occurrence)	First Floors (% occurrence)
<1	22	37
1-4	51	49
>4-10	19	13
> 10	8	1

Note: Analysis on grab samples collected by Argonne National Laboratory. In each case, basements and first floors, 124 measurements.

Twenty-seven percent of the measurements in basements were greater than the U.S. EPA guideline of 4.0 pCi/L; the maximum concentration measured in a basement was 50 pCi/L. Fourteen percent of the first floor readings exceeded 4.0 pCi/L; 36 pCi/L was the maximum concentration measured.

The homes measured in the Argonne National Laboratory Survey are located east and southeast of the SSC study area. Home construction and physical settings (associations of landscapes and geologic materials) are comparable to conditions in the proposed siting area.

A national survey of indoor radon concentrations is underway that is coordinated by Dr. Bernie Cohen, at the University of Pittsburgh, Pittsburgh, Pennsylvania. Measurements are taken in indoor living space with activated charcoal radon monitors. The results for eight counties in northeastern

Illinois (including the SSC study area) are presented in Table 6. An unfortunate problem with this data set is that the county tabulation did not discriminate between Kankakee and Kane County.

Table 6. ^{222}Rn Concentrations In Indoor Living Space By Counties Northeastern Illinois

County	Number of samples	Geometric Mean	Arithmetic Mean	Samples in Range >4- 20 pCi/L	Samples in Range >20pCi/L
Cook	873	1.4	2.13	95	4
DeKalb	11	1.5	1.5	0	0
DuPage	292	2.03	3.05	66	1
Kendall	7	2.6	2.8	1	0
Lake	144	1.4	1.8	13	0
McHenry	31	1.9	2.6	4	0
Kane*	52	2.3	3.1	14	0
Regional	1410	Weighted Mean	2.31	193	5
U.S.	34,280	1.7	3.64	5,813	775

Note: Analysis by charcoal canister method by Dr. Bernie Cohen, University of Pittsburgh, Pittsburgh, Pennsylvania
* Computer entry includes only first 3 letters of county named, so Kane and Kankakee County data are combined

The University of Pittsburgh data set includes 1410 measurements of radon in indoor living space in residences in the eight counties of Northeastern Illinois compared to 34,280 measurements for the total national survey. The arithmetic mean value for the eight-county region of 2.3 pCi/L is lower than the national value of 3.64 pCi/L. Also, only 0.35% of the measurements in living spaces in the eight-county region exceeded 20 pCi/L (compared to 2.26% of living spaces exceeding 20 pCi/L in the total national survey.)

Airborne concentrations of ^{222}Rn in underground shafts and tunnels

Information is required on the concentrations of ^{222}Rn that will be present in the working environment during excavation of shafts and tunnels for the SSC and during its operation. The information is necessary for sizing the required ventilation systems. The ^{222}Rn emanation power of geologic materials within the SSC study area is being investigated. This investigation includes gathering information on measurements in other regions.

The U.S. Geological Survey has measured ^{222}Rn in soil gas samples collected from in situ unconsolidated geologic materials near the town of Sheffield in Bureau County, Illinois. The measurements were taken in the vicinity of a low-level radioactive waste disposal site, but they represent natural background concentrations (Rob Striegl, 1985, USGS, personal communication). The radon concentrations shown in table 7 are from measurements taken from August 1984 to August 1985 (Rob Striegl, 1985, USGS, personal communication).

Table 7. ^{222}Rn Concentrations In Soil Gas And Atmospheres At A United States Geological Survey Research Area Near Sheffield, Bureau County, Illinois

Stratigraphic Unit	Measurement in Soil Gas (pCi/L)
Peoria Loess	1000-2000
Roxanna Silt	1000-1500
Radnor Till	1000-3000
Toulon Sand	190-290
	Measurements in Atmosphere
Underground research tunnel	50-200
0.5 ft above land surface	1-3

The underground research tunnel is constructed in the Radnor Till. The ^{222}Rn concentrations measured in the poorly ventilated tunnel are of a level for concern, but they are much lower than the values measured in soil gas in the Radnor Till. The contrast in values is possibly due to slow transport of radon from the fine-grained materials. The concentrations measured in the tunnel could easily be controlled by ventilation.

Data on ^{222}Rn concentrations in underground workings other than uranium mines are limited. Measurements in coal mines found low values, principally because ventilation in operating coal mines to control other problems, such as methane, is also very effective in controlling ^{222}Rn. A study by Rock et al. (1975), of 223 coal mines (1,581 samples) found only two mines to have radioactive aerosol concentrations greater than 0.2 WL. Significantly, no measurements indicated concentrations in excess of 0.3 WL. Ventilation is also believed to be the reason for very low ^{222}Rn values measured in the New York subway system (Robert T. Beckman, 1986, personal communication, U.S. Department of Labor).

Results from monitoring Newfoundland fluoride mines (Dory and Corkill, 1985) determined that geologic environments other than uranium resources may supply high radon concentrations to mine environments. Radon daughter monitoring determined values above 100 WL in poorly ventilated wet stopes in the fluoride mines. Values measured in wet stopes were significantly higher than those measured in dry environments. Groundwater is a source of radon in the wet environments. The wet environments are due to fractured and fissured rock that is open to groundwater flow. Radium in encrustations on the fractures and fissures is a significant source of radon in groundwater. The observation of wet underground environments having higher radon concentrations is also supported by measurements in caverns. For example, the highest concentrations for Mammoth Cave in Kentucky (21 WL) are in poorly ventilated wet passageways in the region of groundwater infiltration (Bob Carson, 1986, personal communication, Mammoth Cave, Kentucky). Values in poorly ventilated dry passageways are much lower but still often exceed 1 WL. Also of interest are concentrations measured in a poorly ventilated area at the base of a 256-ft shaft excavated for an elevator at Mammoth Cave. Concentrations are generally 1.1 to 1.2 WL with maximum values of 1.8 WL measured occasionally.

In the SSC study area, the tunnel and research chamber would be constructed in the Galena and Platteville Dolomite Groups. The principal rock unit for the tunnel is the Galena; along the western side, construction of the tunnel and research chambers would also include the upper part of the Platteville. Table 2 presents analyses of radioactive elements in dolomites from the Galena and Platteville Group in the proposed study area. Carbonates have low concentrations of radioactive elements. Furthermore, the concentrations in the Galena - Platteville dolomites in the SSC study area are low compared to the mean concentration measured in carbonate rocks around the world (Table 3).

Uranium and thorium are the long-lived parent isotopes in the decay series of ^{222}Rn and ^{220}Rn; the two radon isotopes of concern for atmospheric environments in the tunnel. The emanation of radon from rock samples of the Galena-Platteville in the study area is being investigated.

The most significant source of radon to the tunnel atmosphere will be emanation of radon from the rock walls. An additional minor source of radon will be from inflows of groundwater during the boring of the tunnel and research chambers. Groundwater sources of radon will be insignificant after the grouting program to seal fractures and crevices.

A groundwater sampling program is being conducted to evaluate the dissolved radon concentration in the Galena-Platteville dolomites in the SSC study area. This program also includes the collection of groundwater samples from wells finished in the glacial drift and the Silurian dolomite. The analytical results are presented in Table 8. The location of wells is presented in Figure 24. Dissolved ^{222}Rn concentrations in groundwater from wells open to the Galena-Platteville dolomite vary from 129 to 740 pCi/L. The mean concentration for measurements from 19 wells is 295 pCi/L. The low values for dissolved concentrations of ^{222}Rn indicate that the small quantities of groundwater that are expected to infiltrate the tunnel will not be a significant source term for radon in tunnel atmospheres.

Table 8. Concentrations of ^{222}Rn, ^{238}U plus ^{234}U in Groundwater from the glacial drift, dolomite bedrock, and St.Peter Sandstone in the SSC Study Area

Well* No.	Location (Sec.-T-R)	Units in Open Borehole **	^{222}Rn (pCi/L)	^{238}U (ppb)	Activity Ratio $^{234}U/^{238}U$	$^{234}U + ^{238}U$ (pCi/L)
23	15-40N-8E	D	670	1.12	1.16	0.8
30	14-42N-8E	D	641			
20	28-40N-8E	D	462			
11	21-38N-7E	D	499	3.15	1.06	1.1
25	19-39N-9E	S	740	0.258	2.03	0.2
26	32-39N-9E	S	706			
1	17-38N-9E	S/M	277	<0.008		<0.1
12	26-39N-6E	S/M/G	277			
2	2-37N-8E	S/M/G	315	0.104	3.9	0.1
16	16-40N-7E	M/G/P	190			
21	33-40N-8E	M/G/P	277	<0.002		<0.1
10	16-38N-6E	M/G	286	<0.003		<0.1
18	21-40N-7E	G/P	183			
3	17-37N-8E	M/G	448			
6	24-37N-7E	M/G/P/ST.P	162			
5	24-37N-7E	M/G	172			
14	6-39N-7E	G/P	247	0.347	11.26	1.4
24	10-40N-8E	M/G/P	380			
7	22-37N-7E	G/P	458			
8	16-37N-7E	G	459			
15	6-40N-7E	G/P	223			
19	16-40N-8E	G	324	<0.02		<0.1
9	2-37N-8E	G/P	346			
18	7-40N-8E	G/P	129	0.25	4.57	0.4
4	18-37N-8E	G	227			
13	3-39N-6E	G/P/ST.P	510			
SSC1-400		G		0.146	2.02	0.1
SSC1-460		G		0.477	2.56	0.56
SSC1-540		P		0.859	5.64	1.9
SSC1-800		ST.P		2.86	6.64	7.21

* The location of wells is shown on Figure 24

** D - drift, sand and gravel; S - Silurian; M - Maquoketa; G - Galena; P - Platteville; ST.P - St. Peter

The available data indicate that natural radon concentrations within shafts and tunnels cut into the geologic materials at the SSC study area may exceed occupational levels, but that ventilation will readily reduce the concentrations to acceptable values. It is very likely that ventilation necessary for other parameters will be adequate to eliminate concern for radon. The low concentrations of uranium and thorium in the dolomites and the low concentrations of radon in groundwater from these rocks are indicators that high radon concentrations will not pose a problem to construction or operation of the SSC. A program is underway to determine the radon levels that will occur

in the tunnel and research chambers.

NATURAL RADIOACTIVE ELEMENTS IN GROUNDWATER

Several aquifers are used for groundwater resources in the SSC study area. Stratigraphic columns of geologic materials in the glacial drift and bedrock are presented in Figures 25 and 26. The three most significant aquifers are: 1.) sand and gravel deposits in the glacial drift; 2.) fractures and crevices in the shallow Silurian or Maquoketa dolomite bedrock (there is often hydraulic connection between glacial drift and shallow bedrock); and 3.) deep sandstones (St. Peter and Ironton-Galesville)in the Cambrian and Ordovician bedrock. Dolomites confined within the Maquoketa Shale Group and the Galena-Platteville Group that provide limited groundwater supplies to a relatively small number of wells are a fourth source of groundwater. Wells are often finished in the confined dolomites in localities where the sand and gravel or shallow bedrock do not provide an adequate domestic groundwater supply.

The naturally occurring radioactive elements in groundwater that are of public health concern are members of the ^{238}U and ^{232}Th decay series. Two radium isotopes, ^{226}Ra (^{238}U series) and ^{228}Ra (^{232}Th series) are of primary concern. The U.S. Environmental Protection Agency drinking water standard is 5.0 pCi/L for the combined concentration of the two nuclides. The other isotopes of concern are ^{238}U, ^{234}U, and ^{222}Rn. Methods of analysis for all dissolved radionuclides discussed in this report are cited in Gilkeson et al.,1983. U.S. EPA expects to promulgate a uranium standard for drinking water soon. The Agency has issued a health advisory for uranium of 10 pCi/L, based on considerations of radio-toxicity and chemical toxicity (Richard Cothern, 1986, personal communication, U.S. EPA).

A U.S. EPA drinking water standard for ^{222}Rn does not exist now. Hess et al. (1979) proposed a maximum contaminant level of 10,000 pCi/L for ^{222}Rn in household water supplies based on a concern for radon released from groundwater to indoor air. A recent analysis by Nero et al. (1985) estimates that a groundwater supply with a ^{222}Rn concentration of 10,000 pCi/L will increase the indoor air concentration of ^{222}Rn by 0.65 pCi/L.

Aquifers in the glacial drift and shallow bedrock

There is very limited information on the concentrations of specific radioactive nuclides present in groundwater from these aquifers. Table 8 presents analyses for ^{222}Rn and uranium isotopes for groundwater samples collected from four wells in the SSC study area that produce from the glacial drift and for three wells that are open to the shallow bedrock (Silurian and/or Maquoketa). ^{222}Rn concentrations are low and vary from 277 to 740 pCi/L. Dissolved uranium concentrations are also low and vary from 0.2 to 1.1 pCi/L for the combined concentration of ^{238}U plus ^{234}U.

Uranium analyses were performed on groundwater samples collected from two public supply wells finished in the Silurian dolomite at locations east of the SSC study area in Cook and DuPage Counties. The measured concentrations for ^{238}U plus ^{234}U were 0.14 pCi/L for Well No. 2 at Mt. Prospect (Cook County) and 0.28 pCi/L for Well No. 7 at Elmhurst (DuPage County). A ^{222}Rn concentration of

269 pCi/L was measured in groundwater from Well No. 7 at Elmhurst. Radium analyses were performed on groundwater samples collected from an Aurora test well that was constructed to produce groundwater from sand and gravel deposits in the glacial drift. The analytical results were 0.0 ± 0.2 pCi/L for ^{226}Ra and 0.2 ± 0.2 pCi/L for ^{228}Rn.

Although data on specific nuclides are very limited, there is a significant data base on measurement of gross alpha and gross beta radioactivity in groundwater from public supply wells in the SSC study area that are finished in these aquifers. The analytical data are presented in Appendix A. The low values are evidence that radium and uranium concentrations are low and in compliance with drinking water standards.

Confined aquifers in the Maquoketa Shale Group and Galena-Platteville Dolomite

Table 8 presents analyses for ^{222}Rn and/or ^{234}U plus ^{238}U for groundwater samples collected from wells that are open to the Maquoketa Shale Group and/or the Galena-Platteville Dolomite Group. ^{222}Rn concentrations in groundwater from these rock units are low (ranging from 128 to 439 pCi/L). The concentration of ^{234}U plus ^{238}U is also low, ranging from <0.1 to 1.9 pCi/L, for analyses on groundwater samples collected from six wells and from three depths in the borehole of SSC-1.

Actual measurements of specific nuclides in groundwater from the Maquoketa Shale Group are very limited for northeastern Illinois. The following concentrations were measured at one well producing groundwater from the Maquoketa at a location northwest of Elgin: ^{226}Ra, 0.2 pCi/L; ^{234}U plus ^{238}U, 0.003 pCi/L; and ^{222}Rn, 201 pCi/L.

The available measurements of gross alpha and beta activities for groundwater from confined aquifers in the Maquoketa Shale Group across northeastern illinois (Appendix A) indicate that radium and uranium concentrations are very low. Representative examples are the Bangs-Union Parker well, the two wells at Lake Marian in the Woods, and the Wermes Well No. 2 listed under Kane County in Appendix A. A groundwater sample from the Bangs-Union Parker well was analyzed for radium concentrations. The results were 0.53 pCi/L for ^{226}Ra and 0.62 pCi/L for ^{228}Ra.

Groundwater from Sandstone Aquifers in the Cambrian-Ordovician Bedrock

Research has been conducted on the distribution of radioactive isotopes in groundwater from the deep sandstones in northeastern Illinois (Gilkeson et al., 1983, 1984). The research was concerned with identifying geochemical mechanisms responsible for the occurrence of high concentrations of ^{226}Ra and ^{228}Ra in groundwater produced from public water supply wells finished in the Cambrian and Ordovician bedrock. A finding of the research was that the high radium concentrations were in groundwater produced from the sandstones, with the highest concentrations present in groundwater from the Ironton-Galesville, the major aquifer.

Figures 27 through 31 present the regional distribution of ^{226}Ra, ^{228}Ra, ^{234}U plus ^{238}U, and ^{222}Rn in groundwater from the Cambrian-Ordovician, with the

Ironton-Galesville as the significant source of groundwater for most supply wells.

Figures 27 and 28 present the regional distribution of ^{226}Ra and ^{228}Ra, respectively. ^{226}Ra concentrations vary from 0.5 to greater than 15 pCi/L; concentrations increase from west to east across the region, with the lowest values measured in the southwest where the Maquoketa Shale Group is eroded. Figure 28 shows a few supply wells that also receive groundwater from the Mt. Simon sandstone. An interesting feature is that groundwater from wells that reach only the upper section of the Mt. Simon have somewhat lower ^{226}Ra concentrations than nearby wells that are not drilled deeper than the Galesville. However, wells that are finished deep in the Mt. Simon produce brackish groundwater with significantly higher ^{226}Ra concentrations. A good example of this relationship is shown in Figure 27 by a cluster of wells in T 38 N, R 8 E.

There are fewer measurements of ^{228}Ra concentrations in groundwater than of ^{226}Ra. The regional trend is an increase in concentration from west to east, with ^{228}Ra values of less than 2.5 pCi/L in the western part of DeKalb County. Values are generally 5.0 pCi/L and greater within and east of the Fox River Valley. Similar to the observation for ^{226}Ra, ^{228}Ra concentrations are somewhat lower in wells that produce more groundwater from the carbonate sections or are deepened to produce from the upper part of the Mt. Simon. Brackish groundwater from the Mt. Simon has exceptionally high ^{228}Ra concentrations. This is illustrated in Figure 27 by the cluster of wells in T 38 N, R 8 E.

Figure 29 is a map of northern Illinois that presents the regional distribution of ^{228}Ra plus ^{226}Ra in potable groundwater from the Cambrian-Ordovician bedrock. This map predicts that the combined concentration of the two nuclides in the SSC study area ranges from 5 to greater than 15 pCi/L.

The regional variation of ^{234}U plus ^{238}U concentrations in groundwater from the Cambrian-Ordovician bedrock is shown in Figure 30. Combined concentrations range from 0.02 pCi/L to 2.5 pCi/L and are less than 0.5 pCi/L over most of the region. Values less than 0.1 pCi/L reflect the low solubility of uranium in reducing environments. Concentrations greater than 1.5 pCi/L occur in the southeastern part of the region and reflect an anomalous enrichment of ^{234}U in groundwater. The analyses indicate that the combined concentration of ^{234}U plus ^{238}U in potable groundwater from the Cambrian-Ordovician bedrock is much lower than the U.S. EPA health advisory of 10 pCi/L.

^{222}Rn concentrations in groundwater from supply wells open to the Cambrian-ordovician bedrock are presented in Figure 31. Values range from 44 to 385 pCi/L, with concentrations less than 200 pCi/L over most of the region. The values are very low with regard to the proposed drinking water standard of 10,000 pCi/L.

SUMMARY

A large data base has been gathered that is pertinent to natural background radioactivity in the region of northeastern Illinois proposed for siting the SSC.

Within the SSC study area, the concentrations of the three radioactive elements are relatively low in surficial material. They are comparable to values that occur throughout the Aurora Quadrangle, and to concentrations measured by NURE surveys flown over the Rockford Quadrangle to the north and the Chicago Quadrangle to the east. For example, the average concentrations determined for the Chicago Quadrangle are 1.0% for potassium, 3.6 ppm for eTh, and 1.5 ppm for eU (DOE, 1981b). The average concentrations for radioactive elements in surface materials in northeastern Illinois are relatively low when compared to average values measured in surficial materials (soils) around the world (Table 3).

The data gathered on the concentrations of radioactive elements in rocks of the SSC siting area demonstrate that the rocks have low concentrations of radioactive elements, and that rock debris generated during construction of shafts or the tunnel does not pose a radioactivity hazard that requires special handling or disposal.

Measurements of radon in indoor living space in 1410 residences in the eight counties of Northeastern Illinois by the University of Pittsburgh had an arithmetic mean value of 2.3 pCi/L. This is lower than the national value of 3.64 pCi/L, which is based on 34,280 measurements. Also, only 0.35% of the measurements in living spaces in the eight-county region exceeded 20 pCi/L (compared to 2.26% of living spaces exceeding 20 pCi/L in the total national survey.)

There is very limited information on the concentrations of specific radioactive nuclides present in groundwater from the glacial drift and shallow bedrock aquifers in the SSC siting area. Table 8 presents analyses for ^{222}Rn and uranium isotopes for groundwater samples collected from four wells in the SSC study area that produce from the glacial drift and for three wells that are open to the shallow bedrock (Silurian and/or Maquoketa). ^{222}Rn concentrations are low and vary from 277 to 740 pCi/L. Dissolved uranium concentrations are also low and vary from 0.2 to 1.1 pCi/L for the combined concentration of ^{238}U plus ^{234}U.

The general picture that emerges from analysis of the data is that the natural radioactivity in the siting area is normal for values that occur throughout the midwestern region of the United States.

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Appendix A

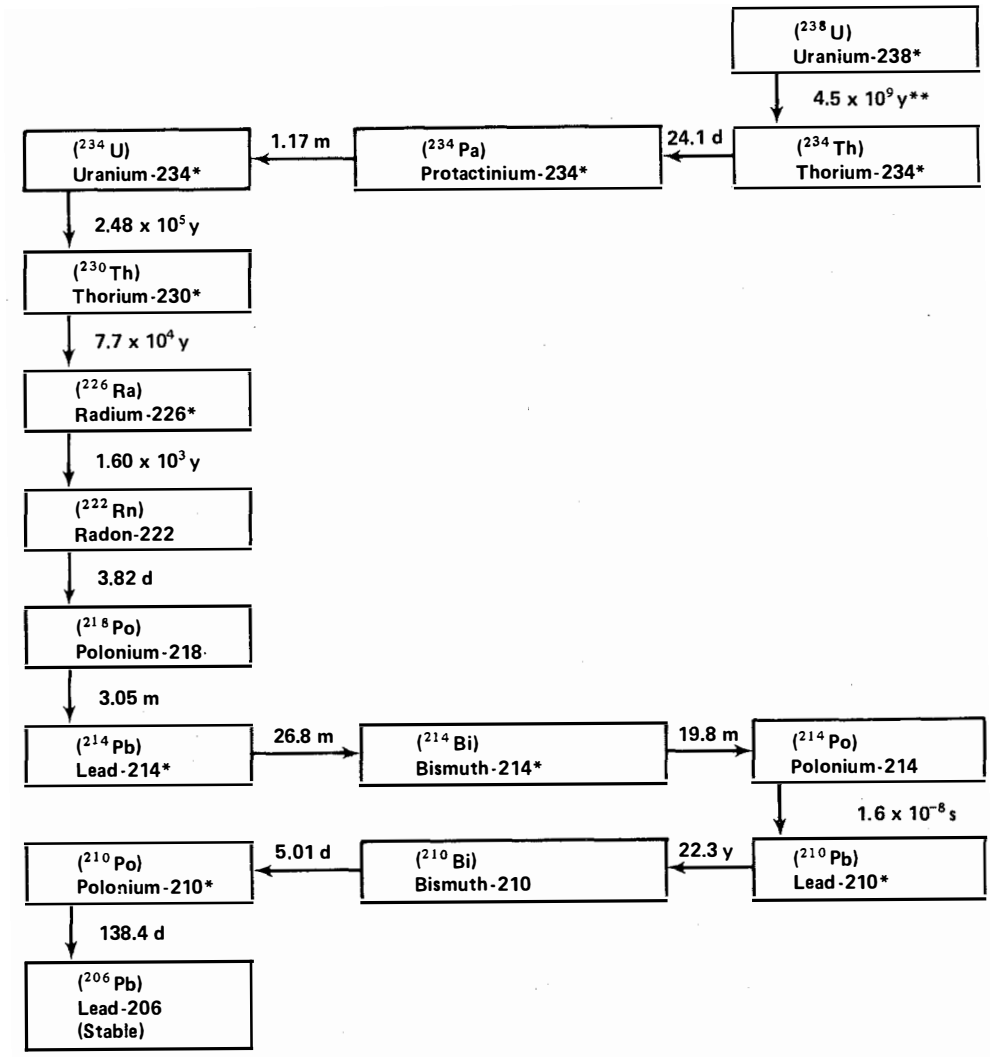
Gross Alpha and Beta Radiation in Groundwater
From Public Water Supply Wells

Well no.	Location (Sec.-T-R)	Depth (ft)	Date	Gross Radiation Alpha	Beta
				(pCi/L)*	
Dupage County Sand and Gravel					
Bartlett #3	34-41N-9E	99	2/8/72	1±1	1±1
DuPage County Shallow Bedrock					
Bartlett #1	34-41N-9E	200	2/8/72	1±1	1±1
			8/21/73	0.2±1.4	9.2±2.8
Bartlett #2	34-41N-9E	200	2/8/72	1±1	1±1
			5/7/74	1.1±1.5	0.4±2.2
Naperville #10	1-38N-9E	223	10/1/73	1.3±1.6	3.5±1.9
			1/7/76	4.6±2.6	5.9±2.3
#11	23-38N-9E	210	1/7/76	4.0±2.8	3.2±2.5
#14	22-38N-9E	248	10/1/73	2.3±1.6	3.8±1.8
			1/7/76	1.4±1.6	3.8±1.8
#15	14-38N-9E	233	1/7/76	4.4±3.7	6.7±2.9
#17	9-38N-9E	205	11/11/74	1.6±1.4	3.2±1.9
			9/9/75	1.7±1.3	2.6±1.4
#18	9-38N-9E	290	11/11/74	4.3±2.4	2.5±1.9
#19	8-38N-9E	310	11/11/74	3.6±2.1	5.9±2.1
Winfield #2	13-39N-9E	335	10/1/73	0.2±2.4	3.8±2.6
			1/19/76	3.5±2.5	7.7±2.9
#4	13-39N-9E	348	4/20/72	1±2	0±2
			1/19/76	2.3±1.9	3.1±2.2
Warrenville#1	35-39N-9E	125	10/14/73	0.9±1.7	8.2±2.7
			1/7/76	2.1±2.3	2.0±2.6
#2	2-38N-9E	300	11/11/74	2.7±2.3	11.4±2.7
			7/16/75	2.1±1.8	16.1±2.7
Warrenville#3	35-39N-9E	256	4/17/72	1±2	1±2
			10/4/72	0.5±1.3	11.6±2.1
#4	34-39N-9E	365	11/11/74	0.9±1.4	8.2±2.3
#5	33-39N-9E	200	11/11/74	1.9±1.7	3.2±1.9
#6	36-39N-9E	178	10/4/73	0.7±1.2	5.2±1.6
			4/19/76	0.3±1.2	1.6±1.6
Warrenville (Albright St. Homeowners)					
#1	35-39N-9E	135	3/19/72	1±1	1±2
Warrenville (Roy St. Homeowners)					
#2	35-39N-9E	125	4/15/72	1±2	3±2

Well no.	Location (Sec.-T-R)	Depth (ft)	Date	Gross Radiation Alpha (pCi/L)*	Beta (pCi/L)*
Kendall County Sand and Gravel					
Plano #1	23-37N-6E	40	9/4/71	0±0	1±1
				0.9±1.3	4.1±1.7
#3	23-37N-6E	39.5	9/5/71	0±1	2±1
				0.1±0.7	2.5±1.4
#4	23-37N-6E	28	9/5/71	0±1	3±2
#5	23-37N-6E	40.7	8/2/71	0±1	3±2
			3/23/76	1.6±1.3	2.3±1.6
Yorkville #2	4-36N-7E	45	9/14/71	2±1	1±2
Kendall County Shallow Bedrock					
Marina Village #1	8-37N-8E	187	10/16/71	2±1	7±3
Kane County Sand and Gravel					
Carpentersville					
#3	15-42N-8E	76	11/14/73	0.6±1.0	3.6±1.5
			3/20/75	0.8±1.4	2.6±2.0
#4	14-42N-8E	175	9/8/71	0±1	1±2
#5	14-42N-8E	183	9/28/71	0±1	1±2
			3/17/75	0.8±1.3	1.5±1.8
#6	14-42N-8E	215	7/23/75	1.6±1.7	2.7±1.8
East Dundee					
#1	23-42N-8E	Spring	12/18/74	1.2±1.6	2.5±1.8
#2	23-42N-8E	72	11/13/73	0.9±1.4	3.6±1.8
#3	23-42N-8E	128	12/18/74	1.0±1.7	0.9±1.7
Elburn #2	5-39N-7E	153	9/13/71	1.0±1.0	0±2
Elgin North State Street	14-41N-8E	48	12/11/73	0.5±1.6	4.6±2.5
Ferson Creek	16-40N-7E	186	5/12/75	2.0±1.3	3.2±1.7
Maple Park #3	30-40N-6E	182	7/12/72	0.0±1.4	0.3±0.8
Montgomery #7	31-38N-8E	46	7/19/73	0.8±1.6	8.8±2.6
			12/23/75	2.7±2.3	7.9±2.2
St.Charles #7	28-40N-8E	175	3/31/75	0.5±1.4	3.3±2.0
St Charles Skyline #2	11-40N-8E	135	2/19/76	0.6±1.2	4.5±1.7
Sugar Grove#2	21-38N-7E	107	2/17/76	4.1±2.6	5.3±2.6
Sleepy Hollow	28-42N-8E	34	9/5/72	0.4±1.7	3.2±2.5
South Elgin#2	35-41N-8E	128	11/4/71	1±1	3±2
			8/26/74	1.8±1.6	0.4±2.3
South Elgin#3	35-41N-8E	112	12/15/71	1±1	1±2
			11/1/71	1±1	3±2
			11/4/71	1±1	2±2
			11/29/71	1±1	0±0
			11/22/71	0±1	2±3
			11/29/71	0±0	1±3
			11/29/71	1±1	0±0

Well no.	Location (Sec.-T-R)	Depth (ft)	Date	Gross Radiation Alpha (pCi/L)*	Beta
South Elgin #3	35-41N-83	112	12/2/71	0±2	5±2
			12/2/71	0±3	0±0
			12/3/71	0±1	2±2
			12/1/71	1±1	1±2
			12/8/71	1±1	0±2
			12/9/71	0±1	1±2
			12/9/71	1±1	1±2
			3/27/74	1.4±1.3	3.8±2.8
West Dundee#2	22-42N-8E	87	2/3/72	0±1	1±1
Kane County Shallow Bedrock					
Elgin Estates 1	28-41N-8E	300	2/12/76	0±1.1	2.6±1.8
Highland #1	15-40N-8E	152	3/23/76	2.3±1.6	2.2±1.6
Moecherville #2	26-38N-8E	180	12/3/73	2.0±1.4	2.3±1.7
#3	26-38N-8E	196	4/21/76	1.6±1.3	3.4±1.5
Montgomery #5	35-38N-8E	186	1/21/76	0±1	1±1
#6	31-38N-8E	160	12/23/75	3.1±3.5	4.8±2.0
Ogden Gardens #3	24-38N-8E	185	2/24/76	1.3±1.2	3.8±1.4
Park View #1	35-38N-8E	250	3/76	0.0±0.0	3.4±1.6
Prestbury #1	10-38N-7E	200	2/25/72	0.0±0.0	1±2
			11/8/73	1.1±1.1	2.5±1.9
			3/11/76	0.9±1.8	2.9±2.1
River Grange Lakes #1	9-40N-8E	180	3/76	1.8±1.5	5.0±1.6
Kane County Maquoketa Shale Group					
Bangs-Union Parker Sub #1	34-38N-8E	250	3/2/76	0.4±1.5	8.7±2.4
Lake Marian in the Woods #1	14-42N-8E	208	2/28/73	2.1±1.5	11.6±2.5
#2	11-42N-8E	251	2/28/73	1.3±1.3	6.8±2.2
Wermes #2	25-38N-8E	253	8/7/74	1.9±1.8	8.6±2.9

* Gross radiation analysis performed by the Illinois Environmental Protection Agency. The coefficient of variation is shown for each analytical value.

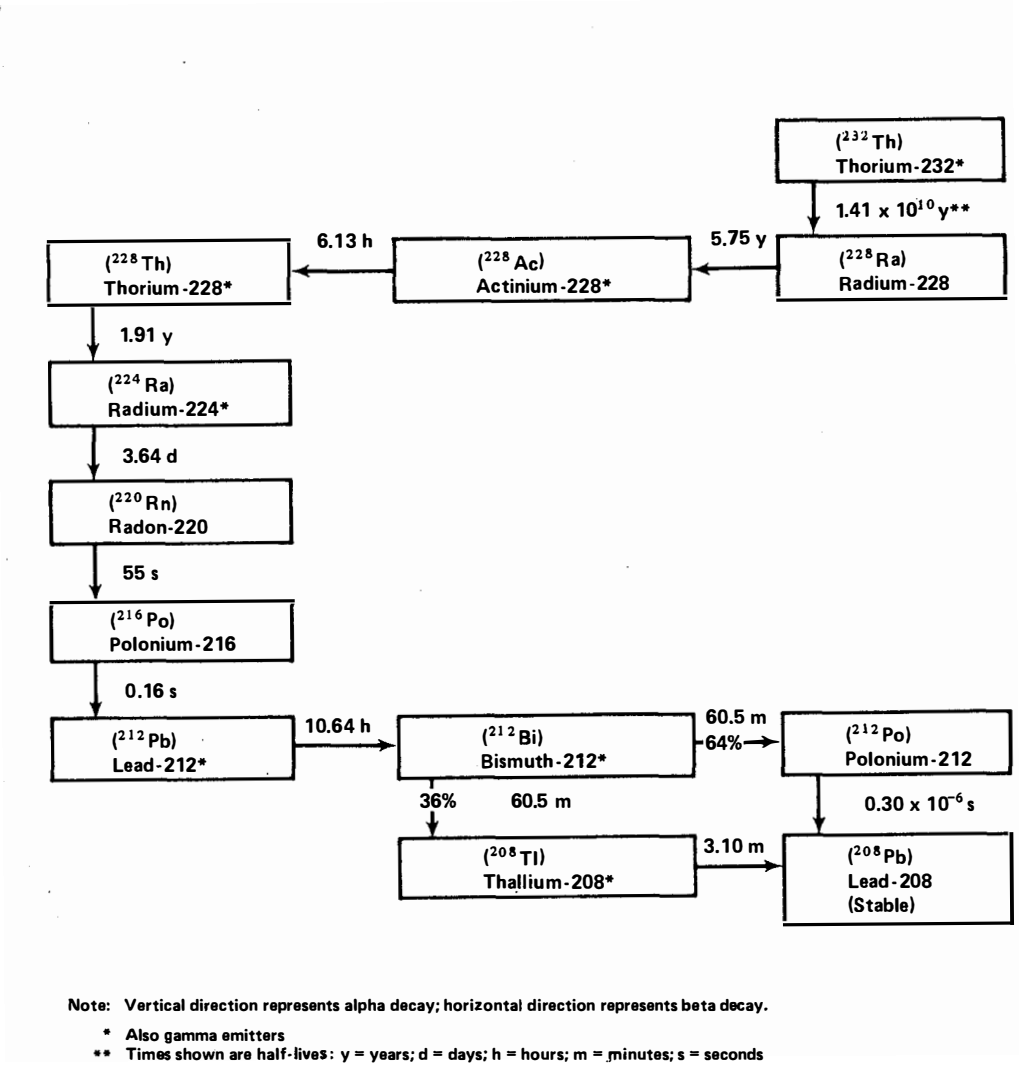


Note: Vertical direction represents alpha decay; horizontal direction represents beta decay.

* Also gamma emitters

** Times shown are half-lives: y = years; d = days; h = hours; m = minutes; s = seconds

Figure 1. Radioactive decay series of ^{238}U.



Note: Vertical direction represents alpha decay; horizontal direction represents beta decay.

* Also gamma emitters

** Times shown are half-lives: y = years; d = days; h = hours; m = minutes; s = seconds

Figure 2. Radioactive decay series of ^{232}Th.

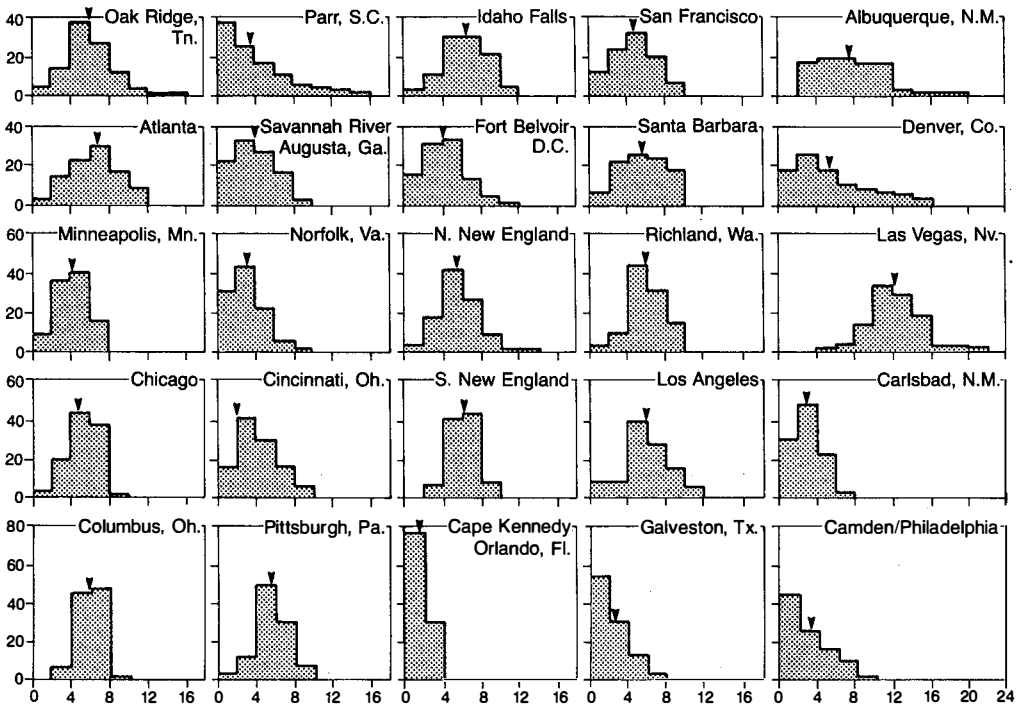


Figure 3. Whole-body absorbed dose rates in ARMS areas (mean denoted by arrow) (from Oakley, 1972).

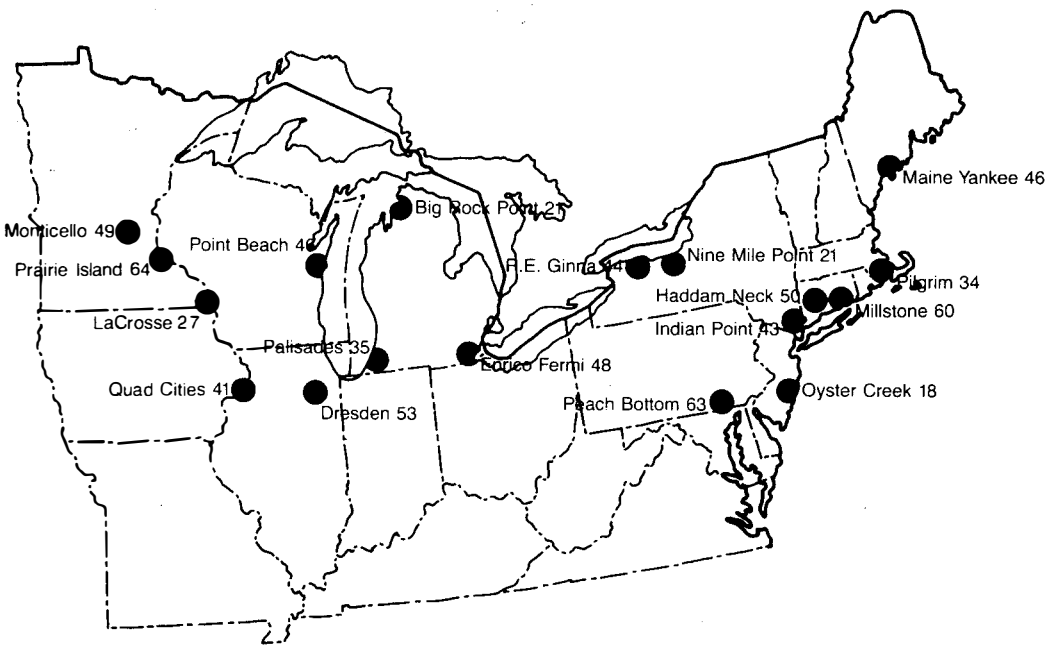


Figure 4. Aerial surveys over nuclear reactor sites. Numbers shown mean absorbed dose rates in air in mrad/yr (from Burson, 1974).

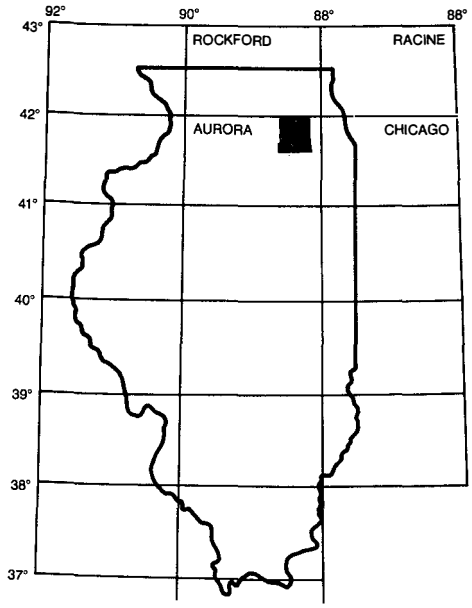


Figure 5. Location of Aurora, Rockford, Chicago, and Racine Quadrangles, and the locations of the SSC study area within the Aurora Quadrangle.

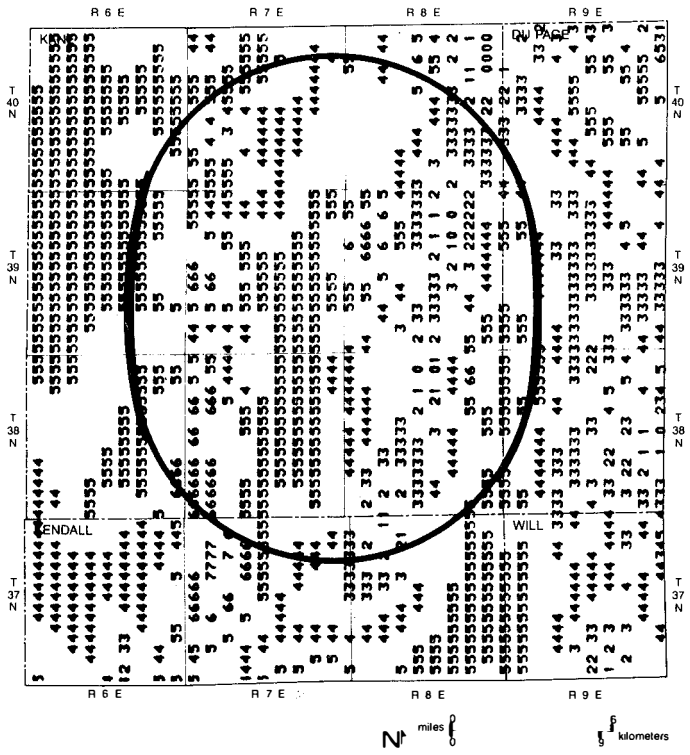


Figure 6. A pseudo contour plot of the variation in total count of gamma radiation from surficial geologic materials in the SSC study area (modified from U.S. DOE, 1981a). A scale for converting pseudo contour numbers to counts per second of gamma radiation is presented in Table 1.

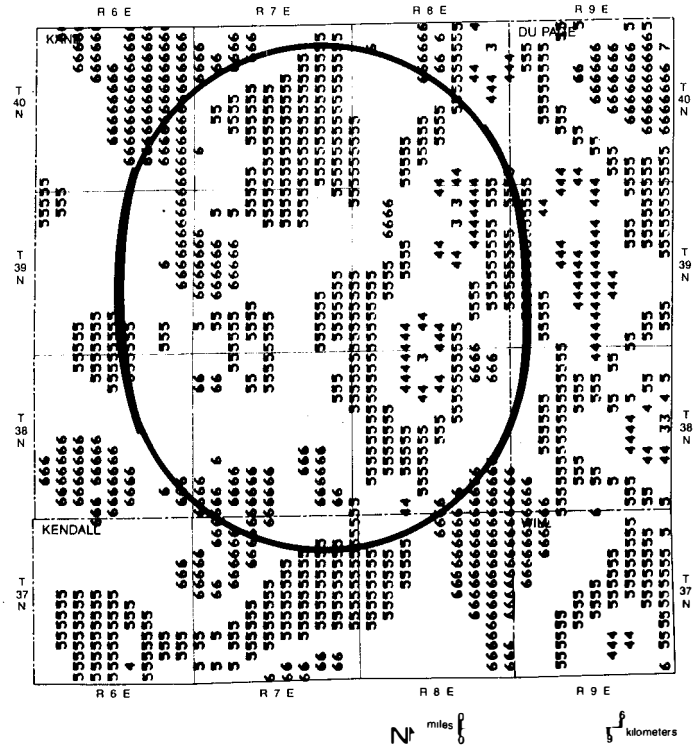


Figure 7. A pseudo contour plot of the variation in concentration of potassium in surficial geologic material in the SSC study area (modified from U.S. DOE, 1981a). Table 1 presents a scale for converting the pseudo contour numbers to concentrations in percent of total potassium.

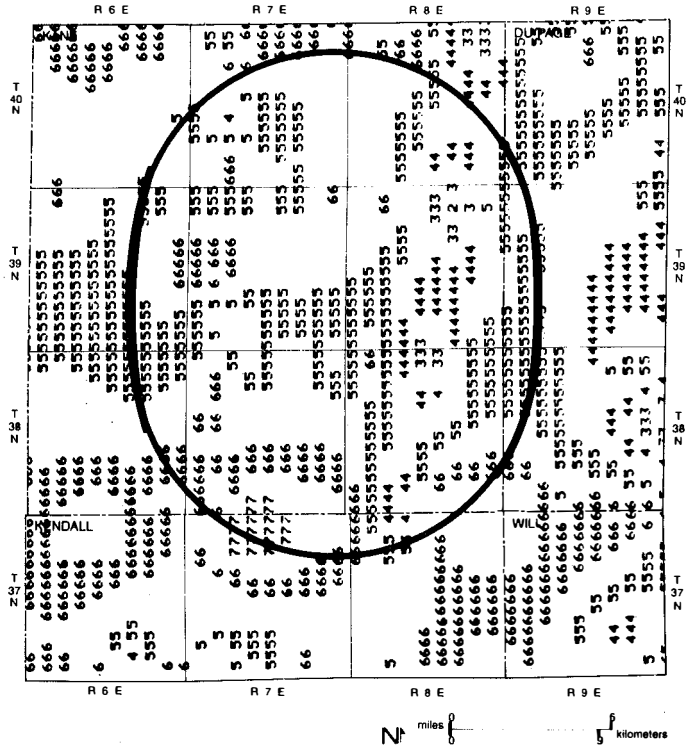


Figure 8. A pseudo contour plot of the variation in equivalent thorium in surficial geologic materials in the SSC study area (modified from U.S. DOE, 1981a). Table 1 presents a scale for converting the pseudo contour numbers to concentrations in parts per million of equivalent thorium.

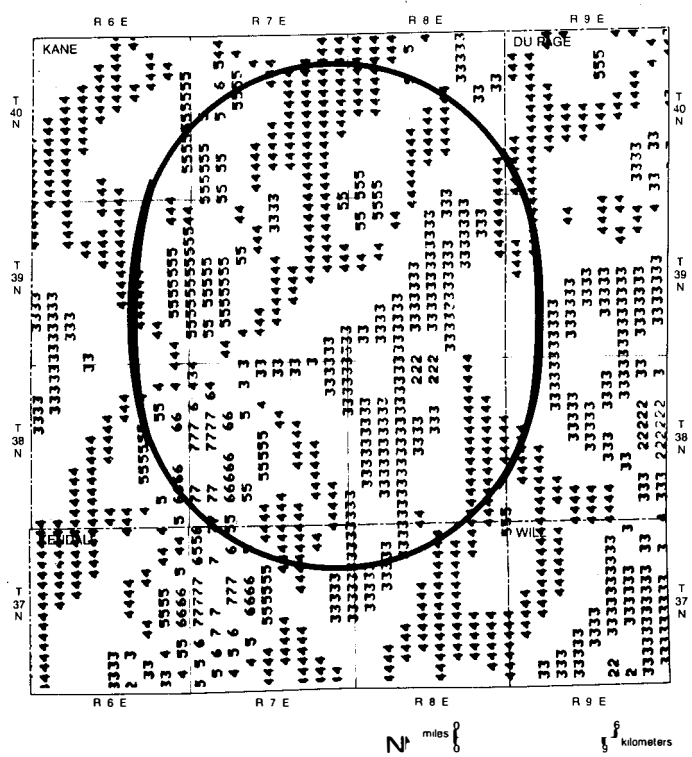


Figure 9. A pseudo contour plot of the variation in equivalent uranium in surficial geologic materials in the SSC study area (modified from U.S. DOE, 1981a). Table 1 presents a scale for converting the pseudo contour numbers to concentrations in parts per million of equivalent uranium.

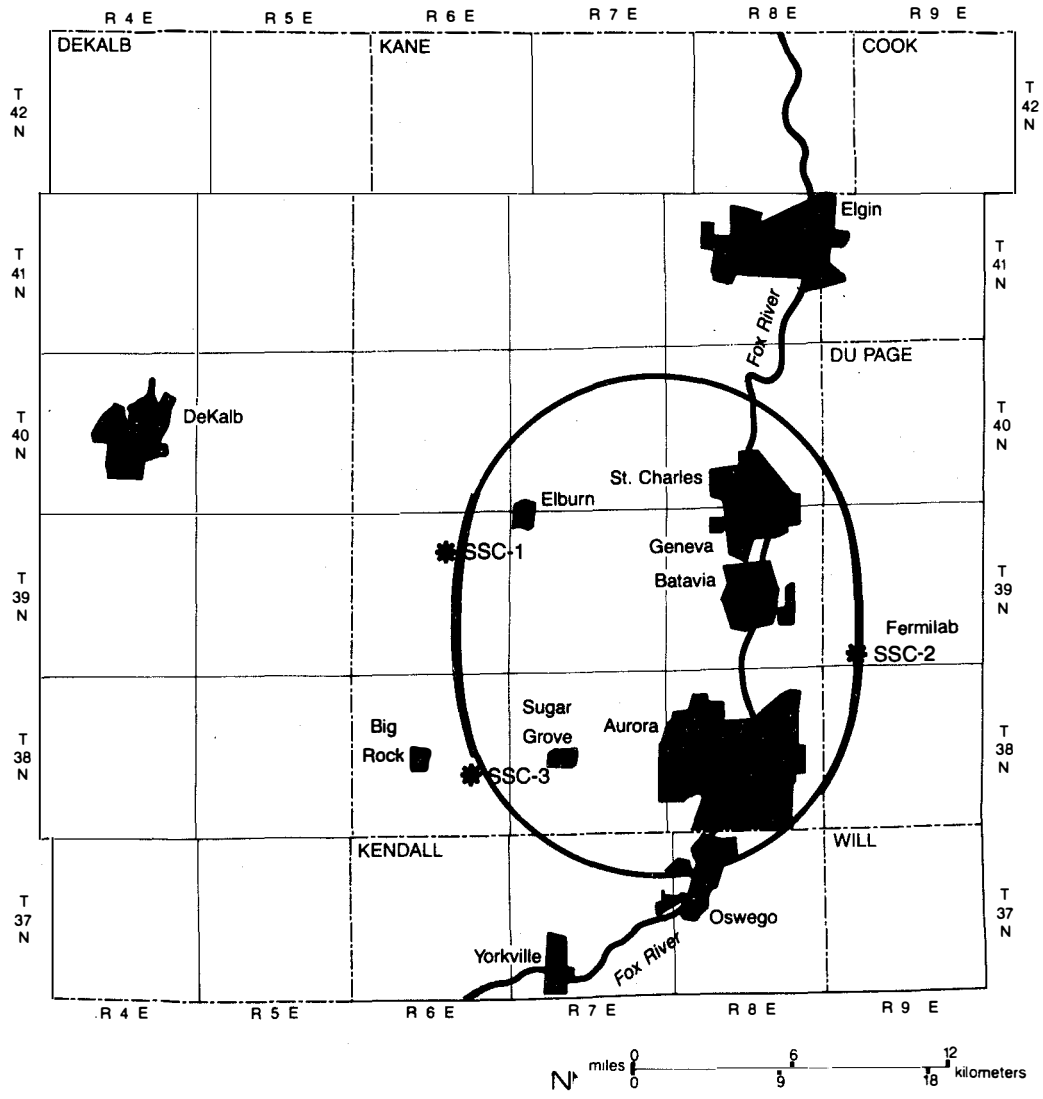


Figure 10. Map of the SSC study area showing the location of three eight inch boreholes where geologic materials were characterized for natural radioactivity.

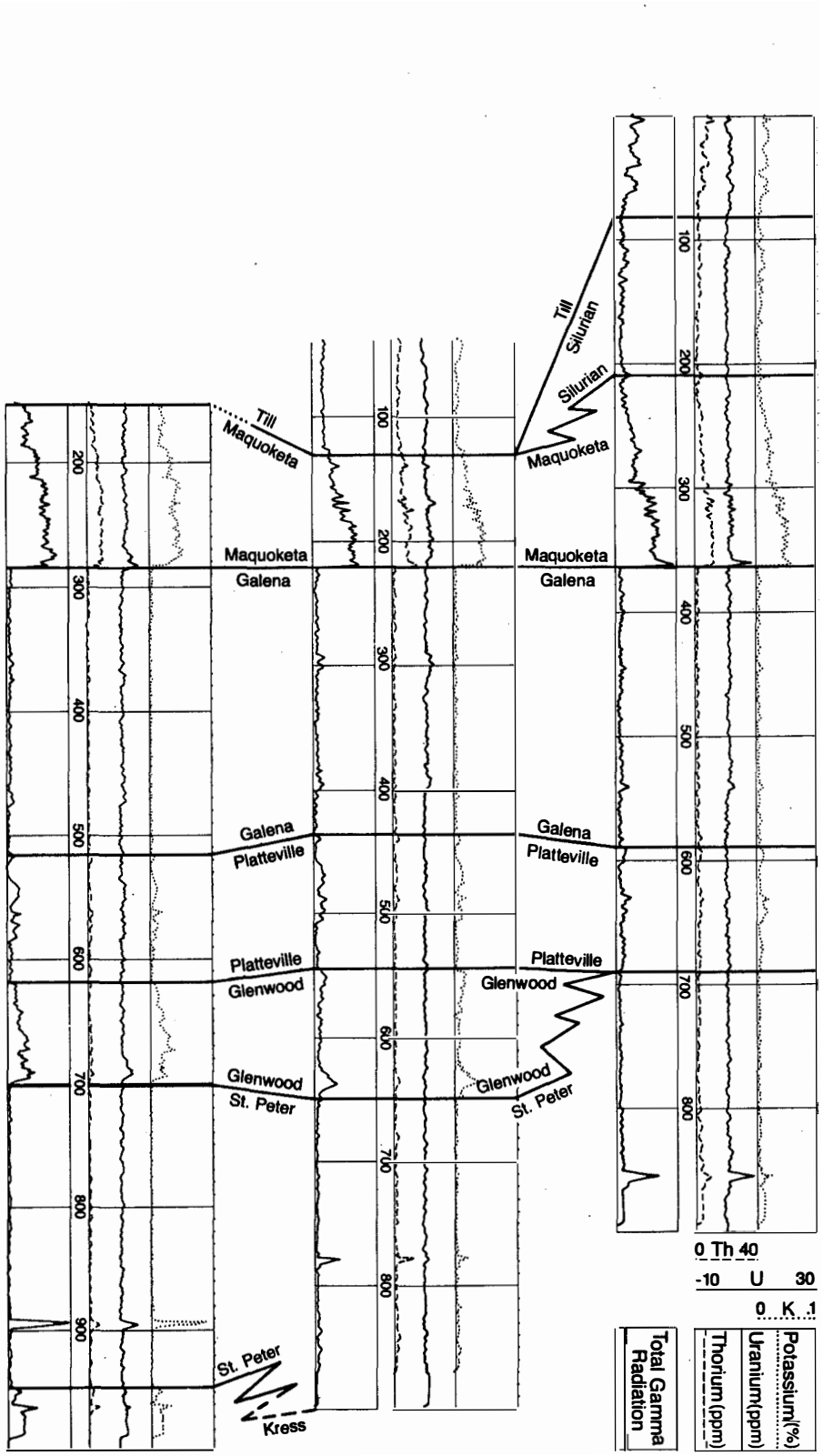


Figure 11. Spectral gamma ray records showing concentrations of total potassium (%), equivalent thorium (ppm) and equivalent uranium (ppm) for in situ measurements in three boreholes in the SSC study area. The location of boreholes is shown in Figure 10.

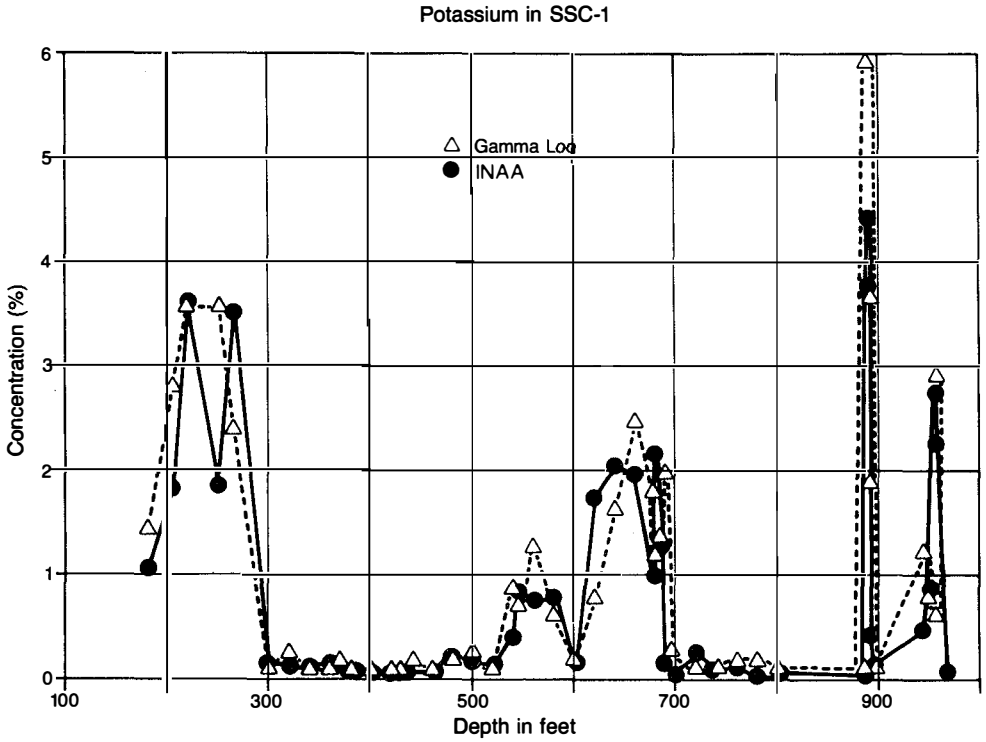


Figure 12. Concentrations of total potassium (%) measured in geologic materials in SSC-1. The plot compares laboratory instrumental neutron activation analyses on rock chips to in situ measurements with a spectral gamma ray sonde.

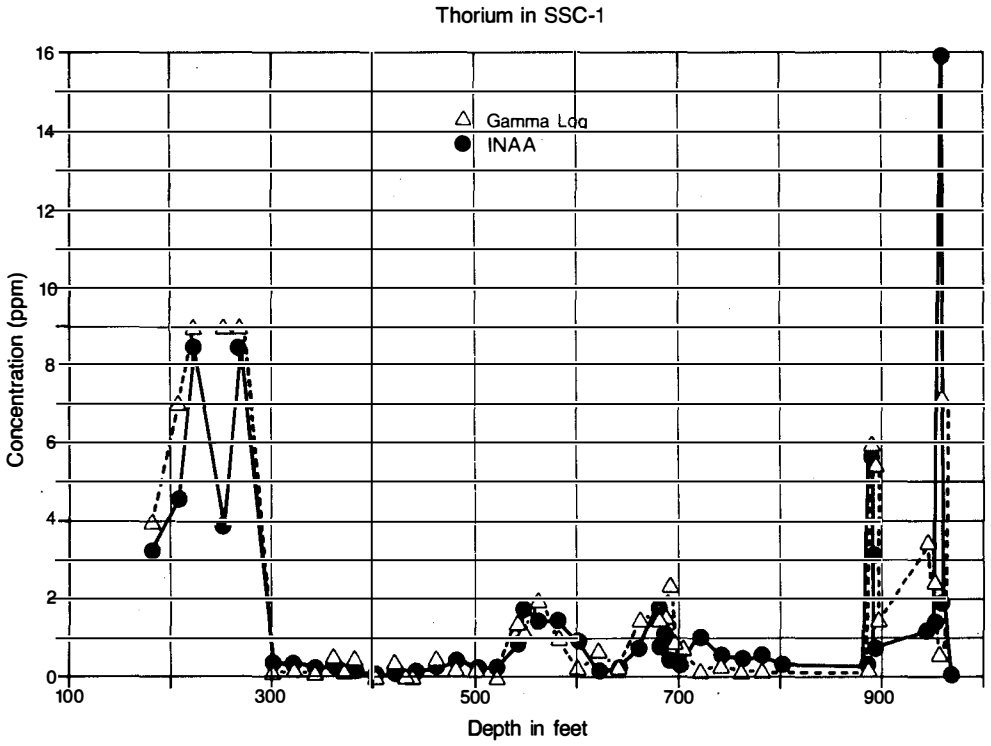


Figure 13. Concentrations of thorium (ppm) measured in geologic materials in SSC-1. The plot compares laboratory instrumental neutron activation analyses on rock chips to in situ measurements with a spectral gamma ray sonde.

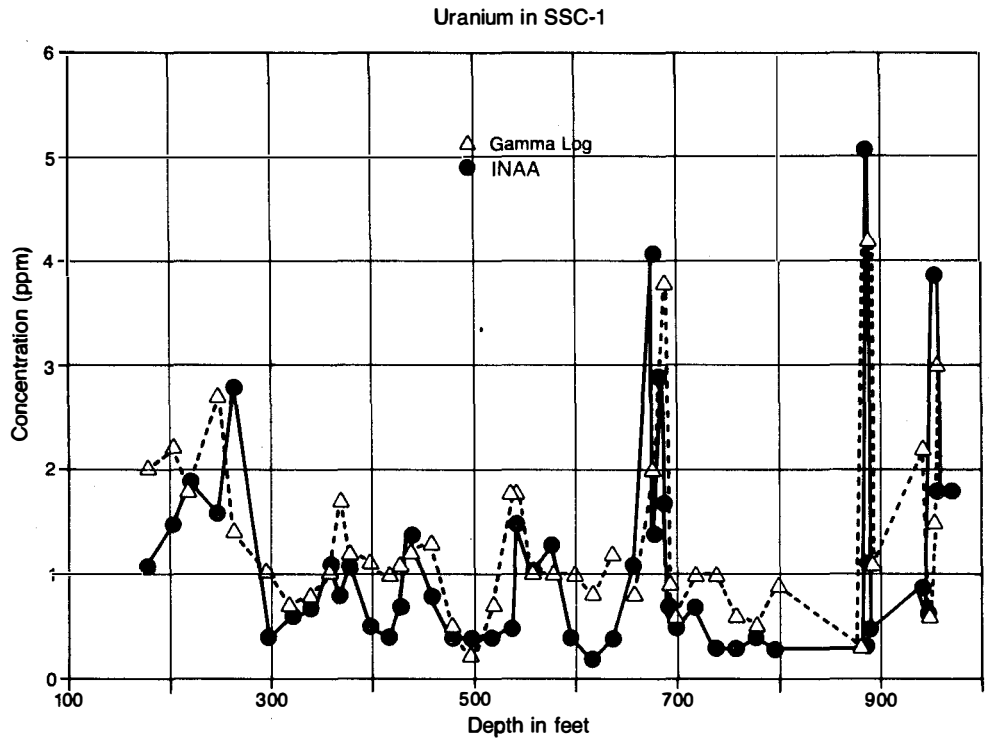


Figure 14. Concentrations of uranium (ppm) measured in geologic materials in SSC-1. The plot compares laboratory instrumental neutron activation analyses on rock chips to in situ measurements with a spectral gamma ray sonde.

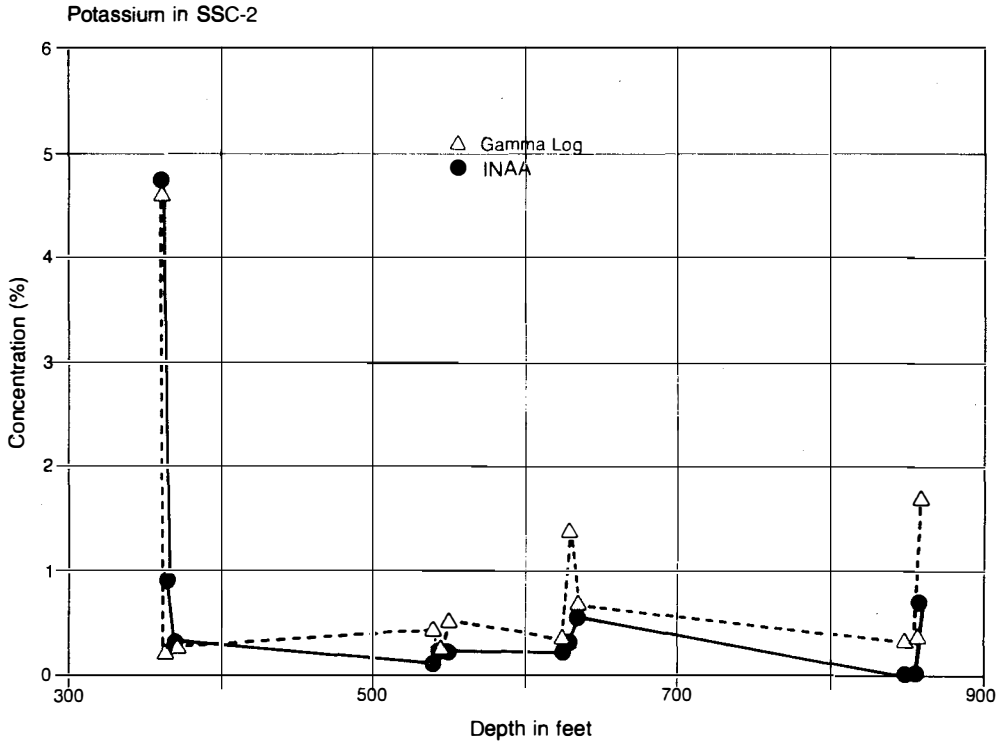


Figure 15. Concentrations of total potassium (%) measured in geologic materials in SSC-2. The plot compares laboratory instrumental neutron activation analyses on rock chips to in situ measurements with a spectral gamma ray sonde.

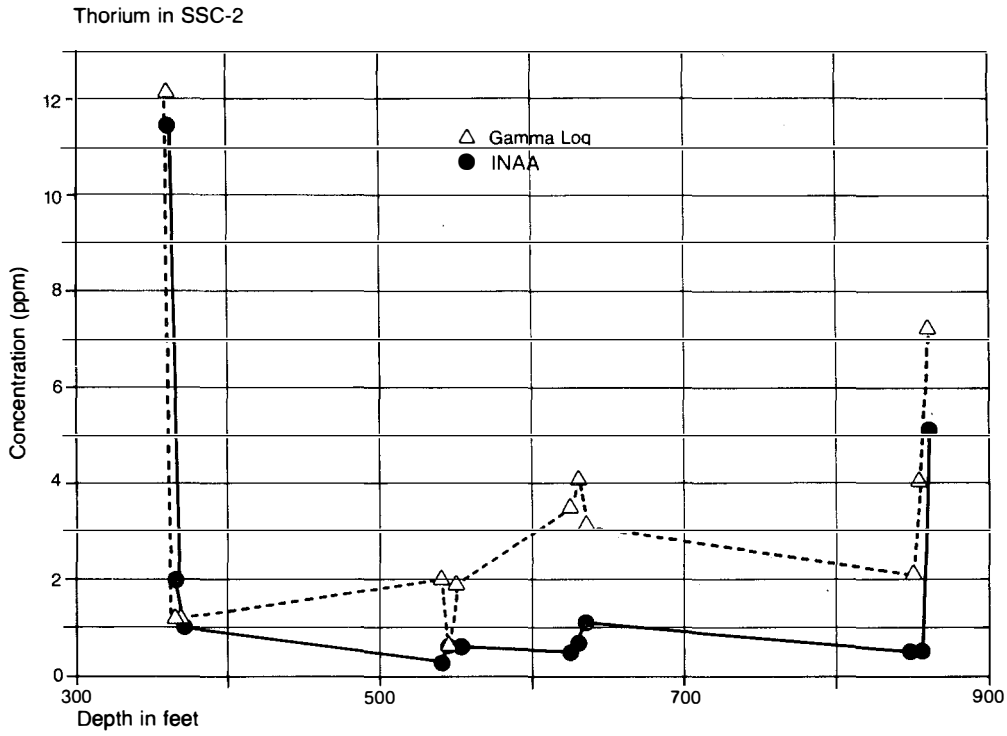


Figure 16. Concentrations of thorium (ppm) measured in geologic material in SSC-2. The plot compares laboratory instrumental neutron activation analyses on rock chips to in situ measurements with a spectral gamma ray sonde.

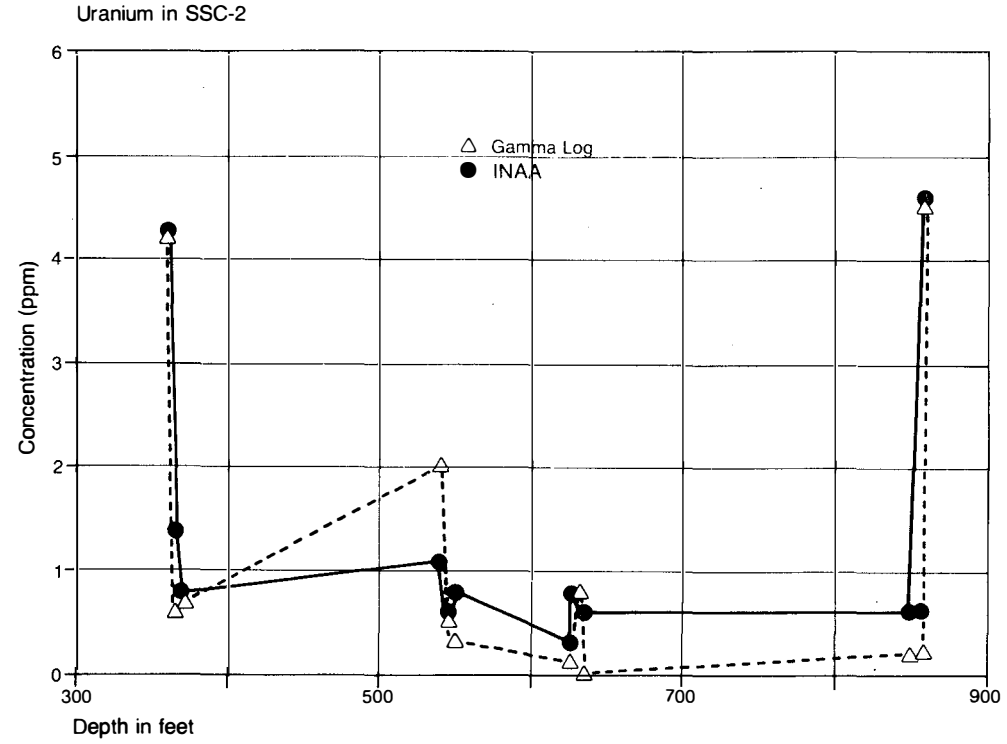


Figure 17. Concentrations of uranium (ppm) measured in geologic materials in SSC-2. The plot compares laboratory instrumental neutron activation analyses on rock chips to in situ measurements with a spectral gamma ray sonde.

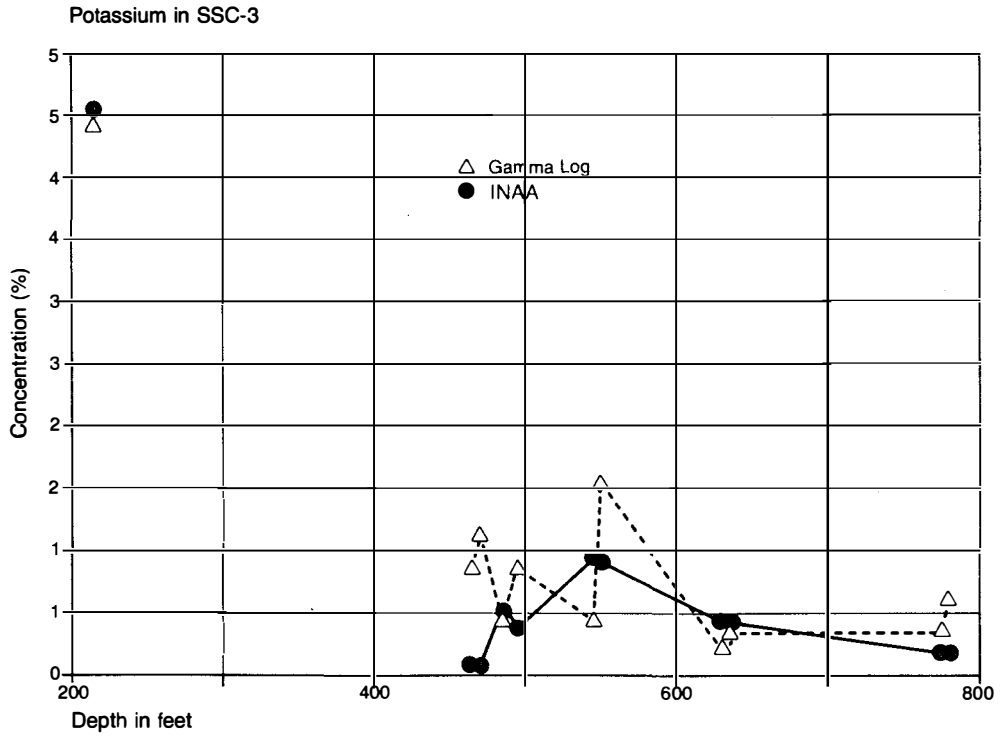


Figure 18. Concentrations of total potassium (%) measured in geologic materials in SSC-3. The plot compares laboratory instrumental neutron activation analyses on rock chips to in situ measurements with a spectral gamma ray sonde.

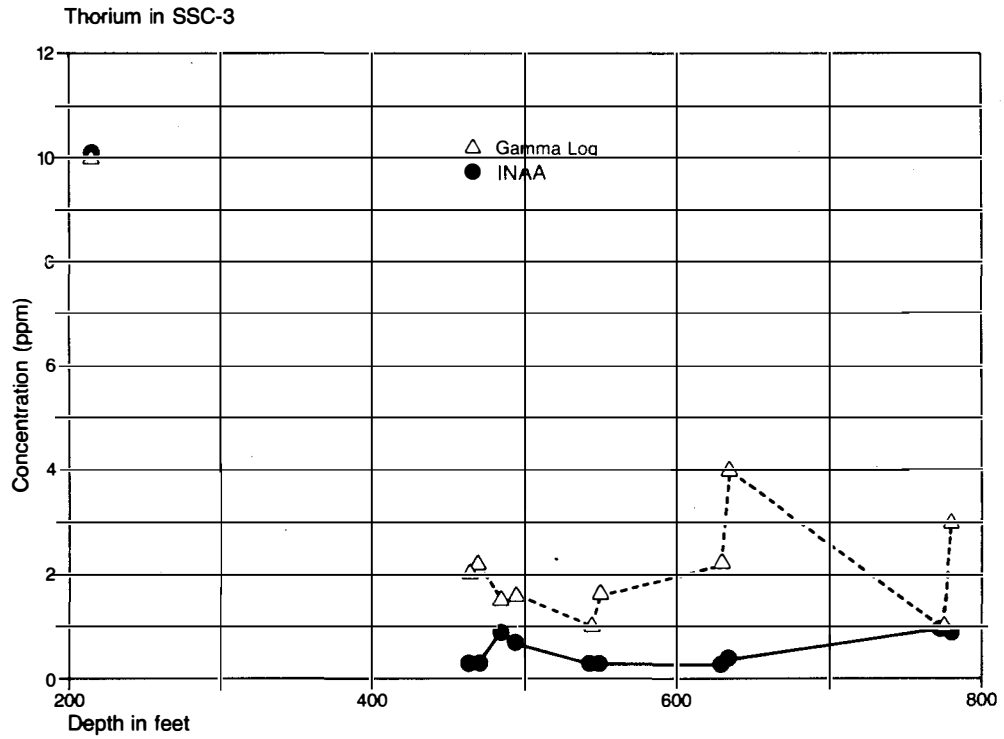


Figure 19. Concentrations of thorium (ppm) measured in geologic materials in SSC-3. The plot compares laboratory instrumental neutron activation analyses on rock chips to in situ measurements with a spectral gamma ray sonde.

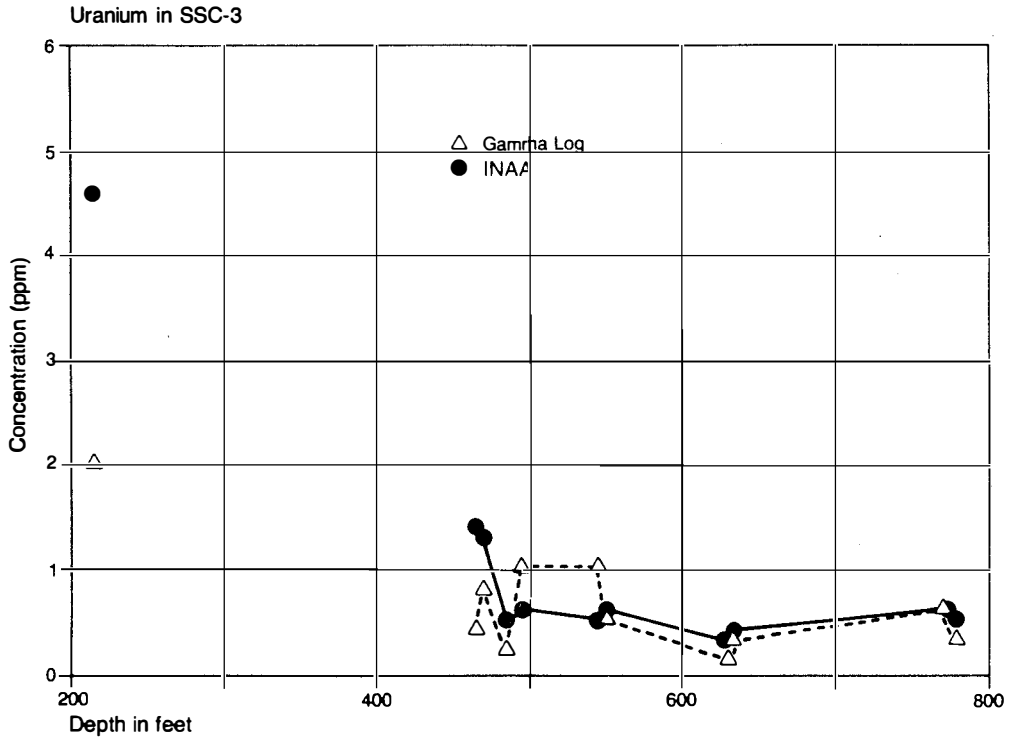


Figure 20. Concentrations of uranium (ppm) measured in geologic materials in SSC-3. The plot compare laboratory instrumental neutron activation analyses on rock chips to in situ measurements with a spectral gamma ray sonde.

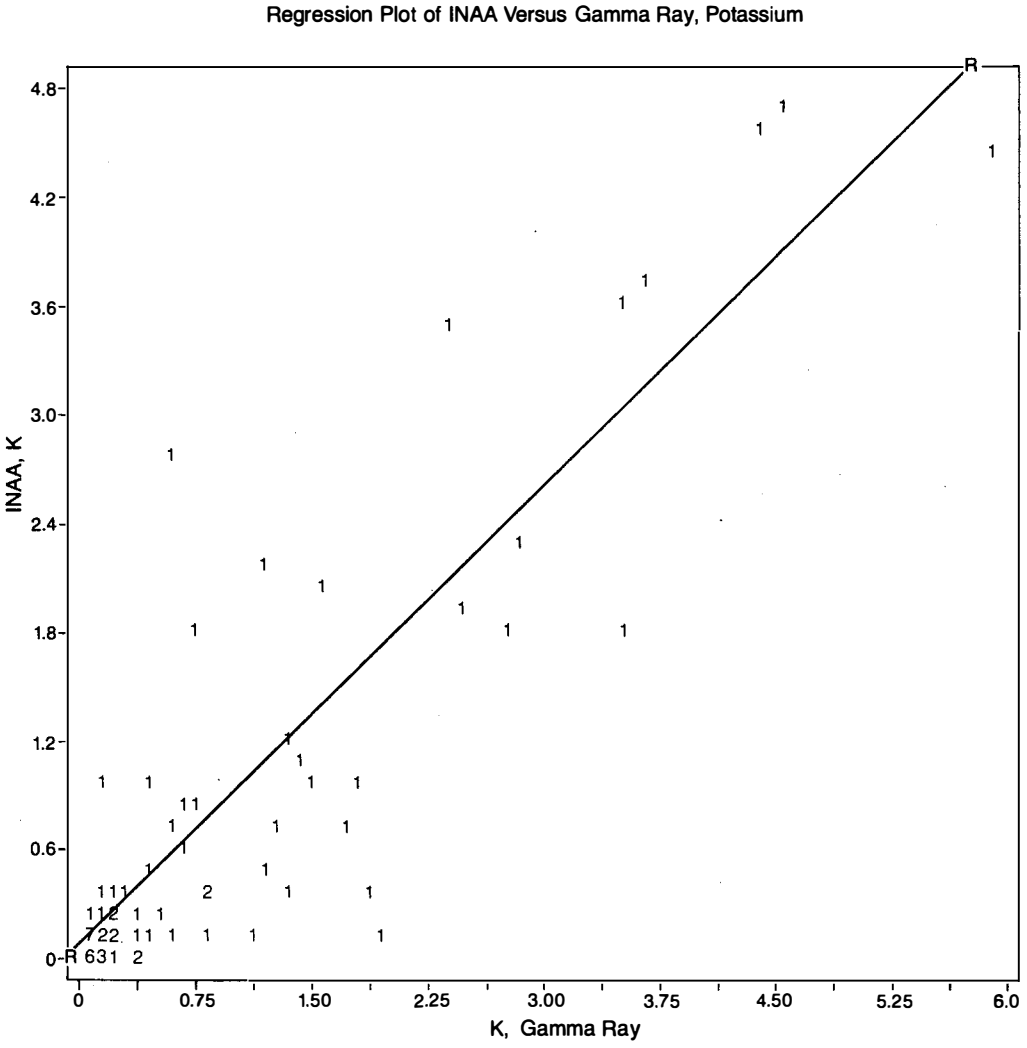


Figure 21. Plot of potassium concentrations measured with instrumental neutron activation analysis versus potassium concentrations measured in situ with a borehole spectral gamma radiation sonde. Regression analysis determined a correlation coefficient of 0.87448.

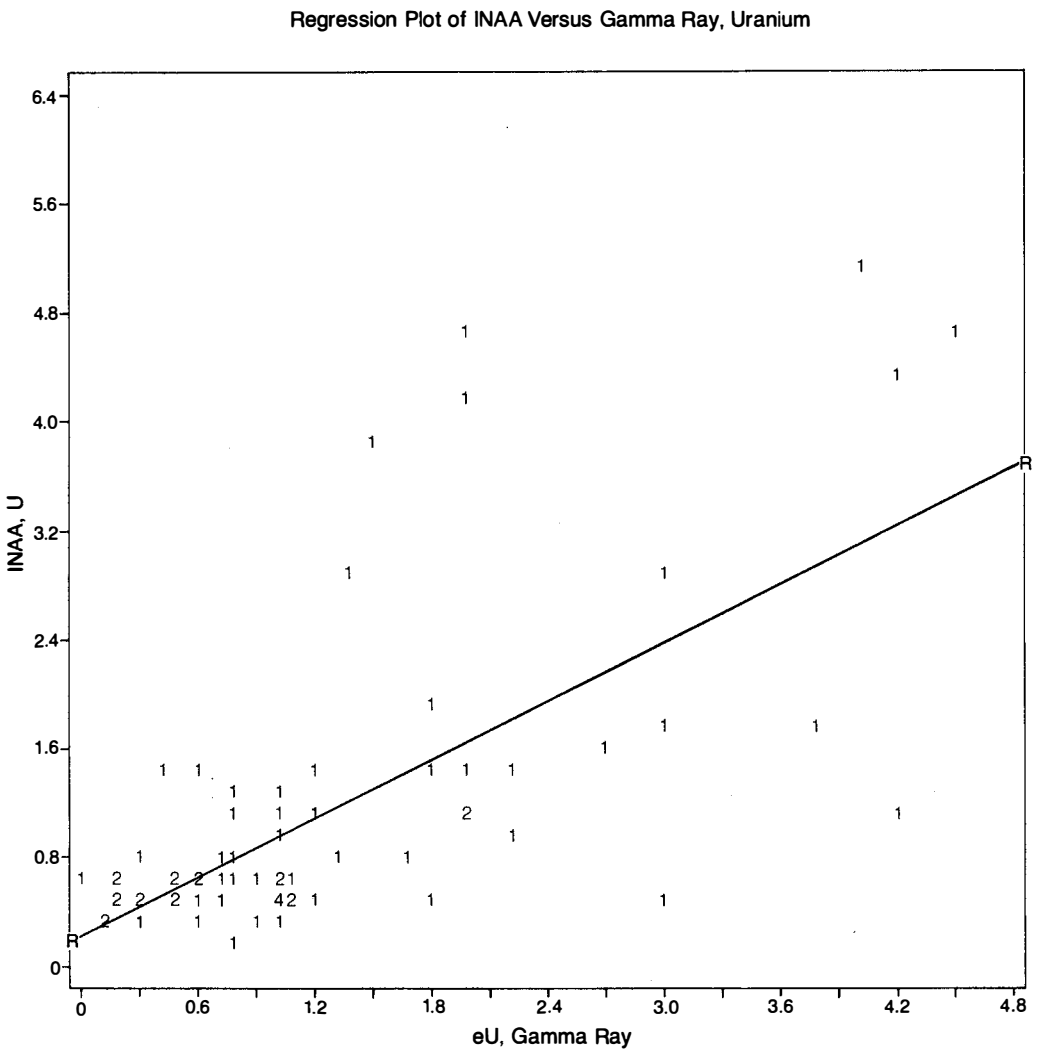


Figure 22. Plot of uranium concentrations measured with instrumental neutron activation analysis versus equivalent uranium concentrations measured in situ with a borehole spectral gamma radiation sonde. Regression analysis determined a correlation coefficient of 0.66951.

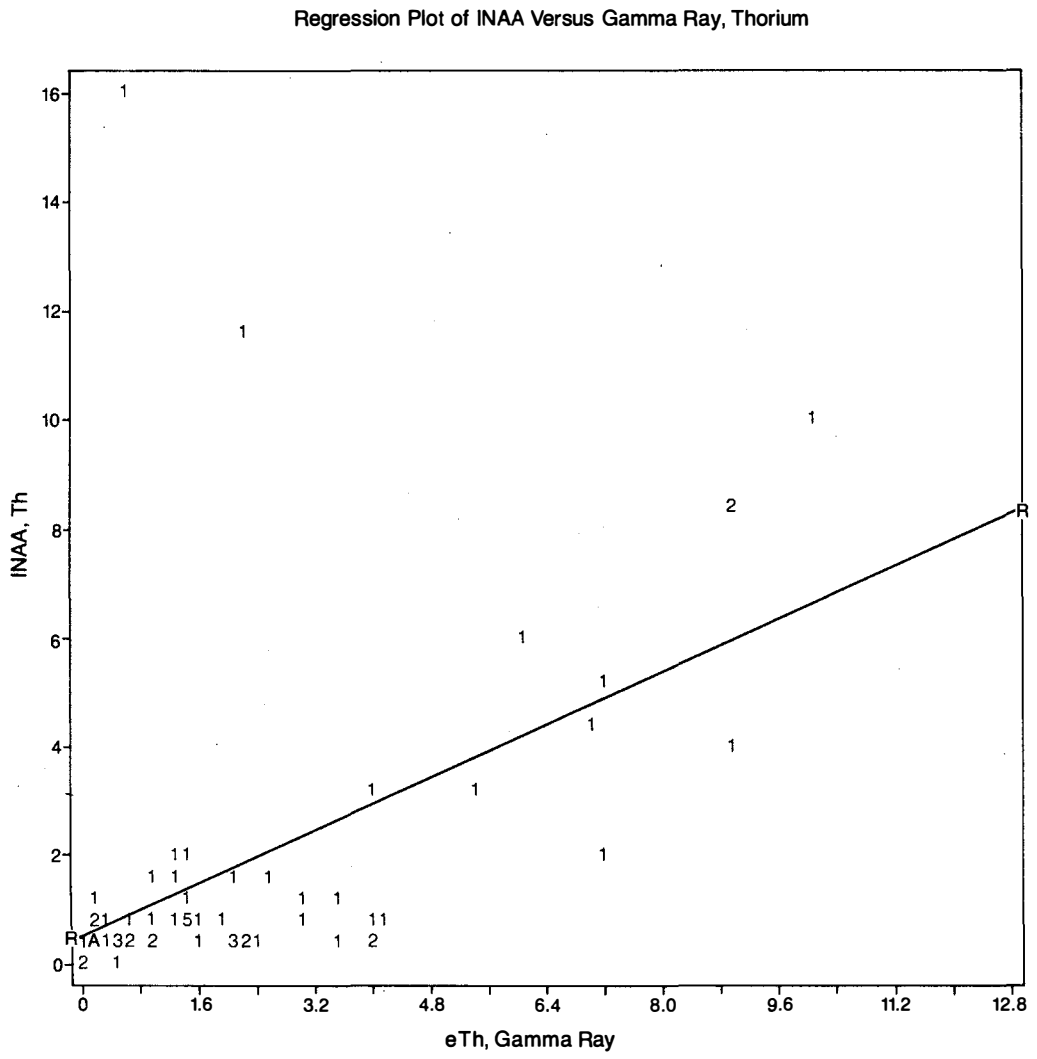


Figure 23. Plot of thorium concentrations measured with instrumental neutron activation analysis versus equivalent thorium concentrations measured in situ with a borehole spectral gamma radiation sonde. Regression analysis determined a correlation coefficient of 0.53413.

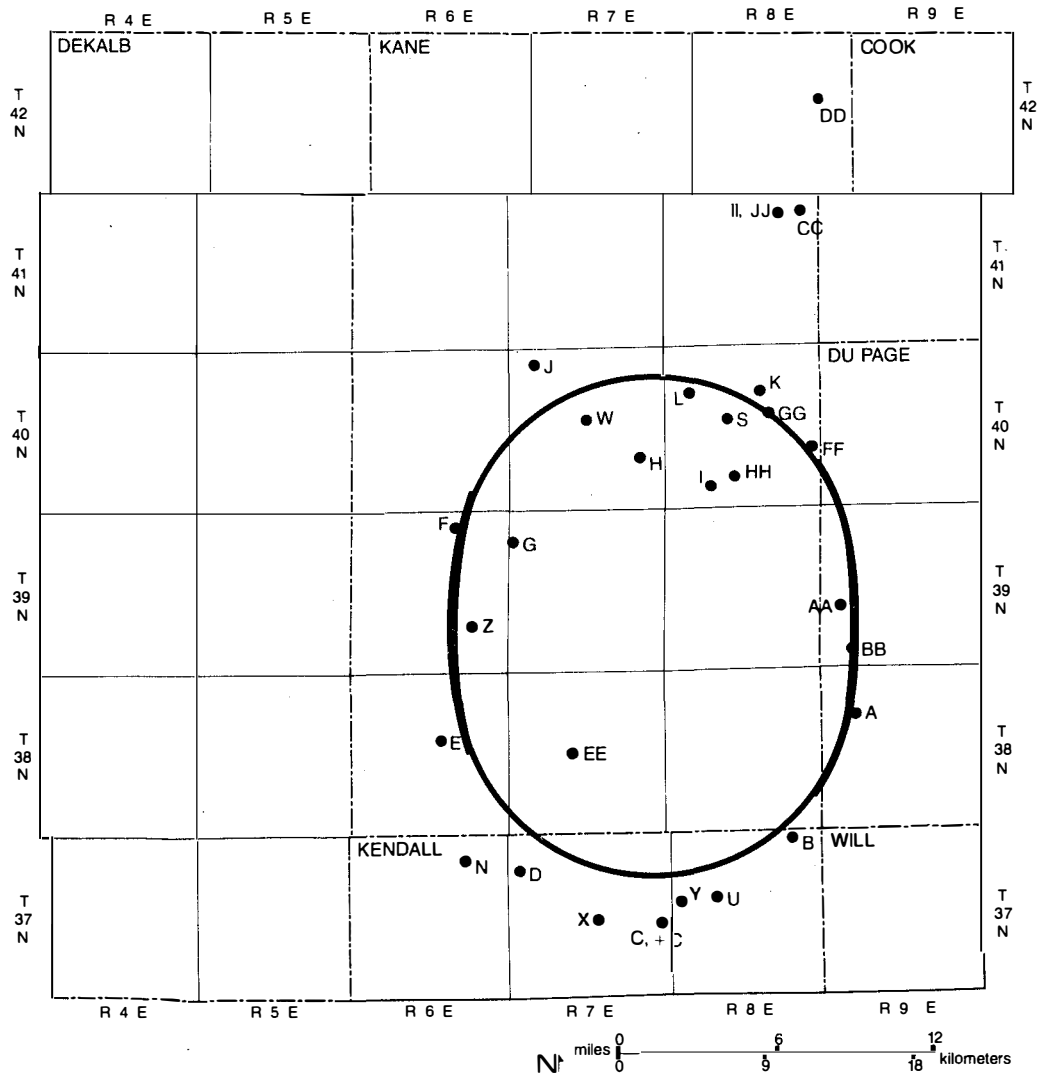


Figure 24. Map of the SSC study area showing the locations where groundwater samples were collected for analyses of natural radioactive elements. Analytical results are presented in table 8.

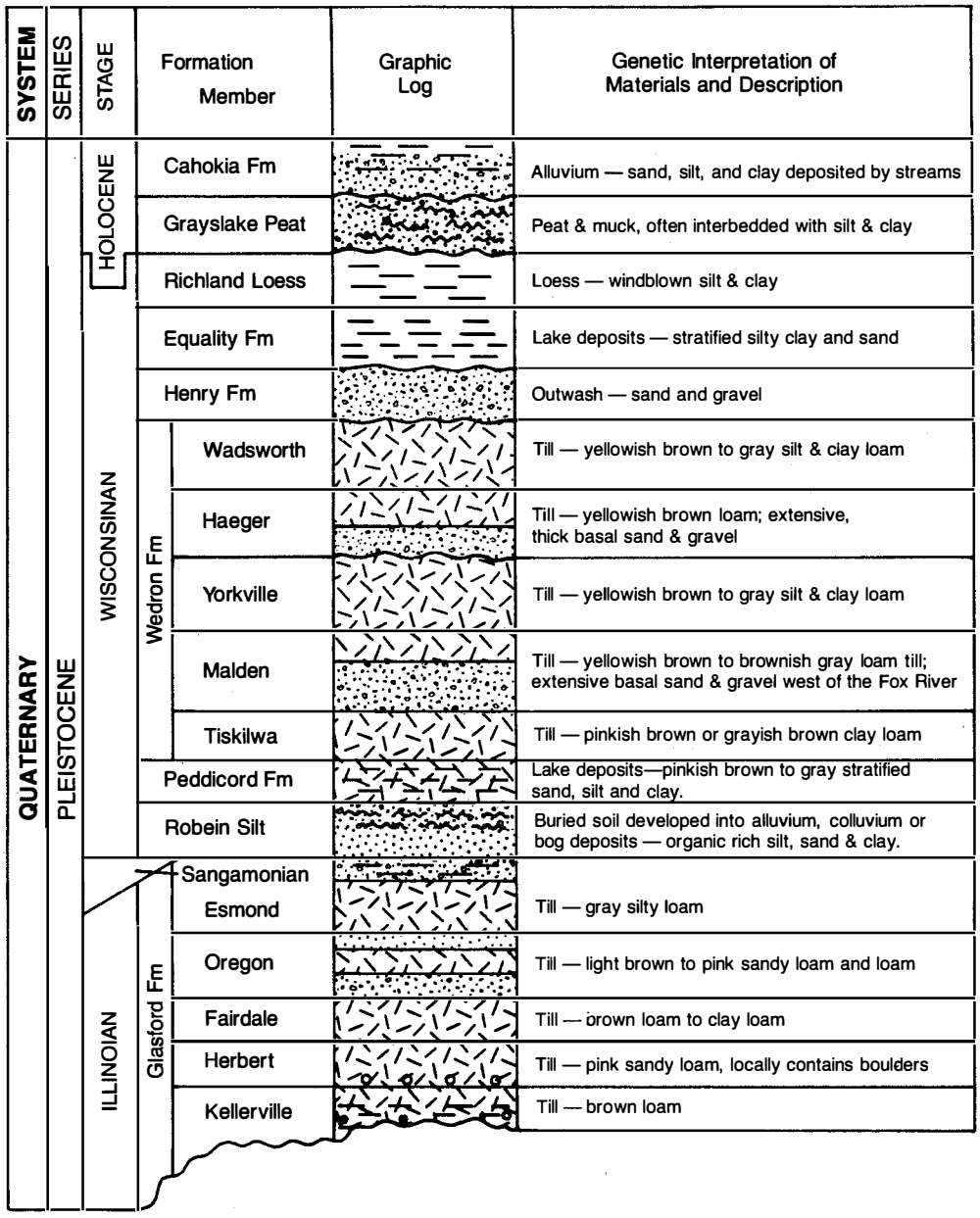


Figure 25. Stratigraphic column of drift (Quaternary) deposits in northern Illinois (from Kempton et al., 1985).

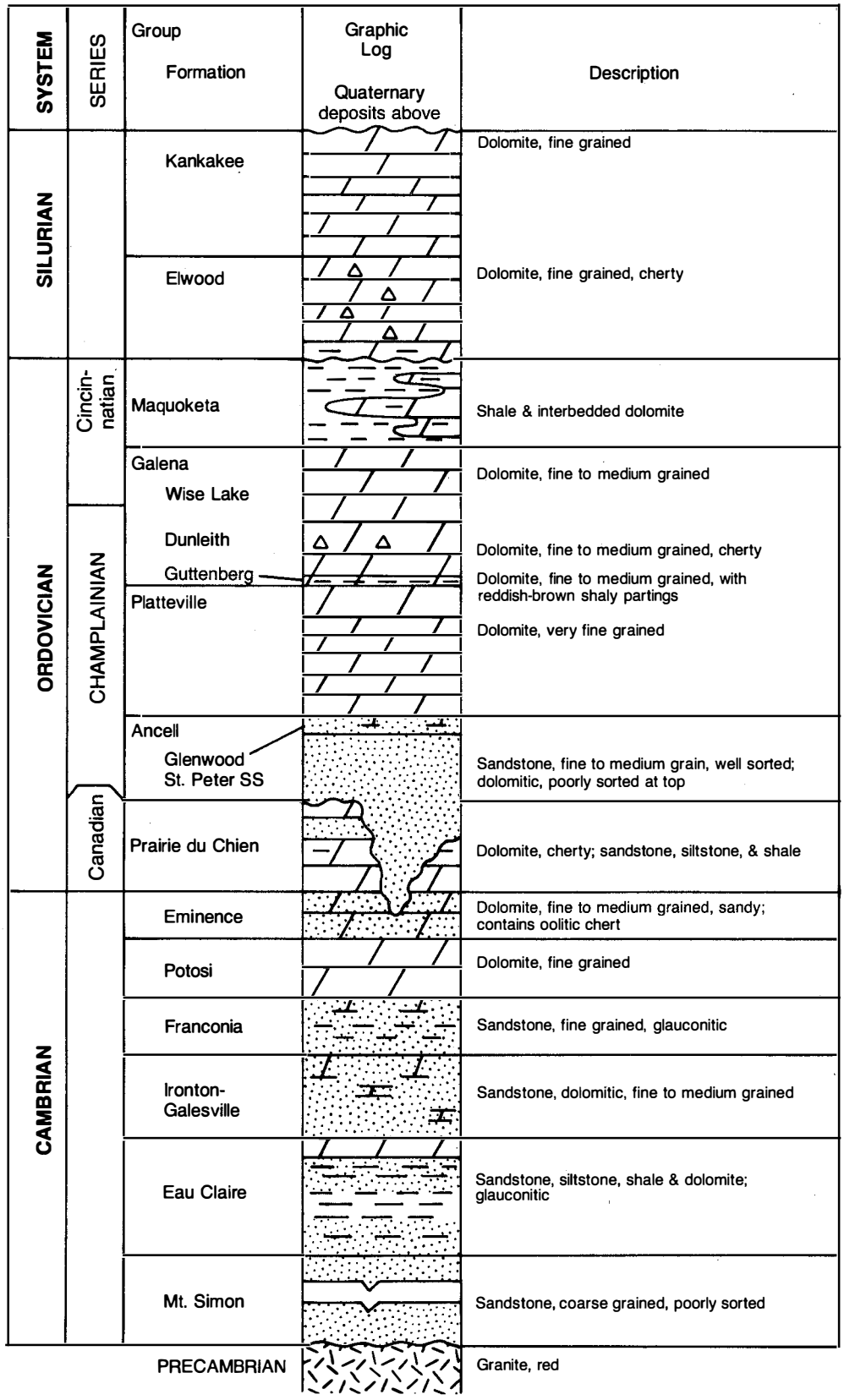


Figure 26. Stratigraphic column of bedrock units in the SSC study area (from Kempton et al., 1985).

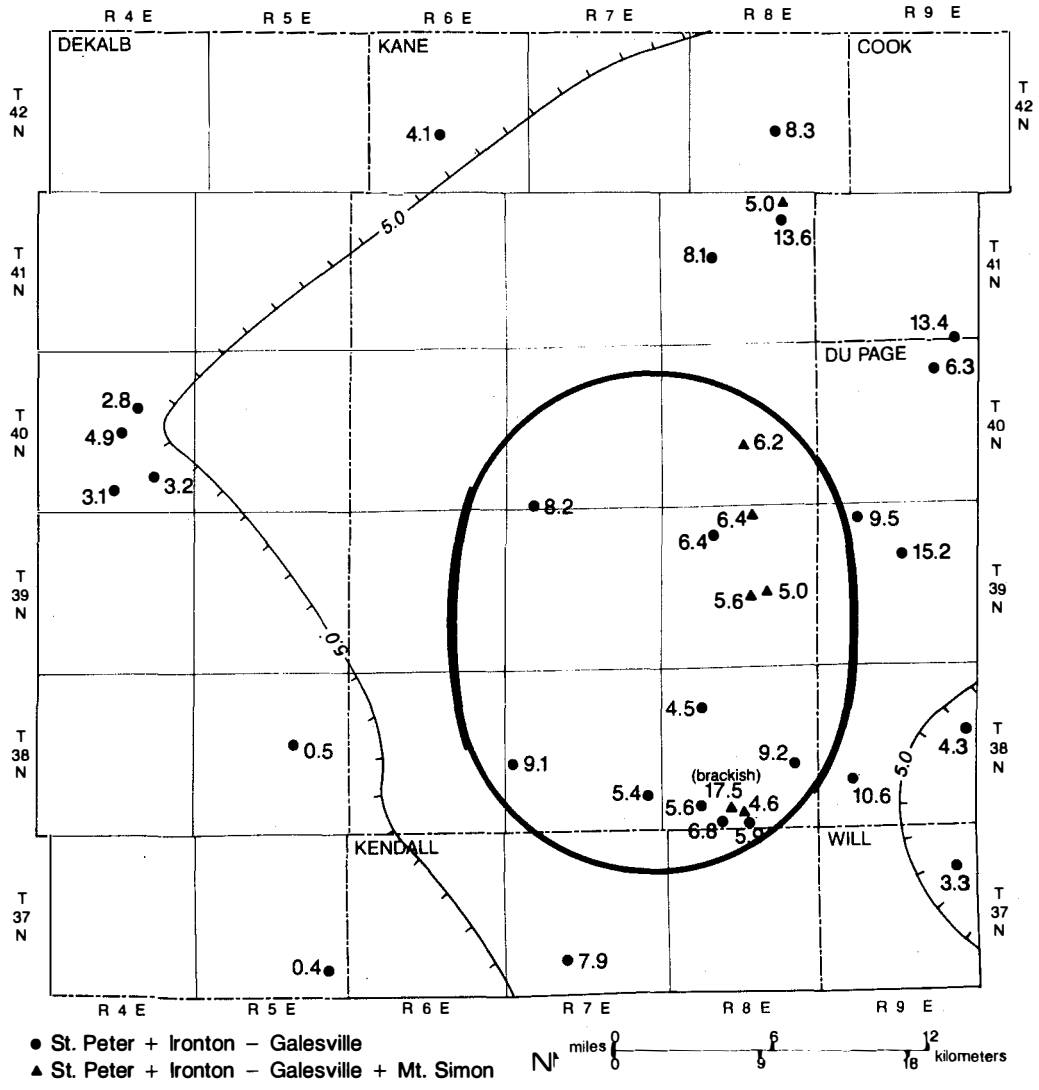


Figure27. Map of the region of the SSC study area showing variation of dissolved concentration of ^{226}Ra in groundwater from the Cambrian-Ordovician bedrock (principal aquifer is the Iron-Galesville Sandstone).

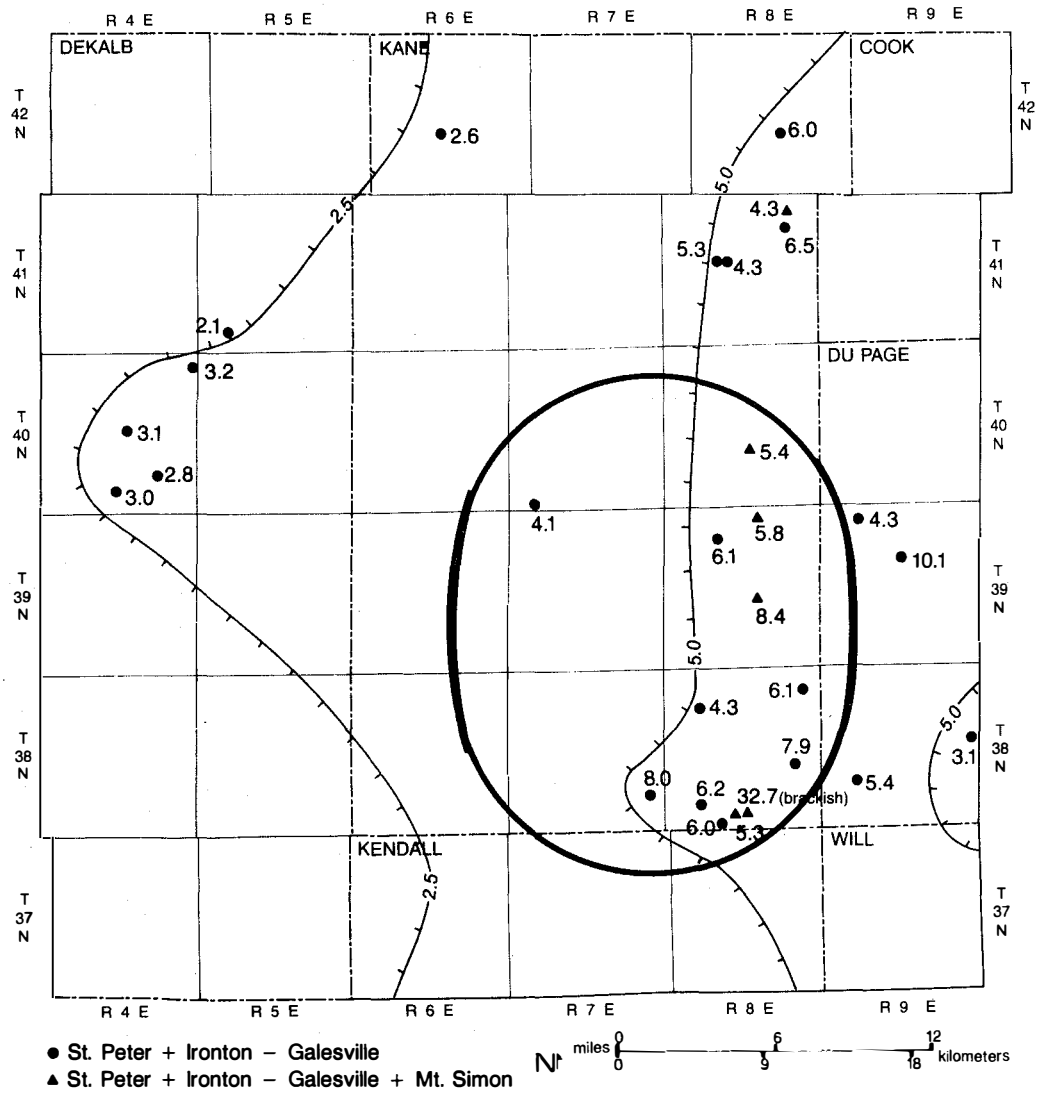


Figure 28. Map of the region of the SSC study area showing the dissolved concentration of ^{228}Ra in groundwater from the Cambrian-Ordovician bedrock (principal aquifer is the Ironton-Galesville Sandstone).

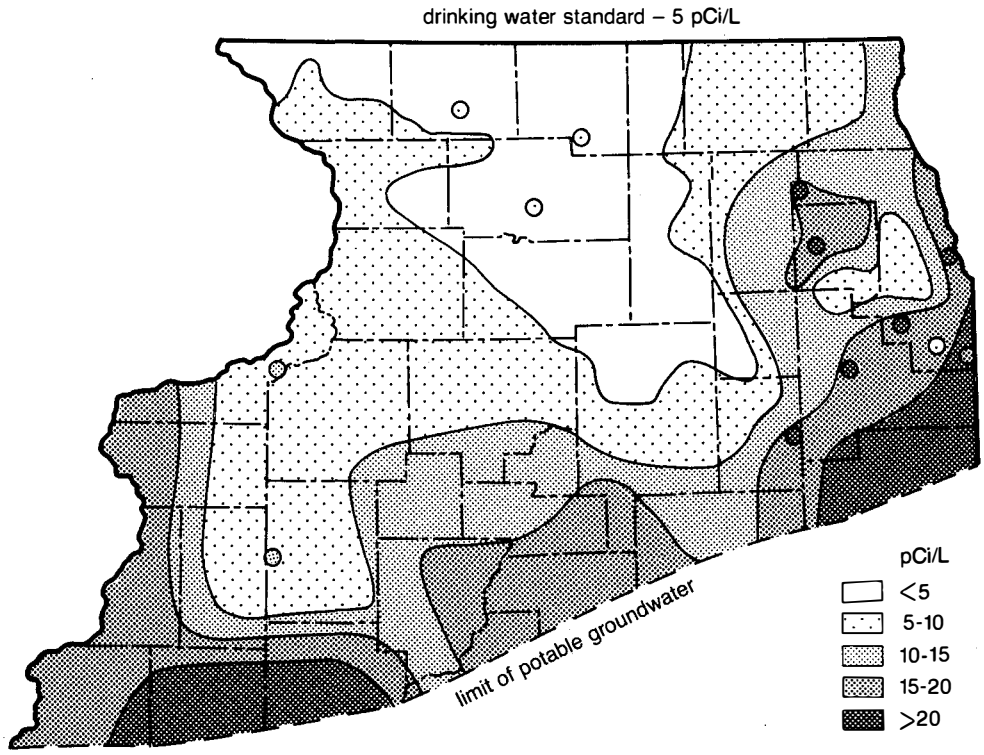


Figure 29. Map of northern Illinois showing the variation of dissolved concentration of ^{226}Ra plus ^{228}Ra in groundwater from the Cambrian-Ordovician bedrock (principal aquifer is the Ironton-Galesville Sandstone).

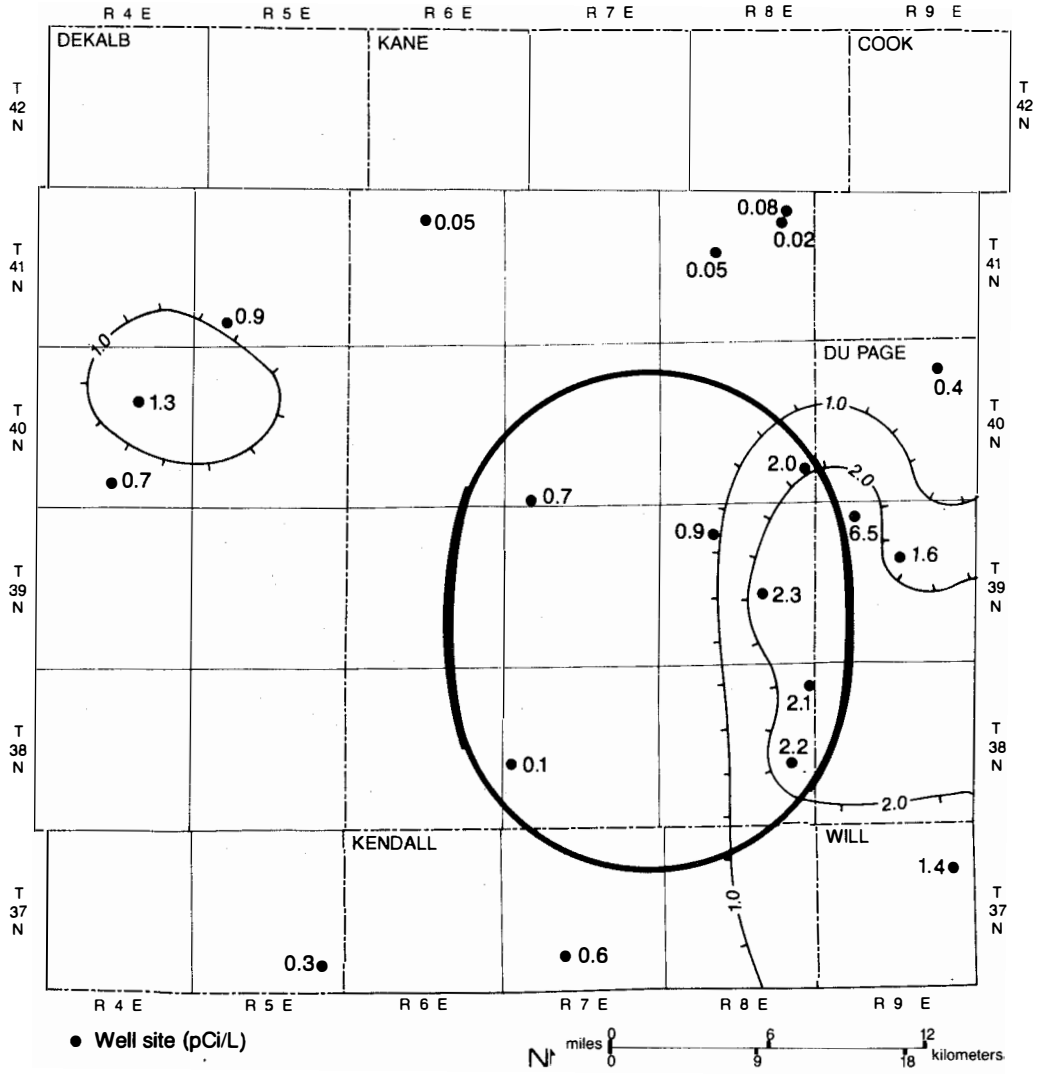


Figure 30. Map of the region of the SSC study area showing the variation of dissolved concentration of ^{234}U plus ^{238}U in groundwater from the Cambrian-Ordovician bedrock (principal aquifer is the Ironton-Galesville Sandstone).

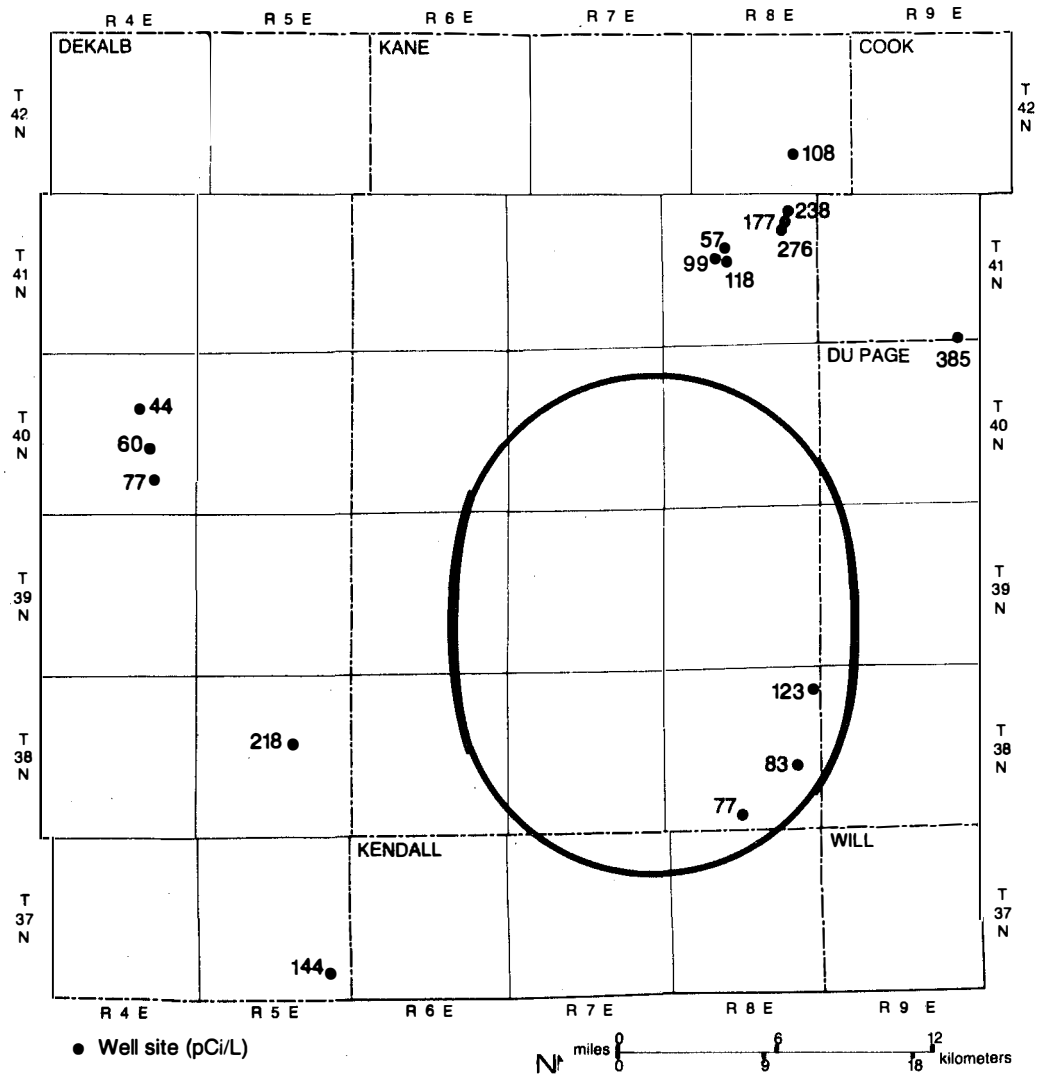


Figure 31. Map of the region of the SSC study area showing the variation of dissolved concentration of ^{222}Rn in groundwater from the Cambrian-Ordovician bedrock (principal aquifer is the Ironton-Galesville Sandstone).