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October 3, 1994

BY FEDERAL EXPRESS

Ms. Rebecca Frey
Mr. David P. Seely
Remedial Response Branch (HSRL-6J)
U.S. EPA, Region 5
77 West Jackson Blvd.
Chicago, IL 60604

Re: West Chicago Superfund Sites

Dear Rebecca and David:

As you know, Kerr-McGee Chemical Corporation ("Kerr-McGee") has submitted extensive comments on Region 5's contemplated removal program for the West Chicago Residential and Kress Creek Sites. Among other things, these comments describe the expected variability of natural background radiation in the West Chicago area and the importance of accounting for such variability during the removal program. See Section-by-Section Comments of Kerr-McGee Chemical Corporation on the Engineering Evaluation/Cost Analysis -- Kerr-McGee Residential Areas Site and Portions of the Kress Creek Site In and Near West Chicago, Illinois, 12-15, 17-19 (Sept. 16, 1994). See also Comments of Kerr-McGee Chemical Corporation on the Action Criteria for Superfund Removal Actions, West Chicago, Illinois and the Associated Fact Sheet, 21-23, 33-33, 37-38 (Mar. 29, 1993).

I am writing to bring to your attention a draft Regulatory Guide that has recently been issued by the U.S. Nuclear Regulatory Commission ("NRC") in connection with its rulemaking to establish criteria for decommissioning of NRC-licensed facilities. NRC, Background as a Residual Radioactivity Criterion for Decommissioning, Chapter 2 (NUREG-1501) (Draft Report) (Aug. 1994) (copy attached). The draft guide provides a valuable discussion of the wide variations in background radiation that are observed in a

variety of circumstances. That discussion reflects the NRC's expert recognition of the important role background variability must play in the design of radiation cleanup standards. It shows the impracticality of establishing cleanup standards at background levels and demonstrates the infeasibility of EPA's contemplated application of ALARA.

I would appreciate it if you would include this letter and the enclosure in the administrative record that you have established for the West Chicago sites. Please call if you have any questions.

Very truly yours,

Richard A. Meserve

Counsel for Kerr-McGee
Chemical Corporation

cc: Marc M. Radell, Esq.

NUREG-1501

Background as a Residual Radioactivity Criterion for Decommissioning

Appendix A to the Generic Environmental Impact Statement in Support of Rulemaking on Radiological Criteria for Decommissioning of NRC-Licensed Nuclear Facilities

Draft Report

Manuscript Completed: July 1994
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2 OVERVIEW OF BACKGROUND RADIATION

2.1 Introduction

A number of the elements, present on Earth since its formation, have unstable forms that transmute to other elements in a process called radioactive decay. In this process, energy is released in the form of radiation. This energy can take the form of subatomic-size particles such as alpha and beta particles, or it can be in the form of electromagnetic energy such as x-ray and gamma rays, which are sometimes referred to as "photons." These forms of radiation fall in a category called ionizing radiation, meaning they can create electrical charge when they interact with matter.

Another source of ionizing radiation in our environment originates in outer space, producing particles in the atmosphere that penetrate to ground level. This radiation is energetic enough to also create new radioactive elements by interacting with otherwise stable elements present on Earth. Everything on the planet, including every living thing, is bathed in a sea of radiation from these various sources. This is commonly referred to as "natural background," "background radiation," or more simply, "background."

For perspective, a handful of typical garden soil contains several billion billion unstable atoms that over time will ultimately decay to a stable form. Each second, scores of these atoms undergo this decay process and emit radiation. In a typical environment, thousands of gamma rays impinge on the body each second. The air that people breathe contains naturally occurring radioactivity, and even a person's body contains natural radioactive elements that tend to concentrate in certain tissues, according to their respective chemistry.

In addition to natural sources of radiation, people are exposed to man-made sources of ionizing radiation. Perhaps the most commonly known is x-rays, which are used in dental and medical examinations. Despite this and other sources of ionizing radiation that have been produced during the technological developments of the 20th century, background remains the principal source of exposure for most people. In this and the following sections of this report, the various sources of background, their degree of variability, and the manner in which they are measured and distinguished from man-made sources of radiation will be examined in some detail.

2.1.1 Units of Measurement

To understand background and the significance of its various components, it is necessary to deal with various units of measurement. The degree of radioactivity of a material is a measure of the rate at which its atoms are undergoing decay. For a chemically pure radioactive substance, the decay rate can be calculated from the amount of material and the half-life of that particular radionuclide. The current internationally recognized unit is called the "becquerel" (abbreviated as Bq), which is one disintegration of an atom per second.

Older style units such as the "curie" (abbreviated as Ci) are sometimes still used. Frequently, the concentration of radioactivity in a medium such as soil, water, or air is given, in which case the unit may take such forms as Bq per gram, per liter, or per cubic meter. Frequently, the prefixes milli (one-thousandth), abbreviated as "m," and micro (one-millionth), abbreviated as "μ," are used with radiation units.

2.1.1.1 Units of Measurement for External Radiation

Apart from the measurement of the rate at which a substance is undergoing decay, there is the measurement of the effect of the emitted radiation at some distance from the radioactive material. This can be in terms of the amount of electric charge that is created in air ("roentgen" in the old system, abbreviated as "R," or coulombs per kilogram in the new system, abbreviated as C/kg) or the energy that is transferred to surrounding matter ("rads" in the old system, or "grays" in the new system, abbreviated as "Gy").

2.1.1.2 Units of Measurement for Internal Radiation

When the energy released from a radioactive material is absorbed by body tissues, the energy is transmitted to cells and surrounding fluids and noncellular structures. This absorbed energy has the potential to cause damage at a microscopic level, the effects of which could be immediate (cell death) or delayed (cancer). To provide a common footing in the measurement of different types of radiation and their effects on different parts of the human body, be it from sources external or internal to a person, scientists have introduced a quantity known as the effective dose equivalent, which has lately become known simply as the effective dose. In the current internationally accepted system, the unit is the "sievert" (abbreviated as Sv). The old system of units used "rem," which is equal to one hundredth of a sievert.

2.2 Sources of Radiation

Background is comprised of four major sources (or components) of ionizing radiation. The first source discussed in this report is terrestrial radiation, which produces the largest dose to people living in the Unites States. The remaining components of background, which are cosmic. cosmogenic, and man-made radiation sources, are relatively minor contributors to the dose from background compared to terrestrial radiation. Each of these sources is discussed in the next four sections of this report to give the reader a basic understanding of their origins, physical properties, and relative contributions to the total background dose rate.

2.2.1 Terrestrial Radiation

The naturally occurring forms of radioactive elements that were incorporated into Earth during its formation and that are still present are referred to as "terrestrial radionuclides." Virtually all materials found in nature have some degree of natural radioactivity. Rocks, soil, water, air, plants, and animal life all have varying concentrations of terrestrial radionuclides. The most significant of these are uranium-238 and thorium-232, which both decay in a long chain (or series) of various radionuclides, and potassium-40 and rubidium-87, which have much simpler decay schemes. These principal radionuclides and their decay products, which are commonly referred to as "progeny," are listed in Table 2.1 along with their corresponding half-life, which is the average amount of time it takes for half of the atoms of that radionuclide to undergo decay. The listing is given in order to indicate the immediate parent and decay product for each radionuclide. This table also gives the major types of radiation given off in the decay of each radionuclide. Among these, alpha radiation is the least penetrating, beta radiation and x-rays are somewhat more penetrating, and gamma radiation is the most penetrating.

Table 2.1. Principal Natural Radionuclide Decay Series

Nuclide	Half-Life	Major Radiations
Uranium-238	4.47 billion years	alpha, x-rays
Thorium-234	24.1 days	beta, gamma, x-rays
Protactinium-234m	1.17 minutes	beta, gamma
Uranium-234	245,000 years	alpha, x-rays
Thorium-230	77,000 years	alpha, x-rays
Radium-226	1600 years	alpha, gamma
Radon-222	3.83 days	alpha
Polonium-218	3.05 minutes	alpha
Lead-214	26.8 minutes	beta, gamma, x-rays
Bismuth-214	19.7 minutes	beta, gamma
Polonium-214	164 microseconds	alpha
Lead-210	22.3 years	beta, gamma, x-rays
Bismuth-210	5.01 days	beta
Polonium-210	138 days	alpha
Lead-206	stable	
Thorium-232	14.1 billion years	alpha, x-rays
Radium-228	5.75 years	beta
Actinium-228	6.13 hours	beta, gamma, x-rays
Thorium-228	1.91 years	alpha, gamma, x-rays
Radium-224	3.66 days	alpha, gamma
Radon-220	55.6 seconds	alpha
Polonium-216	0.15 seconds	alpha
Lead-212	10.64 hours	beta, gamma, x-rays
Bismuth-212	60.6 minutes	alpha, beta, gamma, x-rays
Polonium-212	0.305 microseconds	alpha
Thallium-208	3.07 minutes	beta, gamma
Lead-208	stable	
Potassium-40	1.28 billion years	beta, gamma
Argon-40	stable	
Calcium-40	stable	
Rubidium-87	47 billion years	beta
Strontium-87	stable	

Two of the more commonly known radioactive elements in Table 2.1 are radium, which was discovered by Marie Curie and used extensively for luminous watch dials and medical treatments years ago, and radon, a gaseous decay product of radium for which many people now have their homes tested. Another long-lived nuclide not listed here that has a series decay scheme is uranium-235. This radionuclide occurs in nature at a concentration of less than 1 percent of the more abundant uranium-238 and is therefore much less significant in terms of its contribution to background. A number of other less abundant radionuclides can be found in nature; however, they exist in such low concentrations that their contributions to background are negligible.

As an example of the range of concentrations for naturally occurring radionuclides that can be found on Earth, Table 2.2 gives information that has been collected by researchers around the world for the uranium-238 and thorium-232 series and potassium-40. Although the ranges given in this table are typical for soil, even larger variation is possible in certain mineral-rich areas. The concentrations of uranium and thorium in ore-grade deposits of these elements would of course be orders of magnitude higher than the values in these tables.

Table 2.2. Typical Ranges in Average Concentration of Background Radionuclides (Bq per kg)

Material	Uranium-238	Thorium-232	Potassium-40	Reference
Bauxite ore	250	200	n/a	UNSCEAR, 1988
Coal, U.S.	18 (1-540)	21 (2-320)	52 (1-710)	Beck et al, 1980
Copper ore	30-80	23-110	n/a	UNSCEAR, 1988
Crustal rock, U.S.	36	44	850	NCRP, 1987b
Oil shale	56 (37-74)	24 (19-37)	481 (185-962)	Gogolak, 1982
Phosphate fertilizer, U.S.	9200	n/a	n/a	UNSCEAR, 1988
Soil, worldwide	25 (10-50)	25 (7-50)	370 (100-700)	UNSCEAR, 1988
Soil, U.S.	37 (4-141)	36 (4-126)	n/a	Myrick, 1983

Since many people spend most of their time indoors, radiation exposure from background is very much affected by the concentrations of the naturally-occurring radionuclides in building materials. Table 2.3 gives the radionuclide content for some building materials used in the United States. Wood, a principal component in a light frame structure (e.g., a typical home) would generally have negligible natural radionuclide concentrations as compared with stone and masonry materials. As an example of data collected from around the world, Table 2.4 gives radionuclide concentrations for common brick.

Table 2.3 Natural Radionuclide Content of Some Building Materials for the United States (Bq per kg)

Material	Uranium-238 (Radium-226)	Thorium-232	Potassium-40	Reference
Adobe Brick	31	27	583	Ingersoll, 1981
Brick	4-178	1-144	7-1184	Eichholz et al, 1980
Concrete	19-89	15-118	262-1147	"
Concrete Block	41-777	37-81	285-1147	"
Gypsum	13	2	61	Ingersoll, 1981
Red Brick	45	42	522	"
Rock, Storage	57	53	921	"

Table 2.4. Natural Radionuclide Contents of Bricks
(Bq per kg)

Country (type)	Uranium-238 (Radium-226)	Thorium-232	Potassium-40	Reference
Canada (various)	4–120	8–160	200–800	Zikovsky, 1992
Finland (red)	78	62	962	NEA, 1979
Germany (traditional)	59	67	673	"
India	48	26	3	Ramachandran, 1989
Italy (various)	28–81	40–148	365–1060	Bruzzi, 1992
Norway	104	62	1058	NEA, 1979
Sweden	96	127	962	"
United Kingdom (clay)	52	44	703	"

2.2.2 Cosmic Radiation

Cosmic radiation, commonly known as cosmic rays, consists of highly energetic particles, mostly the nuclei of the elements hydrogen and helium. Supernova explosions and other phenomena that occur throughout the universe are believed to be the source and driving force of cosmic rays. When they enter Earth's upper atmosphere, they undergo interactions that lead to the production of charged particles, gamma rays, and neutrons (uncharged particles that are principal constituents of the nuclei of atoms).

Decay and additional interactions ultimately lead to a makeup of "secondary" radiation near the surface of Earth that consists mainly of directly ionizing muons and electrons with a smaller proportion of neutrons that indirectly ionize matter. Although interactions with the atmosphere cause the secondary production of cosmic rays, the air surrounding Earth nonetheless serves as an important shield to living things. Without this shield, the more energetic primary cosmic ray particles would reach Earth's surface.

Another source of radiation from space is charged particles that are associated with flares on the sun. On rare occasions, a solar flare is strong enough to produce a significant radiation dose in the lower reaches of Earth's atmosphere.

2.2.3 Cosmogenic Radiation

Cosmic radiation, which itself leads to a direct radiation dose to people, is also responsible for the production of radioactive elements called "cosmogenic" radionuclides. These radionuclides arise from the collision of the highly energetic cosmic ray particles with stable elements in the atmosphere and in the ground. Many different cosmogenic radionucludes are produce, although the most important is carbon-14. Other less significant cosmogenic radionuclides include hydrogen-3 (also known as tritium), beryllium-7, and sodium-22. Concentrations of these cosmogenically produced nuclides in the air and ocean water are given in Table 2.5. Another source of cosmogenic radionuclides is extraterrestrial matter that intercepts and is captured by Earth's orbit. This contribution is very small,

however, and can be ignored. The entire cosmogenic contribution to background is very small compared with that of the terrestrial and cosmic components.

Table 2.5. Concentrations of Principal Cosmogenically Produced Radionuclides[1]

Nuclide	Troposphere (Bq/kg air)	Oceans (Bq/kg water)
Beryllium-7	0.01	n/a
Carbon-14	n/a	5×10^{-3}
Hydrogen-3	1.2×10^{-3}	n/a
Sodium-22	1×10^{-6}	n/a

[1] From NCRP (1987b).

2.2.4 Man-Made Sources

Human activities have resulted in the production of various sources of radiation. Nuclear reactors and weapons have produced large quantities of radionuclides through the fissioning of uranium and other heavy elements and the activation of various elements. Particle accelerators used in scientific research have produced smaller quantities. Although most of these radionuclides are short lived and quickly decay to stable forms, a few have half lives of several to thousands of years. In this category are cesium-137, strontium-90, the gas krypton-85, and various isotopes of plutonium that have been deposited throughout the globe as the result of nuclear weapons tests conducted in the atmosphere. Concentrations of cesium in surface soil might typically be about a few Bq per kg; however, values as high as 740 Bq per kg have been found from weapons test fallout (Miller and Helfer, 1985).

The global inventory of the naturally produced cosmogenic radionuclides carbon-14 and hydrogen-3 have also been increased through human activities in the nuclear field. Although not "natural," these sources of radiation have very much become part of the background to which humans are exposed. It is sometimes necessary to separately measure these globally distributed radionuclides and to distinguish them from locally produced sources.

2.3 Variability of Background

This section of the report is intended to give the reader a better understanding of the causes and magnitude of background variability. Although background is ubiquitous, each of its components and the corresponding dose they deliver to the United States resident is by no means constant. Background variability can result from natural means, whether terrestrial or extraterrestrial, and human activities. The following sections discuss the causes of variation and the temporal and spatial variability of background for each of its major components.

2.3.1 Causes of Variation

For terrestrial radiation, changes to the land and the makeup of the radionuclide content of soil can result from geophysical phenomena such as mountain formation, earthquakes, volcanoes, glaciers, and changes in ocean levels and river courses and flood plains. On shorter time scales, the outdoor

radiation field is affected by climate and weather through the action of precipitation and wind. Human activities such as soil excavation, building construction, mining, nuclear power production, and fossil fuel combustion can alter the radiation field. To a large extent, humans affect their exposure to inhaled radioactivity from radon with the degree and type of ventilation they use inside homes, schools, and workplaces. Humans also alter the dietary intake of radioactivity through regional, countrywide, and even worldwide food distribution.

The intensity of cosmic radiation depends upon the degree of shielding provided by the atmosphere. It thus depends upon altitude and barometric pressure. Shielding provided by the structures that people inhabit, particularly large apartment and office buildings, reduces cosmic ray exposure. Earth's magnetic field also deflects the incoming cosmic ray particles, and the temperature of the atmosphere has some effect as well. The sun goes through cycles (with a period of about 11 years) that modulate cosmic radiation through interactions with solar wind and magnetic disturbances. The frequency and intensity of solar flares is also tied to the solar cycles.

The production rate of cosmogenic radionuclides depends upon the intensity of the cosmic radiation. Thus, the same phenomena observed with cosmic ray variations can be expected for the rate at which cosmogenic radionuclides are created. Because some of these radionuclides are long-lived, however, the overall amount present on Earth does not change over the short term. Rather, local variations result after atmospheric mixing occurs, and these radionuclides are deposited to Earth's surface according to seasonal precipitation patterns around the globe.

The variability of man-made sources of radiation and radioactivity relates directly to the population distribution and level of technology found in different areas around the world. In some cases, locally produced radioactive materials are dispersed throughout the Earth's atmosphere, land areas, and water bodies. The level of deposition in an area, as in the case of cosmogenic radionuclides, depends upon wind and precipitation patterns.

The temporal and spatial variability of each of the major components of background is discussed separately in the following sections.

2.3.2 Temporal Variability

2.3.2.1 Terrestrial Radionuclides

The changes in background radioactivity concentrations and radiation levels that are associated with various physical phenomena occur on time scales ranging from short duration (hours to days) to medium duration (months and years) to long duration (centuries or more). While only general effects can be predicted for long term changes based on our understanding of geological processes and the history of Earth, a good deal of knowledge has been gathered in recent years on short and medium duration effects by actually measuring the level of radiation at environmental monitoring stations.

2.3.2.1.1 External Terrestrial Radionuclides. The radiation coming from background sources external to the body has been observed to change over time periods ranging from minutes to months. Data collected at the Chester Regional Baseline Station, a rural field site in western New Jersey, is used here to demonstrate the degree of variability (EML, 1978, 1979, 1980, 1981, 1982, 1984, 1985, 1988, 1991).

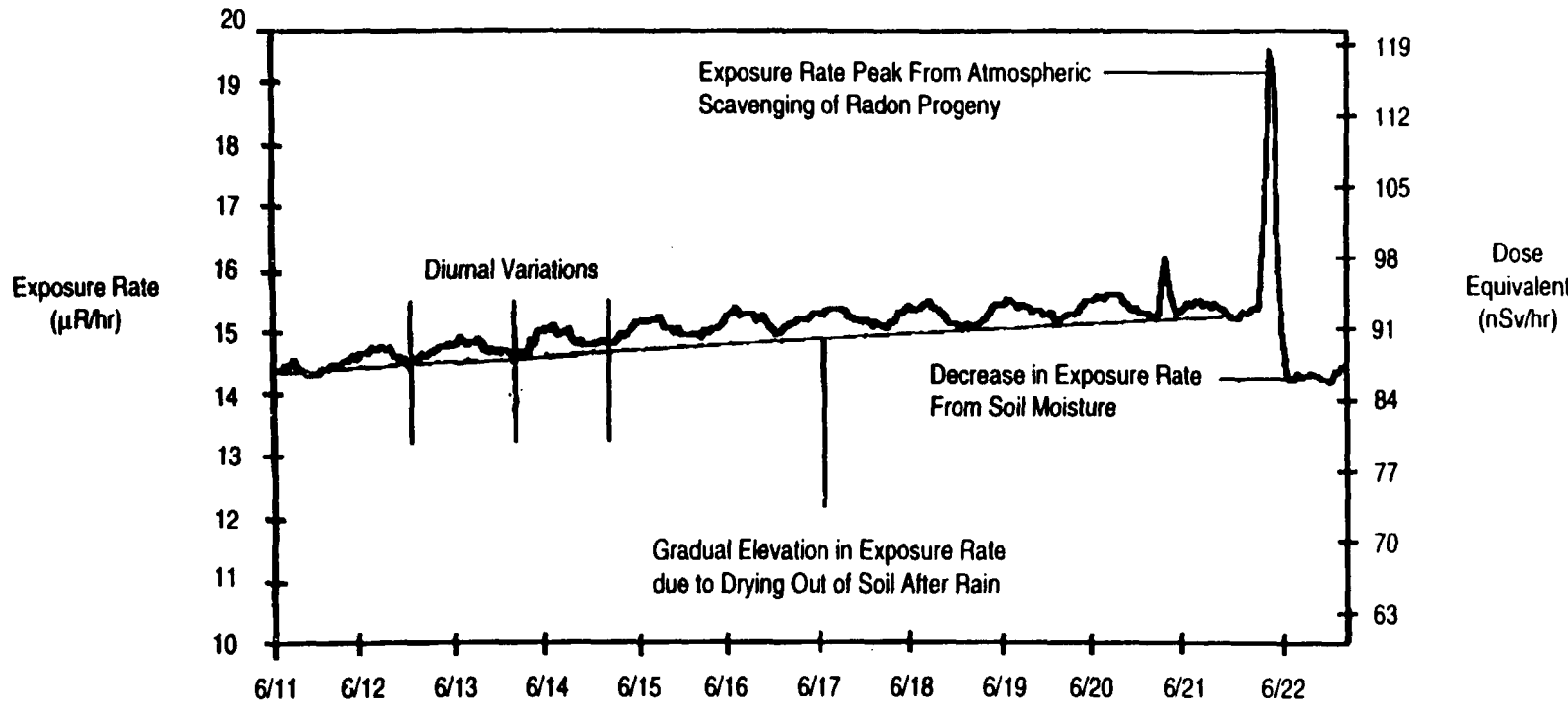
Figure 2.1 graphically illustrates the typical short-term variations observed in the rates of exposure from the penetrating component of background (gamma rays from terrestrial sources plus cosmic secondary radiation). These rates were measured hourly for a period of 11 days.

Several commonly observed effects on background gamma radiation are readily observable in this graph. The first feature to note is the somewhat wavering baseline, which represents the usual background level present at this site. This level gradually rose each day until some abrupt changes occurred at the end of the period. This rise resulted from the soil drying out, because this period of time was characterized by hot weather with no rainfall. (The effect of soil moisture is one principal factor in the variability of the external radiation levels. Water acts as a shield against the radiation coming from radionuclides contained in the ground, and dilutes the concentration of the radionuclides in the soil). The peaks toward the end of the period coincided with rainstorms. The quick rise in the radiation level resulted from a natural fallout process, one in which the airborne decay products of radon-222, primarily lead-214 and bismuth-214 (see Table 2.1) were scavenged (that is, washed out by rain). The radioactivity that was distributed throughout the lower region of the atmosphere caused the radiation level to rise when it was brought down to the ground. The second, larger peak in this graph shows the background exposure rate level increasing by approximately 30 percent or, in terms of effective dose equivalent, about 0.03 μSv per hour (equivalent to about 5 μR per hour in terms of exposure in air).

Natural washout events have been observed to double, and in rare cases even triple, the normal terrestrial gamma-ray level at a site during particularly heavy downpours associated with thunderstorms. These sharp increases from washout are not sustained, however, as the short-lived, gamma-emitting radon progeny decay away over the course of a couple of hours once the rain stops or the air is cleared of radioactivity. Also clearly evident in this graph is the return to more normal background levels with the addition of water to the soil. The first small peak represented in this figure was associated with a rather small rainfall event, but the second larger peak was associated with enough rain that the baseline level dropped markedly after the peak. The features shown in this particular graph can be repeated many times over the course of a season.

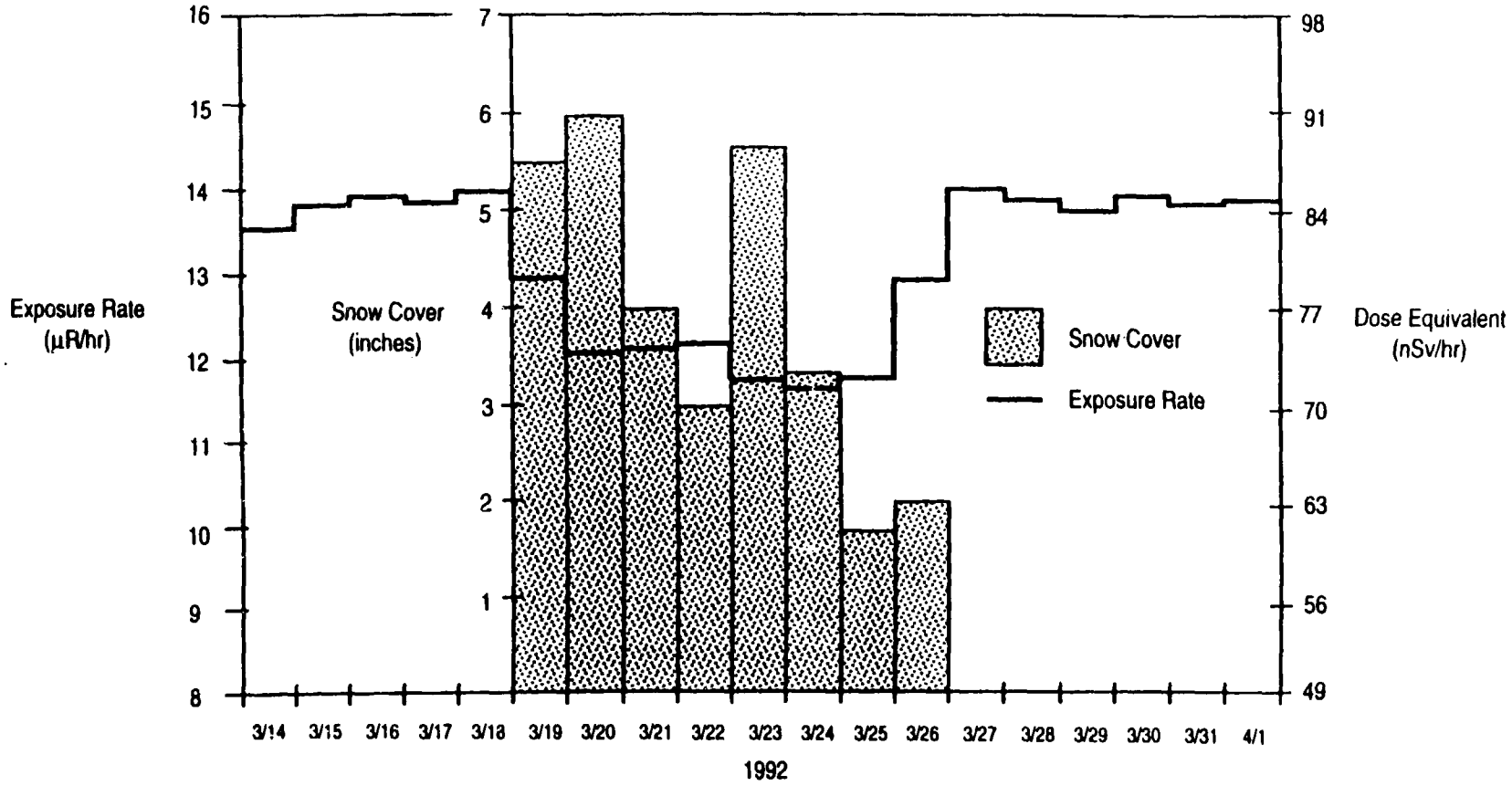
Another generally observable phenomenon in Figure 2.1 is that the waviness of the baseline during the first 10 days is not random. Rather, the cyclic action occurred on a daily basis as a result of changes in the radon progeny levels in the air which, in turn, arose from changes in the stability of the atmosphere. Extremely stable conditions produce what is known as an inversion layer (that is, the air temperature is lower at ground level than above, which is opposite to the norm). In the early morning hours before sunrise, conditions are typically calm, and the radon (which seeps from the soil into the air) stays near ground level, thus causing the radiation level to rise. When the sun rises, the ground warms up and air near it rises, producing a mixing effect that sweeps away the radon and its progeny to higher levels in the atmosphere, thus lowering the radiation level. The process cycles like this from day to day.

One of the most dramatic changes in gamma radiation levels occurs during periods of snow. While adding water to the soil decreases the radiation level to some degree, the shielding effect is much greater when water, in the form of snow or other frozen precipitation, accumulates on top of the ground. As shown in Figure 2.2, a period of snow cover with a depth of several inches reduced the radiation exposure rate by about 15 percent, or about 0.012 μSv per hour (2 μR per hour). The actual degree of shielding depends on the water equivalent of the snow, because a heavy wet snow is more effective than a dry light snow. After the snow melts away, the radiation returns to its usual



Note: Conversion of exposure to dose made by using 1R = 0.0087 Gy. For environmental radiation, coversion of absorded dose in air to effective dose in the human body is 1 Gy = 0.7 Sv.

Figure 2.1 Typical short-term variations observed in the out door exposure rate.



Note: Conversion of exposure to dose made by using 1R = 0.0087 Gy. For environmental radiation, coversion of absorded dose in air to effective dose in the human body is 1 Gy = 0.7 Sv.

Figure 2.2 The effects of snow cover on the outdoor exposure rate

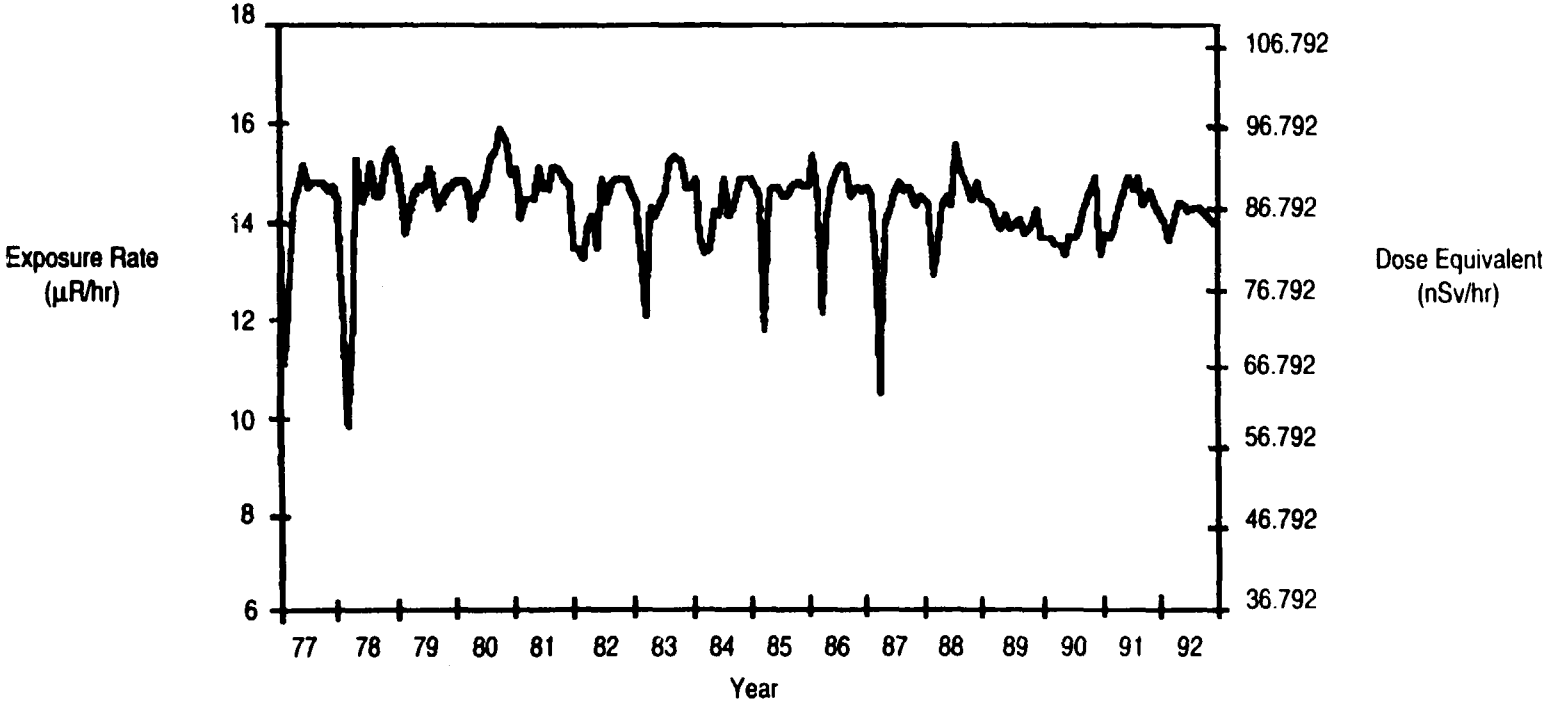
level. Calculations, supported by experimental data, have shown that 5 cm (2 inches) of water equivalent (that is, melted snow) would reduce the external gamma radiation level near the ground by almost 40 percent, while 15 cm (6 inches) would reduce it by nearly 70 percent (Saito, 1991). Mountainous areas that receive extremely heavy snowpack, say 50 cm (20 inches) water equivalent, would see the external gamma level drop by more than 95 percent. If this type of snowpack were sustained for a few months, it might lower the annual dose at a typical site by 0.1 mSv (10 mrem).

Variations in radiation levels from month to month primarily result from changes in soil moisture content and snow cover. Figure 2.3 shows a plot of average monthly outdoor exposure rates at a site over a period of 16 years. In this plot, seasonal trends can be seen as winter months tend toward lower radiation levels because of the higher soil moisture, while the summer months tend toward higher levels because of lower soil moisture. The sharp valleys in this plot correspond to those winter months where there was appreciable snow cover.

Average outdoor exposure rates over full-year periods show less variation as the seasonal effects even out the pattern. This can be seen in Figure 2.4, which shows the annual average along with the minimum and maximum daily average at a site over a 14-year period. The minimum daily value in any given year would generally occur on the day of heaviest snow cover, while the maximum daily value would generally occur on the day with driest soil or the day when a series of rainstorms produced many radon progeny washout events. For this site, over this time period, the typical daily high was about 10 percent or about 0.0085 μSv per hour (1.4 μR per hour) above the yearly average, while the typical daily low was about 25 percent or about 0.021 μSv per hour (3.5 μR per hour) below the yearly average.

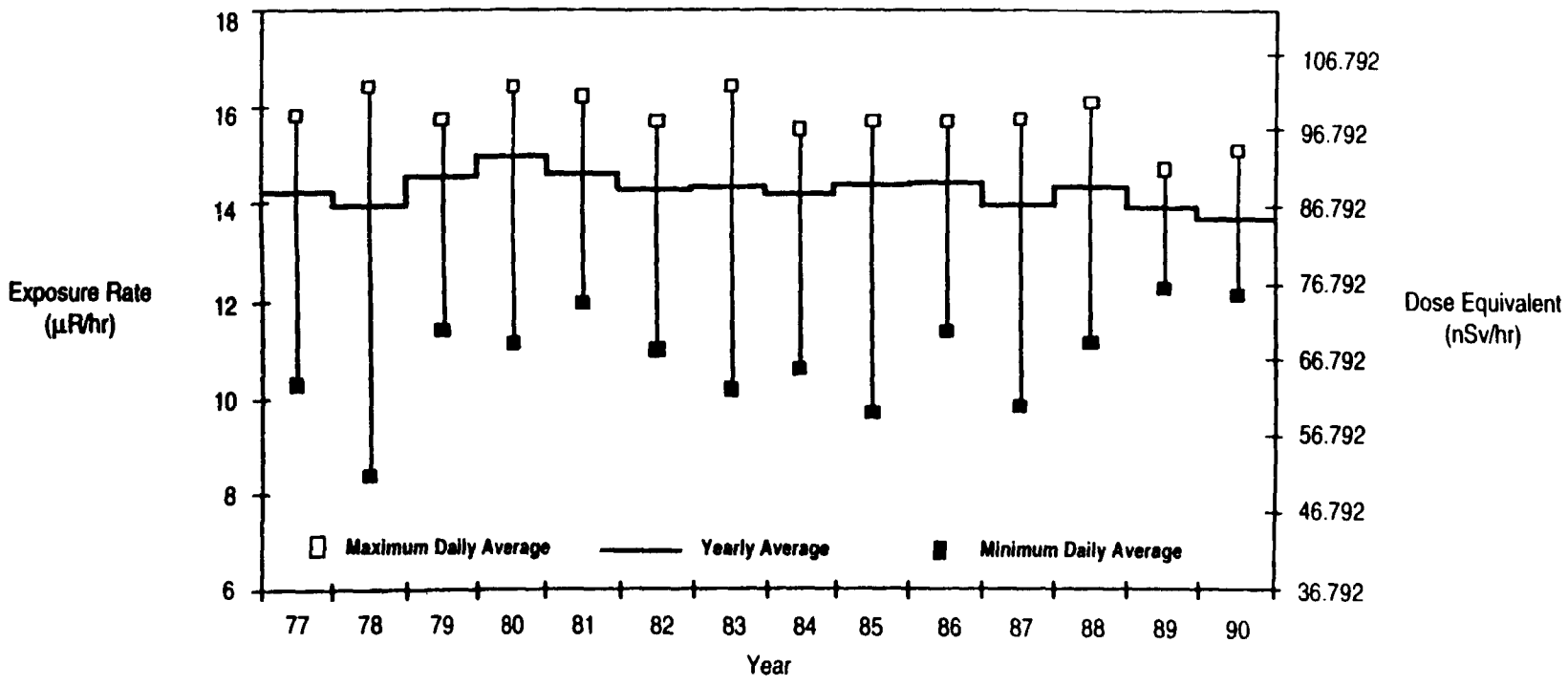
Over geological time frames, dramatic changes in the terrestrial radiation levels could take place in a region. If an area were covered by an ice sheet or a half meter (20 inches) or more of water, the gamma ray level could drop close to zero. On the other hand, upwelling of material from within Earth and erosional processes that transport soil and sediment could leave an area rich in mineralization, and the gamma ray level might quadruple from the extra uranium and thorium in the soil. In absolute terms, this would leave a range of about 0 to 1 mSv (0 to 100 mrem) per year, although there are some unusual areas that have been documented around the world where gamma levels are substantially higher. Climatic changes that lead to desertification of a region would lead to potential variations in background as areas become subject to wind erosion. Volcanic eruptions and the deposition an abrupt change in radiation of heavy amounts of ash in an area could causelevels depending upon the concentration of the natural radionuclides in the ash. The variation that is seen from place to place across the country (see next section) is a reasonable indicator of the degree of variation that might occur over long periods of time at any one location.

Human activities affect the local radiation level, and changes could therefore occur over time. On open ground, about two-thirds of the gamma radiation dose comes from radionuclides contained in the top 15 cm (6 inches) of soil out to a distance of 6 meters (20 feet) from where a person stands. Thus, changes in the radiation level could occur when the natural land is altered on a scale typical for home building and landscaping. The fact that building materials contain varying amounts of natural radioactivity means that background could be affected by any construction, including such work as building a house, making alterations to it, adding topsoil, or installing a swimming pool or patio. Public works, such as paving a road or parking lot, could also alter the radiation field. The magnitude of the change at any one site would depend upon the amount of material that is removed, added, or modified, and the relative radionuclide concentration in the old and new surroundings.



Note: Conversion of exposure to dose made by using 1R = 0.0087 Gy. For environmental radiation, coversion of absorded dose in air to effective dose in the human body is 1 Gy = 0.7 Sv.

Figure 2.3 Average monthly outdoor exposure rates at a site over 16 years



Note: Conversion of exposure to dose made by using 1R = 0.0087 Gy. For environmental radiation, coversion of absorded dose in air to effective dose in the human body is 1 Gy = 0.7 Sv.

Figure 2.4 Maximum and minimum daily averages as compared to the yearly average of the outdoor exposure rate over a 14-year period

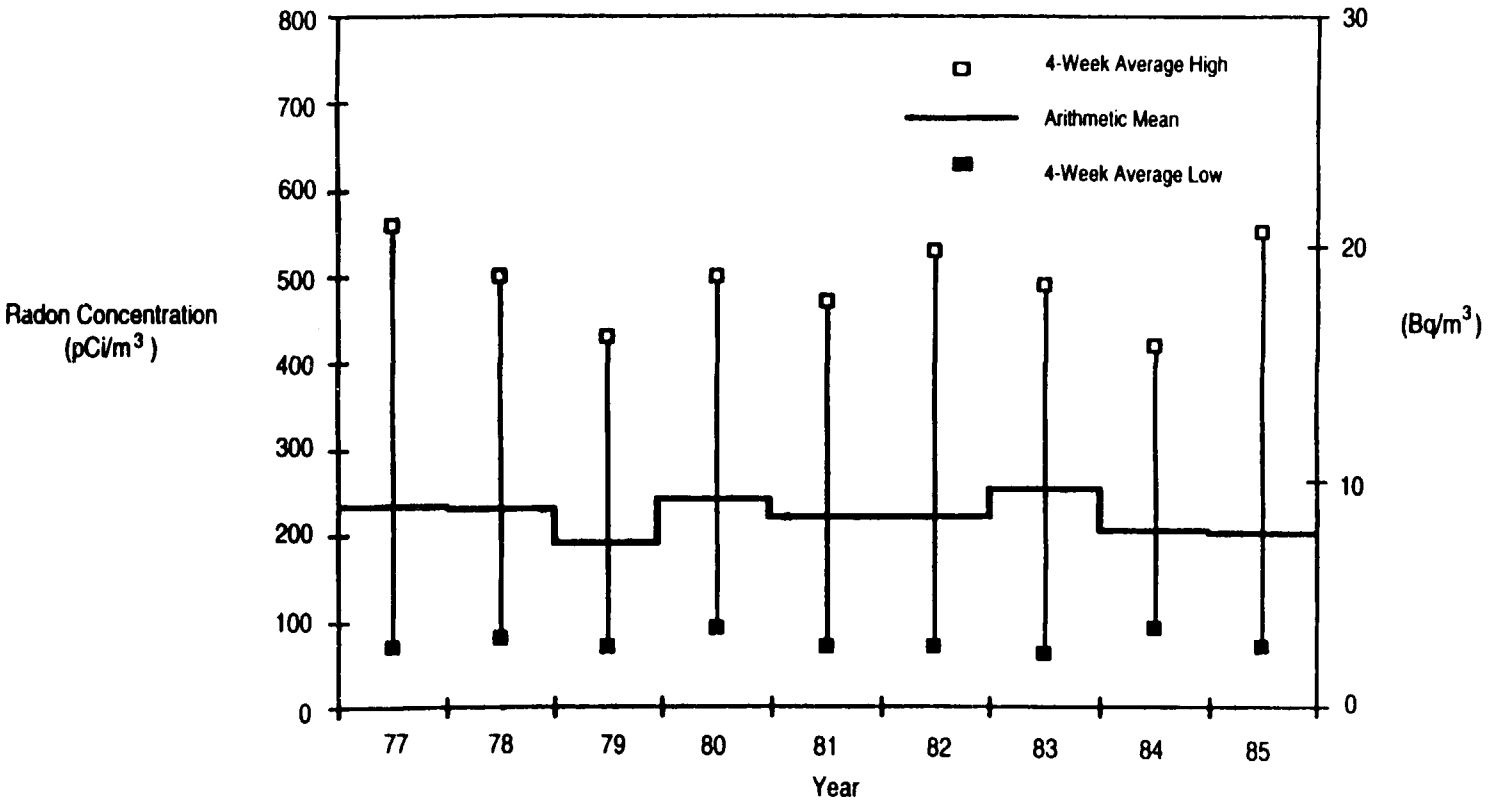
2.3.2.1.2 **Inhaled Terrestrial Radionuclides.** Although external terrestrial gamma radiation is highly penetrating and affects the entire body, the largest contributor to the total effective dose equivalent from background comes from the inhalation of radon gas and its short-lived decay products. This is because the radioactive particles are airborne and can be inhaled into the lungs, where the full energy of the emitted alpha particles associated with their decay is deposited in a small volume of tissue. As in the case of gamma radiation, various physical phenomena affect the concentration of radon in the environment and, consequently, variations occur over time.

Outdoor radon levels vary over time because of weather conditions. Data collected for many years at the station in Chester, New Jersey, demonstrate the degree of these variations (EML, 1978, 1979, 1980, 1981, 1982, 1984, 1985, 1988, 1991). In particular, the effect of atmospheric inversions, as discussed above, can cause ground level concentrations to increase by as much as 200 times those found during the day, although the average increase has been found to be about a factor of 2. Variations over longer terms show that the seasonal minimum in the winter is about three times lower than the seasonal maximum that occurs in August. Figure 2.5 shows a plot of average annual outdoor radon-222 concentrations for a 9-year period, along with the minimum and maximum averages over 4-week intervals in each year. In this figure, the annual average varies by up to 30 percent, or about 2.6 Bq per cubic meter of air (70 pico (one trillionth) curies per cubic meter), while the 4-week averages indicate that a single measurement over a month would only be within a factor of two or three of the annual average, again reflecting the seasonal differences that occur.

Indoor radon levels can be expected to vary over time as well. Since a principal source of radon entry into a building is the soil surrounding the building's foundation, weather can affect the air exchange rate between the soil and indoors. Wind, atmospheric pressure, andthe freezing and water logging of soil can all influence the movement of radon through the soil pore space and into a building. Variations can occur on time scales of hours, days, or months. Rapid changes in radon levels can occur from showering with well water containing dissolved radon gas, or from cooking with natural gas containing radon. Compared to outdoors, radon gas can build up to rather high levels indoors if there is a slow rate of air exchange with the outside.

Highly energy-efficient houses with snug-fitting windows and doors and other good weather stripping can fall in this category. In such situations, the radon level is subject to wide variations from changes in the ventilation rate, as would result from opening windows. Continuous monitoring of indoor air in houses has shown that the radon concentration can change by a factor of 10 or more (Nazaroff and Nero, 1988) from hour to hour. Seasonal differences are also found, as the concentration during winter months is generally higher than during the summer months, although there are exceptions to this rule. Another important process that influences the dose from radon is the attachment of its decay products (those that ultimately deliver the dose to the lung from being inhaled) to fine particles, or aerosols, in the air. The sizes of these particles and their removal from the air we breathe by attachment to walls and other interior finishes, called plate out, ultimately affect how much radioactivity we breathe in and retain. The aerosol concentration itself can vary with time depending upon such factors as cooking, smoking, and using kerosene heaters.

Radon decay products are not the only form of radioactivity that can be inhaled. Fine particles of soil, which contain all of the other natural radionuclides, can be suspended in air through the action of wind or human activities such as soil excavation. Dry periods and soil that lacks ground cover provide a ready environment for resuspension. Since wind conditions can abruptly change over short time periods, the amount of resuspended soil and the natural radioactivity that it contains can be



Note: 1 pCi equals 0.037 Bq.

Figure 2.5 Average outdoor radon-222 concentration in air at a site along with the average 4-week low and high values for a 9-year period

expected to vary accordingly. Seasonal changes related to wind as well as the dryness and vegetative cover of the soil can also be expected. Episodic increases from unusual natural or man-made activity in an area are also possible.

2.3.2.1.3 Internal Terrestrial Radionuclides. The intake of radioactivity to the body from eating food and drinking water can be expected to vary over time to some degree as well. Bananas and some other popular foods contain relatively high levels of potassium. However, the body maintains a fairly constant amount of this element, and the radioactive form, potassium-40, will not build up to higher levels even when larger than average quantities of these foods are eaten. The amount of potassium-40 will vary depending on body size and thus will change over time as adulthood is reached. On average, women would receive an annual dose that is about 25 percent, or about 0.05 mSv (5 mrem), less than men.

For some radionuclides such as uranium and radium, however, buildup within the body results from intake over time, and variations in diet therefore play a role. Also, geologic processes can influen the amount of natural radionuclides contained in well water in an area; if this is the primary source of drinking water, changes in intake and the dose from internal sources would result.

2.3.2.2 Cosmic Rays

Cosmic ray variations from day to day tend to be small, a few percent or about 0.001 μSv (0.1 μrem) per hour, and result primarily from changes in the barometric pressure. Under a high pressure system, for example, a larger mass of air above provides a greater shielding effect, compared to a low-pressure system in which there is less air and less shielding.

To a lesser degree, the temperature of the atmosphere plays a role as well. A higher temperature expands the atmosphere, which causes the cosmic ray level to decrease because there are longer path lengths that allow some of the cosmic ray secondaries more time to decay before reaching ground level. Cosmic ray intensity also changes over a period of years. The sun's 11-year cycle (as measured by sunspot activity) affects the cosmic ray intensity at ground level by raising or lowerir from its average value by up to 10 percent, or about 0.03 mSv (3 mrem) per year at sea level. The solar cycle is also related to the frequency of solar flares. Short-term increases in background from this source are possible, as was seen during the unusually energetic flare in September 1989, which produced an increase of about 200 percent in the neutron counting rate and an increase of about 35 percent or 0.01 μSv (1 μrem) per hour in the ionizing component at sea level (EML, 1992).

2.3.2.3 Cosmogenic Radionuclides

The cosmogenic radionuclide production in the atmosphere can be expected to vary according to changes in the cosmic ray intensity. From 1985 to 1990, a 30 to 40 percent decrease in the concentration of beryllium-7 was observed in surface air monitoring stations around the world (Larsen, 1993). This decrease coincided with the decrease in galactic cosmic ray intensity, which in turn coincided with the increase in the sun's activity during this time period. A more active sun, as evidenced by more sunspots, produces changes in the solar wind and magnetic field, which oppose the cosmic rays coming from outside our solar system. Seasonal changes also occur in the deposition of cosmogenic radionuclides to the surface of Earth. Deposition is greater during the spring months when air in the stratosphere tends to mix with air in the troposphere, where it can be washed out by precipitation.

2.3.2.4 Man-Made Radionuclides

Background variations can arise from the input of man-made radionuclides to ecosystems. Both nuclear weapon detonations and accidents dispersing nuclear material have the potential to cause radiation and radioactivity levels to increase at sites quite distant from the source. The large-scale testing of nuclear weapons in the atmosphere that took place during the 1950s and early 1960s resulted in the fallout of a variety of radionuclides that caused significant short-term increases in external radiation levels. Most of these have decayed away, although a few percent or less of the gamma radiation levels in many areas is still due to cesium-137, which has a 30-year half-life and can still be found in surface soils. Strontium-90, which has a 29-year half-life, has contributed significantly to internal dose through dietary intake over the past 30 years, although this source of exposure has gradually diminished over the years. Plutonium from fallout has contributed to internal dose through the inhalation pathway; however, the concentrations in surface air fell rapidly after the initial injection to the atmosphere. More recently, tests conducted by China in the late 1970s produced temporary increases in radiation and radioactivity levels. Immediately following the fallout, increases in gamma radiation were measured to be on the order of 20 percent or about 0.02 μSv per hour (3 μR per hour) above background, gradually declining over a period of a few weeks (HASL, 1976).

Temporal changes in the concentration of helium-3 in precipitation were considerable during the period of atmospheric nuclear weapons testing. The value of 360 Bq per liter recorded for the peak fallout year (1963) can be compared to the natural (pre-1952) level of only 0.6 for Ottawa, Canada (NCRP, 1987b). Changes of a factor of two or more were not unusual from year to year during the period 1953 through 1968.

Accidents at nuclear facilities, in particular the Chernobyl power plant in 1986, also produced measurable contamination around the globe, although the contribution to dose was quite small for people in the United States. The impact for an event of this magnitude would be abrupt and quite considerable for a local area, however. In a region about 160 km (100 miles) from Chernobyl, for example, measurements show cesium-137 concentrations in surface soil as high as 60,000 Bq per kg (Miller et al, 1991), which represents an increase of several orders of magnitude above pre-accident levels.

2.3.3 Spatial Variability

2.3.3.1 Terrestrial Radionuclides

The concentration of terrestrial radionuclides varies from place to place in much the same way that mineral deposits can be expected to vary from geologic processes that occur over time. Soils are mixtures of various chemical compounds, including major constituent elements such as silicon, aluminum, iron, carbon, hydrogen, and oxygen. Many other elements exist in either minor or trace quantities that can vary greatly. Elements that have naturally occurring radioactive forms (that is, potassium, uranium, and thorium) fall in this category. For instance, granitic rock is known to contain higher than average uranium concentrations, and monazite sand can have particularly high concentrations of thorium. Apart from naturally occurring variations, humans frequently alter the makeup of soil with the addition of amendments for cultivation. For example, one of the three principal components of fertilizer is potassium, most of which is in the stable forms, potassium-39 and potassium-41, but a fraction of a percent of which is the radioactive form potassium-40.

2.3.3.1.1 **External Terrestrial Radionuclides.** Surveys around the country have shown concentrations of uranium and thorium in the soil to range from as little as one tenth to as much as four times the average value (Myrick et al, 1983). In addition, aircraft mounted with radiation detectors have surveyed large tracts of land in various areas, and these measurements have been supplemented with a number of ground-based surveys. As a general rule, the Atlantic and Gulf coastal plains tend to average about half of the gamma ray level seen for middle America, although the distribution of the levels overlaps, and exceptional areas have been documented (NCRP, 1987b). For instance, the Denver, Colorado, area has gamma radiation levels about twice the average for Middle America. Measurements in sections of Nevada stretching into Utah contain similarly high natural gamma radiation levels (Miller et al, 1980).

The variation within a State, or even a smaller region, can be large. Monitoring stations operated by the Environmental Protection Agency in southern Nevada show background (combined cosmic and terrestrial gamma) to vary by a factor of three among the sites, or about 0.6 mSv (60 mrem or 100 mR) per year (EPA, 1990). While some of this variation results from differences in altitude and cosmic ray intensity, most of the variation arises from differences in the terrestrial gamma component. In certain regions (such as the Reading Prong formation that cuts across northwestern New Jersey), gamma radiation levels can be found to triple across a small field because of variations in the concentration of natural radionuclides in the soil. Venturing near rock outcroppings that may contain 100 times the average soil concentration will produce even larger fluctuations. In contrast to these areas of relatively high radiation in this part of the state, just 100 km (62 miles) to the southeast are sandy beach areas where the gamma radiation levels fall to less than 10 percent of the average measured over the Prong, which in absolute terms is only about 0.05 mSv (5 mrem) per year.

The variation in the total gamma radiation levels among sites relates directly to the concentrations of the principal gamma-emitting radionuclides in the local soil. Table 2.6 gives an example of the degree of variation that can be found in a local area, in this case, the vicinity of Three Mile Island. To some degree, soil cultivation by humans further adds to the natural variations in the radionuclide concentrations among different soil types in an area.

Areas where human activities have been known to alter background levels of radiation include the phosphate regions in northern and central Florida. In these regions, the phosphate rock is mined for fertilizer production, but the rock itself and the tailings contain elevated concentrations of radium. Backfilling operations in mined areas have led to areas of topsoil with higher concentrations than the original (NCRP, 1987b). Survey data show that gamma dose rate levels range from slightly less than to about double the national average.

Similar background variations can be found in western states where uranium mining and milling operations have produced tailings containing similarly and higher elevated concentrations of natural radionuclides. Of particular note are Uravan and Grand Junction, Colorado, where the gamma dose rate on top of tailings piles has been observed to be on the order of 100 times normal background (a few μSv per hour or a few hundred μR per hour) (NCRP, 1987b).

Another example of background alteration can be found on land where pipes from oil drilling operations are cleaned of scale containing relatively high concentrations of radium (Wilson and Scott, 1992). Concentrations in surface soil were found in the range of 5.3 to 62.2 Bq per gram, which is two to three orders of magnitude above normal background levels for the United States.

Table 2.6. *In Situ* Radionuclide Concentrations in the Vicinity of Three Mile Island[1]
(Bq per kg)

Site	Uranium-238	Thorium-232	Potassium-40
A	32	27	244
B	29	30	216
C	16	19	203
D	23	31	403
E	14	17	184
F	43	40	512
G	26	29	383
H	24	32	257

[1] From unpublished data collected by USDOE Environmental Measurements Laboratory.

Apart from outdoor variations in gamma ray levels, indoor variations occur because building materials vary among structures and even within the same structure. Measurements made in a variety of houses around the country in recent years show that in a typical wood frame house, gamma ray levels are generally about 50 percent, or on average 0.1 mSv (10 mrem) per year, higher in a basement than on a second floor (Miller, 1992). Rooms that contain stone or brick wall fireplaces tend to have gamma ray levels about 50 percent higher than those with normal drywall panels. Houses of full brick construction have average concentrations about 50 percent higher than wood frame houses without any brick. The use of cinder blocks, which are produced from ash residue in the combustion of fuels such as coal, also yields a higher than average radiation level. Within a large, concrete, commercial-type building, measurements have shown the gamma radiation level to vary up to 50 percent or about 0.15 mSv (15 mrem) per year among different floors, and on the order of 20 percent or about 0.05 mSv (5 mrem) per year on the same floor (Miller and Beck, 1984). In such situations, differing composition of interior partition walls and the effects of windows at the building edge can lead to variations in otherwise homogenous structural compositions.

The gamma radiation level inside a building results from the penetration of radiation from outside and the contribution from the building itself. It thus reflects the concentrations of radionuclides in the soil as well as in building materials. In light frame structures, the outside component is significant; however, in large massive buildings, it is generally quite small. In some sense, the concentration of the radionuclides in building materials relative to those outdoors is the determining factor in whether the building acts more as a shield against outdoor radiation or a source of radiation itself. Data presented in Table 2.7 indicate the variability in the concentration of the natural radionuclides in ordinary concrete samples from around the country (Ingersoll, 1981). As these data show, the variation among cities ranges from a factor of about 3 to 6 for the various nuclides. Variation can be expected even within a region, and the data of Eichholz et al (1980) showed variations of a similar range for concrete within the local area of Atlanta, Georgia. Available brick showed an even broader range (see Table 2.3).

Table 2.7. Natural Radionuclide Content of Ordinary Concrete[1]
(Bq per kg)

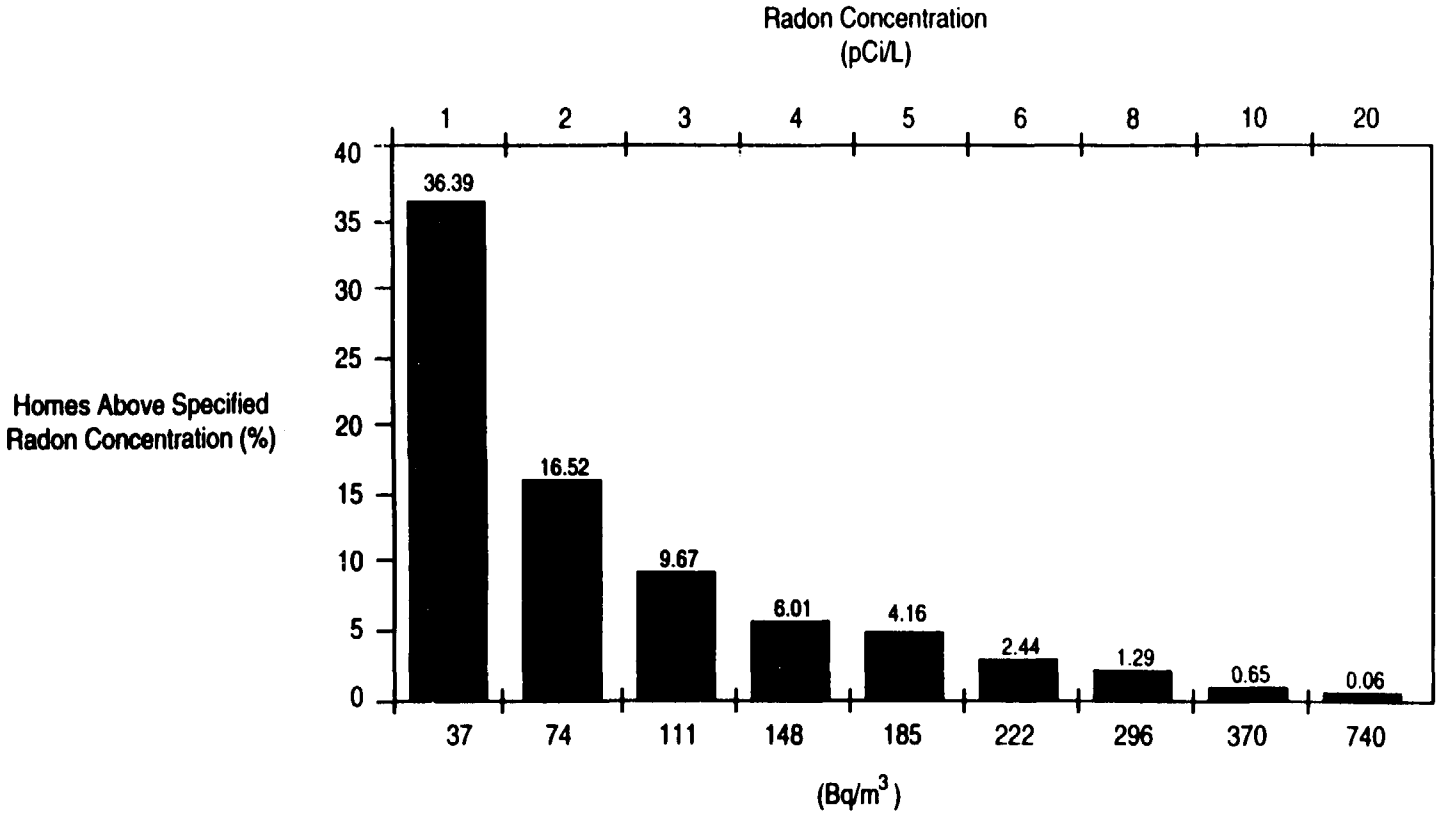
City, State	Uranium-238	Thorium-232	Potassium-30
Albuquerque, NM	31	24	461
Austin, TX	16	6	246
Chicago, IL	19	8	154
Kansas City, MO	13	8	215
Knoxville, TN	13	5	154
Philadelphia, PA	8	6	215
Salt Lake City, UT	25	16	184
San Antonio, TX	38	31	461
San Francisco-Oakland, CA	19	12	184
St. Paul-Minneapolis, MN	19	16	461

[1] From Ingersoll (1981).

2.3.3.1.2 Inhaled Terrestrial Radionuclides. The dose associated with the inhalation of terrestrial radionuclides is subject to spatial variations as well. Outdoor radon concentrations in air can be expected to vary according to the local radium levels in the surface soil. This is reflected in outdoor measurements around the country that range between 4 Bq per cubic meter of air (0.1 pCi per liter) in New York City to 44 (1.2 pCi per liter) in Colorado Springs (NCRP, 1987b). Coastal communities that receive air circulation off the oceans (where there is virtually no source of radon) tend to have lower concentrations than inland areas. Other local meteorological conditions, such as the degree and frequency of atmospheric inversions, play a role as well. Within a region, topography can be a factor, because it has been observed that the concentration of radon and its decay products in the air along a hillside can be five times lower than the concentration in a valley during a strong nighttime inversion (Porstendorfer, 1993).

Apart from outdoor variations from place to place, large differences can occur with indoor radon levels. Data collected from around the country indicate the average value for some counties can be several times the average for the state (Cohen and Shah, 1991). Individual homes can, in turn, have concentrations many times those of the county average. The results of the U.S. Environmental Protection National Residential Radon Survey are shown in Figure 2.6. About 6 percent, or roughly 6 million homes, exceed the EPA Action Level of 150 Bq per cubic meter (4 pCi per liter) (Marcinowski, 1992). Because of the highly variable nature of the radon source and entry pathways, it is possible for a house to have a concentration many times greater than a neighboring house. Within the same house, differences in concentration can occur, particularly when basement areas are closed off. As in the case of temporal variations, the concentration of aerosols to which the radon decay products attach can be expected to vary from place to place, as well as in the amount of plate out that occurs.

Variations in the dose associated with the inhalation of resuspended soil can be expected because radionuclide concentrations in the soil vary from place to place, as does the degree of resuspension that occurs in an area. In general, arid regions have higher resuspension. Within a local region, the degree of inhalation of radionuclides could depend upon the proximity to and frequency of use of dusty unpaved roads, and whether the population engages in agricultural, construction, or a similar type of work that produces resuspension.



Note: 37 Bq/m^3 equals 1 pCi/L

Figure 2.6 Results of the EPA National Residential Radon Survey program (Marcinowski, 1992)

The addition of natural radioactivity to the air can result from fossil fuel combustion where ash containing natural radionuclides is released directly to the air. For instance, in the process of burning coal, releases of ash as well as volatilized radionuclides such as lead-210, can lead to dose increases as high as a few percent above normal background levels in areas downwind of a large power plant with poor emission controls (Beck et al, 1980). Local variations relate to distance from such a facility, wind patterns, and other meteorological phenomena.

2.3.3.1.3 Internal Terrestrial Radionuclides. Although information on the variation of natural radioactivity contained within the body for people living in different places is not as extensive as that for external radiation, the available data indicate that variations do exist. Data have been collected from around the world for a number of the natural long-lived radionuclides that indicate the degree of variation in the concentration in human soft tissue, blood, and bone (Fisenne, 1993). For a nuclide such as lead-210, differences of about a factor of three have been measured among samples from various parts of the United States.

One potential source of variation among the population arises from the intake and retention of polonium-210 and lead-210 from cigarette smoking, because these radionuclides are volatile and are inhaled with smoke. For radium-226, somewhat larger differences can be seen for the mainland United States (NCRP, 1987b). In addition, variations in internal radionuclide levels result from differences in dietary intake, as well as the radionuclide concentration in foodstuffs in different areas of the country (NCRP, 1987b; Fisenne, 1993). Crops grown in different regions contain varying amounts of natural radionuclides because of differences in radionuclide concentration in the soil and uptake by the plant. To some extent, differences exist based on whether the diet is urban or rural in nature, because the relative proportion of foodstuffscontaining different concentrations of radionuclides varies according to market access. Also, intake of radionuclides can be expected to vary with concentrations in drinking water. People living in certain regions, such as those where there is a high concentration of uranium in well water used for drinking, develop higher body burdens over time. In contrast, intake is much lower where people rely on surface water for consumption. Measurements of uranium in water have shown that certain midwestern areas have concentrations 35 times greater than certain eastern states, while certain western areas have uranium concentrations in water 350 times greater than eastern states. Substantially higher intake of radium-226 has been documented for certa... deep municipal wells in northern Illinois (NCRP, 1987b).

2.3.3.2 Cosmic Rays

Cosmic ray variations from place to place primarily result from variations in altitude, although some smaller variation results from latitude. In short, the higher the elevation, the higher the cosmic ray dose. Figure 2.7 shows the relationship between dose rate and altitude (Bouville and Lowder, 1988). The population in a city such as Denver, at an altitude of 1610 meters (5300 feet), receives an annual cosmic-ray dose about 0.2 mSv (20 mrem), or a factor two, higher than the average for the United States.

Since the magnetic field of Earth curves inward toward the north and south poles, the cosmic ray particles undergo less deflection and their intensity is stronger. At sea level, the cosmic ray dose is estimated to be about 10 percent lower in regions near the equator compared to high latitudes. At sea level, this amounts to a difference on the order of 0.03 mSv (3 mrem) per year in the effective dose equivalent. Given the range of latitude of the United States, the variations are just a few percent or

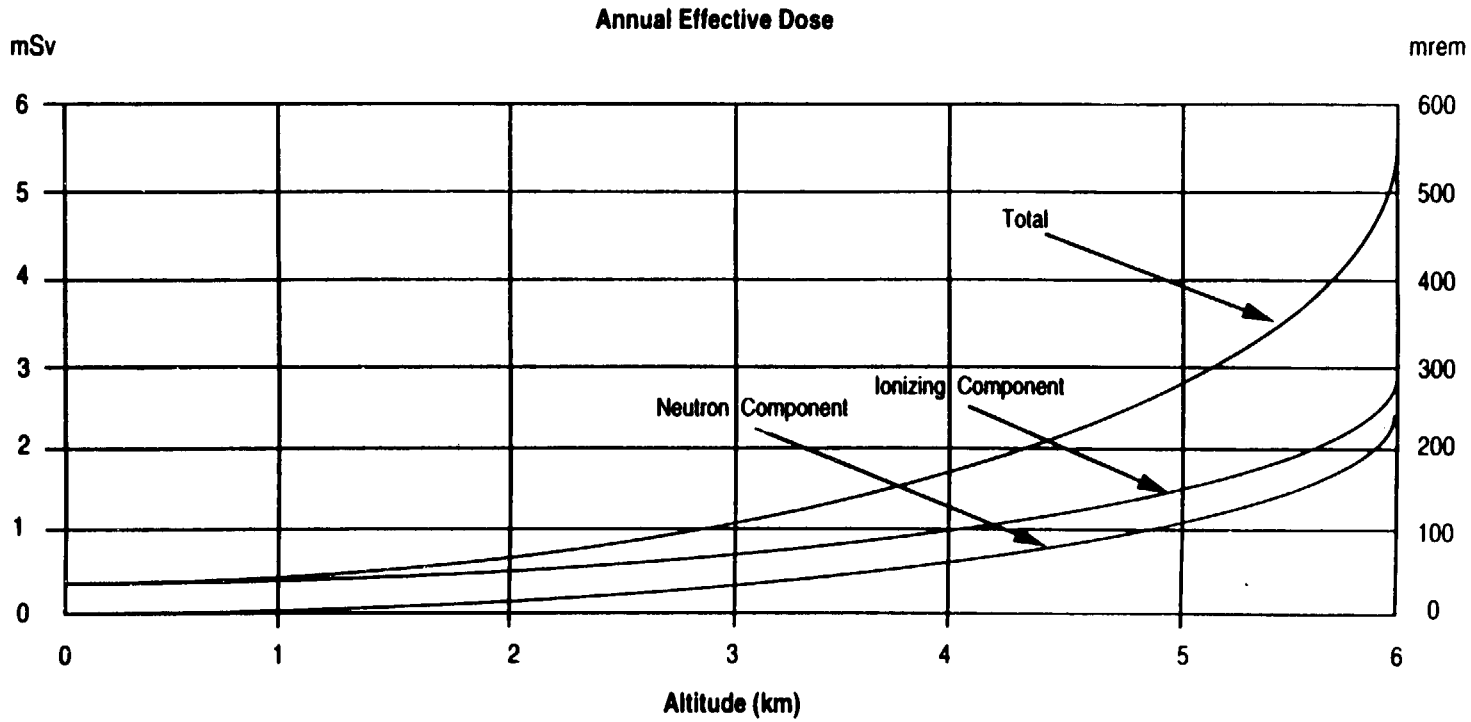


Figure 2.7 Annual dose from cosmic radiation as a function of altitude

about 0.01 mSv (1 mrem) per year about the average, with the exception of the northern regions of Alaska.

Cosmic radiation levels in small residential-type structures are only a few percent less than those outdoors, because there is little shielding provided by wood framing and roofing materials. However, in large buildings with relatively thick concrete ceilings and floors, significant shielding exists and the cosmic ray dose can drop sharply with the first overhead layer and more slowly with each successive layer thereafter. Measurements performed in a 12-story structure showed a 36 percent drop, or 0.1 mv (10 mrem) per year, on the top floor and a 73 percent drop, or 0.2 mSv (20 mrem) per year, at the basement level relative to the outdoor value (Miller and Beck, 1984).

2.3.3.3 Cosmogenic Radionuclides

Although the cosmogenic component of background is much smaller than that from terrestrial radionuclides and cosmic rays, the production of these radionuclides is nonetheless higher near the poles because of the greater cosmic ray intensity, as mentioned previously. However, many cosmogenic radionuclides are produced in the upper atmosphere, and the concentrations are therefore higher near the equator, since stronger convection leads to a much higher degree of mixing with surface air. For example, the concentrations of beryllium-7 in surface air show a clear trend toward higher values approaching the equator and lower values approaching the poles (Larsen, 1993). For the United States, the air in Miami, Florida, exhibits concentrations about 2 to 4 times higher than those at Point Barrow, Alaska. As for deposition to the ground, an additional source of variation occurs with climate, because arid areas receive less deposition than regions where there is more precipitation.

2.3.3.4 Man-Made Radionuclides

Differences in the distribution and deposition of fallout from nuclear weapon tests can be found across the United States. Globally dispersed fallout varies with latitude and, in particular, with the amount of precipitation an area receives. The arid southwestern portions of the United States have inventori of radionuclides from fallout in soils which are lower than average, whereas certain moist mountainous regions contain concentrations of fallout radionuclides that are a factor of two or three higher. Areas downwind of the Nevada Test Site are characterized by a heterogeneous distribution of local fallout from the tests conducted there.

Measurements of cesium-137 in undisturbed soil throughout Utah indicate that the deposition of fallout radionuclides varies by about a factor of three (Beck and Krey, 1980). However, because of differences in the degree of penetration through the soil layers and in density amongst soil types, the concentration in the top 2.5 cm of soil varies by a factor of 20. Even within the region around the Great Salt Lake, which is a more limited geographical area, the deposition varies by about 50 percent. This degree of variability is reflected in the data in Table 2.8, which gives the average concentration for a number of cities over a soil depth of 0 to 30 cm.

Table 2.8. Concentrations of Cesium-137 in Soil[1] in The Great Salt Lake Vicinity[2]

City	Concentration (Bq per kg)
Bountiful	15.3
Brigham	14.4
Layton	10.9
Layton	13.0
Logan	10.8
Ogden	13.7
Magna	12.3
Midvale	11.6
Salt Lake City	15.0
Salt Lake City	12.6
Salt Lake City	12.0
Toole	12.7
Tremonton	11.6
Tremonton	12.1

[1] Based on a soil depth of 0 to 30 cm.

[2] Computed from the data of Beck and Krey (1980).

Apart from regional differences in the original deposition, even larger variations can be found in the concentrations of fallout radionuclides in an area because of natural or man-made disturbances to the soil. Redistribution has occurred as a result of wind and water erosion, and many places have been plowed or had soil removed or brought in as fill. Thus, concentrations can span a range from nearly zero (or below detection limits) where runoff has occurred to several times the average for an area because of sediment accumulation. Despite these differences, the total dose from fallout radionuclides, like cosmogenic radionuclides, is quite small compared to terrestrial natural radionuclides and cosmic rays.

2.3.4 Summary of Background Variability

To give the reader a better understanding of the radiation environment, the preceding sections provide detailed information on the causes and magnitude of background variability. Temporal variability is affected by weather, climatic changes, geological processes, human activities, the 11-year solar cycle, and other naturally occurring processes. The most variable component of background over time is radon. Over the course of a day, or from season to season, outdoor radon concentrations can change by more than a factor of two, while indoor radon concentrations can vary even more as a result of building ventilation changes. Over the course of a day, changes in the distribution of radon decay products in the atmosphere cause changes in the external gamma exposure rate ranging from a few percent to 100 percent or more.

Temporal variability of background is affected by seasonal changes in soil moisture and snow cover, which typically lead to changes in external radiation levels of 10 to 50 percent. To a lesser extent, cosmic radiation and the production rate of cosmogenic radionuclides varies up to 10 percent throughout the course of the solar cycle. However, abrupt changes in background can occur from the

input of man-made radionuclides from fallout after a nuclear weapon test or distant reactor accident, which can increase background levels for a few months to a few decades.

The spatial variation of external radiation is largely related to the makeup of the soil in a locale. The greatest spatial variation in background arises from the differences in levels of radon gas, which can vary from one tenth the national average to more than ten times the average because of differences in the radium concentration in soil. Outdoor gamma radiation levels over sandy soil along a coast may be only one fourth the average for the whole country, whereas it might typically be three times the average in mountainous areas with a high degree of mineralization. Indoor gamma radiation levels vary by about 50 percent because of the use of different construction materials.

Human activities also affect spatial variability of background. Mining and milling have redistributed natural radionuclides, adding to the variation that occurs in some areas. Variations in the dose from internal radionuclides primarily results from differences in the concentration of natural radionuclides in drinking water. A significant fraction of internal dose arises from potassium-40; however, this is relatively constant, whereas the concentration of nuclides such as lead-210 in body tissues has been observed to vary by about a factor three throughout the United States. Cosmic radiation increases by a factor of two between areas above sea level, such as Denver, Colorado, and areas that are at sea level. Variations of a few percent also occur with latitude. On a local scale, cosmic ray levels are lower for residents and workers in tall, massive buildings because of the shielding effects of concrete floors. Measurements inside a building have shown a drop ranging between one to two thirds below that outdoors. Cosmogenic and man-made radionuclide concentrations vary in air and soil, although the overall effect on the total variation in dose from background is quite small.

When considered on a large scale, this widely variable and ubiquitous source of naturally-occurring radiation produces doses to the human population that are, in turn, widely variable as well. The magnitude and variability of radiation doses among a given population is directly proportional to the population's activities and the background level to which the population is exposed. Current estimates of the minimum, maximum, and average dose per year to a United States resident from background are provided in the next section, along with comparisons to worldwide estimates and doses from oth sources of radiation.

2.4 Estimated Doses From Background

A comprehensive review of background sources and the resultant doses received by the population of the United States has been performed by the National Council on Radiation Protection and Measurements (NCRP, 1987b). Figure 2.8 shows a breakdown of the estimated total effective dose equivalent, with regard to the average contributions from each of the principal sources. Of the rounded total of 3 mSv (300 mrem) per year, two-thirds or 2 mSv (200 mrem) comes from inhaling radionuclides (by and large, the indoor radon decay products). The other radionuclides internal to the body from ingestion and inhalation contribute about 13 percent or 0.4 mSv (40 mrem) of the total dose. External terrestrial (gamma) radiation and cosmic ray components are about equal and together make up about 18 percent or 0.55 mSv (55 mrem) of the total, whereas the annual dose from the cosmogenic radionuclides is very small, on the order of 0.01 mSv (1 mrem) or less than one percent.

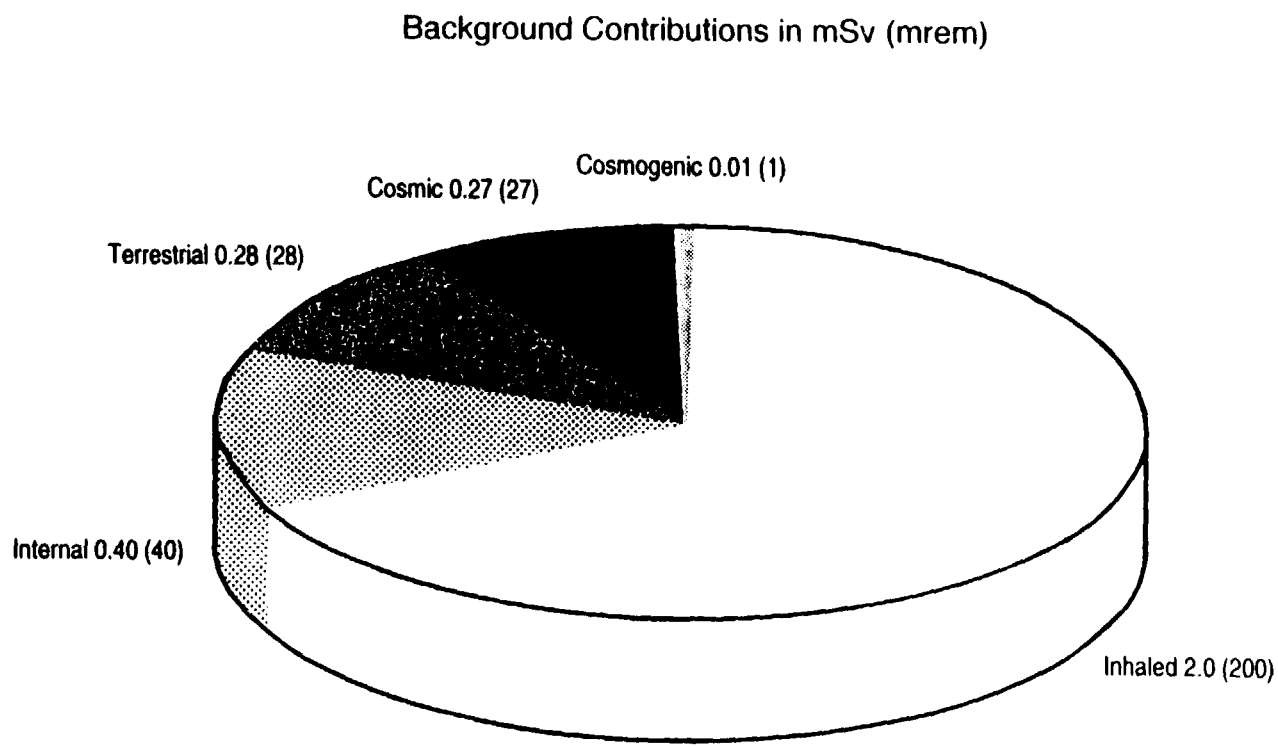


Figure 2.8 The average contribution to the total effective dose equivalent from various sources of background for the United States (NCRP, 1987b)

Given the previous discussion concerning the temporal and spatial background variations, it is imperative to remember that the estimated total dose of 3 mSv (300 mrem) is an annual average, and that the actual dose received by any one individual could be quite different. Figure 2.9 shows the average contributions of the four most significant components in perspective to the estimated typical maximums and minimums. These ranges are not to be taken as the absolute limits, but should indicate the variability generally encountered. In the inhalation category, the maximum of 8 mSv (800 mrem) per year is taken to be the dose corresponding to the current EPA Action Level of 150 Bq of radon per cubic meter of air (4 pCi per liter). Obviously, many United States homes exceed this level; however, indoor radon represents a category of natural radiation that is controllable by remediation. The minimum annual dose for radon, 0.2 mSv (20 mrem), corresponds to a level only one-tenth the national average, which is taken to be typical of well ventilated houses in areas with low radium concentrations in the soil. For internal radiation, about half of the average is taken to be constant, corresponding to the dose from radionuclides such as carbon-14 and potassium-40. The other half of the average internal dose is then varied from one-third to four times the average, based on data for the range of radionuclides measured in human tissues. This yields a minimum of somewhat less than 0.3 mSv (30 mrem) to a maximum of 1 mSv (100 mrem) per year.

The external terrestrial radiation maximum of three times the average is not unusual for areas in the western United States with a high degree of mineralization in the soil, whereas the minimum of one-fourth the average is representative of sandy soil along a coastline. This leads to a range of less than 0.1 mSv (10 mrem) to more than 0.8 mSv (80 mrem) per year for the gamma component. For cosmic radiation, the typical maximum is taken as twice that of the dose at sea level (a resident of Denver), while the minimum is half (a resident of New York City who lives and works in tall buildings). This corresponds to a difference of 0.4 mSv (40 mrem) per year in dose between the extremes for cosmic radiation.

The variability of major background components can average out in many cases so that many people receive similar total doses. Nonetheless, some degree of correlation exists among these components. High gamma levels can be found in mountainous areas, and accordingly, the higher levels of uranium in the soil lead to a larger source of radon gas in the soil, as well as higher concentrations of radionuclides in well water and food grown in those areas. The higher altitude also leads to a higher dose from cosmic rays.

As an example of the typical dose range, consider that people who live in well-ventilated wooden houses on sandy soil near the ocean would receive a minimal dose from radon — one tenth of the United States average -- and a minimal external gamma dose — about one-fourth the average. With an internal and cosmic ray component of about average, the total dose to these individuals is only 1 mSv (100 mrem) per year. In contrast, people living in Denver, Colorado, could receive double the cosmic ray dose, triple the gamma dose, and quadruple the radon dose. With a somewhat higher intake of radionuclides from drinking water, the total dose is about 10 mSv (1000 mrem) per year. Although even higher doses are possible for people living in houses with very high radon concentrations, this value could be taken as an upper limit, allowing for extremes associated with unusual situations. Overall, this range of 1 to 10 mSv (100 to 1000 mrem) — a span of a factor of ten — is typical of the variation in background doses for most United States citizens in a given year.

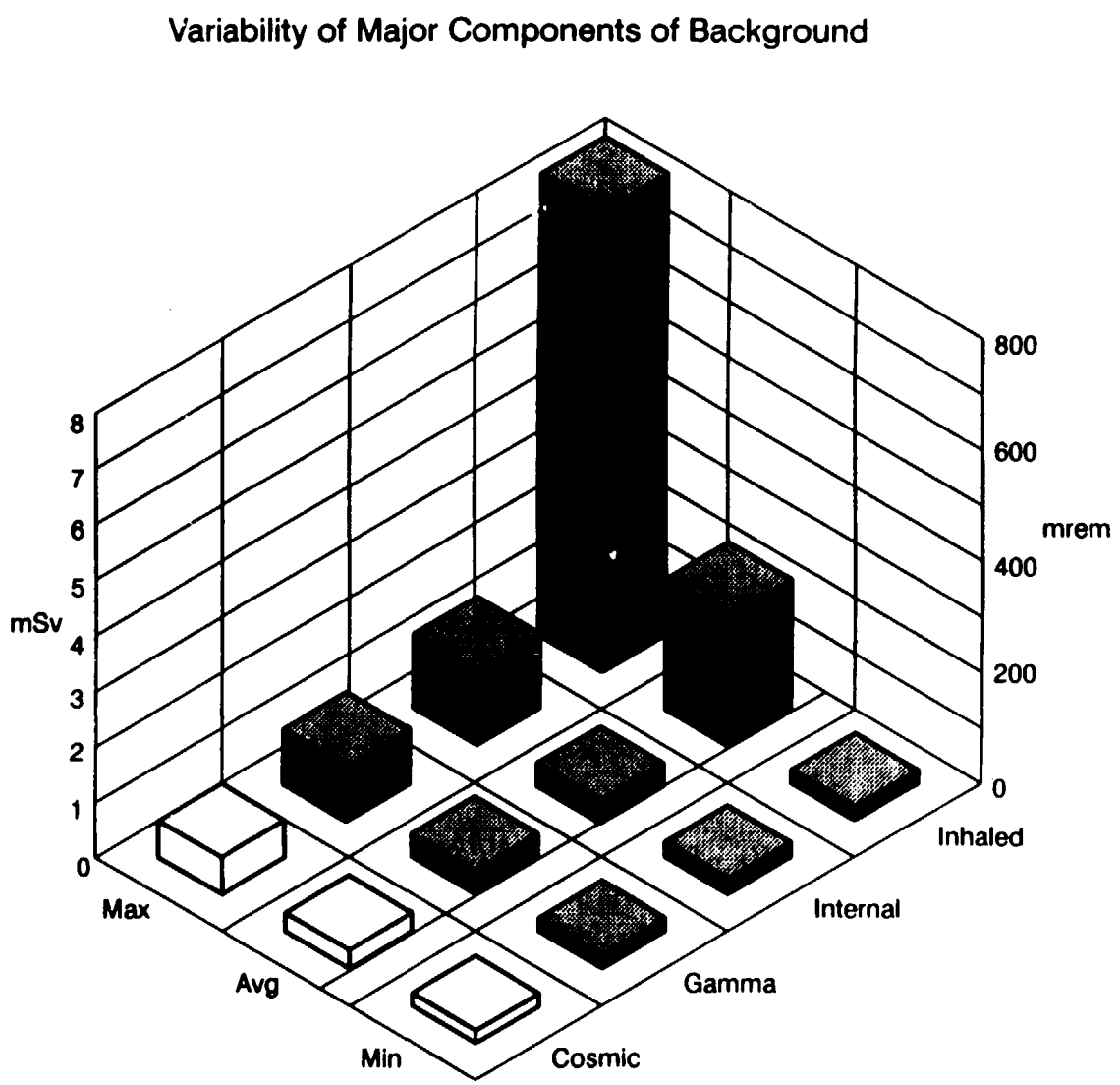


Figure 2.9 Typical maximum and minimum contributions of the major sources of background compared to their respective averages for the United States

2.4.1 Comparison to Worldwide Averages

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) issues a report every few years to update information on the sources, effects, and risks of ionizing radiation. The 1988 UNSCEAR report summarized data that was collected from around the world in the various categories of natural radiation exposure. Table 2.9 shows a comparison of the averages estimated by UNSCEAR and the range (excluding extremes) of effective dose equivalents as compared to the NCRP United States data that were published in 1987. As more information becomes available with each passing year, it is likely that both the worldwide and U.S.-specific values will be modified to some degree, particularly with regard to the radon component.

Table 2.9. Comparison of the Principal Components of Background Between Estimated Populations of the United States and the World

	Annual Effective Dose Equivalent(mSv)		
Component	U.S. Mean[1]	World Mean[2]	World Range[2]
Cosmic	0.27	0.36	0.3–2.0
Indoor radon and progeny	2.0	1.1	0.3–5.0
Internal (other inhaled, ingested)	0.4	0.5	0.2–1.0
Terrestrial gamma	0.28	0.41	0.2–1.0
Totals (rounded)	**3.0**	**2.4**	**1.5–6.0**

[1] From NCRP (1987).
[2] From UNSCEAR (1988).

2.4.2 Comparison to Some Man-Made Sources

After background, the next largest contributor of human exposure to ionizing radiation is medical procedures, such as those involving x-ray examinations and nuclear medicine. Table 2.10 compares the dose estimates for these, as well as a few other man-made sources, to dose estimates from background (NCRP, 1987a). All other sources are much smaller in magnitude. Included in consumer products are such contributions as ceramics, dental prostheses, and luminous watches and clocks, among others.

Again, these are average values; in other words, the total dose is distributed across the population. In fact, certain sub-population groups (such as sick or injured people who undergo the majority of the x-ray exams) are exposed to most of the radiation dose in various categories.

Table 2.10. Comparison of Average Background Doses to Those from Other Sources[1]

Source	Dose[2] (mSv)	% of Total
Background	3.0	82
Consumer products	0.05–0.13	3
Diagnostic x-rays	0.39	11
Nuclear medicine	0.14	4
Occupational	0.009	<1
Weapons test fallout	<0.01	<1
Rounded Total	**3.6–3.7**	**100**

[1] From NCRP (1987a).
[2] Annual effective dose equivalent.

NUREG-0904
Supplement No. 1
Volume 1

Supplement to the Final Environmental Statement

related to the decommissioning of the Rare Earths Facility, West Chicago, Illinois

Docket No. 40-2061
Kerr-McGee Chemical Corporation

Volume 1: Main Text and Appendices A-G

U.S. Nuclear Regulatory Commission

Office of Nuclear Material Safety and Safeguards

April 1989

2.1.2.2 Chemical Characterization

Some data are available on the chemical characteristics of the waste components. Fourteen samples were taken from seven boreholes: two in the ore tailings, drilled to 5.2 m (17 ft); two in the sludge pile, drilled to 3.4 m (11 ft); two in the pond 1 sediments, drilled to 4.4 m (14.5 ft); and one in the pond 2 sediments, drilled to 2.7 m (9 ft). These samples were analyzed for priority pollutant metals, priority and nonpriority organic pollutants (based on the Resource Conservation and Recovery Act, RCRA), pesticides, and polychlorinated biphenyls (PCBs). In addition, 1,822 samples from the Disposal Site, Intermediate Site, and Factory Site were analyzed for soil pH, conductivity, and total organic carbon (TOC); the results are summarized in Tables 2.5 and 2.6 (details are given in Kerr-McGee [1986--Vol. VIII]).

Appreciable concentrations of some metals occur in the Disposal Site wastes (Table 2.5). Average concentrations of lead in the ore tailings and sludge pile are 1,700 parts per million (ppm) and 740 ppm, respectively. Average concentrations of copper, chromium, and nickel range from 4.0 to 42 ppm. The pond 1 sediments contain 200 ppm zinc and 0.81 ppm mercury. Concentrations of selenium and cyanide (except for pond 2) are given as detection limits, which are so high that they are meaningless. The range of cyanide values for pond 2 is explained by the fact that the one individual value used to compute the average was a real value and the rest were detection limits. The concentrations given in Table 2.5 for metals, phenols, and cyanide are given as parts per million or as milligrams per kilogram wet weight; concentration values given in terms of milligrams per kilogram dry weight would be higher. For example, dry weight concentrations of the sediments and sludge would be higher by factors of 2.4 and 1.6, respectively. The only acidic waste component is the ore tailings pile with a pH of 3.54; the other components are approximately neutral (Table 2.5).

Some of the Disposal Site waste components were analyzed for priority pollutant organics; most were not detected. The results for organics that were detected in one or more samples are given in Table 2.6. The concentrations of organics in most of the 14 samples tested were below the detection limits (indicated by hyphens in the table). For some samples, detection limits are quite high -- up to 1,500 parts per billion (ppb) for priority organics and 160 ppb for some PCBs (Kerr-McGee 1986--Vol. VIII, Exhibit I).

Some priority pollutant organics were present at concentrations ranging up to 2,000 ppb, e.g., benzo(a)pyrene in the ore tailings (Table 2.6). Benozo(a)pyrene and some of the organic pollutants detected are typical constituents of coal tar or asphalt and may be derived from the asphalt used as a covering material. Phthalates are used as plasticizers in many vinyl and plastic materials and are becoming widespread in the environment (Kerr-McGee

Table 2.5. Concentrations of Priority Pollutant Metals and Other Parameters in the Waste Components

Parameter	Average Concentrations (ppm)[a]						
			Disposal Site				
	Factory Site	Intermediate Site	Ore Tailings	Sludge Pile	Pond 1 Sediments	Pond 2 Sediments	Contaminated Soil
Antimony	-	-	13	18	14	26	-
Arsenic	-	-	1.9	1.5	<1.2	4.2	-
Beryllium	-	-	<1	<1	<1	<1	-
Cadmium	-	-	0.78	0.80	0.65	0.85	-
Chromium	-	-	6.7	22	16	30	-
Copper	-	-	42	34	20	11	-
Lead	-	-	1700	740	57	31	-
Mercury	-	-	0.48	0.10	0.81	0.045	-
Nickel	-	-	23	8.9	4.0	20	-
Selenium	-	-	<69	<60	<60	<60	-
Silver	-	-	8.7	0.91	1.4	0.8	-
Thallium	-	-	<10	<10	<10	<10	-
Zinc	-	-	3.2	110	200	38	-
Phenol	-	-	<0.002	<0.002	<0.0071	<0.002	-
Cyanide	-	-	<22	<72	<76	1.1-1.6[b]	-
TOC (% dry wt)	0.67(562)	0.44(146)	0.42(125)	1.0(72)	0.88(108)	0.52(184)[c]	0.54(625)
pH (pH unit)	7.33(562)	8.06(146)	3.54(125)	6.56(72)	6.44(108)	7.64(184)[c]	7.86(625)

[a] All concentrations are rounded to two significant figures. A hyphen indicates that no data are available. Concentration units are parts per million unless otherwise indicated. Concentrations of metals, phenol, and cyanide refer to wet materials. The numbers in parentheses are the number of samples used to generate the average. The metal, phenol, and cyanide values are averages of two samples for all sites except pond 2; pond 2 values are for one sample only.

[b] The upper value, 1.6, was calculated by assuming that each detection limit is a real value. The lower value, 1.1, was calculated by replacing each detection limit by the value 0.

[c] Average of samples from ponds 2, 3, 4, and 5.

Source: Kerr-McGee (1986--Vol. VIII, Exhibit I).

Table 2.6. Concentrations of Priority Pollutant Organics in the Waste Components

Chemical Species	Concentration (ppb) in Waste Components at Various Depth Ranges[a]							
	Sludge Pile[b]		Ore Tailings[c]		Pond 1 Sediments[d]		Pond 2 Sediments	
	0-5 ft	5-11 ft	0-9 ft	9-17 ft	0-10 ft	10-14 ft	0-5 ft	5-9 ft
Purgeable Organics								
Methylene chloride	-	-	-	-	-	50,22[e]	-	-
Base/Neutral Extractable Organics								
Fluoranthene	1,550	230	-	-	-	400	-	-
Bis (2-ethylhexyl) phthalate	220	190	-	270	-	-	440	-
Di-n-butyl phthalate	510	600	-	570	300	-	440	490
Benz(a)anthracene	500	-	-	-	-	-	-	-
Benzo(a)pyrene	340	-	-	2,000	-	-	-	-
Benzo(k)fluoranthene	1,230	-	-	1,900	-	-	-	-
Chrysene	650	-	-	-	-	-	-	-
Anthracene	140	-	-	-	-	-	-	-
Phenanthrene	1,020	350	-	-	-	410	-	-
Pyrene	800	190	-	-	-	380	-	-
Diethyl phthalate	250	-	-	200	250	-	180	230
Pesticides								
a-Benzene hexachloride	-	-	10	-	-	-	-	-

[a] A hyphen indicates that no chemical was detected at the detection level for that sample. Only those priority pollutant organics that were detected are listed in the table. Most were not detected.

[b] Values refer to one boring location. No organics were detected at another boring location.

[c] Organics were detected at two boring locations at a depth of 0 to 2.7 m (0 to 9 ft) and at one location at a depth of 2.7 to 5.2 m (9 to 17 ft).

[d] Organics were detected at two boring locations at a depth of 3.0 to 4.3 m (10 to 14 ft) and at one location at a depth of 0 to 3.0 m (0 to 10 ft).

[e] The two concentrations refer to two different locations at about the same depth range.

Source: Kerr-McGee (1986--Vol. VIII, Exhibit I).

1986--Vol. VIII, Exhibit I). Only one waste component, the ore tailings pile, had positive results for the presence of a pesticide (β-benzene hexachloride); however, its concentration (10 ppb) is barely above the detection limit of 8 ppb.

The waste components have been tested in some detail to determine whether they are hazardous wastes as defined by RCRA. These tests (EP toxicity tests, as described in 40 CFR Part 261) were carried out on many samples, and the results were analyzed statistically (Kerr-McGee 1986--Vol. VIII, Exhibit I). The results are summarized in Table 2.7 as 99% upper confidence limits for each metal. Comparison of the concentrations given in Table 2.7 with the EP toxicity limits (second column) shows that the upper 99% confidence limit concentrations for lead and arsenic from the tailings pile, 3.3 mg/L and 3.9 mg/L, respectively, are close to the EP toxicity limit of 5 mg/L. The value for silver for the tailings pile (1.9 mg/L) is also appreciable compared with the limit of 5 mg/L. All other concentration limits in the table are 20% or less of the EP toxicity limits for metals.

Because the concentrations in Table 2.7 are 99% upper confidence limits, it is fairly certain that the on-site wastes are not RCRA hazardous as far as the metal parameters are concerned. (This assessment assumes that the samples chosen for each waste component give an unbiased representation of the component and that no sources of systematic error are present whose removal would raise the test concentrations above the EP toxicity limits.) No test results were reported for the off-site waste components. However, on the basis of the data presented, it appears likely that the off-site waste components are not RCRA hazardous for metals.

The EP toxicity tests for pesticides and herbicides were also carried out on 14 samples taken from the tailings pile, sludge pile, and sediments from ponds 1 and 2 (these are parts of the same samples, described earlier, that were analyzed for RCRA pollutants [Kerr-McGee 1986--Vol. VIII, Exhibit I]). The resulting EP concentrations were 3% or less of the EP toxicity limits for all pesticides (lindane, endrin, methoxychlor, and toxaphene) and herbicides (2,4-D and silvex) for all samples. Consequently, the waste components sampled are also not RCRA hazardous for pesticides and herbicides. No data are available for contaminated soil from the Factory Site, the Intermediate Site, or the Disposal Site, or for off-site waste components. However, on the basis of data obtained thus far, it appears likely that these waste components are also not RCRA hazardous for pesticides and herbicides.

Table 2.7. Concentrations, at the 99% Upper Confidence Limit, of the EP Toxicity Test Means for Metals in Some of the Waste Components[a]

EP Toxicity[b]		Factory Site (mg/L)		Intermediate Site (mg/L)	Disposal Site (mg/L)				
Metals	Limits (mg/L)	North (154)	South (217)	Contaminated Soil (6)	Contaminated Soil (112)	Pond 1 Sediments (15)	Ponds 2-5 Sediments (72)	Sludge Pile (15)	Tailings Pile (21)
Silver	5	0.044	0.025	0.017	0.043	0.017	0.009	0.22	1.9
Arsenic	5	0.28	0.26	0.48	0.30	0.27	0.20	0.63	3.3
Barium	100	0.48	0.18	0.21	0.26	0.26	0.25	0.11	3.4
Cadmium	1	0.010	0.040	0.007	0.011	0.009	0.006	0.019	0.10
Chromium	5	0.038	0.018	0.049	0.029	0.016	0.016	0.023	0.28
Mercury	0.2	0.0012	0.00041	0.00020	0.00094	0.0012	0.00074	0.00028	0.0078
Lead	5	0.17	0.24	0.21	0.15	0.27	0.16	1.1	3.9
Selenium	1	0.12	0.11	0.15	0.097	0.097	0.11	0.10	0.20

[a] The numbers in parentheses indicate the number of samples analyzed for each waste component. Confidence limit values are rounded to two significant figures.

[b] Limits are from 40 CFR Part 261.

Source: Kerr-McGee (1986--Vol. VIII, Exhibit I).

HAZARDOUS
SITE CONTROL
DIVISION

Remedial Planning Field Investigation Team (REM FIT)

ZONE II

CONTRACT NO.
68-01-6692

CH2M HILL
Ecology &
Environment

REMEDIAL INVESTIGATION
REPORT

Kerr-McGee Radiation Sites
West Chicago, Illinois

WA No. 82-5L94.0

September 29, 1986

EXECUTIVE SUMMARY

INTRODUCTION

The Kerr-McGee Radiation Sites are located in the City of West Chicago, which is about 30 miles west of Chicago, Illinois. The Rare Earths Facility (REF) which is the original source of the contaminated waste material, has been owned by several companies. The primary activity at the facility has been associated with the processing of ores containing radioactive thorium, radium, uranium, rare earths, and heavy metals such as lead. The facility was operated from the early 1930's to 1973 when the present site owner, Kerr-McGee Chemical Corporation, (Kerr-McGee) ceased operations.

Over the years, tens of thousands of cubic yards of radioactive waste materials were removed from the REF site and were widely distributed to various locations in the West Chicago area. Later, in recognizing that these wastes were radioactive, numerous studies and investigations were conducted to identify these locations and determine the levels of contamination. Radiation emitted from the REF waste materials and ores has the potential to cause cancer and genetic defects. There is also the potential for groundwater contamination from these residuals.

The studies sponsored by the U.S. Environmental Protection Agency (EPA), U.S. Nuclear Regulatory Commission (NRC), and the City of West Chicago (City) identified two major sites, each of which contained about 10,000 cubic yards of thorium residuals; over 100 residential or commercial properties (Properties) in West Chicago contaminated with the thorium residuals; a contaminated river and creek; and other

contaminated properties in the West Chicago area. The two major sites are the West Chicago Sewage Treatment Plant (STP) and Reed-Keppler Park (RKP), a West Chicago City Park. Subsequent to surveys by NRC and the City, Kerr-McGee conducted radiation surveys throughout the city and identified 117 properties with radiation exposure rates exceeding 30 microR/hour[a], the survey criteria agreed to by the City and concurred with by EPA.

Kress Creek which receives runoff and waste water from the REF site was also found to be contaminated. The West Branch DuPage River was found to be contaminated at its confluence with Kress Creek and also in the area of the STP. Other areas inside and outside of the City have also been found to contain waste residuals from operations at the REF.

The U.S. Environmental Protection Agency has placed these off-site contaminated areas, exclusive of the REF, on the proposed National Priorities List (NPL) for remediation. As of August 1986, the sites have not been placed on the final list. Furthermore, Kerr-McGee has signed a Consent Decree in U.S. District Court with the City to remove contaminated materials located at RKP, and the STP, and has already performed removal of contaminated materials at the other Properties within West Chicago. Properties located outside of the City have reportedly been surveyed by Kerr-McGee. This

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[a] A microR/hour is the abbreviation for 10^{-6} (micro) of a unit of external radiation exposure, the roentgen. External radiation exposure was used as the field techniques to determine the presence of the contamination.

information has not been forwarded to EPA nor have the sites been remediated. Kerr-McGee initiated the removal of materials from the STP in May of 1986. The contaminated materials from these sites have been returned to the REF for storage, pending final disposal. Due to the aforementioned activities, the methodologies used in this remedial investigation (RI) have differed from the traditional approach normally taken. Since remedial actions have been and are currently underway and additional work is planned by other parties and agencies, work has centered on performing data validation and using data generated by other parties to determine present risks. In addition, future risks are assessed based upon completion by Kerr-McGee and the City of the planned remediation.

This Phase of Remedial Investigation (RI) focused on the RKP, STP, and Properties within the City. The RI addresses the relevant data, information and assessment of contamination for the sites located at RKP, the STP, and the Properties in the City to the extent information has been provided to EPA. The locations of the RKP, STP and Kerr-McGee REF sites are illustrated in Figure 1. The Properties are distributed throughout the City. Agreement was reached between EPA and Kerr-McGee to obtain all relevant Kerr-McGee data. These data and prior studies performed for the U.S. Nuclear Regulatory Commission, with appropriate validation activities, form the principal data bases for the RI. The REF, Kress Creek, the West Branch DuPage River (River) and Properties outside of West Chicago were outside the focus of the RI because of other agency enforcement actions and data gaps. These other sites are within the preview of the EPA activities and will be addressed in subsequent phases of the RI. The REF is subject to decommissioning and termination of the radioactive material license under the authority of the NRC.

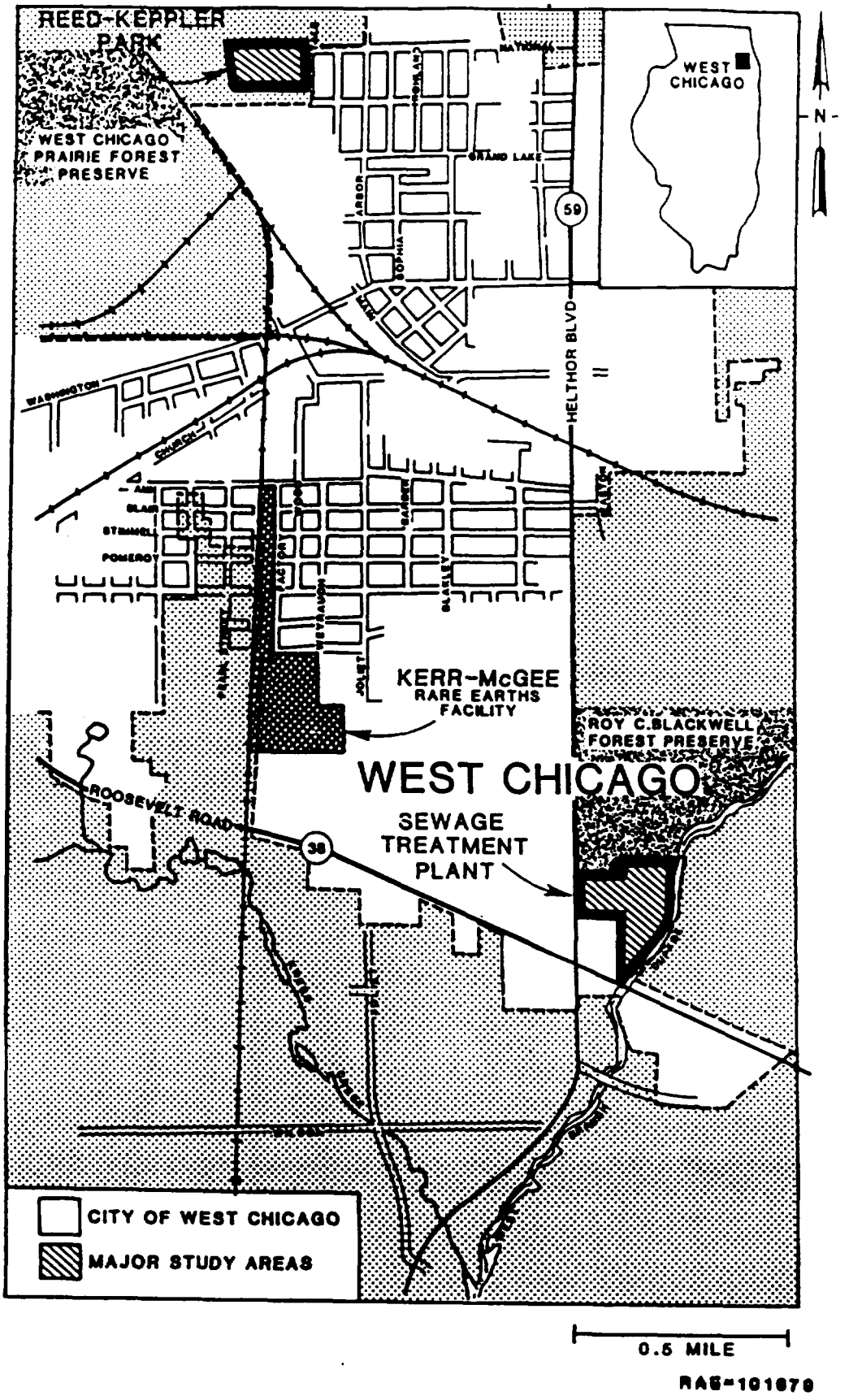

FIGURE 1. WEST CHICAGO SITES.

SITE DESCRIPTIONS AND BACKGROUND

The RKP and STP sites are generally located in suburban settings with residences adjoining both sites in the downwind direction. The Properties are located throughout West Chicago area and outside of the West Chicago City limits in DuPage County.

Reed-Keppler Park is a West Chicago City Park. Its facilities include ball diamonds and a swimming pool. The area to the east of RKP is composed of high density residential housing, primarily single family dwellings. The closest residents downwind of the site are at a distance of about 300 feet east of the main area of wastes. The area immediately to the south, west, and north of the RKP is generally undeveloped. It is estimated that about 20,000 cubic yards of thorium contaminated soil will have to be excavated to remove the contamination from the park. Most of the contaminated material has been placed inside an unguarded fenced area within the park. A plan has been developed by Kerr-McGee and the City to excavate the contaminated waste materials and move them to the REF.

The West Chicago Municipal Sewage Treatment Plant (STP) is located in the southeast corner of the City and occupies an area of about 25 acres. The STP is situated in a low density development area with residential areas to the west, scattered residences to the east and south, and the Blackwell Forest Preserve to the north. The closest resident is located downwind at about 300 feet to the east. The residential area west of the STP is more than 500 feet from the STP. On the STP site, all land area is committed to the sewage treatment plant facilities. Kerr-McGee started excavating thorium residuals from STP in late May of 1986. As

of early August about 7,000 cubic yards of contaminated material remained at the STP.

Residuals from the REF have also been identified at 117 additional sites throughout the West Chicago area. These sites lie primarily east of the REF. Kerr-McGee had removed known residuals from nearly all of these sites within the City of West Chicago by 1985. Surveys of the contaminated sites outside the City limits have been made, but these contaminated sites have not been remediated.

DATA ASSESSMENT AND CONCLUSIONS

There are several routes of potential risks to the environment and public health; including direct external radiation exposure; inhalation exposure; and ingestion of contaminated soils, groundwater, and surface water. The contaminated media at the subject sites are wastes from the REF mixed with soils on the subject sites.

The hazardous characteristics of the thorium residuals are primarily due to the radioactive constituents. The potential for release of heavy metals to the groundwater appears to be minimal, based on the RI activities and assessments. Specifically, validation tests using the EP Toxicity Test to determine the leachability of hazardous substances indicate a low potential for significant groundwater pollution.

The primary radionuclides present are thorium-232 and uranium-238 and their associated decay products. The principal potential risks to man include external gamma radiation exposure, and radiation exposure from inhalation of airborne decay products of thoron (Rn-220) and radon (Rn-222). The REF wastes, which are the original source of the contamination, contain nominal concentrations of Th-232 up to 4000

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THORIUM RESIDUALS IN WEST CHICAGO, ILLINOIS

by

N. A. Frigerio, T. J. Larson,
and R. S. Stowe

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Prepared for the U. S. NUCLEAR REGULATORY COMMI:
under Interagency Agreement DOE 40-550-75

THORIUM RESIDUALS IN WEST CHICAGO, ILLINOIS

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Abstract

Lindsay and Company began operation of its West Chicago, Illinois, plant in 1931, processing thorium ores for thorium and rare earths. From that time until normal operations ceased in 1973, thorium residuals from the operation found their way offsite to Reed-Keppler City Park, the West Chicago Sewage Treatment Plant, and numerous other locations about the city and its environs. The present study located and identified such thorium residuals in the West Chicago area, a total of 75 epicenters having been found in addition to deposits at Reed-Keppler Park, the sewage-treatment plant, and down Kress Creek and the DuPage River. Deposits proved to be almost exclusively the dense, gray, insoluble particles of thorium-ore tailings from the process, which have been historically stored in two large piles in the site waste area. Epicenter locations and associated radiological parameters are given for the 75 locations, along with quantitative descriptions of the larger collections of material at the park, at the sewage-treatment plant, and on the banks of Kress Creek and the DuPage River. Not one of the areas of thorium residuals located outside security fences was found to violate the requirements of 10 CFR 20.

INTRODUCTION

GENERAL

In 1931 Lindsay and Company (which became Lindsay Light and Chemical Company in 1935) commenced operation of its West Chicago, Illinois, plant. This plant processed thorium ores, chiefly monazite, originally to extract thorium for gas mantles. In later years the rare-earth elements contained became of more value, and operation shifted so that the thorium component of the ore became more of a waste and less of a product. In the 1930s and 1940s some of these waste tailings were used in a landfill operation in an unimproved area of what is now Reed-Keppler Park, a public park in northern West Chicago. During that time waste material found its way out of the factory site and into various public and private areas around West Chicago. These included the watershed down Kress Creek into the DuPage River, the present West Chicago

Sewage Treatment Plant, and numerous other places about the city. The waste material so transported was almost exclusively thorium-ore residue from the chemical-extraction processes, a very dense, usually gray to white material, containing about 1%-6% thorium, along with its radioactive-decay products, but only relatively small amounts of uranium and associated uranium daughters. In 1973 all normal operations at the site had ceased, and the current owner, Kerr-McGee Corporation, applied to delicense and decommission the factory and its waste site. This activity began in 1974. The overwhelming bulk of radioactive material was contained in two large open piles in the waste area to the south of the factory, and it became a matter of concern to locate thorium residuals offsite, to control them as needed, and to plan for their eventual removal. The first phase was to secure the relatively large amount of material present in the unimproved area of the park (the "spoil area") and the much smaller amount on the east side of the tennis courts nearby. The latter was exhumed to the spoil area in July 1976, and the entire area was enclosed with a security fence in the spring of 1977. Once that was done, it became our task to locate and quantify the remaining thorium residuals in the West Chicago area.

THE EXTERNAL NATURAL-RADIATION BACKGROUND IN THE WEST CHICAGO AREA

The external natural-radiation background in this area varies from 12 to 36 uR/hr, with about 95% of the values ranging between 14 and 25 uR/hr. This includes both cosmic and terrestrial components. The lower values are generally found over roadways, where shielding is effected by the roadbed. The higher values are generally found over open grassy fields, especially if they have been fertilized with phosphate fertilizers, as is often the case in this area. The highest values are obtained over these same fields in the early morning, whenever meteorological inversion occurs in such a way as to trap natural-soil radon close to the earth surface. The distribution of values was such that values in excess of 20 uR/hr near roadways, or in excess of 25 uR/hr on open fields, were taken as presumptive evidence of the presence of thorium residuals. Such areas were further investigated by spectrometry to determine the presence of excess thorium, if any.

NATURAL RADIOACTIVITY IN THE WEST CHICAGO AREA

These values are relatively high for Illinois as a consequence of several factors. The soil in the West Chicago area is considerably higher in uranium, thorium, and their daughters than many other soils in Illinois. Phosphate fertilization has been common in the past and both the originally fertilized fields, and adjacent fields subject to runoff, have had their uranium-daughter content increased as a consequence. In addition, the city wells of West Chicago, and a number of other wells in the area, tap water from deep sandstone aquifers notable for their high natural radioactivity. As these waters were brought to the surface over the years, and evaporated, they left behind them a notable residue of radioactivity.

THE FACTORY AND WASTE AREA

The primary source of excess thorium is the pair of large tailings piles in the waste area to the south of the factory. This material is so dense, and so thoroughly concreted by weathering, that we were unable to find any evidence of it having been transported offsite by atmospheric dispersion. However, a good deal of the material in waste pond No. 1 had been of a much more easily airborne nature, and some of this was detected in areas immediately adjacent to the site. In the process of transporting material about the city, between the factory and the waste area, and to such sites as Reed-Keppler Park, other thorium-bearing material found its way from the site into various parts of the city. In such cases the transport was purely mechanical. Additionally, the open nature of the piles of thorium-bearing waste made them particularly subject to runoff, especially during heavy rains. Such material, along with factory waste, found its way into the storm sewer along one edge of the property, across the fields, and down into the Kress Creek watershed. The material is so dense, and so insoluble, that it was transported purely as grains of sand-like material, and these grains were found and identified down along the watershed. These grains move by placer action, and their deposition is characteristic of placer movement, as has been noted in similar situations.[1] We were able to map material transported in this way all down the creek, and then, sparingly, along the DuPage River as far south as Warrenville. However, movement by this method is very slow, and in the 47 years since the beginning of plant operation the overwhelming bulk of material carried by this process had moved only about a third of the way down the creek to the river. A foot-by-foot survey was made of both banks of the creek from above the storm-sewer entrance to the junction with the DuPage River. Below that point, material was so sparsely deposited that only a general survey was made, and only outstanding deposits were identified and confirmed.

REED-KEPPLER PARK AND THE WEST CHICAGO SANITARY TREATMENT PLANT

During the first two decades of plant operation the excellent mechanical properties of the thorium-bearing residue commended its use as landfill in the area. There was no recognition of any potential hazard associated with it, and it was used as landfill at the edge of what was to become Reed-Keppler Park and, to a lesser extent, at the present waste-treatment plant. A minor deposit at the park, east of and adjacent to the present tennis courts, was exhumed in July 1976 and consolidated with the larger amount in the spoil area, next to which a sanitary landfill is in operation. In early 1977 a security fence was installed around the spoil area. The fence was placed at the 0.2-mrad/hr isodose line.

Because of uncertainty as to just what parts of the park had been filled, and at what time, we performed a foot-by-foot survey of the entire park. To date no thorium residuals have been found outside of what little remains below the present tennis courts, the spoil area behind the fence, and some minor areas in the sanitary landfill.

At the waste-treatment plant the bulk of the material is contained in two relatively circumscribed regions. The possibility existed that thorium residuals had found their way into the sewage system by way of the combined sewer

system of West Chicago. However, to date we have been unable to identify any thorium exiting from the treatment plant, either in its effluent or in its sludge. A report that its sludge was contaminated by thorium from the site proved to be untrue. The sludge was, in fact, somewhat abnormally radioactive. However, quantitative spectrometry showed that this was simply the result of concentration of the naturally quite radioactive West Chicago well water in the sludge-drying ponds.

WEST CHICAGO AND ENVIRONS

Partly through the normal traffic associated with plant operations, but more notably through the traffic associated with use of thorium residue as landfill, small deposits can be found in many parts of the city and its environs. Overwhelmingly, these lie in an area connecting the factory and waste area on the south with Reed-Keppler Park on the north. In order to identify and quantify these, we performed a street-by-street survey with instrumented vehicles and, where appropriate, on foot. In addition, clues were obtained by extensive conversations with residents, with employees of the City of West Chicago and of the Lindsay Chemical Company, and with contractors and landfill operators in the area. Some residual deposits were also discovered by deduction, e.g. if small spills seemed to constitute a probable truck route, it could be deduced that a final deposit could probably be found at the end of the route so defined.

This process was also greatly aided by an Aerial Radiological Monitoring Survey (ARMS) flyover that was completed in September 1977. Although the flyover could not identify with certainty small local deposits of thorium residuals, it clearly outlined areas of suspicion, and aided greatly in reducing the area requiring intensive scanning by vehicle or on foot. It also provided an excellent basis for determining the contours and levels of X and gamma radiation emanating from the three major sources: the factory and waste site, Reed-Keppler Park, and the sanitary treatment plant. This radiation is referred to as "skyshine" because it contains both direct and scattered components.

METHODS AND OBSERVATIONS

STUDY AREA

The study area chosen was defined on the DuPage County grid system. It extended from 4S000 on the south to 4N000 on the north, a distance of eight miles, and from 28W000 on the east to 32W000 on the west, a distance of four miles, for a total area of 32 mi^2. The study period began in March 1976 and extended through May 1978. Places are identified by street name and address, using the West Chicago numbering system within the city limits and the county numbering system outside. Addresses do not necessarily correspond to a residence, because in many cases locations were in unused fields, alleys, and the like. But they do represent an absolute location on either the West Chicago or county grid system. The study area, and its numbering, is shown in Figure 1. Because they are subjects of a separate action, the factory, the

sewage-treatment-plant effluent and Kress Creek strongly suggests that the present effluent condition extends back into history, and that excess thorium has never found its way through the treatment plant and into the river.

REED-KEPPLER PARK

In mid-1976 it was discovered that thorium residuals had been used as landfill at Reed-Keppler Park. Subsequent to USNRC Office of Inspection and Enforcement Investigation Report Number 76-01 (20 August 1976), thorium-bearing soil was moved from underneath the tennis courts to the spoil area bordering the landfill that lies on the west edge of the park proper. This was accomplished, and a security fence was completed around the residuals, on 28 February 1977. The center of the residual pile is located at 41°53'36" N Lat. and 88°12'30" W Long. The park proper covers 80 acres; the DuPage County Airport is 2.5 miles northwest, the closest edge of the Fermi National Accelerator Laboratory 1.5 miles southwest, and the nearest approach of the DuPage River 1.7 miles northeast. Figure 8 shows the pertinent area of the park, with a 100-foot grid that we erected for surveying purposes. Figure 9 shows the topography of that part of the park, which we produced using standard surveying methods. Figure 10 is an overlay of the latter figure on the former one. The fenced area has one of the highest elevations in the park and it drains directly into a gully to its immediate west, in the present landfill operation. Then the entire park, gully and all, drain to the northwest into a slough and lake. These are bordered on their northern and western edges by mounds, the northern one carrying a branch of the railroad. A number of monitoring wells were drilled into the fenced area, and we sampled these periodically. In addition, we sampled water and soil outside the fenced area, down along the gully, and into the slough and lake. Despite the fact that some of the material within the fenced area came to rest only in early 1977, which might be expected to promote runoff and leaching, we have been unable to find any evidence of soluble material leached out of these thorium residuals into the local groundwater or soil. A certain amount of runoff has occurred from the pile itself down into the gully in much the same manner in which heavy rains have caused similar runoff from the waste area into Kress Creek. However, in this case, the quantities are very much smaller than those involved from the waste area. Relative excess-radiation-field strength is shown in Figure 11, in units of microrem per hour multiplied by 10 (i.e. 50 = 5 urem/hr, 10 000 = 1000 urem/hr). The general terrestrial background in this area is 4-9 urem/hr. Figure 12 shows the radiation-field overlay on Figure 8. In fact, these plots contain all the anomalous radioactivity that we were able to find in the entire park. All the rest of the park was surveyed both by vehicle and on foot, but nothing suggestive of excess thorium was found. Table 2 gives the various characteristics of the area enclosed by the radiation-field isopleths and an estimate of the volume of thorium-bearing material lying beneath these areas. The estimate was based on core samples taken throughout the park. In addition to these, we have located a few minor spills along the roadway running on the west side of the fenced area, through the landfill, and over to the maintenance building.

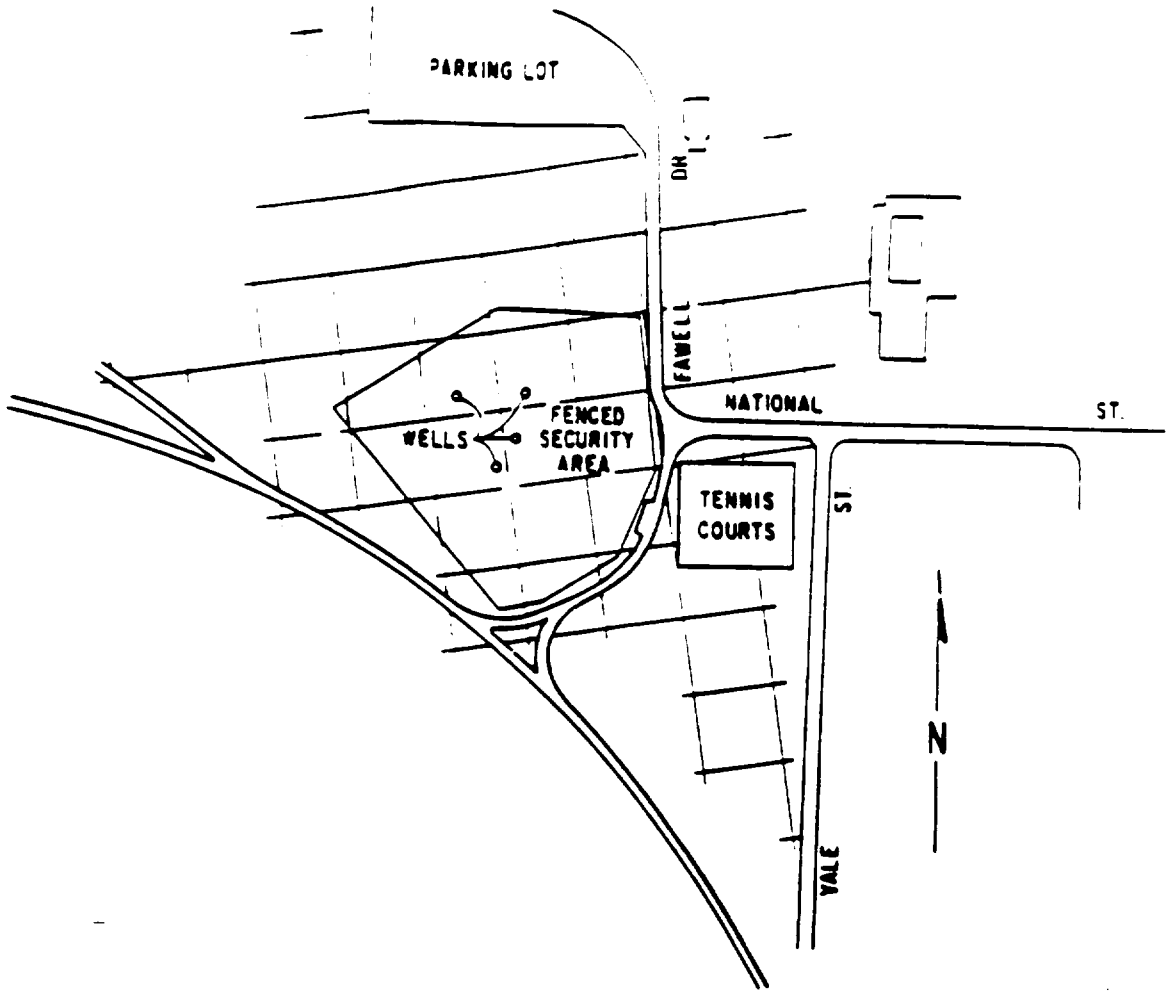

Fig. 8. Land-Surveyor's Grid and Plot Plan of Reed-Keppler Park.

Cores taken within the fenced area showed no anomalous radioactivity below 756 feet MSL. Values below that level were in the range of 0.5-3.0 pCi/g for both ^{232}Th and ^{226}Ra, values typical of the soil in this region. The greater bulk of the anomalous radioactivity lies above 760 feet MSL. However, above that level the material is extremely heterogeneous, and soil concentrations ranging from 3 pCi/g to 40 000 pCi/g of ^{232}Th were found within a few centimeters of one another.

Outside the fenced area, small patches of radioactive soil ranging from 5-50 pCi/g of ^{232}Th were found. These were almost exclusively along the roadway from the northeast corner of the fenced area around to the landfill area on its west side (Fig. 10). Even these patches were only 5-15 cm deep,

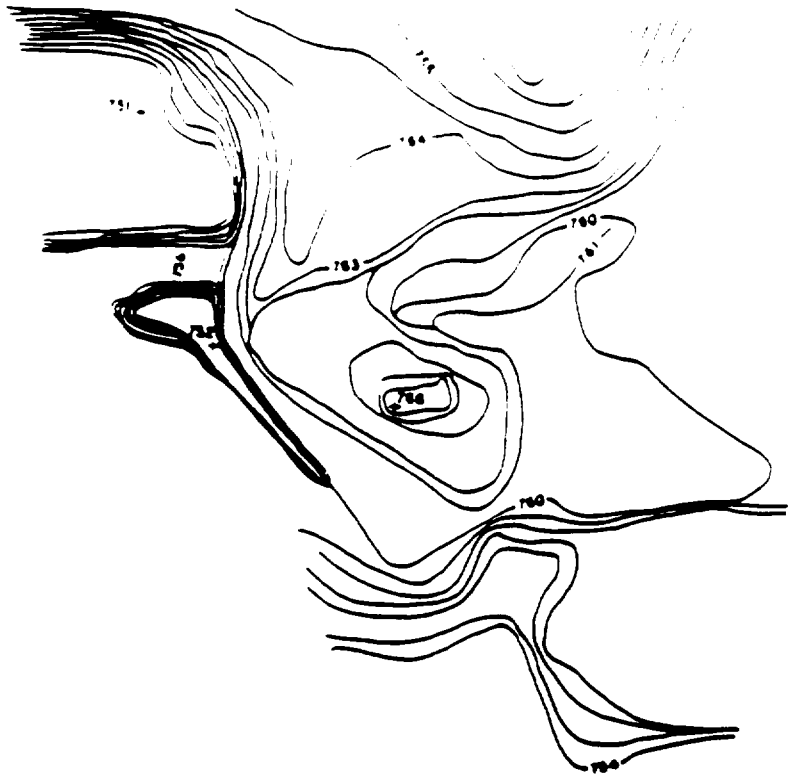

Fig. 9. Topography of Reed-Keppler Park (ft MSL).

and cores taken outside the fence showed no anomalous radioactivity below 15 cm within the 5-urem/hr contour (Fig. 12), and no anomalous soil radioactivity at all outside this contour.

Both ground and surface waters from the fenced area necessarily drain into the small gully just to the west of the fence (Fig. 10), and from there into the slough and lake just northwest of the park. Water from these three bodies was sampled weekly, and no anomalous radioactivity was found in the lake or adjacent slough. In the small gully just below the fence, sediment levels ranged from 5-50 pCi/g of ^{232}Th and 2-10 pCi/g of ^{226}Ra, depending on the season and the occurrence of recent rainfall. Dissolved activity in the same slough was more variable, and ran from background levels to reasonably high levels as a function of rain and season, e.g. 0.5-15 pCi/L of ^{226}Ra or ^{228}Ra, and 0.2-1.5 pCi/L of ^{232}Th or ^{228}Th.

Long-lived, airborne, particulate radioactivity was sampled several times a month at the fence line, both upwind and downwind of the main residual pile. The values obtained were well within typical backgrounds for the area; none

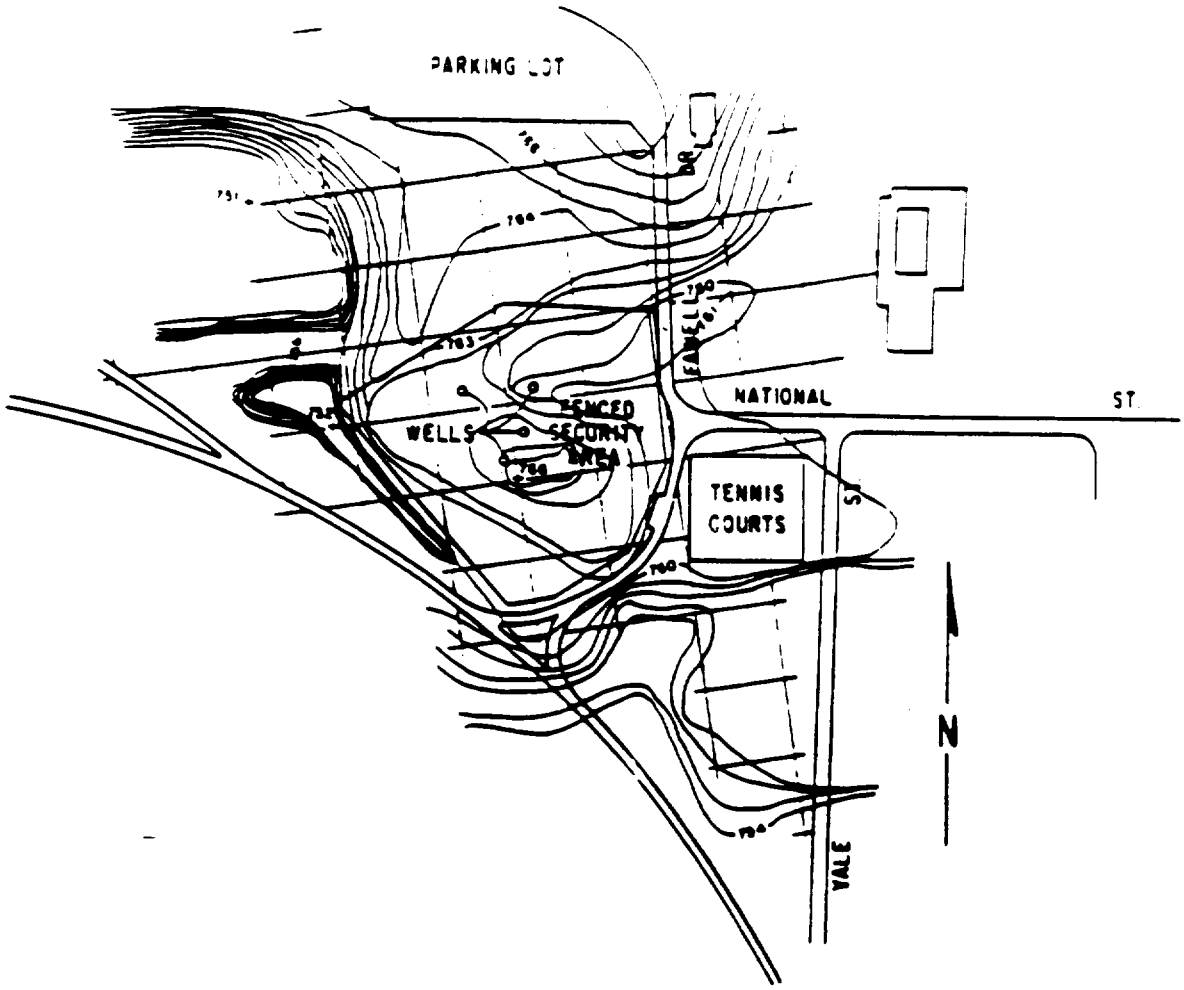

Fig. 10. Reed-Keppler Park Topography (ft MSL) and Surveyor's Grid.

exceeded 0.01 pCi/m^3 of gross alpha, and none gave downwind-to-upwind ratios indicative of significant release from the residual pile. However, ^{220}Rn and ^{222}Rn values were consistently elevated at the downwind fence line relative to the upwind fence line. Under conditions of extreme inversion and very low windspeed, downwind values of 30 nCi/m^3 of ^{222}Rn and 4 nCi/m^3 of ^{220}Rn have been observed, i.e. about ten times the simultaneous upwind or background values. However, the annual average ratio was only about 1.5. Radon concentrations dropped rapidly with distance from the fence line, and excess concentrations were never detected at the nearest residences, e.g. the homes on Yale and National Streets.

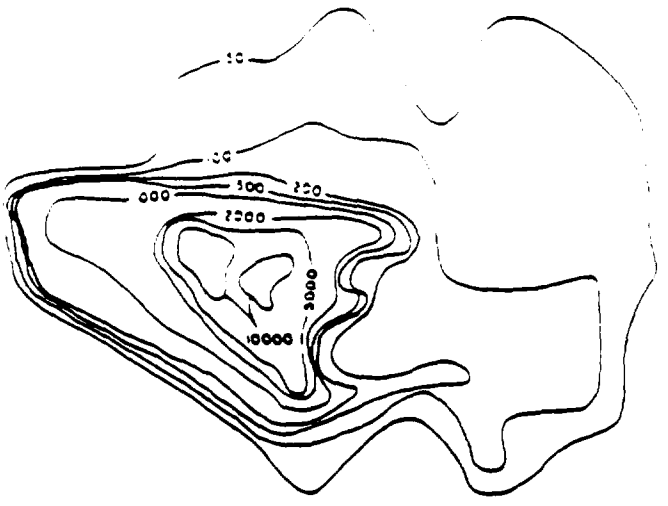

Fig. 11. Isopleths of Relative Radioactivity in Reed-Keppler Park (10^1 urem/hr).

SANITARY TREATMENT PLANT

There are only three thorium-bearing areas here, and no more were found despite repeated foot and vehicular surveys. The major area has been staked off and extends all across the north end of the two northernmost sludge ponds. It extends from a large oak tree on the west to the last metal stake on the east. It contains four epicenters with maximum dose rates of 250-400 urem/hr. The rest of the field averages about 100 urem/hr. The entire area covers about 2000 ft^2. In this case, the source is largely below the surface and seems to be something of the order of 1-2 yd^3 of thorium tailings, partly filling an old buried Imhof tank. The second area is just to the south of the analytical laboratory, with its epicenter exactly eight feet east of the rear door of a concrete-block storage shed. The epicenter has a maximum dose rate of 750 urem/hr, but in this case it appears to have been largely a drop, or small fill, because the dose rate drops off sharply. At the north side of the building and over past a very large filter drum the dose rate runs about 150 urem/hr, and over the rest of this 500-ft^2 field the average is about 50 urem/hr. This storage shed sits on a hill along with a large brick tank, and at the foot of that hill there is a gentle flat field running down to the large southern aeration pond. The half acre of field right at the foot of this hill, and running almost to the water's edge, has no detectable epicenter, but shows a quite uniform dose rate of 20-25 urem/hr. This field appears to be the result of spill from up at the top of the hill being dropped to the bottom, and then graded out as the land was graded to form a lawn. All three of these areas lie outside the normal work area and are more in the nature of storage or reserve areas. As a consequence occupancy is quite low, and although we assigned 100 hr/yr to each area, this is probably a gross overesti-

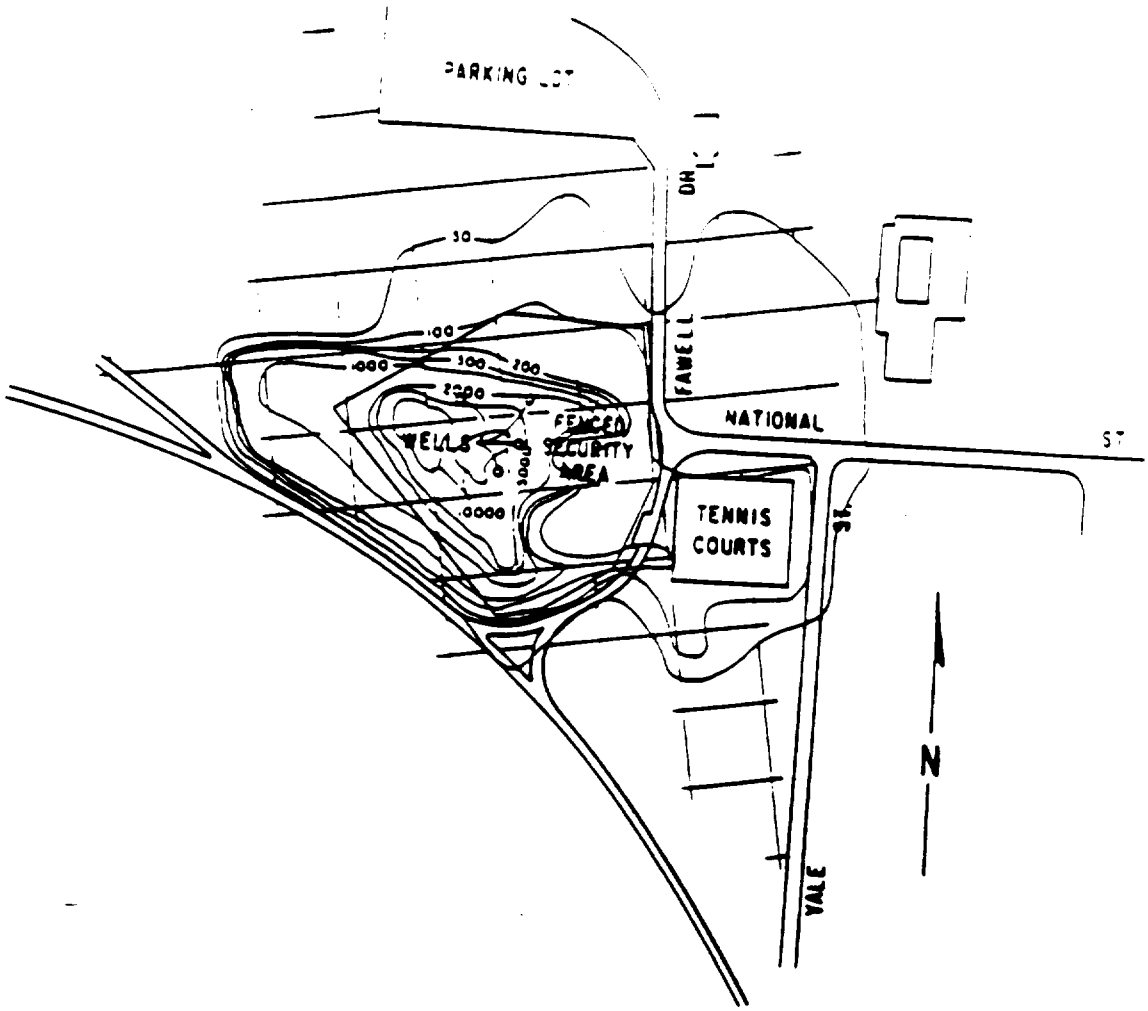

Fig. 12. Isopleths of Relative Radioactivity (10^1 μrem/hr) and Surveyor's Grid in Reed-Keppler Park.

mate. This is especially so inasmuch as the epicenters are of the order of 12 or 15 inches on a side, and standing over them would be more in the nature of an athletic feat than an occupation. In any case, this leads to annual dose values of 75, 40, and 2.5 mrem respectively. There is no public occupancy, partly because the public is excluded, and partly because a sanitary treatment plant can hardly be regarded as an "attractive nuisance". Dose contours are quite narrowly confined to the three areas, and there is no discernable dose from excess thorium beyond the fence.

Table 3. Volume of Radioactive Material for Consideration in Reed-Keppler Park

Relative Radiation Field Strength[a]	Perimeter (ft)	Area (ft^2)	Area Between Isopleths (ft^2)	Volume (yd^3)	Volume Between Isopleths (yd^3)
≥ 10 000	500	8 333	8 333	3 342	3 342
≥ 5 000	700	29 111	20 778	11 677	8 335
≥ 2 000	860	44 889	15 778	18 005	6 328
≥ 1 000	1 250	77 667	32 778	31 153	13 148
≥ 500	1 440	111 333	44 666	44 657	13 504
≥ 200	1 790	132 778	21 445	50 884	6 227
≥ 100	2 100	229 222	96 444	78 889	28 005
≥ 50	2 640	405 222	176 000	132 602	53 713
			405 222		132 602

[a] *As shown in Figures 11 and 12.*

SKYSHINE AND POPULATION DOSE

"Skyshine" is a term used to include the total radiation received at one point from a source at another, and includes both direct and scattered components. In the case of the sewage-treatment plant, as noted above, there is no discernable skyshine beyond the fence, so there is no public exposure from this source. In the case of Reed-Keppler Park the 5-urem/hr thorium excess-dose contour is shown in Figure 12. Below 5 urem/hr it proved difficult to discern excess thorium dose from the natural background, the park being a large grassy field and having the relatively high natural-background characteristic of such fields in this area. However, the excess dose beyond the 5-urem/hr contour certainly was found to drop very rapidly, and was certainly no more than 1 urem/hr at its highest point on the park boundary, the corner of National and Yale Streets. The overwhelming bulk of park usage lies outside the 5-urem/hr contour; there is a very small amount within it, and virtually none at all at higher contours. This is partly a consequence of the fact that the higher contours are associated with an area that is not really park at all, but sanitary landfill. It is neither attractive nor really kept open for public use. Considering maximum feasible park occupancy, occupational occupancy at the landfill, and the residences along National and Yale Streets, it was still impossible to discern a total population dose in excess of 0.2 manrem/yr from the present thorium-residual situation in Reed-Keppler Park.

The situation around the factory site and waste area is somewhat different. There are essentially two primary sources here, the factory itself, and the two large tailings piles in the waste area. Thus, the dose-rate contour about this area is necessarily asymmetric. The 10-mrem/hr (170-mrem/yr) contour is shown on Figure 10. It contains, at most, four or five residences. The 1-mrem/hr excess-dose contour is shown in Figure 2. This is given because it is the level of confusion below which it is impossible to detect any difference above natural background. This contour contains several hundred residences, as well as the regular transients represented by the shopping area to the south, the Pioneer School to the west, and the Gary and West Chicago Junior High Schools to the east. From contours such as these, combined with surveys of the present resident and transient populations, we obtained a maximum value for the annual population dose of 20 manrem/yr.

CONCLUSIONS

A glance at the epicenter maps indicates that the thorium-residual areas in West Chicago are widely scattered. Nonetheless, and interesting as the situation may be, there is no hazard to the public health and safety. As things stand at present there are no areas that exceed the limits of 10 CFR 20 inasmuch as the three major areas of thorium residual are contained within security fences, and the remaining areas are too small and of too low a dose rate to be of serious concern. Thus, no epicenter exceeds the limit of 2 mrem in any one hour. The only epicenter that could conceivably exceed the limit of 100 mrem in one week, No. 6, is about 15 inches on a side and located in the entranceway to a little-used parking lot. It is not even remotely reasonable that anyone could spend the required 110 hours located rigidly above this spot for one week. And, as a glance at Table 1 shows, there are no epicenters that even remotely approach the limit of 0.5 rem/yr. The total population dose from all sources is certainly less than 30 manrem/yr, and this can be contrasted with the roughly 2000 manrem/yr obtained by the population of this area from the natural-radiation background. Even so, the situation does constitute a public nuisance of some magnitude and, although no regulatory action is mandated, some action to relieve the nuisance is probably in order.

NUREG-1501

Background as a Residual Radioactivity Criterion for Decommissioning

Appendix A to the Generic Environmental Impact Statement in Support of Rulemaking on Radiological Criteria for Decommissioning of NRC-Licensed Nuclear Facilities

Draft Report

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2 OVERVIEW OF BACKGROUND RADIATION

2.1 Introduction

A number of the elements, present on Earth since its formation, have unstable forms that transmute to other elements in a process called radioactive decay. In this process, energy is released in the form of radiation. This energy can take the form of subatomic-size particles such as alpha and beta particles, or it can be in the form of electromagnetic energy such as x-ray and gamma rays, which are sometimes referred to as "photons." These forms of radiation fall in a category called ionizing radiation, meaning they can create electrical charge when they interact with matter.

Another source of ionizing radiation in our environment originates in outer space, producing particles in the atmosphere that penetrate to ground level. This radiation is energetic enough to also create new radioactive elements by interacting with otherwise stable elements present on Earth. Everything on the planet, including every living thing, is bathed in a sea of radiation from these various sources. This is commonly referred to as "natural background," "background radiation," or more simply, "background."

For perspective, a handful of typical garden soil contains several billion billion unstable atoms that over time will ultimately decay to a stable form. Each second, scores of these atoms undergo this decay process and emit radiation. In a typical environment, thousands of gamma rays impinge on the body each second. The air that people breathe contains naturally occurring radioactivity, and even a person's body contains natural radioactive elements that tend to concentrate in certain tissues, according to their respective chemistry.

In addition to natural sources of radiation, people are exposed to man-made sources of ionizing radiation. Perhaps the most commonly known is x-rays, which are used in dental and medical examinations. Despite this and other sources of ionizing radiation that have been produced during the technological developments of the 20th century, background remains the principal source of exposure for most people. In this and the following sections of this report, the various sources of background, their degree of variability, and the manner in which they are measured and distinguished from man-made sources of radiation will be examined in some detail.

2.1.1 Units of Measurement

To understand background and the significance of its various components, it is necessary to deal with various units of measurement. The degree of radioactivity of a material is a measure of the rate at which its atoms are undergoing decay. For a chemically pure radioactive substance, the decay rate can be calculated from the amount of material and the half-life of that particular radionuclide. The current internationally recognized unit is called the "becquerel" (abbreviated as Bq), which is one disintegration of an atom per second.

Older style units such as the "curie" (abbreviated as Ci) are sometimes still used. Frequently, the concentration of radioactivity in a medium such as soil, water, or air is given, in which case the unit may take such forms as Bq per gram, per liter, or per cubic meter. Frequently, the prefixes milli (one-thousandth), abbreviated as "m," and micro (one-millionth), abbreviated as "μ," are used with radiation units.

2.1.1.1 Units of Measurement for External Radiation

Apart from the measurement of the rate at which a substance is undergoing decay, there is the measurement of the effect of the emitted radiation at some distance from the radioactive material. This can be in terms of the amount of electric charge that is created in air ("roentgen" in the old system, abbreviated as "R," or coulombs per kilogram in the new system, abbreviated as C/kg) or the energy that is transferred to surrounding matter ("rads" in the old system, or "grays" in the new system, abbreviated as "Gy").

2.1.1.2 Units of Measurement for Internal Radiation

When the energy released from a radioactive material is absorbed by body tissues, the energy is transmitted to cells and surrounding fluids and noncellular structures. This absorbed energy has the potential to cause damage at a microscopic level, the effects of which could be immediate (cell death) or delayed (cancer). To provide a common footing in the measurement of different types of radiation and their effects on different parts of the human body, be it from sources external or internal to a person, scientists have introduced a quantity known as the effective dose equivalent, which has lately become known simply as the effective dose. In the current internationally accepted system, the unit is the "sievert" (abbreviated as Sv). The old system of units used "rem," which is equal to one hundredth of a sievert.

2.2 Sources of Radiation

Background is comprised of four major sources (or components) of ionizing radiation. The first source discussed in this report is terrestrial radiation, which produces the largest dose to people living in the Unites States. The remaining components of background, which are cosmic, cosmogenic, and man-made radiation sources, are relatively minor contributors to the dose from background compared to terrestrial radiation. Each of these sources is discussed in the next four sections of this report to give the reader a basic understanding of their origins, physical properties, and relative contributions to the total background dose rate.

2.2.1 Terrestrial Radiation

The naturally occurring forms of radioactive elements that were incorporated into Earth during its formation and that are still present are referred to as "terrestrial radionuclides." Virtually all materials found in nature have some degree of natural radioactivity. Rocks, soil, water, air, plants, and animal life all have varying concentrations of terrestrial radionuclides. The most significant of these are uranium-238 and thorium-232, which both decay in a long chain (or series) of various radionuclides, and potassium-40 and rubidium-87, which have much simpler decay schemes. These principal radionuclides and their decay products, which are commonly referred to as "progeny," are listed in Table 2.1 along with their corresponding half-life, which is the average amount of time it takes for half of the atoms of that radionuclide to undergo decay. The listing is given in order to indicate the immediate parent and decay product for each radionuclide. This table also gives the major types of radiation given off in the decay of each radionuclide. Among these, alpha radiation is the least penetrating, beta radiation and x-rays are somewhat more penetrating, and gamma radiation is the most penetrating.

Table 2.1. Principal Natural Radionuclide Decay Series

Nuclide	Half-Life	Major Radiations
Uranium-238	4.47 billion years	alpha, x-rays
Thorium-234	24.1 days	beta, gamma, x-rays
Protactinium-234m	1.17 minutes	beta, gamma
Uranium-234	245,000 years	alpha, x-rays
Thorium-230	77,000 years	alpha, x-rays
Radium-226	1600 years	alpha, gamma
Radon-222	3.83 days	alpha
Polonium-218	3.05 minutes	alpha
Lead-214	26.8 minutes	beta, gamma, x-rays
Bismuth-214	19.7 minutes	beta, gamma
Polonium-214	164 microseconds	alpha
Lead-210	22.3 years	beta, gamma, x-rays
Bismuth-210	5.01 days	beta
Polonium-210	138 days	alpha
Lead-206	stable	
Thorium-232	14.1 billion years	alpha, x-rays
Radium-228	5.75 years	beta
Actinium-228	6.13 hours	beta, gamma, x-rays
Thorium-228	1.91 years	alpha, gamma, x-rays
Radium-224	3.66 days	alpha, gamma
Radon-220	55.6 seconds	alpha
Polonium-216	0.15 seconds	alpha
Lead-212	10.64 hours	beta, gamma, x-rays
Bismuth-212	60.6 minutes	alpha, beta, gamma, x-rays
Polonium-212	0.305 microseconds	alpha
Thallium-208	3.07 minutes	beta, gamma
Lead-208	stable	
Potassium-40	1.28 billion years	beta, gamma
Argon-40	stable	
Calcium-40	stable	
Rubidium-87	47 billion years	beta
Strontium-87	stable	

Two of the more commonly known radioactive elements in Table 2.1 are radium, which was discovered by Marie Curie and used extensively for luminous watch dials and medical treatments years ago, and radon, a gaseous decay product of radium for which many people now have their homes tested. Another long-lived nuclide not listed here that has a series decay scheme is uranium-235. This radionuclide occurs in nature at a concentration of less than 1 percent of the more abundant uranium-238 and is therefore much less significant in terms of its contribution to background. A number of other less abundant radionuclides can be found in nature; however, they exist in such low concentrations that their contributions to background are negligible.

As an example of the range of concentrations for naturally occurring radionuclides that can be found on Earth, Table 2.2 gives information that has been collected by researchers around the world for the uranium-238 and thorium-232 series and potassium-40. Although the ranges given in this table are typical for soil, even larger variation is possible in certain mineral-rich areas. The concentrations of uranium and thorium in ore-grade deposits of these elements would of course be orders of magnitude higher than the values in these tables.

Table 2.2. Typical Ranges in Average Concentration of Background Radionuclides (Bq per kg)

Material	Uranium-238	Thorium-232	Potassium-40	Reference
Bauxite ore	250	200	n/a	UNSCEAR, 1988
Coal, U.S.	18 (1-540)	21 (2-320)	52 (1-710)	Beck et al, 1980
Copper ore	30-80	23-110	n/a	UNSCEAR, 1988
Crustal rock, U.S.	36	44	850	NCRP, 1987b
Oil shale	56 (37-74)	24 (19-37)	481 (185-962)	Gogolak, 1982
Phosphate fertilizer, U.S.	9200	n/a	n/a	UNSCEAR, 1988
Soil, worldwide	25 (10-50)	25 (7-50)	370 (100-700)	UNSCEAR, 1988
Soil, U.S.	37 (4-141)	36 (4-126)	n/a	Myrick, 1983

Since many people spend most of their time indoors, radiation exposure from background is very much affected by the concentrations of the naturally-occurring radionuclides in building materials. Table 2.3 gives the radionuclide content for some building materials used in the United States. Wood, a principal component in a light frame structure (e.g., a typical home) would generally have negligible natural radionuclide concentrations as compared with stone and masonry materials. As an example of data collected from around the world, Table 2.4 gives radionuclide concentrations for common brick.

Table 2.3 Natural Radionuclide Content of Some Building Materials for the United States (Bq per kg)

Material	Uranium-238 (Radium-226)	Thorium-232	Potassium-40	Reference
Adobe Brick	31	27	583	Ingersoll, 1981
Brick	4-178	1-144	7-1184	Eichholz et al, 1980
Concrete	19-89	15-118	262-1147	"
Concrete Block	41-777	37-81	285-1147	"
Gypsum	13	2	61	Ingersoll, 1981
Red Brick	45	42	522	"
Rock, Storage	57	53	921	"

Table 2.4. Natural Radionuclide Contents of Bricks
(Bq per kg)

Country (type)	Uranium-238 (Radium-226)	Thorium-232	Potassium-40	Reference
Canada (various)	4–120	8–160	200–800	Zikovsky, 1992
Finland (red)	78	62	962	NEA, 1979
Germany (traditional)	59	67	673	"
India	48	26	3	Ramachandran, 1989
Italy (various)	28–81	40–148	365–1060	Bruzzi, 1992
Norway	104	62	1058	NEA, 1979
Sweden	96	127	962	"
United Kingdom (clay)	52	44	703	"

2.2.2 Cosmic Radiation

Cosmic radiation, commonly known as cosmic rays, consists of highly energetic particles, mostly the nuclei of the elements hydrogen and helium. Supernova explosions and other phenomena that occur throughout the universe are believed to be the source and driving force of cosmic rays. When they enter Earth's upper atmosphere, they undergo interactions that lead to the production of charged particles, gamma rays, and neutrons (uncharged particles that are principal constituents of the nuclei of atoms).

Decay and additional interactions ultimately lead to a makeup of "secondary" radiation near the surface of Earth that consists mainly of directly ionizing muons and electrons with a smaller proportion of neutrons that indirectly ionize matter. Although interactions with the atmosphere cause the secondary production of cosmic rays, the air surrounding Earth nonetheless serves as an important shield to living things. Without this shield, the more energetic primary cosmic ray particles would reach Earth's surface.

Another source of radiation from space is charged particles that are associated with flares on the sun. On rare occasions, a solar flare is strong enough to produce a significant radiation dose in the lower reaches of Earth's atmosphere.

2.2.3 Cosmogenic Radiation

Cosmic radiation, which itself leads to a direct radiation dose to people, is also responsible for the production of radioactive elements called "cosmogenic" radionuclides. These radionuclides arise from the collision of the highly energetic cosmic ray particles with stable elements in the atmosphere and in the ground. Many different cosmogenic radionucludes are produce, although the most important is carbon-14. Other less significant cosmogenic radionuclides include hydrogen-3 (also known as tritium), beryllium-7, and sodium-22. Concentrations of these cosmogenically produced nuclides in the air and ocean water are given in Table 2.5. Another source of cosmogenic radionuclides is extraterrestrial matter that intercepts and is captured by Earth's orbit. This contribution is very small,

however, and can be ignored. The entire cosmogenic contribution to background is very small compared with that of the terrestrial and cosmic components.

Table 2.5. Concentrations of Principal Cosmogenically Produced Radionuclides[1]

Nuclide	Troposphere (Bq/kg air)	Oceans (Bq/kg water)
Beryllium-7	0.01	n/a
Carbon-14	n/a	5×10^{-3}
Hydrogen-3	1.2×10^{-3}	n/a
Sodium-22	1×10^{-4}	n/a

[1] From NCRP (1987b).

2.2.4 Man-Made Sources

Human activities have resulted in the production of various sources of radiation. Nuclear reactors and weapons have produced large quantities of radionuclides through the fissioning of uranium and other heavy elements and the activation of various elements. Particle accelerators used in scientific research have produced smaller quantities. Although most of these radionuclides are short lived and quickly decay to stable forms, a few have half lives of several to thousands of years. In this category are cesium-137, strontium-90, the gas krypton-85, and various isotopes of plutonium that have been deposited throughout the globe as the result of nuclear weapons tests conducted in the atmosphere. Concentrations of cesium in surface soil might typically be about a few Bq per kg; however, values as high as 740 Bq per kg have been found from weapons test fallout (Miller and Helfer, 1985).

The global inventory of the naturally produced cosmogenic radionuclides carbon-14 and hydrogen-3 have also been increased through human activities in the nuclear field. Although not "natural," these sources of radiation have very much become part of the background to which humans are exposed. It is sometimes necessary to separately measure these globally distributed radionuclides and to distinguish them from locally produced sources.

2.3 Variability of Background

This section of the report is intended to give the reader a better understanding of the causes and magnitude of background variability. Although background is ubiquitous, each of its components and the corresponding dose they deliver to the United States resident is by no means constant. Background variability can result from natural means, whether terrestrial or extraterrestrial, and human activities. The following sections discuss the causes of variation and the temporal and spatial variability of background for each of its major components.

2.3.1 Causes of Variation

For terrestrial radiation, changes to the land and the makeup of the radionuclide content of soil can result from geophysical phenomena such as mountain formation, earthquakes, volcanoes, glaciers, and changes in ocean levels and river courses and flood plains. On shorter time scales, the outdoor

radiation field is affected by climate and weather through the action of precipitation and wind. Human activities such as soil excavation, building construction, mining, nuclear power production, and fossil fuel combustion can alter the radiation field. To a large extent, humans affect their exposure to inhaled radioactivity from radon with the degree and type of ventilation they use inside homes, schools, and workplaces. Humans also alter the dietary intake of radioactivity through regional, countrywide, and even worldwide food distribution.

The intensity of cosmic radiation depends upon the degree of shielding provided by the atmosphere. It thus depends upon altitude and barometric pressure. Shielding provided by the structures that people inhabit, particularly large apartment and office buildings, reduces cosmic ray exposure. Earth's magnetic field also deflects the incoming cosmic ray particles, and the temperature of the atmosphere has some effect as well. The sun goes through cycles (with a period of about 11 years) that modulate cosmic radiation through interactions with solar wind and magnetic disturbances. The frequency and intensity of solar flares is also tied to the solar cycles.

The production rate of cosmogenic radionuclides depends upon the intensity of the cosmic radiation. Thus, the same phenomena observed with cosmic ray variations can be expected for the rate at which cosmogenic radionuclides are created. Because some of these radionuclides are long-lived, however, the overall amount present on Earth does not change over the short term. Rather, local variations result after atmospheric mixing occurs, and these radionuclides are deposited to Earth's surface according to seasonal precipitation patterns around the globe.

The variability of man-made sources of radiation and radioactivity relates directly to the population distribution and level of technology found in different areas around the world. In some cases, locally produced radioactive materials are dispersed throughout the Earth's atmosphere, land areas, and water bodies. The level of deposition in an area, as in the case of cosmogenic radionuclides, depends upon wind and precipitation patterns.

The temporal and spatial variability of each of the major components of background is discussed separately in the following sections.

2.3.2 Temporal Variability

2.3.2.1 Terrestrial Radionuclides

The changes in background radioactivity concentrations and radiation levels that are associated with various physical phenomena occur on time scales ranging from short duration (hours to days) to medium duration (months and years) to long duration (centuries or more). While only general effects can be predicted for long term changes based on our understanding of geological processes and the history of Earth, a good deal of knowledge has been gathered in recent years on short and medium duration effects by actually measuring the level of radiation at environmental monitoring stations.

2.3.2.1.1 External Terrestrial Radionuclides. The radiation coming from background sources external to the body has been observed to change over time periods ranging from minutes to months. Data collected at the Chester Regional Baseline Station, a rural field site in western New Jersey, is used here to demonstrate the degree of variability (EML, 1978, 1979, 1980, 1981, 1982, 1984, 1985, 1988, 1991).

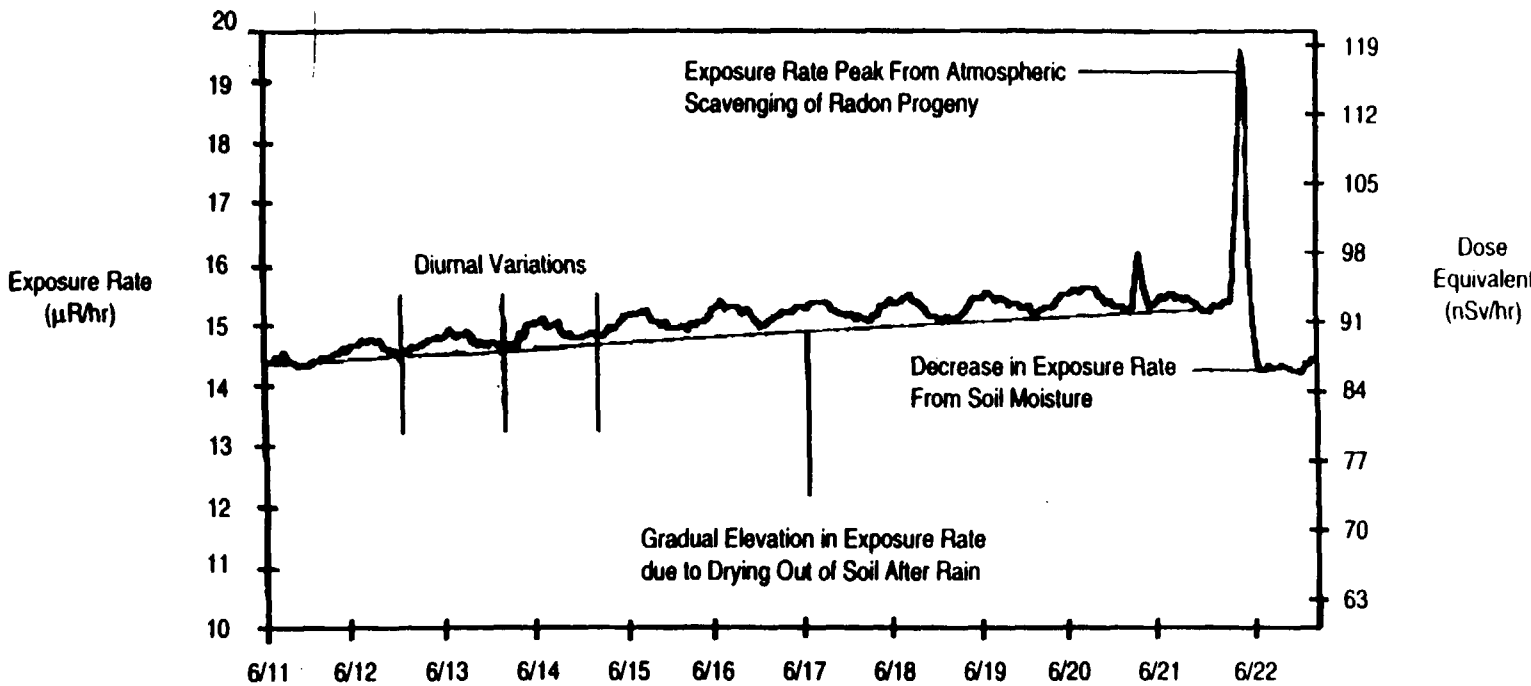
Figure 2.1 graphically illustrates the typical short-term variations observed in the rates of exposure from the penetrating component of background (gamma rays from terrestrial sources plus cosmic secondary radiation). These rates were measured hourly for a period of 11 days.

Several commonly observed effects on background gamma radiation are readily observable in this graph. The first feature to note is the somewhat wavering baseline, which represents the usual background level present at this site. This level gradually rose each day until some abrupt changes occurred at the end of the period. This rise resulted from the soil drying out, because this period of time was characterized by hot weather with no rainfall. (The effect of soil moisture is one principal factor in the variability of the external radiation levels. Water acts as a shield against the radiation coming from radionuclides contained in the ground, and dilutes the concentration of the radionuclides in the soil). The peaks toward the end of the period coincided with rainstorms. The quick rise in the radiation level resulted from a natural fallout process, one in which the airborne decay products of radon-222, primarily lead-214 and bismuth-214 (see Table 2.1) were scavenged (that is, washed out by rain). The radioactivity that was distributed throughout the lower region of the atmosphere caused the radiation level to rise when it was brought down to the ground. The second, larger peak in this graph shows the background exposure rate level increasing by approximately 30 percent or, in terms of effective dose equivalent, about 0.03 μSv per hour (equivalent to about 5 μR per hour in terms of exposure in air).

Natural washout events have been observed to double, and in rare cases even triple, the normal terrestrial gamma-ray level at a site during particularly heavy downpours associated with thunderstorms. These sharp increases from washout are not sustained, however, as the short-lived, gamma-emitting radon progeny decay away over the course of a couple of hours once the rain stops or the air is cleared of radioactivity. Also clearly evident in this graph is the return to more normal background levels with the addition of water to the soil. The first small peak represented in this figure was associated with a rather small rainfall event, out the second larger peak was associated with enough rain that the baseline level dropped markedly after the peak. The features shown in this particular graph can be repeated many times over the course of a season.

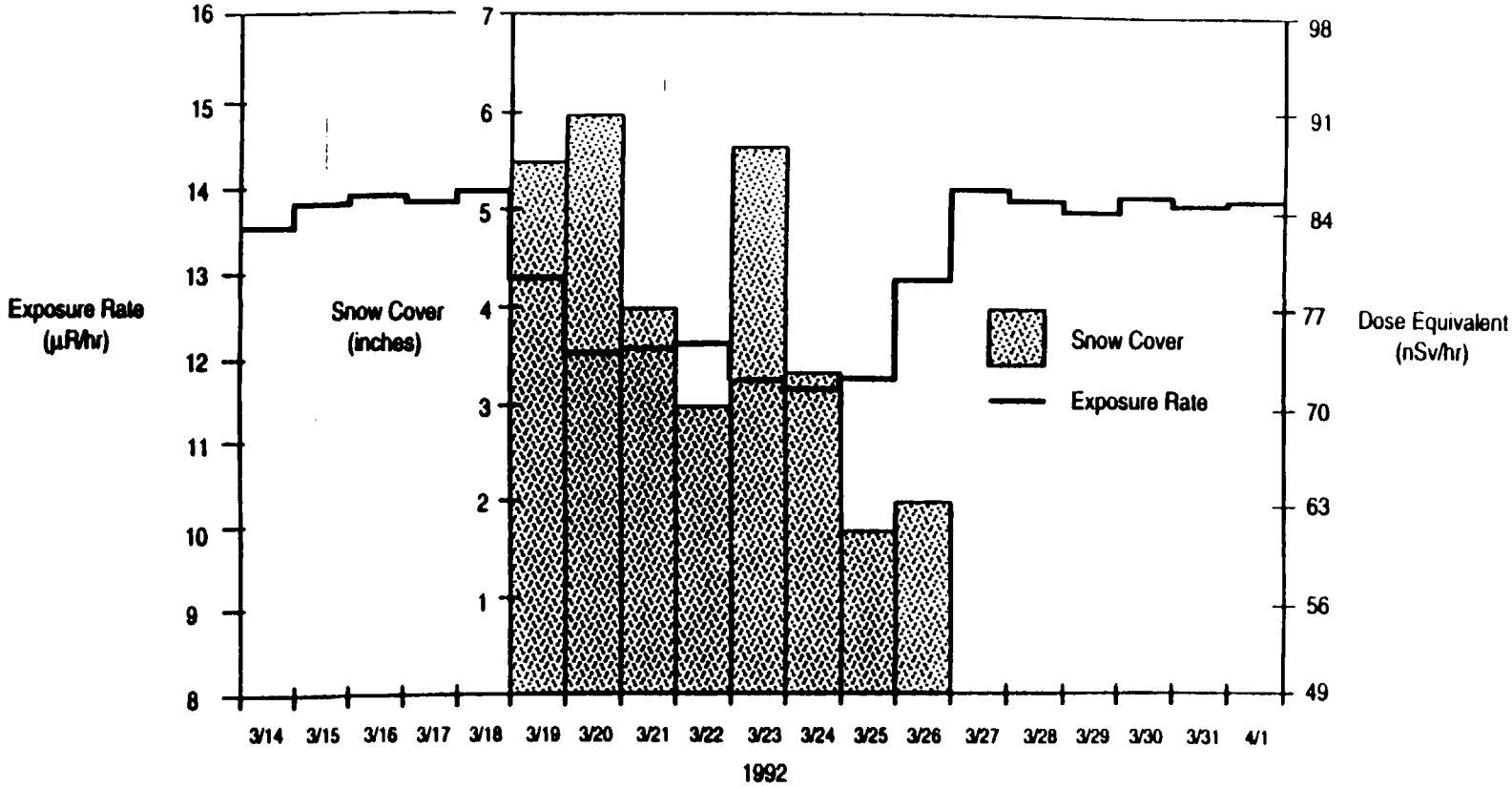
Another generally observable phenomenon in Figure 2.1 is that the waviness of the baseline during the first 10 days is not random. Rather, the cyclic action occurred on a daily basis as a result of changes in the radon progeny levels in the air which, in turn, arose from changes in the stability of the atmosphere. Extremely stable conditions produce what is known as an inversion layer (that is, the air temperature is lower at ground level than above, which is opposite to the norm). In the early morning hours before sunrise, conditions are typically calm, and the radon (which seeps from the soil into the air) stays near ground level, thus causing the radiation level to rise. When the sun rises, the ground warms up and air near it rises, producing a mixing effect that sweeps away the radon and its progeny to higher levels in the atmosphere, thus lowering the radiation level. The process cycles like this from day to day.

One of the most dramatic changes in gamma radiation levels occurs during periods of snow. While adding water to the soil decreases the radiation level to some degree, the shielding effect is much greater when water, in the form of snow or other frozen precipitation, accumulates on top of the ground. As shown in Figure 2.2, a period of snow cover with a depth of several inches reduced the radiation exposure rate by about 15 percent, or about 0.012 μSv per hour (2 μR per hour). The actual degree of shielding depends on the water equivalent of the snow, because a heavy wet snow is more effective than a dry light snow. After the snow melts away, the radiation returns to its usual



Note: Conversion of exposure to dose made by using 1R = 0.0087 Gy. For environmental radiation, coversion of absorded dose in air to effective dose in the human body is 1 Gy = 0.7 Sv.

Figure 2.1 Typical short-term variations observed in the out door exposure rate.



Note: Conversion of exposure to dose made by using 1R = 0.0087 Gy. For environmental radiation, coversion of absorded dose in air to effective dose in the human body is 1 Gy = 0.7 Sv.

Figure 2.2 The effects of snow cover on the outdoor exposure rate

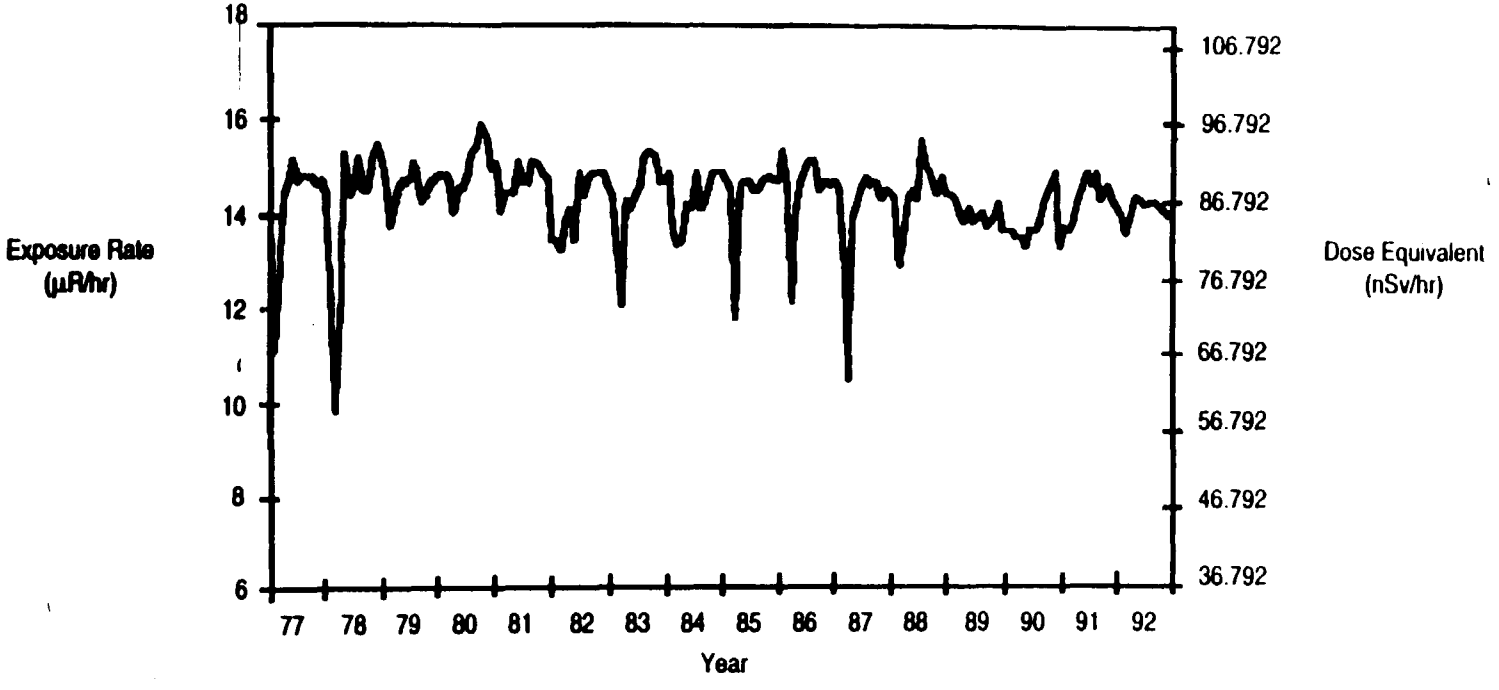
level. Calculations, supported by experimental data, have shown that 5 cm (2 inches) of water equivalent (that is, melted snow) would reduce the external gamma radiation level near the ground by almost 40 percent, while 15 cm (6 inches) would reduce it by nearly 70 percent (Saito, 1991). Mountainous areas that receive extremely heavy snowpack, say 50 cm (20 inches) water equivalent, would see the external gamma level drop by more than 95 percent. If this type of snowpack were sustained for a few months, it might lower the annual dose at a typical site by 0.1 mSv (10 mrem).

Variations in radiation levels from month to month primarily result from changes in soil moisture content and snow cover. Figure 2.3 shows a plot of average monthly outdoor exposure rates at a site over a period of 16 years. In this plot, seasonal trends can be seen as winter months tend toward lower radiation levels because of the higher soil moisture, while the summer months tend toward higher levels because of lower soil moisture. The sharp valleys in this plot correspond to those winter months where there was appreciable snow cover.

Average outdoor exposure rates over full-year periods show less variation as the seasonal effects even out the pattern. This can be seen in Figure 2.4, which shows the annual average along with the minimum and maximum daily average at a site over a 14-year period. The minimum daily value in any given year would generally occur on the day of heaviest snow cover, while the maximum daily value would generally occur on the day with driest soil or the day when a series of rainstorms produced many radon progeny washout events. For this site, over this time period, the typical daily high was about 10 percent or about 0.0085 μSv per hour (1.4 μR per hour) above the yearly average, while the typical daily low was about 25 percent or about 0.021 μSv per hour (3.5 μR per hour) below the yearly average.

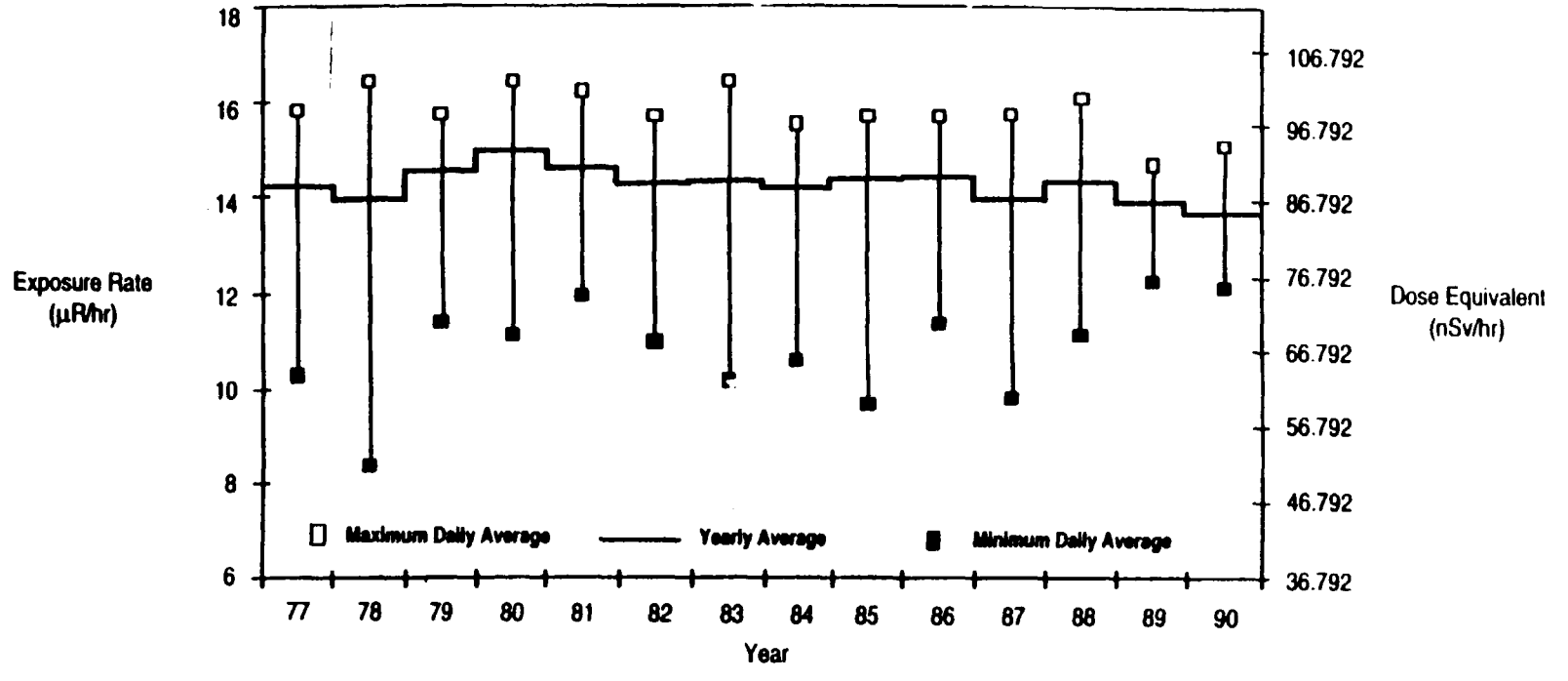
Over geological time frames, dramatic changes in the terrestrial radiation levels could take place in a region. If an area were covered by an ice sheet or a half meter (20 inches) or more of water, the gamma ray level could drop close to zero. On the other hand, upwelling of material from within Earth and erosional processes that transport soil and sediment could leave an area rich in mineralization, and the gamma ray level might quadruple from the extra uranium and thorium in the soil. In absolute terms, this would leave a range of about 0 to 1 mSv (0 to 100 mrem) per year, although there are some unusual areas that have been documented around the world where gamma levels are substantially higher. Climatic changes that lead to desertification of a region would lead to potential variations in background as areas become subject to wind erosion. Volcanic eruptions and the deposition an abrupt change in radiation of heavy amounts of ash in an area could causelevels depending upon the concentration of the natural radionuclides in the ash. The variation that is seen from place to place across the country (see next section) is a reasonable indicator of the degree of variation that might occur over long periods of time at any one location.

Human activities affect the local radiation level, and changes could therefore occur over time. On open ground, about two-thirds of the gamma radiation dose comes from radionuclides contained in the top 15 cm (6 inches) of soil out to a distance of 6 meters (20 feet) from where a person stands. Thus, changes in the radiation level could occur when the natural land is altered on a scale typical for home building and landscaping. The fact that building materials contain varying amounts of natural radioactivity means that background could be affected by any construction, including such work as building a house, making alterations to it, adding topsoil, or installing a swimming pool or patio. Public works, such as paving a road or parking lot, could also alter the radiation field. The magnitude of the change at any one site would depend upon the amount of material that is removed, added, or modified, and the relative radionuclide concentration in the old and new surroundings.



Note: Conversion of exposure to dose made by using 1R = 0.0087 Gy. For environmental radiation, coversion of absorded dose in air to effective dose in the human body is 1 Gy = 0.7 Sv.

Figure 2.3 Average monthly outdoor exposure rates at a site over 16 years



Note: Conversion of exposure to dose made by using 1R = 0.0087 Gy. For environmental radiation, coversion of absorded dose in air to effective dose in the human body is 1 Gy = 0.7 Sv.

Figure 2.4 Maximum and minimum daily averages as compared to the yearly average of the outdoor exposure rate over a 14-year period

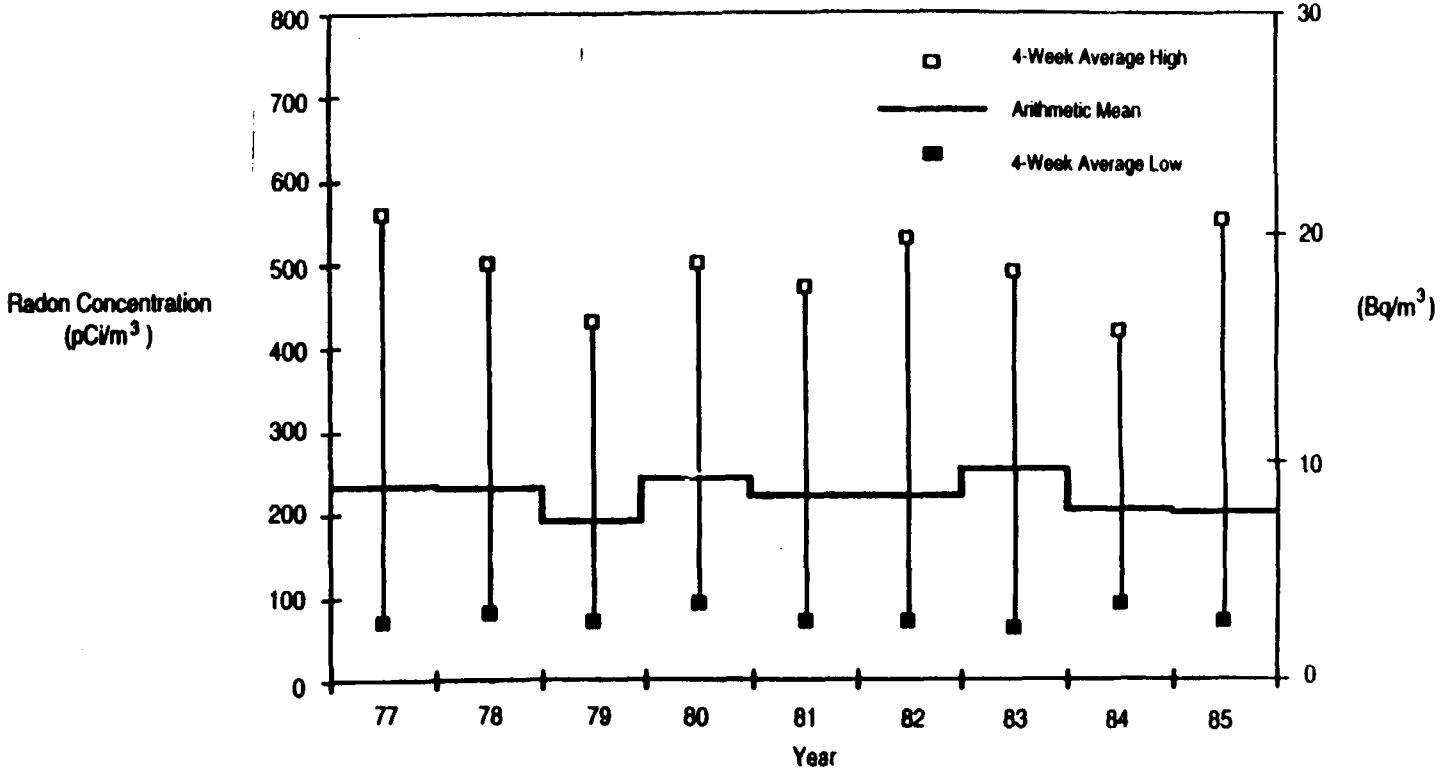
2.3.2.1.2 **Inhaled Terrestrial Radionuclides.** Although external terrestrial gamma radiation is highly penetrating and affects the entire body, the largest contributor to the total effective dose equivalent from background comes from the inhalation of radon gas and its short-lived decay products. This is because the radioactive particles are airborne and can be inhaled into the lungs, where the full energy of the emitted alpha particles associated with their decay is deposited in a small volume of tissue. As in the case of gamma radiation, various physical phenomena affect the concentration of radon in the environment and, consequently, variations occur over time.

Outdoor radon levels vary over time because of weather conditions. Data collected for many years at the station in Chester, New Jersey, demonstrate the degree of these variations (EML, 1978, 1979, 1980, 1981, 1982, 1984, 1985, 1988, 1991). In particular, the effect of atmospheric inversions, as discussed above, can cause ground level concentrations to increase by as much as 200 times those found during the day, although the average increase has been found to be about a factor of 2. Variations over longer terms show that the seasonal minimum in the winter is about three times lower than the seasonal maximum that occurs in August. Figure 2.5 shows a plot of average annual outdoor radon-222 concentrations for a 9-year period, along with the minimum and maximum averages over 4-week intervals in each year. In this figure, the annual average varies by up to 30 percent, or about 2.6 Bq per cubic meter of air (70 pico (one trillionth) curies per cubic meter), while the 4-week averages indicate that a single measurement over a month would only be within a factor of two or three of the annual average, again reflecting the seasonal differences that occur.

Indoor radon levels can be expected to vary over time as well. Since a principal source of radon entry into a building is the soil surrounding the building's foundation, weather can affect the air exchange rate between the soil and indoors. Wind, atmospheric pressure, andthe freezing and water logging of soil can all influence the movement of radon through the soil pore space and into a building. Variations can occur on time scales of hours, days, or months. Rapid changes in radon levels can occur from showering with well water containing dissolved radon gas, or from cooking with natural gas containing radon. Compared to outdoors, radon gas can build up to rather high levels indoors if there is a slow rate of air exchange with the outside.

Highly energy-efficient houses with snug-fitting windows and doors and other good weather stripping can fall in this category. In such situations, the radon level is subject to wide variations from changes in the ventilation rate, as would result from opening windows. Continuous monitoring of indoor air in houses has shown that the radon concentration can change by a factor of 10 or more (Nazaroff and Nero, 1988) from hour to hour. Seasonal differences are also found, as the concentration during winter months is generally higher than during the summer months, although there are exceptions to this rule. Another important process that influences the dose from radon is the attachment of its decay products (those that ultimately deliver the dose to the lung from being inhaled) to fine particles, or aerosols, in the air. The sizes of these particles and their removal from the air we breathe by attachment to walls and other interior finishes, called plate out, ultimately affect how much radioactivity we breathe in and retain. The aerosol concentration itself can vary with time depending upon such factors as cooking, smoking, and using kerosene heaters.

Radon decay products are not the only form of radioactivity that can be inhaled. Fine particles of soil, which contain all of the other natural radionuclides, can be suspended in air through the action of wind or human activities such as soil excavation. Dry periods and soil that lacks ground cover provide a ready environment for resuspension. Since wind conditions can abruptly change over short time periods, the amount of resuspended soil and the natural radioactivity that it contains can be



Note: 1 pCi equals 0.037 Bq.

Figure 2.5 Average outdoor radon-222 concentration in air at a site along with the average 4-week low and high values for a 9-year period

expected to vary accordingly. Seasonal changes related to wind as well as the dryness and vegetative cover of the soil can also be expected. Episodic increases from unusual natural or man-made activity in an area are also possible.

2.3.2.1.3 **Internal Terrestrial Radionuclides.** The intake of radioactivity to the body from eating food and drinking water can be expected to vary over time to some degree as well. Bananas and some other popular foods contain relatively high levels of potassium. However, the body maintains a fairly constant amount of this element, and the radioactive form, potassium-40, will not build up to higher levels even when larger than average quantities of these foods are eaten. The amount of potassium-40 will vary depending on body size and thus will change over time as adulthood is reached. On average, women would receive an annual dose that is about 25 percent, or about 0.05 mSv (5 mrem), less than men.

For some radionuclides such as uranium and radium, however, buildup within the body results from intake over time, and variations in diet therefore play a role. Also, geologic processes can influence the amount of natural radionuclides contained in well water in an area; if this is the primary source of drinking water, changes in intake and the dose from internal sources would result.

2.3.2.2 Cosmic Rays

Cosmic ray variations from day to day tend to be small, a few percent or about 0.001 μSv (0.1 μrem) per hour, and result primarily from changes in the barometric pressure. Under a high pressure system, for example, a larger mass of air above provides a greater shielding effect, compared to a low-pressure system in which there is less air and less shielding.

To a lesser degree, the temperature of the atmosphere plays a role as well. A higher temperature expands the atmosphere, which causes the cosmic ray level to decrease because there are longer path lengths that allow some of the cosmic ray secondaries more time to decay before reaching ground level. Cosmic ray intensity also changes over a period of years. The sun's 11-year cycle (as measured by sunspot activity) affects the cosmic ray intensity at ground level by raising or lowering it from its average value by up to 10 percent, or about 0.03 mSv (3 mrem) per year at sea level. The solar cycle is also related to the frequency of solar flares. Short-term increases in background from this source are possible, as was seen during the unusually energetic flare in September 1989, which produced an increase of about 200 percent in the neutron counting rate and an increase of about 35 percent or 0.01 μSv (1 μrem) per hour in the ionizing component at sea level (EML, 1992).

2.3.2.3 Cosmogenic Radionuclides

The cosmogenic radionuclide production in the atmosphere can be expected to vary according to changes in the cosmic ray intensity. From 1985 to 1990, a 30 to 40 percent decrease in the concentration of beryllium-7 was observed in surface air monitoring stations around the world (Larsen, 1993). This decrease coincided with the decrease in galactic cosmic ray intensity, which in turn coincided with the increase in the sun's activity during this time period. A more active sun, as evidenced by more sunspots, produces changes in the solar wind and magnetic field, which oppose the cosmic rays coming from outside our solar system. Seasonal changes also occur in the deposition of cosmogenic radionuclides to the surface of Earth. Deposition is greater during the spring months when air in the stratosphere tends to mix with air in the troposphere, where it can be washed out by precipitation.

2.3.2.4 Man-Made Radionuclides

Background variations can arise from the input of man-made radionuclides to ecosystems. Both nuclear weapon detonations and accidents dispersing nuclear material have the potential to cause radiation and radioactivity levels to increase at sites quite distant from the source. The large-scale testing of nuclear weapons in the atmosphere that took place during the 1950s and early 1960s resulted in the fallout of a variety of radionuclides that caused significant short-term increases in external radiation levels. Most of these have decayed away, although a few percent or less of the gamma radiation levels in many areas is still due to cesium-137, which has a 30-year half-life and can still be found in surface soils. Strontium-90, which has a 29-year half-life, has contributed significantly to internal dose through dietary intake over the past 30 years, although this source of exposure has gradually diminished over the years. Plutonium from fallout has contributed to internal dose through the inhalation pathway; however, the concentrations in surface air fell rapidly after the initial injection to the atmosphere. More recently, tests conducted by China in the late 1970s produced temporary increases in radiation and radioactivity levels. Immediately following the fallout, increases in gamma radiation were measured to be on the order of 20 percent or about 0.02 μSv per hour (3 μR per hour) above background, gradually declining over a period of a few weeks (HASL, 1976).

Temporal changes in the concentration of helium-3 in precipitation were considerable during the period of atmospheric nuclear weapons testing. The value of 360 Bq per liter recorded for the peak fallout year (1963) can be compared to the natural (pre-1952) level of only 0.6 for Ottawa, Canada (NCRP, 1987b). Changes of a factor of two or more were not unusual from year to year during the period 1953 through 1968.

Accidents at nuclear facilities, in particular the Chernobyl power plant in 1986, also produced measurable contamination around the globe, although the contribution to dose was quite small for people in the United States. The impact for an event of this magnitude would be abrupt and quite considerable for a local area, however. In a region about 160 km (100 miles) from Chernobyl, for example, measurements show cesium-137 concentrations in surface soil as high as 60,000 Bq per kg (Miller et al, 1991), which represents an increase of several orders of magnitude above pre-accident levels.

2.3.3 Spatial Variability

2.3.3.1 Terrestrial Radionuclides

The concentration of terrestrial radionuclides varies from place to place in much the same way that mineral deposits can be expected to vary from geologic processes that occur over time. Soils are mixtures of various chemical compounds, including major constituent elements such as silicon, aluminum, iron, carbon, hydrogen, and oxygen. Many other elements exist in either minor or trace quantities that can vary greatly. Elements that have naturally occurring radioactive forms (that is, potassium, uranium, and thorium) fall in this category. For instance, granitic rock is known to contain higher than average uranium concentrations, and monazite sand can have particularly high concentrations of thorium. Apart from naturally occurring variations, humans frequently alter the makeup of soil with the addition of amendments for cultivation. For example, one of the three principal components of fertilizer is potassium, most of which is in the stable forms, potassium-39 and potassium-41, but a fraction of a percent of which is the radioactive form potassium-40.

2.3.3.1.1 **External Terrestrial Radionuclides.** Surveys around the country have shown concentrations of uranium and thorium in the soil to range from as little as one tenth to as much as four times the average value (Myrick et al, 1983). In addition, aircraft mounted with radiation detectors have surveyed large tracts of land in various areas, and these measurements have been supplemented with a number of ground-based surveys. As a general rule, the Atlantic and Gulf coastal plains tend to average about half of the gamma ray level seen for middle America, although the distribution of the levels overlaps, and exceptional areas have been documented (NCRP, 1987b). For instance, the Denver, Colorado, area has gamma radiation levels about twice the average for Middle America. Measurements in sections of Nevada stretching into Utah contain similarly high natural gamma radiation levels (Miller et al, 1980).

The variation within a State, or even a smaller region, can be large. Monitoring stations operated by the Environmental Protection Agency in southern Nevada show background (combined cosmic and terrestrial gamma) to vary by a factor of three among the sites, or about 0.6 mSv (60 mrem or 100 mR) per year (EPA, 1990). While some of this variation results from differences in altitude and cosmic ray intensity, most of the variation arises from differences in the terrestrial gamma component. In certain regions (such as the Reading Prong formation that cuts across northwestern New Jersey), gamma radiation levels can be found to triple across a small field because of variations in the concentration of natural radionuclides in the soil. Venturing near rock outcroppings that may contain 100 times the average soil concentration will produce even larger fluctuations. In contrast to these areas of relatively high radiation in this part of the state, just 100 km (62 miles) to the southeast are sandy beach areas where the gamma radiation levels fall to less than 10 percent of the average measured over the Prong, which in absolute terms is only about 0.05 mSv (5 mrem) per year.

The variation in the total gamma radiation levels among sites relates directly to the concentrations of the principal gamma-emitting radionuclides in the local soil. Table 2.6 gives an example of the degree of variation that can be found in a local area, in this case, the vicinity of Three Mile Island. To some degree, soil cultivation by humans further adds to the natural variations in the radionuclide concentrations among different soil types in an area.

Areas where human activities have been known to alter background levels of radiation include the phosphate regions in northern and central Florida. In these regions, the phosphate rock is mined for fertilizer production, but the rock itself and the tailings contain elevated concentrations of radium. Backfilling operations in mined areas have led to areas of topsoil with higher concentrations than the original (NCRP, 1987b). Survey data show that gamma dose rate levels range from slightly less than to about double the national average.

Similar background variations can be found in western states where uranium mining and milling operations have produced tailings containing similarly and higher elevated concentrations of natural radionuclides. Of particular note are Uravan and Grand Junction, Colorado, where the gamma dose rate on top of tailings piles has been observed to be on the order of 100 times normal background (a few μSv per hour or a few hundred μR per hour) (NCRP, 1987b).

Another example of background alteration can be found on land where pipes from oil drilling operations are cleaned of scale containing relatively high concentrations of radium (Wilson and Scott, 1992). Concentrations in surface soil were found in the range of 5.3 to 62.2 Bq per gram, which is two to three orders of magnitude above normal background levels for the United States.

Table 2.6. *In Situ* Radionuclide Concentrations in the Vicinity of Three Mile Island[1]
(Bq per kg)

Site	Uranium-238	Thorium-232	Potassium-40
A	32	27	244
B	29	30	216
C	16	19	203
D	23	31	403
E	14	17	184
F	43	40	512
G	26	29	383
H	24	32	257

[1] From unpublished data collected by USDOE Environmental Measurements Laboratory.

Apart from outdoor variations in gamma ray levels, indoor variations occur because building materials vary among structures and even within the same structure. Measurements made in a variety of houses around the country in recent years show that in a typical wood frame house, gamma ray levels are generally about 50 percent, or on average 0.1 mSv (10 mrem) per year, higher in a basement than on a second floor (Miller, 1992). Rooms that contain stone or brick wall fireplaces tend to have gamma ray levels about 50 percent higher than those with normal drywall panels. Houses of full brick construction have average concentrations about 50 percent higher than wood frame houses without any brick. The use of cinder blocks, which are produced from ash residue in the combustion of fuels such as coal, also yields a higher than average radiation level. Within a large, concrete, commercial-type building, measurements have shown the gamma radiation level to vary up to 50 percent or about 0.15 mSv (15 mrem) per year among different floors, and on the order of 20 percent or about 0.05 mSv (5 mrem) per year on the same floor (Miller and Beck, 1984). In such situations, differing composition of interior partition walls and the effects of windows at the building edge can lead to variations in otherwise homogenous structural compositions.

The gamma radiation level inside a building results from the penetration of radiation from outside and the contribution from the building itself. It thus reflects the concentrations of radionuclides in the soil as well as in building materials. In light frame structures, the outside component is significant; however, in large massive buildings, it is generally quite small. In some sense, the concentration of the radionuclides in building materials relative to those outdoors is the determining factor in whether the building acts more as a shield against outdoor radiation or a source of radiation itself. Data presented in Table 2.7 indicate the variability in the concentration of the natural radionuclides in ordinary concrete samples from around the country (Ingersoll, 1981). As these data show, the variation among cities ranges from a factor of about 3 to 6 for the various nuclides. Variation can be expected even within a region, and the data of Eichholz et al (1980) showed variations of a similar range for concrete within the local area of Atlanta, Georgia. Available brick showed an even broader range (see Table 2.3).

Table 2.7. Natural Radionuclide Content of Ordinary Concrete[1]
(Bq per kg)

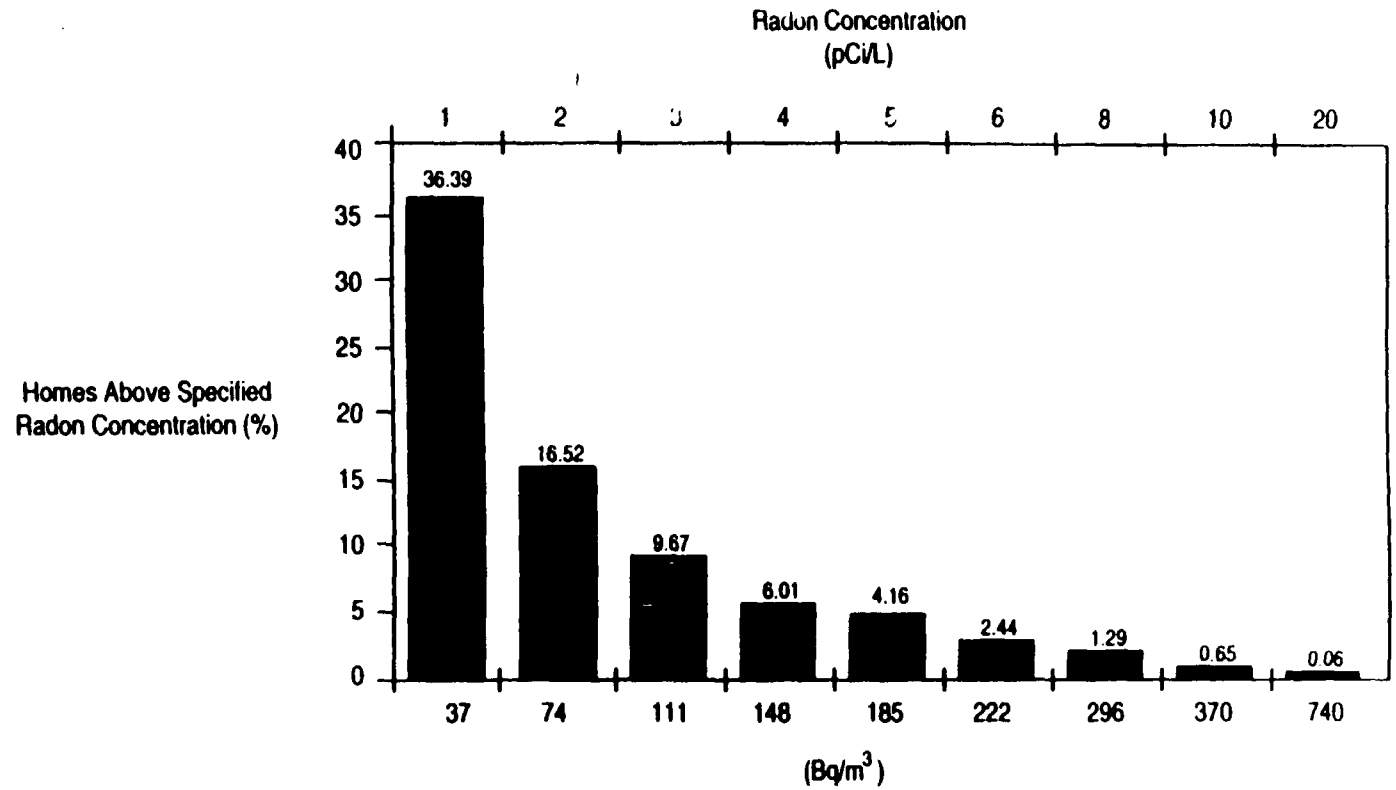
City, State	Uranium-238	Thorium-232	Potassium-30
Albuquerque, NM	31	24	461
Austin, TX	16	6	246
Chicago, IL	19	3	154
Kansas City, MO	13	8	215
Knoxville, TN	13	5	154
Philadelphia, PA	8	6	215
Salt Lake City, UT	25	16	184
San Antonio, TX	38	31	461
San Francisco-Oakland, CA	19	12	184
St. Paul-Minneapolis MN	19	16	461

[1] From Ingersoll (1981).

2.3.3.1.2 Inhaled Terrestrial Radionuclides. The dose associated with the inhalation of terrestrial radionuclides is subject to spatial variations as well. Outdoor radon concentrations in air can be expected to vary according to the local radium levels in the surface soil. This is reflected in outdoor measurements around the country that range between 4 Bq per cubic meter of air (0.1 pCi per liter) in New York City to 44 (1.2 pCi per liter) in Colorado Springs (NCRP, 1987b). Coastal communities that receive air circulation off the oceans (where there is virtually no source of radon) tend to have lower concentrations than inland areas. Other local meteorological conditions, such as the degree and frequency of atmospheric inversions, play a role as well. Within a region, topography can be a factor, because it has been observed that the concentration of radon and its decay products in the air along a hillside can be five times lower than the concentration in a valley during a strong nighttime inversion (Porstendorfer, 1993).

Apart from outdoor variations from place to place, large differences can occur with indoor radon levels. Data collected from around the country indicate the average value for some counties can be several times the average for the state (Cohen and Shah, 1991). Individual homes can, in turn, have concentrations many times those of the county average. The results of the U.S. Environmental Protection National Residential Radon Survey are shown in Figure 2.6. About 6 percent, or roughly 6 million homes, exceed the EPA Action Level of 150 Bq per cubic meter (4 pCi per liter) (Marcinowski, 1992). Because of the highly variable nature of the radon source and entry pathways, it is possible for a house to have a concentration many times greater than a neighboring house. Within the same house, differences in concentration can occur, particularly when basement areas are closed off. As in the case of temporal variations, the concentration of aerosols to which the radon decay products attach can be expected to vary from place to place, as well as in the amount of plate out that occurs.

Variations in the dose associated with the inhalation of resuspended soil can be expected because radionuclide concentrations in the soil vary from place to place, as does the degree of resuspension that occurs in an area. In general, arid regions have higher resuspension. Within a local region, the degree of inhalation of radionuclides could depend upon the proximity to and frequency of use of dusty unpaved roads, and whether the population engages in agricultural, construction, or a similar type of work that produces resuspension.



Note: 37 Bq/m^3 equals 1 pCi/L

Figure 2.6 Results of the EPA National Residential Radon Survey program (Marcinowski, 1992)

The addition of natural radioactivity to the air can result from fossil fuel combustion where ash containing natural radionuclides is released directly to the air. For instance, in the process of burning coal, releases of ash as well as volatilized radionuclides such as lead-210, can lead to dose increases as high as a few percent above normal background levels in areas downwind of a large power plant with poor emission controls (Beck et al, 1980). Local variations relate to distance from such a facility, wind patterns, and other meteorological phenomena.

2.3.3.1.3 Internal Terrestrial Radionuclides. Although information on the variation of natural radioactivity contained within the body for people living in different places is not as extensive as that for external radiation, the available data indicate that variations do exist. Data have been collected from around the world for a number of the natural long-lived radionuclides that indicate the degree of variation in the concentration in human soft tissue, blood, and bone (Fisenne, 1993). For a nuclide such as lead-210, differences of about a factor of three have been measured among samples from various parts of the United States.

One potential source of variation among the population arises from the intake and retention of polonium-210 and lead-210 from cigarette smoking, because these radionuclides are volatile and are inhaled with smoke. For radium-226, somewhat larger differences can be seen for the mainland United States (NCRP, 1987b). In addition, variations in internal radionuclide levels result from differences in dietary intake, as well as the radionuclide concentration in foodstuffs in different areas of the country (NCRP, 1987b; Fisenne, 1993). Crops grown in different regions contain varying amounts of natural radionuclides because of differences in radionuclide concentration in the soil and uptake by the plant. To some extent, differences exist based on whether the diet is urban or rural in nature, because the relative proportion of foodstuffscontaining different concentrations of radionuclides varies according to market access. Also, intake of radionuclides can be expected to vary with concentrations in drinking water. People living in certain regions, such as those where there is a high concentration of uranium in well water used for drinking, develop higher body burdens over time. In contrast, intake is much lower where people rely on surface water for consumption. Measurements of uranium in water have shown that certain midwestern areas have concentrations 35 times greater than certain eastern states, while certain western areas have uranium concentrations in water 350 times greater than eastern states. Substantially higher intake of radium-226 has been documented for certain deep municipal wells in northern Illinois (NCRP, 1987b).

2.3.3.2 Cosmic Rays

Cosmic ray variations from place to place primarily result from variations in altitude, although some smaller variation results from latitude. In short, the higher the elevation, the higher the cosmic ray dose. Figure 2.7 shows the relationship between dose rate and altitude (Bouville and Lowder, 1988). The population in a city such as Denver, at an altitude of 1610 meters (5300 feet), receives an annual cosmic-ray dose about 0.2 mSv (20 mrem), or a factor two, higher than the average for the United States.

Since the magnetic field of Earth curves inward toward the north and south poles, the cosmic ray particles undergo less deflection and their intensity is stronger. At sea level, the cosmic ray dose is estimated to be about 10 percent lower in regions near the equator compared to high latitudes. At sea level, this amounts to a difference on the order of 0.03 mSv (3 mrem) per year in the effective dose equivalent. Given the range of latitude of the United States, the variations are just a few percent or

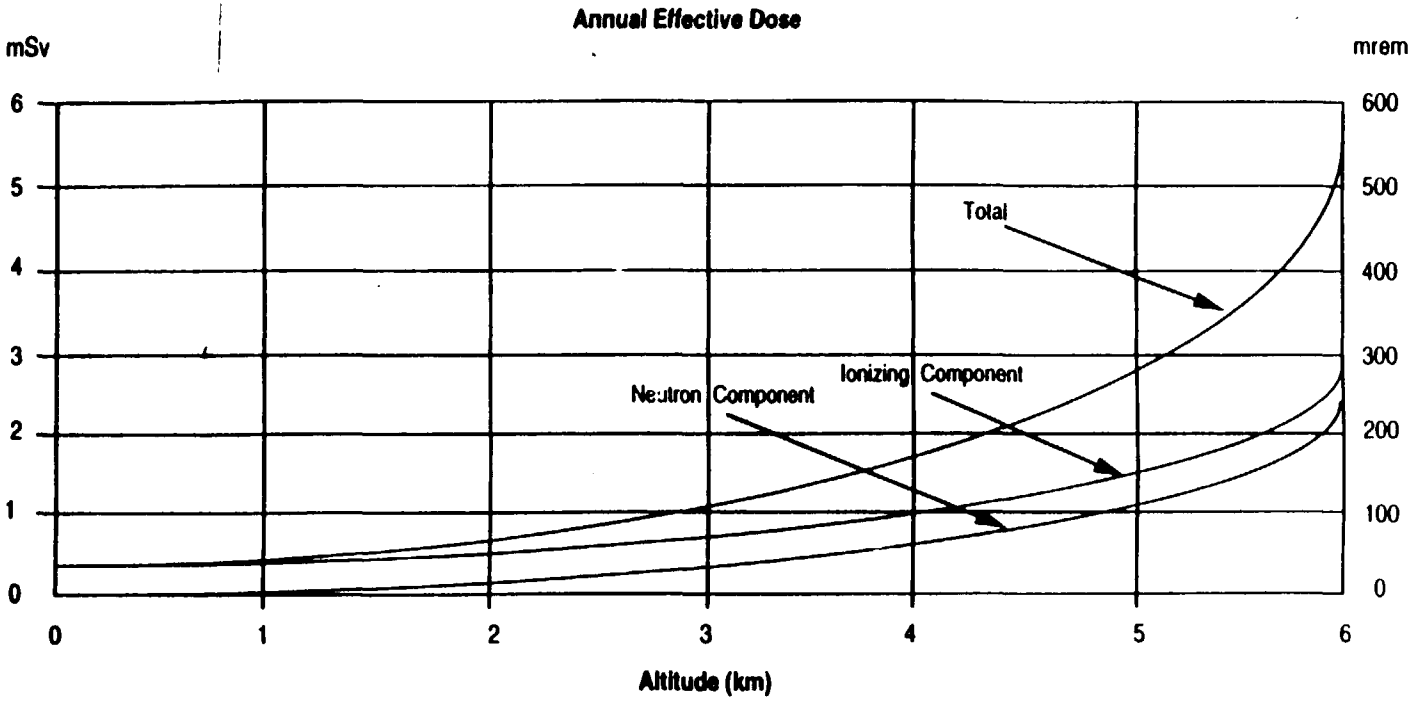


Figure 2.7 Annual dose from cosmic radiation as a function of altitude

about 0.01 mSv (1 mrem) per year about the average, with the exception of the northern regions of Alaska.

Cosmic radiation levels in small residential-type structures are only a few percent less than those outdoors, because there is little shielding provided by wood framing and roofing materials. However, in large buildings with relatively thick concrete ceilings and floors, significant shielding exists and the cosmic ray dose can drop sharply with the first overhead layer and more slowly with each successive layer thereafter. Measurements performed in a 12-story structure showed a 36 percent drop, or 0.1 mv (10 mrem) per year, on the top floor and a 73 percent drop, or 0.2 mSv (20 mrem) per year, at the basement level relative to the outdoor value (Miller and Beck, 1984).

2.3.3.3 Cosmogenic Radionuclides

Although the cosmogenic component of background is much smaller than that from terrestrial radionuclides and cosmic rays, the production of these radionuclides is nonetheless higher near the poles because of the greater cosmic ray intensity, as mentioned previously. However, many cosmogenic radionuclides are produced in the upper atmosphere, and the concentrations are therefore higher near the equator, since stronger convection leads to a much higher degree of mixing with surface air. For example, the concentrations of beryllium-7 in surface air show a clear trend toward higher values approaching the equator and lower values approaching the poles (Larsen, 1993). For the United States, the air in Miami, Florida, exhibits concentrations about 2 to 4 times higher than those at Point Barrow, Alaska. As for deposition to the ground, an additional source of variation occurs with climate, because arid regions receive less deposition than regions where there is more precipitation.

2.3.3.4 Man-Made Radionuclides

Differences in the distribution and deposition of fallout from nuclear weapon tests can be found across the United States. Globally dispersed fallout varies with latitude and, in particular, with the amount of precipitation an area receives. The arid southwestern portions of the United States have inventories of radionuclides from fallout in soils which are lower than average, whereas certain moist mountainous regions contain concentrations of fallout radionuclides that are a factor of two or three higher. Areas downwind of the Nevada Test Site are characterized by a heterogeneous distribution of local fallout from the tests conducted there.

Measurements of cesium-137 in undisturbed soil throughout Utah indicate that the deposition of fallout radionuclides varies by about a factor of three (Beck and Krey, 1980). However, because of differences in the degree of penetration through the soil layers and in density amongst soil types, the concentration in the top 2.5 cm of soil varies by a factor of 20. Even within the region around the Great Salt Lake, which is a more limited geographical area, the deposition varies by about 50 percent. This degree of variability is reflected in the data in Table 2.8, which gives the average concentration for a number of cities over a soil depth of 0 to 30 cm.

Table 2.8. Concentrations of Cesium-137 in Soil[1] in The Great Salt Lake Vicinity[2]

City	Concentration (Bq per kg)
Bountiful	15.3
Brigham	14.4
Layton	10.9
Layton	13.0
Logan	10.8
Ogden	13.7
Magna	12.3
Midvale	11.6
Salt Lake City	15.0
Salt Lake City	12.6
Salt Lake City	12.0
Toole	12.7
Tremonton	11.6
Tremonton	12.1

[1] Based on a soil depth of 0 to 30 cm.
[2] Computed from the data of Beck and Krey (1980).

Apart from regional differences in the original deposition, even larger variations can be found in the concentrations of fallout radionuclides in an area because of natural or man-made disturbances to the soil. Redistribution has occurred as a result of wind and water erosion, and many places have been plowed or had soil removed or brought in as fill. Thus, concentrations can span a range from nearly zero (or below detection limits) where runoff has occurred to several times the average for an area because of sediment accumulation. Despite these differences, the total dose from fallout radionuclides, like cosmogenic radionuclides, is quite small compared to terrestrial natural radionuclides and cosmic rays.

2.3.4 Summary of Background Variability

To give the reader a better understanding of the radiation environment, the preceding sections provide detailed information on the causes and magnitude of background variability. Temporal variability is affected by weather, climatic changes, geological processes, human activities, the 11-year solar cycle, and other naturally occurring processes. The most variable component of background over time is radon. Over the course of a day, or from season to season, outdoor radon concentrations can change by more than a factor of two, while indoor radon concentrations can vary even more as a result of building ventilation changes. Over the course of a day, changes in the distribution of radon decay products in the atmosphere cause changes in the external gamma exposure rate ranging from a few percent to 100 percent or more.

Temporal variability of background is affected by seasonal changes in soil moisture and snow cover, which typically lead to changes in external radiation levels of 10 to 50 percent. To a lesser extent, cosmic radiation and the production rate of cosmogenic radionuclides varies up to 10 percent throughout the course of the solar cycle. However, abrupt changes in background can occur from the

input of man-made radionuclides from fallout after a nuclear weapon test or distant reactor accident, which can increase background levels for a few months to a few decades.

The spatial variation of external radiation is largely related to the makeup of the soil in a locale. The greatest spatial variation in background arises from the differences in levels of radon gas, which can vary from one tenth the national average to more than ten times the average because of differences in the radium concentration in soil. Outdoor gamma radiation levels over sandy soil along a coast may be only one fourth the average for the whole country, whereas it might typically be three times the average in mountainous areas with a high degree of mineralization. Indoor gamma radiation levels vary by about 50 percent because of the use of different construction materials.

Human activities also affect spatial variability of background. Mining and milling have redistributed natural radionuclides, adding to the variation that occurs in some areas. Variations in the dose from internal radionuclides primarily results from differences in the concentration of natural radionuclides in drinking water. A significant fraction of internal dose arises from potassium-40; however, this is relatively constant, whereas the concentration of nuclides such as lead-210 in body tissues has been observed to vary by about a factor three throughout the United States. Cosmic radiation increases by a factor of two between areas above sea level, such as Denver, Colorado, and areas that are at sea level. Variations of a few percent also occur with latitude. On a local scale, cosmic ray levels are lower for residents and workers in tall, massive buildings because of the shielding effects of concrete floors. Measurements inside a building have shown a drop ranging between one to two thirds below that outdoors. Cosmogenic and man-made radionuclide concentrations vary in air and soil, although the overall effect on the total variation in dose from background is quite small.

When considered on a large scale, this widely variable and ubiquitous source of naturally-occurring radiation produces doses to the human population that are, in turn, widely variable as well. The magnitude and variability of radiation doses among a given population is directly proportional to the population's activities and the background level to which the population is exposed. Current estimates of the minimum, maximum, and average dose per year to a United States resident from background are provided in the next section, along with comparisons to worldwide estimates and doses from other sources of radiation.

2.4 Estimated Doses From Background

A comprehensive review of background sources and the resultant doses received by the population of the United States has been performed by the National Council on Radiation Protection and Measurements (NCRP, 1987b). Figure 2.8 shows a breakdown of the estimated total effective dose equivalent, with regard to the average contributions from each of the principal sources. Of the rounded total of 3 mSv (300 mrem) per year, two-thirds or 2 mSv (200 mrem) comes from inhaling radionuclides (by and large, the indoor radon decay products). The other radionuclides internal to the body from ingestion and inhalation contribute about 13 percent or 0.4 mSv (40 mrem) of the total dose. External terrestrial (gamma) radiation and cosmic ray components are about equal and together make up about 18 percent or 0.55 mSv (55 mrem) of the total, whereas the annual dose from the cosmogenic radionuclides is very small, on the order of 0.01 mSv (1 mrem) or less than one percent.

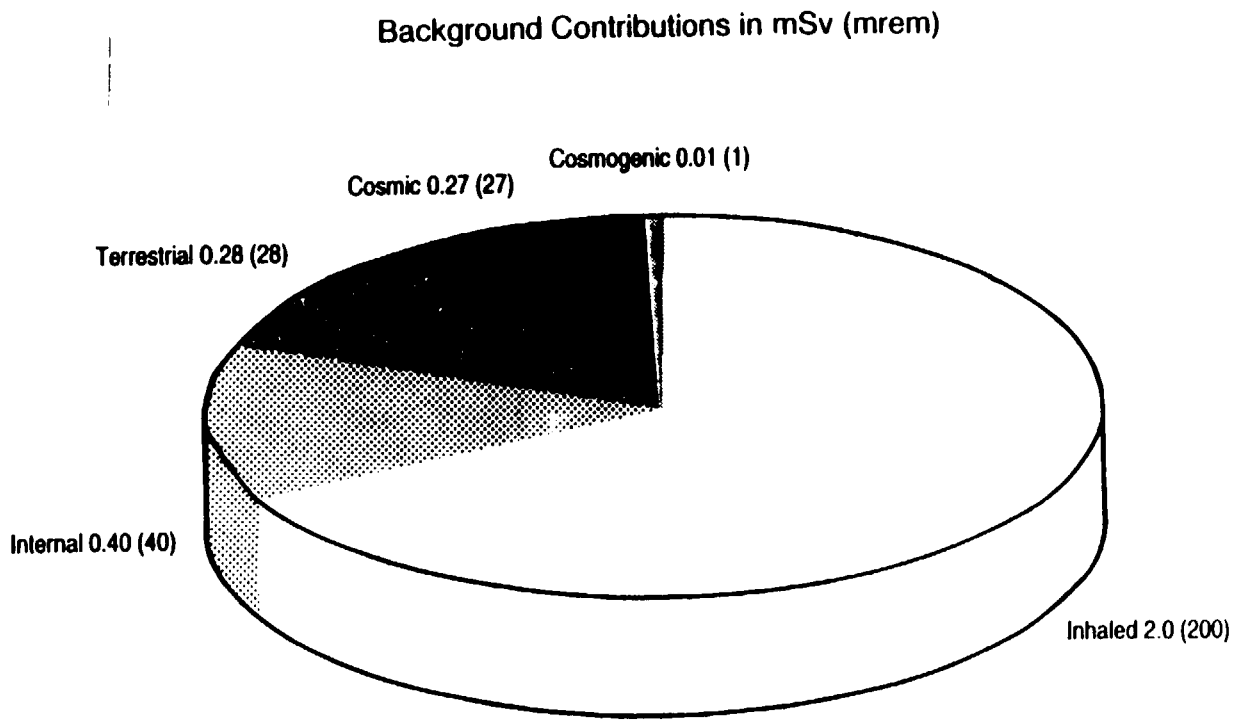


Figure 2.8 The average contribution to the total effective dose equivalent from various sources of background for the United States (NCRP, 1987b)

Given the previous discussion concerning the temporal and spatial background variations, it is imperative to remember that the estimated total dose of 3 mSv (300 mrem) is an annual average, and that the actual dose received by any one individual could be quite different. Figure 2.9 shows the average contributions of the four most significant components in perspective to the estimated typical maximums and minimums. These ranges are not to be taken as the absolute limits, but should indicate the variability generally encountered. In the inhalation category, the maximum of 8 mSv (800 mrem) per year is taken to be the dose corresponding to the current EPA Action Level of 150 Bq of radon per cubic meter of air (4 pCi per liter). Obviously, many United States homes exceed this level; however, indoor radon represents a category of natural radiation that is controllable by remediation. The minimum annual dose for radon, 0.2 mSv (20 mrem), corresponds to a level only one-tenth the national average, which is taken to be typical of well ventilated houses in areas with low radium concentrations in the soil. For internal radiation, about half of the average is taken to be constant, corresponding to the dose from radionuclides such as carbon-14 and potassium-40. The other half of the average internal dose is then varied from one-third to four times the average, based on data for the range of radionuclides measured in human tissues. This yields a minimum of somewhat less than 0.3 mSv (30 mrem) to a maximum of 1 mSv (100 mrem) per year.

The external terrestrial radiation maximum of three times the average is not unusual for areas in the western United States with a high degree of mineralization in the soil, whereas the minimum of one-fourth the average is representative of sandy soil along a coastline. This leads to a range of less than 0.1 mSv (10 mrem) to more than 0.8 mSv (80 mrem) per year for the gamma component. For cosmic radiation, the typical maximum is taken as twice that of the dose at sea level (a resident of Denver), while the minimum is half (a resident of New York City who lives and works in tall buildings). This corresponds to a difference of 0.4 mSv (40 mrem) per year in dose between the extremes for cosmic radiation.

The variability of major background components can average out in many cases so that many people receive similar total doses. Nonetheless, some degree of correlation exists among these components. High gamma levels can be found in mountainous areas, and accordingly, the higher levels of uranium in the soil lead to a larger source of radon gas in the soil, as well as higher concentrations of radionuclides in well water and food grown in those areas. The higher altitude also leads to a higher dose from cosmic rays.

As an example of the typical dose range, consider that people who live in well-ventilated wooden houses on sandy soil near the ocean would receive a minimal dose from radon — one tenth of the United States average — and a minimal external gamma dose — about one-fourth the average. With an internal and cosmic ray component of about average, the total dose to these individuals is only 1 mSv (100 mrem) per year. In contrast, people living in Denver, Colorado, could receive double the cosmic ray dose, triple the gamma dose, and quadruple the radon dose. With a somewhat higher intake of radionuclides from drinking water, the total dose is about 10 mSv (1000 mrem) per year. Although even higher doses are possible for people living in houses with very high radon concentrations, this value could be taken as an upper limit, allowing for extremes associated with unusual situations. Overall, this range of 1 to 10 mSv (100 to 1000 mrem) — a span of a factor of ten — is typical of the variation in background doses for most United States citizens in a given year.

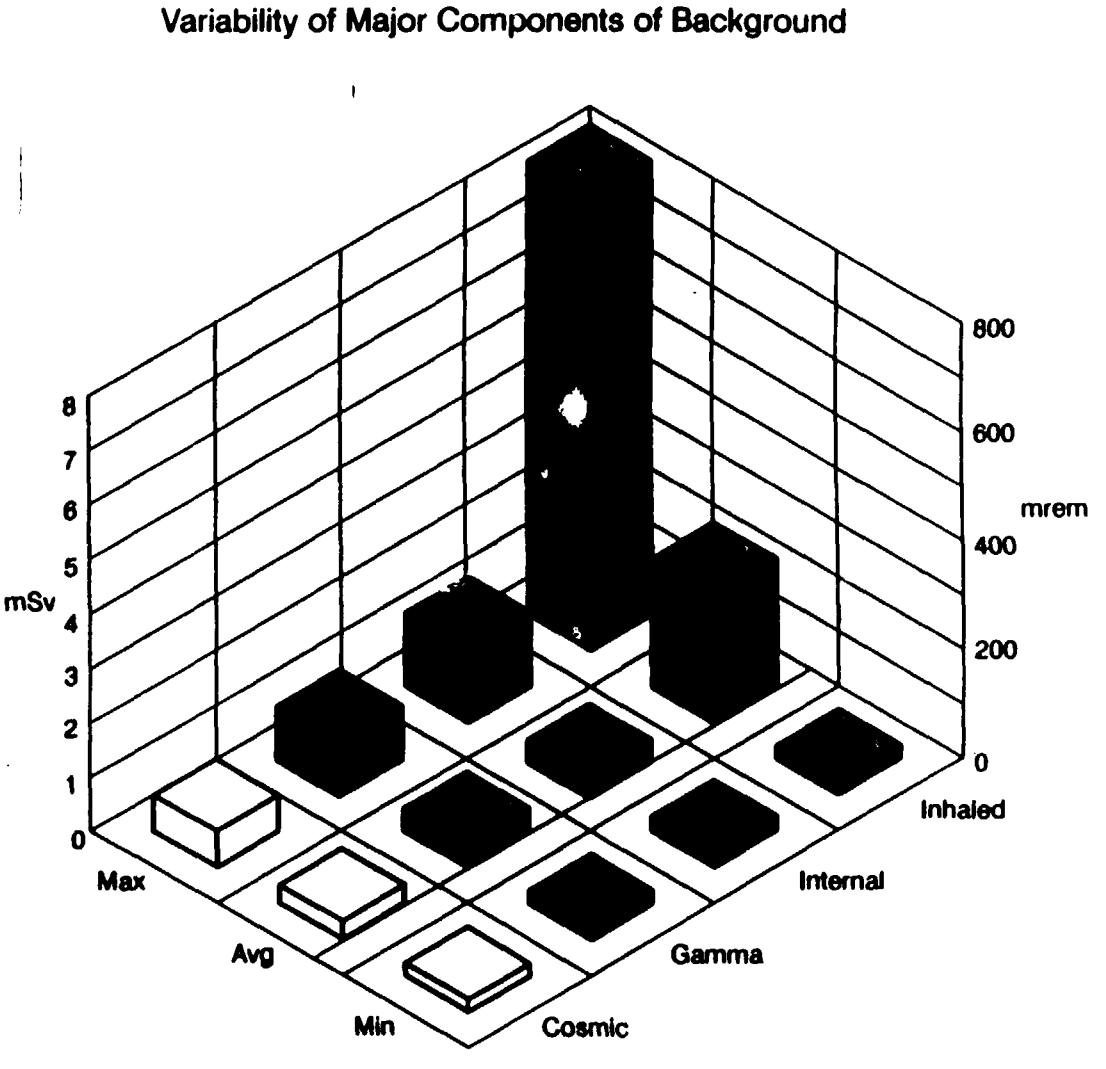


Figure 2.9 Typical maximum and minimum contributions of the major sources of background compared to their respective averages for the United States

2.4.1 Comparison to Worldwide Averages

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) issues a report every few years to update information on the sources, effects, and risks of ionizing radiation. The 1988 UNSCEAR report summarized data that was collected from around the world in the various categories of natural radiation exposure. Table 2.9 shows a comparison of the averages estimated by UNSCEAR and the range (excluding extremes) of effective dose equivalents as compared to the NCRP United States data that were published in 1987. As more information becomes available with each passing year, it is likely that both the worldwide and U.S.-specific values will be modified to some degree, particularly with regard to the radon component.

Table 2.9. Comparison of the Principal Components of Background Between Estimated Populations of the United States and the World

	Annual Effective Dose Equivalent(mSv)		
Component	U.S. Mean[1]	World Mean[2]	World Range[2]
Cosmic	0.27	0.36	0.3–2.0
Indoor radon and progeny	2.0	1.1	0.3–5.0
Internal (other inhaled, ingested)	0.4	0.5	0.2–1.0
Terrestrial gamma	0.28	0.41	0.2–1.0
Totals (rounded)	**3.0**	**2.4**	**1.5–6.0**

[1] From NCRP (1987).
[2] From UNSCEAR (1988).

2.4.2 Comparison to Some Man-Made Sources

After background, the next largest contributor of human exposure to ionizing radiation is medical procedures, such as those involving x-ray examinations and nuclear medicine. Table 2.10 compares the dose estimates for these, as well as a few other man-made sources, to dose estimates from background (NCRP, 1987a). All other sources are much smaller in magnitude. Included in consumer products are such contributions as ceramics, dental prostheses, and luminous watches and clocks, among others.

Again, these are average values; in other words, the total dose is distributed across the population. In fact, certain sub-population groups (such as sick or injured people who undergo the majority of the x-ray exams) are exposed to most of the radiation dose in various categories.

Table 2.10. Comparison of Average Background Doses to Those from Other Sources[1]

Source	Dose[2] (mSv)	% of Total
Background	3.0	82
Consumer products	0.05–0.13	3
Diagnostic x-rays	0.39	11
Nuclear medicine	0.14	4
Occupational	0.009	<1
Weapons test fallout	<0.01	<1
Rounded Total	**3.6–3.7**	**100**

[1] From NCRP (1987a).
[2] Annual effective dose equivalent.

NUREG CR-3035

Radiological Survey of the Reed-Keppler Park Site West Chicago, Illinois

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ABSTRACT

This report presents the results of a radiological survey of the Reed-Keppler Park, West Chicago, Illinois, performed by Radiation Management Corporation during the fall of 1981 and the spring of 1982. Measurements were made to determine external radiation levels, concentrations of water and airborne contaminants and the identity and concentrations of subsurface deposits. Results show that materials containing Th-232 and daughters are present in surface and subsurface locations, comprising a total volume of about 15,000 cubic yards, with concentrations as high as 11,000 pCi/g. These contaminants are a source of radon and daughter radionuclides which may produce slightly elevated airborne radioactivity levels off-site. There is no evidence that materials are moving off-site through ground water, although small subsurface deposits exceeding 5 pCi/g exist north of the fenced site in a landfill area, and to the southeast of the site near the tennis courts. These off-site deposits do not present a significant radiological hazard to the public at this time.

I. INTRODUCTION

In 1981 and 1982, Radiation Management Corporation (RMC) under contract to the U. S. Nuclear Regulatory Commission (NRC) performed radiological evaluations of four burial sites.[1] The Reed-Keppler Park site in West Chicago, Illinois, was the second site to be evaluated. An initial site visit occurred in September 1981, and the detailed radiological evaluation was performed during the fall, winter and spring of 1981-82.

The purpose of this survey was to clearly define the radiological conditions at the Reed-Keppler Park site. The results of this survey should be sufficient to allow an engineering evaluation to determine whether remedial action can, or should be, taken.

The methods used to evaluate this site included the following:

1) Measurement of external gamma exposure rates at one meter above the ground surface and beta-gamma count rates at one cm above the ground surface.

2) Measurement of radionuclide concentrations in

surface soil and vegetation.

3) Measurement of radionuclide concentrations in subsurface deposits.

4) Measurement of activity in surface and subsurface water samples.

5) Measurement of Rn-222 and Rn-220 flux emanating from the ground surface.

6) Measurement of airborne radioactivity.

Measurements were performed on-site using an RMC designed mobile facility. Gamma spectroscopy of selected samples was performed at the RMC Midwest Regional Office in Northbrook, Illinois, and other analyses were performed at the RMC analytical laboratory in Philadelphia, Pennsylvania.

V. CONCLUSIONS

The results of this survey confirm that significant volumes of concentrated thorium residues, apparently originating from the West Chicago facility presently owned by Kerr-McGee Chemical Corporation, have been deposited in Reed-Keppler Park. In general, these materials are contained within the fenced site, although levels and concentrations exceeding applicable target criteria (see Table 11) can be found outside the fence in uncontrolled areas of the park.

Within the fenced site, thorium residues can be found both on the surface and buried to depths of 12 feet. The residues appear to be dense, grayish, granular materials as described in previous reports.[4] The materials on the surface are "weathered" and have acquired an extremely hard, brittle crust in most cases.

All off-site materials are covered by at least one-half foot of normal soil. While there is no routine presence on-site (within the fenced site), some land moving, dumping and possible digging was observed in the fill area to the north of the fenced site, where residues are known to be buried. The remainder of the park area may be occupied by a variety of visitors participating in common recreational ac-

tivities. Of special interest are the tennis courts, located about 35 feet from the southeastern boundary of the fenced site, which enjoy fairly continuous use in good weather. Subsurface deposits and external radiation levels exceeding target criteria have been measured near these courts.

External radiation levels exceeding the target criteria of 20 uR/hr exist outside the fenced area to the north and west of the site, and at a small location south of the tennis courts. However, the maximum levels detected off-site (outside the fenced area) were less than 100 uR/hr (i.e. 70 uR/hr near the tennis courts), and the total area above 20 uR/hr is only about 5000 square feet.

Although surface deposits have been detected on-site, there is no evidence that material is moving off-site by surface runoff. In fact, the physical characteristics of the surface deposits on-site are such that they appear impervious to environmental effects at this time. The total estimated area of surface materials is 25,000 square feet.

Measurements of subsurface deposits indicate a layer of contamination (i. e. concentrations of Th-232 and daughters exceeding five pCi/g) ranging in thickness from about three to eight feet, and covering an area of about 100,000 square

feet. Assuming an average thickness of four feet, a total volume of 400,000 cubic feet (15,000 cubic yards) is estimated to exceed the target criteria. The presence of subsurface activities exceeding target criteria does not necessarily result in external levels exceeding criteria, as is evident in locations north of the site. Also, elevated external radiation levels immediately to the west of the fenced area are apparently not due to buried material, but rather to "shine" from on-site deposits.

Analyses of surface and subsurface materials showed Th-232 and daughters, generally in equilibrium, Ra-226 and daughters, and K-40. In concentrated materials, the ratio of Th-232 to Ra-226 activities is about 10:1.

There is no evidence that thorium is moving off-site via surface or ground water. The only elevated activity found in ground water was from a bore hole on-site, and these levels were within appropriate MPCs for unrestricted areas, although exceeding EPA drinking water standards in one case.

Air sampling results show that the surface (and possibly some subsurface) deposits are a source of airborne radioactivity. The predominant activity is due to the thorium daughter Rn-220, as might be expected. Radon emanation

rates from surface materials are quite high, and elevated concentrations of both Rn-220 and Rn-220 particulate daughters have been detected at the site boundary. Long term monitoring off-site was not undertaken since it was beyond the scope of this study; however, it is reasonable to assume that slightly elevated levels of Rn-220 and daughters could be present in uncontrolled areas off-site. Rn-222 activities were slightly above background, although generally within target criteria.

The values in Table 10 indicated that the present radiological conditions are not significantly different from those reported several years ago. The reduced external exposure rates and possibly lower surface activities suggest the possibility of some slight weathering or altering of surface characteristics, although significant movement is not evident. Based on more extensive subsurface investigations performed during this survey, the estimated volume of contaminated material appears to be 4 or 5 times that estimated in 1976.

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

DEC 2 1986

FCUP:MH
40-2061
STA-583

Kerr-McGee Chemical Corporation
ATTN: Dr. John C. Stauter, Director
Nuclear Licensing and Regulation
Kerr-McGee Center
Oklahoma City, Oklahoma 73125

Gentlemen:

This is in response to your request dated January 28, 1986, for permission to store the materials removed from Reed Keppler Park and the Sewage Treatment Plant on the disposal site of the West Chicago Facility. You received authorization on May 13, 1986, to store material removed from the Sewage Treatment Plant.

As you may be aware, Illinois is in the process of becoming an Agreement State. As an Agreement State, Illinois wishes to assume responsibility for regulating source material. The material covered by the amendment request is considered by the staff to be source material and as such will come under the jurisdiction of the State of Illinois.

The material at Reed Keppler Park and that which will remain at the Sewage Treatment Plant has been in its present location for a number of years. The material is not endangering the public health and safety in anyway and there is no evidence that the material is moving offsite or impacting the surrounding environment. The materials pose no additional dangers if they remain where they are until the State receives jurisdiction.

Since Illinois will soon gain jurisdiction over the material, the NRC has decided not to act on the remainder of your amendment request at this time. Once the Agreement State status is finalized, it will be necessary to discuss the disposition of these materials with Illinois officials.

Sincerely,

W. T. Crow, Acting Chief
Uranium Fuel Licensing Branch
Division of Fuel Cycle and
Material Safety

United States
Environmental Protection
Agency

Office of Public Affairs
Region 5
77 West Jackson Boulevard
Chicago, Illinois 60604

Illinois Indiana
Michigan Minnesota
Ohio Wisconsin

Contaminated Soil Removal Begins at the Kerr-McGee Reed-Keppler Park Superfund Site

West Chicago, Illinois — October 1996

Introduction

The U.S. Environmental Protection Agency (U.S. EPA), with assistance from the Illinois Department of Nuclear Safety (IDNS), will begin overseeing the removal of soils contaminated with low level radioactive material from the Kerr-McGee Reed-Keppler Park **Superfund**[1] Site ("RKP Site") in West Chicago, Illinois, later this year. The work involves excavating contaminated soil from the former landfill areas in the park, disposing of it off site, and restoring the excavated areas. U.S. EPA expects the work to last approximately one year. During that time, small sections of the park may be closed to the public.

At the same time, U.S. EPA will continue its ongoing investigations at the RKP Site to determine the nature and extent of contamination (both radiological and chemical) and evaluate any necessary future cleanup alternatives.

There are four Superfund sites in the West Chicago area. Those sites are: (1) RKP Site; (2) West Chicago's Sewage Treatment Plant; (3) Kress Creek and the West Branch of the DuPage River; and (4) the Residential Areas Site. This fact sheet focuses only on U.S. EPA's oversight of the removal of radioactive contaminated soil at the RKP Site.

Site Location and Description

RKP is located on the north side of West Chicago, DuPage County, Illinois. The park lies north and west of National Street and is west of Arbor Avenue and Yale Street. Access to the park is via a driveway looping through the center of the park. Residential areas lie north, south, and east of the park. A natural **wetlands** area lies west of the park, and the West Chicago Prairie Forest Preserve is located southwest of the Site, across the EJ&E and Union Pacific railroad tracks (please see the site map on page 3).

The park has several ball fields, a Family Aquatic Center, maintenance buildings, tennis courts, and wooded and lawn areas. The Park, which is leased and operated by the West Chicago Park District, covers approximately 100 acres, of which about 10 were used for landfilling in the past.

[1]Words first appearing in **bold** are defined on page 5

History of Contamination

From 1931 to 1973, an ore processing facility located about a mile south of RKP, extracted thorium from monazite sands for use in manufacturing gas mantles. The facility also supplied thorium, radium, uranium, and rare earths to private parties and to the government for a research project. The facility, known as the "Rare Earths Facility," is currently owned by the Kerr-McGee Chemical Corporation. Most of the wastes from this process were stored at the facility. Some of this material was used to fill in low-lying areas or in construction projects, and was transported to various areas of West Chicago. Years later, it was learned these waste materials may have contained potentially harmful radioactive substances.

Studies sponsored by U.S. EPA, the Nuclear Regulatory Commission (NRC), and the City of West Chicago have resulted in the four Kerr-McGee sites being listed on U.S. EPA's **National Priorities List (NPL)**. The Rare Earths Facility is under the jurisdiction of the IDNS and is not on the NPL nor is it one of the Kerr-McGee Superfund sites.

U.S. EPA believes thorium mill tailings were disposed of at the RKP Site along with municipal wastes, although there are no records indicating exactly when, how much, or what types of wastes were disposed of at the site. Most of the contamination is confined to one area of the park within the boundaries of an old landfill. This area is fenced off from public access and does not pose a risk to the users of the Family Aquatic Center or to people using other areas of the park.

U.S. EPA, the U.S. Department of Energy (DOE), the NRC, IDNS, and the West Chicago Park District conducted numerous studies and field investigations to identify the areas of contamination and risks associated with the contamination at RKP Site. The most recent of these are U.S. EPA's ongoing **remedial investigation and feasibility study (RI/FS).**

Status of U.S. EPA's Investigation

In 1993, U.S. EPA's contractor, CH2M Hill, began a RI to determine the nature and extent of contamination at the RKP Site and a feasibility study to identify and evaluate remedial alternatives. CH2M Hill has expertise investigating sites with radioactive contamination. Results of these studies have not yet been finalized.

The RI shows most of the radiological contamination in the former landfill is located within the fenced area, although some contamination extends approximately 20 yards west of the fenced area. The soil sampling results indicated a median concentration of 286 **picoCuries per gram (pCi/g)** of total radium with the highest levels found inside the fence. This is significantly above the U.S. EPA estimated West Chicago background level of just over 2 pCi/g. The contamination is in a layer ranging in thickness from approximately 3 to 8 feet and occurring at depths up to 14 feet. U.S. EPA estimates approximately 22,000 to 29,000 cubic yards of radioactive waste are present in the park.

U.S. EPA used preliminary information from the RI to conduct a focused **risk assessment** which identified human health risks associated with exposure to radioactive materials at the RKP Site. U.S. EPA conducted the focused risk assessment because of evidence that people occasionally trespass the fenced area. The focused risk assessment found radioactive materials present at the RKP Site pose an unacceptable risk for potential trespassers. U.S. EPA has initiated a time-critical **removal action** to address these issues. There are no risks associated with using the Family Aquatic Center from the contamination present at the site.

To reduce any risk while the RI/FS continues, soil with thorium mill tillings will be removed from the fenced area, as well as from other areas U.S. EPA has identified throughout the RKP Site. After completion of the soil excavation, U.S. EPA will complete the RI/FS to characterize the extent of any remaining contamination, evaluate the appropriateness of any further action, and select a final remedy for the entire site. The extent of remaining contamination will not be identified until later in the RI/FS. It is currently anticipated that the removal action will address all the risks posed by the contamination present at the site.

Radiation

Thorium and some of the other elements found at the West Chicago Kerr-McGee Superfund sites, including uranium and radium, are potentially harmful because they are radioactive. "Radioactive" is a term used to describe the behavior of some elements that are unstable and break down or "decay" over a period of years. The materials break down into other, unstable radioactive elements as they decay, and radiation is given off in the process.

There are three types of radiation that can be created. Of the three, gamma radiation has the highest energy and can travel several feet from its source and penetrate skin and clothing. The other two types, alpha and beta radiation, are weaker, but are potentially harmful as well. Internal exposure to alpha and beta radiation can occur in the lungs and other body organs when small radioactive particles and gases are inhaled or swallowed. Exposure to radiation can have many negative health effects on the human body. U.S. EPA is most concerned about radiation's ability to cause cancer. However, no one has been harmed by the contaminated materials in Reed-Keppler Park. The contamination is not readily accessible to the general public and no danger exists to children using the recreational fields or other available park facilities.

EPA/540-R-93-057
Publication 9360.0-32
PB93-963402
August 1993

GUIDANCE ON CONDUCTING NON-TIME-CRITICAL REMOVAL ACTIONS UNDER CERCLA

Office of Emergency and Remedial Response
U.S. Environmental Protection Agency
Washington, DC 20460

1.1 THE SACM APPROACH (CONTINUED)

SACM encourages EPA Regions to explore new ways to use removal authorities under the NCP to achieve prompt risk reduction. An integrated removal and remedial site management strategy under SACM will most likely involve the increased use of non-time-critical removal authority to achieve prompt risk reduction at Superfund sites. Regional Decision Teams (RDTs), a SACM concept introduced in OSWER Publication 9203.1-05I, Volume I, Number 5, "SACM Regional Decisions—Interim Guidance" (December 1992), PB93-96266, are anticipated to emphasize early actions such as non-time-critical removal actions without jeopardizing the Superfund program's commitment to enforcement first. Decisions will be made to ensure that an early action will be consistent with any long-term action that may eventually be required. In the context of non-time-critical removal actions, this means that opportunities for treatment and permanence should be fully evaluated in the EE/CA, where appropriate (see Chapter 2).

For More Information:

1. OSWER Publication 9203.1-05I, Volume 1, Numbers 1-5 (December 1992)
   - "Status of Key SACM Program Management Issues—Interim Guidance," PB93-963262.
   - "Early Action and Long-Term Action Under SACM—Interim Guidance," PB93-963263.
   - "Enforcement Under SACM—Interim Guidance," PB93-963264.
   - "Assessing Sites Under SACM—Interim Guidance," PB93-963265.
   - "SACM Regional Decision Teams—Interim Guidance," PB93-963266.
2. OSWER Publication 9200.2-02, "Accelerated Response at NPL Sites Guidance" (December 15, 1989), PB90-258302/CCE.
3. OSWER Publication 9203.1-03, "Guidance on Implementation of the Superfund Accelerated Cleanup Model (SACM) under CERCLA and the NCP" (July 7, 1992), PB93-963252.
4. OSWER Publication 9203.1-03A, "Exercising Flexibility Through the Superfund Accelerated Cleanup Model (SACM)" (October 26, 1992), PB93-963253.
5. OSWER Publication 9360.0-15, "The Role of Expedited Response Actions Under SARA" (April 21, 1987), PB91-214221/CCE.

1.2 OVERVIEW OF THE REMOVAL ACTION PROCESS

CERCLA and the NCP define removal actions to include "the cleanup or removal of released hazardous substances from the environment, such actions as may necessarily be taken in the event of the threat of release of hazardous substances into the environment, such actions as may be necessary to monitor, assess, and evaluate the release or threat of release of hazardous substances, the disposal of removed material, or the taking of such other actions as may be necessary to prevent, minimize, or mitigate damage to the public health or welfare or to the environment, which may otherwise result from a release or threat of release." EPA has categorized removal actions in three ways: emergency, time-critical, and non-time-critical, based on the type of situation, the urgency and threat of the release or potential release, and the subsequent time frame in which the action must be initiated. Emergency and time-critical removal actions respond to releases requiring action within 6 months; non-time-critical removal actions respond to releases requiring action that can start later than 6 months after the determination that a response is

necessary. Each response is unique and may require more expedited response based on the threatened population, contaminants of concern, and other factors. The following are potential removal actions identified in section 300.415(b)(2)(i)-(viii) of the NCP:

- Prevention or abatement of actual or potential exposure to nearby human populations, animals, or the food chain from hazardous substances, pollutants, or contaminants
- Prevention or abatement of actual or potential contamination of drinking water supplies or sensitive ecosystems
- Stabilization or elimination of hazardous substances in drums, barrels, tanks, or other bulk storage containers that may pose a threat of release
- Treatment or elimination of high levels of hazardous substances, pollutants, or contaminants in soils largely at or near the surface that may migrate
- Minimization or elimination of the effects of weather conditions that may cause hazardous substances, pollutants, or contaminants to migrate or to be released
- Elimination of threat of fire or explosion
- Determination of availability of other appropriate Federal or State response mechanisms to respond to the release
- Mitigation or abatement of other situations or factors that may pose threats to public health, welfare, or the environment.

OSCs/RPMs must always consider section 300.415 in determining the appropriateness of taking any removal action. Section 300.415(d)(1)-(9) of the NCP provides a partial list of removal actions that may be taken to address specific situations. Exhibit 1, on the following page, illustrates the non-time-critical removal action process.

The following steps are for non-time-critical removal actions:

- Section 300.410 of the NCP outlines the process for conducting a **removal site evaluation**, which includes a removal preliminary assessment (PA) and, if warranted, a removal site inspection (SI). The OSC/RPM performs the removal PA, based on readily available information, to identify the source and nature of the release or threatened release and to assess the threat to public health, the magnitude of the threat, and the factors necessary to determine the need for a removal action. The removal PA also determines if more information is needed to characterize the release, such as off-site or on-site inspection of conditions and sampling. If more information is necessary, the OSC/RPM performs a removal SI. Data gathered during the removal site evaluation help OSCs/RPMs determine the need for response, if any, and the urgency of the response. For non-time-critical removal actions, OSCs/RPMs further characterize the release and propose the removal action as a result of the EE/CA process, as discussed in Chapter 2. The subsequent selection of the appropriate response is made in the Action Memorandum.

CHAPTER 2

CONDUCTING THE ENGINEERING EVALUATION/COST ANALYSIS (EE/CA)

2.1 OVERVIEW

In 1987, the Emergency Response Division began development of the first draft guidance on Engineering Evaluations/Cost Analyses (EE/CAs) for non-time-critical removal actions. Because issuance of a final EE/CA guidance was delayed pending the outcome of issues related to the NCP revisions, in 1988 a draft outline was distributed to assist the Regions in preparing EE/CAs. This chapter replaces the 1988 memo to help the Regions in fulfilling the goals of the EE/CA, which are to:

- Satisfy environmental review requirements for removal actions
- Satisfy administrative record requirements for improved documentation of removal action selection
- Provide a framework for evaluating and selecting alternative technologies.

Non-time-critical removal actions will be the appropriate response for a variety of sites and will range in scope from small-scale, low-cost actions to complicated multi-media response actions requiring exemptions from the statutory time and/or dollar limits. Non-time-critical removal actions may be interim or final actions; they may be the first and only action at a site, or one of a series of planned response actions. The scope of the non-time-critical removal action will determine the detail of the EE/CA. The EE/CA is a flexible document tailored to the scope, goals, and objectives of the non-time-critical removal action. It should contain only those data necessary to support the selection of a response alternative, and rely upon existing documentation whenever possible.

The range of site characteristics affecting the non-time-critical removal action forms a continuum. At one end are sites where the non-time-critical removal action is the first and only action expected at a site and where no other data are available. In this case, the EE/CA should provide definitive information on the source, nature, and extent of contamination, and risks presented by the site. At the other end of the continuum are sites where the non-time-critical removal action is one of a series of response actions, where a completed RI is or will be available, and where the nature and extent of contamination and the risk presented by the site have been or will be determined. In this case, the EE/CA would be similar to a focused FS, concentrating on the analysis of perhaps two or three appropriate alternatives and providing reference to existing information on the nature and extent of contamination and risks.

Many non-time-critical removal actions may occur at sites with characteristics that fall within these extremes. OSCs/RPMs should tailor the EE/CA to match the specific goals and objectives of the non-time-critical removal action planned for a given site. The goals of the removal should be based on the relevant factor(s) listed in sections 300.415(b)(2)(i)-(viii) of the NCP. The relevant factors should be cited in the EE/CA Approval Memorandum as justification for conducting the EE/CA. The scope of the action takes into account two major considerations: the physical portion of the site to be addressed and whether the action represents a final or interim step toward addressing a particular exposure pathway.

2.1 OVERVIEW (CONTINUED)

Specific objectives are then developed for the site. Removal action objectives generally consist of environmental medium-specific goals for protecting human health and the environment. The objectives should be as specific as possible, but not so specific that the range of alternatives that can be developed is unduly limited. Removal action objectives should identify, for example, the contaminants of concern and exposure route(s) and receptor(s).

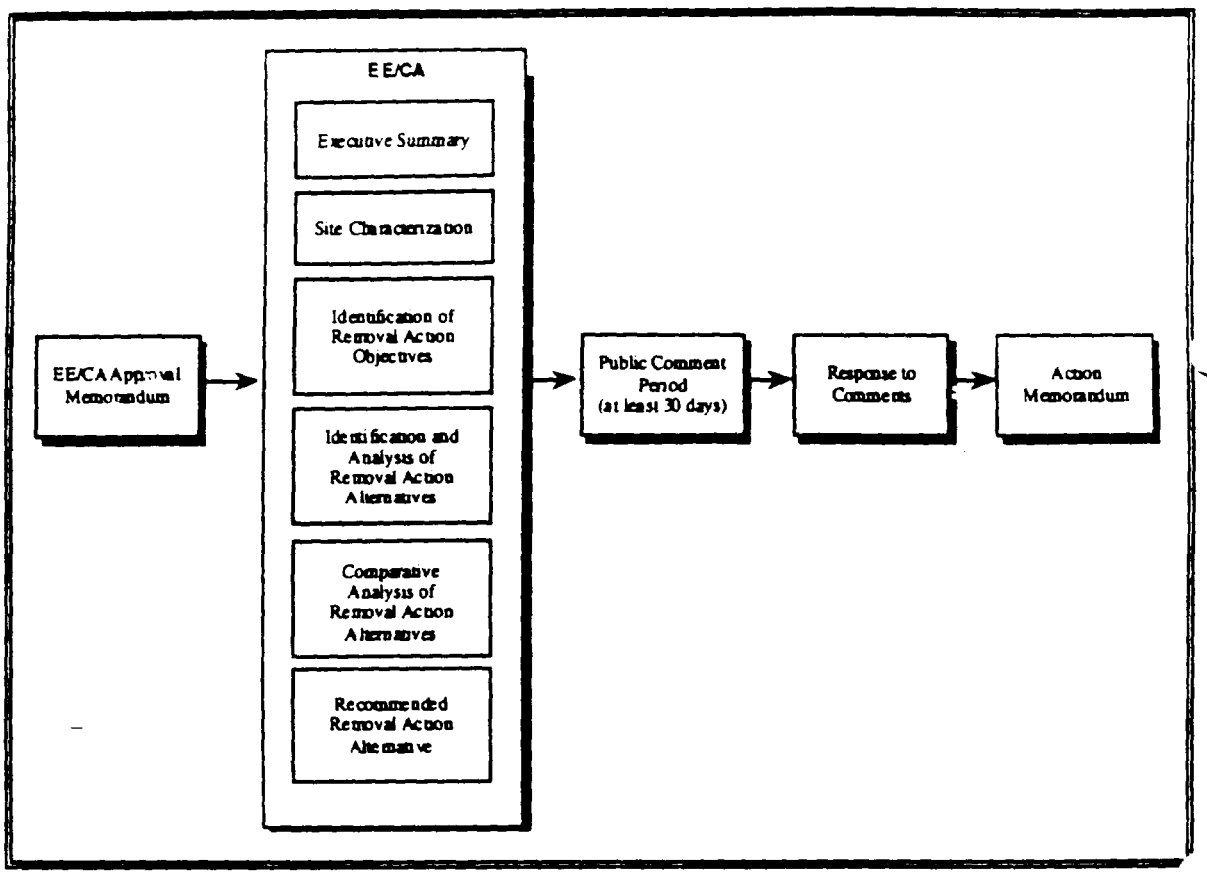
The scope of the non-time-critical removal action (e.g., an interim action conducted during an ongoing remedial effort) and the specific objectives determine the information to be collected during the EE/CA. Accordingly, qualitative risk information that identifies pathways of concern and concentrations of contaminants above standards could have been documented at the site during the RI, and may be referred to in the EE/CA; a separate risk assessment is not necessary to support the non-time-critical removal action. Data to characterize the nature and extent of contamination should be limited to those needed to support the specific objectives of the non-time-critical removal action, supplementing existing data (e.g., the existing RI/FS) to the extent appropriate. Finally, an initial screening of alternatives generally will not be necessary; only a few viable alternatives relevant to the EE/CA objectives should be identified and analyzed.

As noted in Chapter 1, an EE/CA must be completed for all non-time-critical removal actions under CERCLA as required by section 300.415(b)(4)(i) of the NCP. The goals of the EE/CA are to identify the objectives of the removal action and to analyze the effectiveness, implementability, and cost of various alternatives that may satisfy these objectives. Thus, an EE/CA serves an analogous function, but is more streamlined than the RI/FS conducted for remedial actions. Soliciting and responding to public comments on the administrative record, including the EE/CA, is required by section 300.820(a) of the NCP. (See Appendix C for a side-by-side comparison of the EE/CA process and the RI/FS process.)

The results of the EE/CA, along with EPA's response decision, are summarized in the Action Memorandum. The costs of performing an EE/CA, which is considered a CERCLA section 104(b)(1) study, are not counted toward the $2 million statutory limit on removal actions. Exhibit 3, on the following page, depicts the process for developing an EE/CA.

2.1 OVERVIEW (CONTINUED)

EXHIBIT 3
EE/CA Development Process



This chapter provides guidance on the components of the EE/CA Approval Memorandum, as shown in Exhibit 4, on the following page, and the EE/CA, as shown in Exhibit 5. The chapter discusses and provides checklists for each section of the EE/CA; however, each section can be modified to satisfy special requirements of the removal action or to justify the selection of a specific alternative.

For More Information:

1. CERCLA §104(b)(1), Information; Studies and Investigations
2. NCP:
   §300.415, Removal Action
   §300.415(b)(2), Appropriateness Factors
   §300.415(b)(4)(i), EE/CA Requirement

EXHIBIT 4
EE/CA Approval Memorandum

- ❑ Subject
- ❑ Background
- ❑ Threat to Public Health, Welfare, or the Environment (Includes Expected Change If No Action Taken)
- ❑ Imminent and Substantial Endangerment If Present
- ❑ Enforcement Actions
- ❑ Proposed Project/Oversight and Cost
- ❑ Approval/Disapproval

2.2 EE/CA APPROVAL MEMORANDUM

In general, the EE/CA Approval Memorandum is prepared once the need for a non-time-critical removal action has been determined; a removal site evaluation may have been completed, or if the site is on the NPL, information may also be available from other sources. The EE/CA Approval Memorandum is not a part of the EE/CA, but is part of the administrative record for the site.

The EE/CA Approval Memorandum serves important functions. First, it secures management approval and funding approval to conduct the EE/CA or, for PRP-lead actions, to provide oversight of EE/CAs. If the action is PRP-lead, provisions for oversight funding will be contained in an administrative order and should be included in an Approval Memorandum. Second, the memorandum documents that the situation meets the NCP criteria for initiating a removal action and that the required action is non-time-critical. Third, it provides a finding of an actual or threatened release from the site and, if present, a finding of an imminent and substantial endangerment, or refers to a document establishing such a determination. The Approval Memorandum also provides general information pertaining to the site background; threats to public health, welfare, or the environment posed by the site (including expected changes in the site situation if no action is taken or if the action is delayed); enforcement activities related to the site; and estimated EE/CA costs.

The EE/CA Approval Memorandum should indicate a current or potential threat to public health, welfare, or the environment. The memorandum should focus on providing sufficient information that such a threat or potential threat could exist, while the EE/CA will provide the information for EPA to determine that such a threat or potential threat actually exists. The preliminary identification of exposures is based on information obtained from the PA or SI and possibly other previous investigations. The OSC/RPM should develop a conceptual site model as a starting point for this analysis. The model identifies potential releases, potential areas of contamination, chemicals of concern, possible routes of exposure, possible routes of contaminant transport, and potential exposure pathways.

This potential for exposure indicates the likelihood of meeting the NCP criteria for taking a removal action, which in turn justifies the need for conducting the EE/CA. For example, risk consideration can identify the possibility of exposure of nearby populations, animals, or the food chain to hazardous substances, pollutants, or contaminants. Similarly, this preliminary risk

2.2 EE/CA APPROVAL MEMORANDUM (CONTINUED)

information may also indicate the possibility of contamination of drinking water or sensitive environments or other situations or factors that may pose threats to public health, welfare, or the environment.

The Regional Administrator (or authorized designee) evaluates the EE/CA Approval Memorandum and provides authorization. Funds expended to prepare an EE/CA Approval Memorandum are CERCLA 104(b)(1) monies and are not counted toward the $2 million statutory limit for removal actions.

For More Information:

1. CERCLA §104(b)(i), Information; Studies and Investigations.
2. NCP:
   §300.415(m)(4)(i), Community Relations
   §300.415(b)(4), EE/CA Requirement

EXHIBIT 5
EE/CA Outline

- ❑ Executive Summary
- ❑ Site Characterization
  - ❑ Site description and background
  - ❑ Previous removal actions
  - ❑ Source, nature, and extent of contamination
  - ❑ Analytical data
  - ❑ Streamlined risk evaluation
- ❑ Identification of Removal Action Objectives
  - ❑ Statutory limits on removal actions
  - ❑ Determination of removal scope
  - ❑ Determination of removal schedule
  - ❑ Planned remedial activities
- ❑ Identification and Analysis of Removal Action Alternatives
  - ❑ Effectiveness
  - ❑ Implementability
  - ❑ Cost
- ❑ Comparative Analysis of Removal Action Alternatives
- ❑ Recommended Removal Action Alternative

2.3 EE/CA EXECUTIVE SUMMARY

The EE/CA Executive Summary provides a general overview of the contents of the EE/CA. It should contain a brief discussion of the site and the current or potential threat posed by site

2.3 EE/CA EXECUTIVE SUMMARY (CONTINUED)

conditions. The Executive Summary should also identify the scope and objectives of the removal action, as well as the removal action alternatives. Finally, this section of the EE/CA should provide information on the recommended removal action alternative.

The Executive Summary is intended to make the contents of the EE/CA more accessible to review by the public, and is analogous in this respect to the Proposed Plan used in the remedial process. This summary can then be used in the Action Memorandum, which should include a description of the EE/CA.

2.4 SITE CHARACTERIZATION

The EE/CA should summarize available data on the physical, demographic, and other characteristics of the site and surrounding areas. These data may be available from a removal site evaluation, from previous investigations, or from other EPA activities at the site (e.g., work in preparation for NPL listing). Documents providing information for the EE/CA should be placed in the administrative record for the site. Whatever the source, the data on the site must provide background engineering information for analysis of removal alternatives. Because of the CERCLA preference for treatment over containment or land disposal, it is important that alternatives that employ treatment and that yield permanent solutions be fully evaluated for non-time-critical removal actions and early remedial actions. Furthermore, potential differences between early action and long-term action data quality objectives and risk assessment goals should be reconciled as early as possible. Therefore, EPA should coordinate activities of the OSC/RPM with those of the site assessment manager, risk assessor, and enforcement/legal staff to ensure appropriate data are collected to characterize the site.

Information about the site may be readily available from many sources, including:

- Scoring packages for NPL sites
- Removal site evaluations
- Remedial PA/SI reports
- EE/CA Approval Memoranda
- RI/FSs
- RODs
- State and local government reports
- The Agency for Toxic Substances and Disease Registry (ATSDR) or State public health agencies
- State Historic Preservation Officer
- Environmental Impact Statements (EISs)
- CERCLA section 104(e) information requests
- Newspaper articles
- Resource Conservation and Recovery Act (RCRA) enforcement actions
- Published engineering evaluations and technical reference documents
- Documents from other Federal agencies, such as U.S. Geological Survey (USGS) maps and Federal Emergency Management Agency evacuation reports
- Company records
- Employee interviews
- EPCRA—Toxic Release Inventory data.

2.4 SITE CHARACTERIZATION (CONTINUED)

Site Description and Background

The site description includes current and historical information. This information may help identify hazardous substances, pollutants, or contaminants of concern, or areas of the site requiring additional sampling. In gathering this information, OSCs/RPMs should review State, local, and Federal permit files, construction records, and local deed records for information on previous owners to determine materials produced, stored, or disposed of at the site. CERCLA section 104(e) information requests should also be considered. In addition, interviews should be conducted, as necessary, with neighbors of the site or past employees who can describe past operational practices or identify other past employees. The site background may include historical and aerial photographs. The EE/CA should document these data to convey a clear understanding of the nature of the site.

The site description section of the EE/CA should include the following types of information where available and as appropriate to the site-specific conditions and the scope of the removal action:

- Site location
  - Street address and crossroads
  - USGS topographic map quadrangle
  - Latitude/longitude
- Type of facility and operational status
  - Materials manufactured, stored, or disposed on-site
  - Estimated quantities of contaminants and potential hazards
  - Years of operation
  - Present/prior site use
  - Regulatory history, including previous responses, investigations, and litigation by State, local, and Federal agencies
- Structures/topography
  - Facility size/dimensions
  - Boundary descriptions
  - Land cover/vegetation/stresses to topography
  - Utilities/transportation features
  - Buildings
  - Surface water bodies/conveyances
  - Drainage channels/pathways
  - Historically/archaeologically significant features
  - Sewer lines/manholes
  - Stormwater drainage pipes
  - Open ditches/canals
  - Power lines/pipelines
- Geology/soil information
  - Depth to aquifer
  - Soil types (surface and vadose zones)
  - Local geological formulations
  - Surface water hydrology and hydrogeology

- Surrounding land use and populations
  - Residential, industrial, or commercial land use
  - Possible pathways of exposure
  - Identification of sensitive populations
  - Estimate of population densities within potentially affected radius
  - Description of drinking water sources
  - National Historic Preservation Act considerations

- Sensitive ecosystems
  - Wetlands, wildlife breeding areas
  - Wild and scenic rivers
  - Connection to the human food chain or food chains of other organisms
  - Sensitive and/or endangered species
  - Coastal zones

- Meteorology
  - Rainfall/snowfall
  - Temperature ranges
  - Wind conditions

Previous Removal Actions

The site characterization section of the EE/CA should also describe any previous removal actions at the site. Exhibit 6, on the following page, shows useful information that may be obtained from a previous removal action and its applicability to the current EE/CA. Previous information, if relevant, may be organized as follows:

- The scope and objectives of the previous removal action
- The amount of time spent on the previous removal action
- The amount of money spent on the previous removal action
- The nature and extent of hazardous substances, pollutants, or contaminants treated or controlled during the previous removal action
- The technologies used and/or treatment levels used for the previous removal action.

Like all documents that serve as the basis for Superfund decisions, EE/CAs are subject to public review and must be part of the administrative record. Although confidential and enforcement-sensitive documents are typically not relied upon in selecting response actions, when they are relied upon they should be contained in a separate confidential portion of both the EE/CA and the administrative record. Confidential information includes the following:

- Trade secrets, commercial or financial information
- State secrets
- Confidential informant files
- Privacy Act privileged information, attorney-client privileged information, and attorney work product privileged information
- Information exempted by other statutes.

Enforcement-sensitive information that generally should not be placed in the administrative record file includes:

- Financial status of PRPs
- Record of previous negotiations with PRPs and the results
- Investigatory files relating to law enforcement
- Additional information on enforcement history, strategy, discussion, and recommendations.

EXHIBIT 6
Information From Previous Removal Actions Applicable To Current EE/CA

Information From Previous Removals	Applicability To Current EE/CA
Nature and Extent of Contaminants	This information may allow the OSC/RPM to narrow the scope of evaluation to certain areas of the site or to specific analyses.
Treatability of Compounds	Previous use of a technology may affect the decision to use the same technology again.
Equipment/Utilities at Site	If the previous removal action resulted in supplies and equipment being left at the site or provision of specific utilities (e.g., electrical power, sewer line), this information may affect the choice of treatment/control options employed.
Site-Specific Conditions	Lessons learned from a previous removal action are valuable to the current EE/CA. Specific examples could include seasonal weather patterns affecting technology applications or site access limitations because of vehicle transportation routes.

Source, Nature, and Extent of Contamination

To the extent possible, site characterization data should be gathered during the removal site evaluation to support the EE/CA, unless such data were gathered in prior investigations. Existing information may be useful in determining the location(s) of contamination at a particular site. This information may include:

- Location(s) of the hazardous substance(s), pollutant(s), or contaminant(s)
- Quantity, volume, size, or magnitude of the contamination
- Physical and chemical attribute(s) of the hazardous substance(s), pollutant(s), or contaminant(s)
- Target(s) potentially affected by the site.

2.4 SITE CHARACTERIZATION (CONTINUED)

The source of the contamination for a removal action is often well defined. However, if the source, nature, and extent of contamination cannot be readily identified, the OSC/RPM should survey the area. Contamination sources and locations can often be determined by:

- Using nonanalytical methods, including geophysical surveys, which may indicate the presence of buried objects, such as drums
- Examining aerial photographs (especially those taken over a period of time), which may indicate land areas or drainage patterns that have been disturbed
- Reviewing past operations and information from the Toxic Release Inventory and interviewing past or current employees, which may help determine the source of contamination.

If contamination is found in a containment vessel (e.g., under- or above-ground storage tanks, drums, lagoons), the integrity of the vessels should be determined. The integrity may have an impact on the selection of the removal action.

Analytical Data

The analytical data section presents quantifiable data collected for the EE/CA. This section begins with existing data and expands as additional data are collected. When sufficient data are collected, significant findings should be presented in a narrative discussion. The actual data can be presented in tables, either within the section or in an appendix, or incorporated by reference to the document containing the data.

Sampling should typically be performed in accordance with accepted EPA and Contract Laboratory Program (CLP) protocols. Where feasible, sampling should be coordinated through the integrated assessment approach of SACM. Where a SACM approach is used, appropriate data quality objectives should be used for decisions in support of remedial and removal actions. If the site is not already on the NPL, sample collection and analysis should generally ensure that data generated will also support assessment of whether NPL listing and remedial action are appropriate.

Analytical data from studies conducted by EPA or other groups (e.g., State or local health or environmental authorities or PRPs) are useful in characterizing the site. Reviewing any soil, water, or waste analyses will help OSCs/RPMs determine the precision, accuracy, representativeness, completeness, and comparability of previous sampling. These parameters can be evaluated by examining the results of routine quality control procedures, such as replicate samples and/or analyses, replicate spiked samples and/or analyses, field blanks, method blanks, and analysis of standard reference materials.

To reflect SACM's integrated assessment approach, future guidance will further address data collection and analysis to support removal actions, early remedial actions, and long-term actions. The Environmental Response Team (ERT) is currently developing integrated guidance on air, waste, and water sampling, and ecological assessment. All data used to justify a non-time-critical action should be supported by quality control data. Furthermore, these data should be

evaluated based on quality assurance documentation. Following this quality assurance and control process, data can be compared to existing health- or risk-based standards to determine the nature of the threat to public health, welfare, or the environment.

Streamlined Risk Evaluation

The streamlined risk evaluation is a new type of evaluation, intermediate in scope between the limited risk evaluation undertaken for emergency removal actions and the conventional baseline assessment normally conducted for remedial actions. This streamlined risk evaluation can help justify taking a removal action and identify what current or potential exposures should be prevented. The risk evaluation uses sampling data from the site to identify the chemicals of concern, provides an estimate of how and to what extent people might be exposed to these chemicals, and provides an assessment of the health effects associated with these chemicals. A streamlined risk evaluation projects the potential risk of health problems occurring if no cleanup action is taken at a site. Therefore, the results of the streamlined risk evaluation help EPA decide whether to take a cleanup action at the site, what exposures need to be addressed by the action, and in some cases define appropriate cleanup levels.

In planning a non-time-critical removal action, OSCs/RPMs should consult with the Regional risk assessors on potential action and cleanup levels. The risk evaluation at the site should remain the responsibility of EPA. Since removal and remedial action cleanup levels may differ, all early action decisions should consider the possible long-term action and corresponding cleanup levels. The OSC/RPM should ensure that all risk assessment activities are consistent with any future remedial action remaining to be taken (or potential for listing, if the site is not on the NPL) to achieve consistent risk goals. OSCs/RPMs should refer to OSWER Publication 9285.7-01B, "Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual, Part A, Interim Final" (December 1989), EPA/540/1-89/002, PB90-155581, for guidance on conducting risk evaluations.

For the EE/CA, the streamlined risk evaluation should focus on the specific problem that the removal action is intended to address. For example, if the non-time-critical removal action is to install a ground water containment system, the risk evaluation should address risk due to consumption and use of ground water. If the action is intended to address a particular source of contamination, the risk evaluation should address the risks related only to that source of contamination.

To assist in focusing the risk evaluation on specific site problems, OSCs/RPMs should rely on the conceptual site model and data developed during site characterization. A risk evaluation that identifies only contaminants of concern in the affected media, contaminant concentrations, and the toxicity associated with the chemical can be sufficient to justify taking an action. In some situations, exposure pathways can be identified as an obvious threat to human health or the environment by comparing EE/CA contaminant concentrations to standards that are potential chemical-specific applicable or relevant and appropriate requirements (ARARs) for the action. These may include non-zero Maximum Contaminant Level Goals (MCLGs) and Maximum Contaminant Levels (MCLs) for ground water or leachate, or State air quality standards for contaminants that may volatilize or be entrained by the wind. When potential ARARs for chemicals of concern do not exist for a specific contaminant, risk-based chemical concentrations should be used.

2.4 SITE CHARACTERIZATION (CONTINUED)

Where standards for one or more contaminants in a given medium are clearly exceeded, a removal action is generally warranted, and further quantitative assessment that considers all chemicals, their potential additive effects, or additivity of multiple exposure pathways, are generally not necessary. In cases where standards are not clearly exceeded, or where the available information is deficient or of questionable quality, a more thorough risk assessment may be advisable before deciding whether to take a removal action.

In most, if not all, PRP-and State-lead actions with no RI/FS or other site evaluation and little likelihood of future EPA remedial action, a conventional risk assessment will be necessary to evaluate all potential pathways. If more substantial information or data are needed regarding risks posed at a site (e.g., due to insufficient data quality from prior site work), OSCs/RPMs should not hesitate to request supplementary risk information before any type of response action is selected, being careful to justify any additional work that may be required. However, only in the case where the non-time-critical action will be the only Fund-lead action expected at the site should OSCs/RPMs consider performing a risk assessment that addresses all potential exposure pathways.

For More Information:

1. CERCLA §104(e), Information Gathering and Access
2. OSWER Publication 9200.2-16FS, "Quality Assurance for Superfund Environmental Data Collection Activities" (February 1993), PB93-963273.
3. OSWER Publication 9285.7-01B, "Risk Assessment Guidance for Superfund Volume 1: Human Health Evaluation Manual, Part A, Interim Final" (December 1989), EPA/540/1-89/002, PB90-155581.
4. OSWER Publication 9360.4-01, "Quality Assurance/Quality Control Guidance for Removal Activities—Sampling QA/QC Plan and Data Validation Procedures (Interim Final)" (April 1990), EPA/540/G-90/004, PB90-274481.
5. OSWER Publication 9360.4-02, "Compendium of ERT Soil Sampling and Surface Geophysics Procedures" (January 1991), EPA/540/P-91/006, PB91-921273.
6. OSWER Publication 9360.4-03, "Compendium of ERT Surface Water and Sediment Sampling Procedures" (January 1991), EPA/540/P-91/005, PB91-921274.
7. OSWER Publication 9360.4-05, "Compendium of ERT Air Sampling Procedures" (May 1992), PB92-963406.
8. OSWER Publication 9360.4-06, "Compendium of ERT Ground Water Sampling Procedures" (January 1991), EPA/540/P-91/007, PB91-921275.
9. OSWER Publication 9360.4-07, "Compendium of ERT Waste Sampling Procedures" (January 1991), EPA/540/P-91/008, PB91-921276.
10. OSWER Publication 9360.4-08, "Compendium of ERT Toxicity Testing Procedures" (January 1991), EPA/540/P-91/009, PB91-921271.
11. OSWER Publication 9360.4-10, "Removal Program—Representative Soil Sampling Guidance" (November 1991), PB92-963408.

2.5 IDENTIFICATION OF REMOVAL ACTION SCOPE, GOALS, AND OBJECTIVES

Identifying the scope, goals, and objectives for a removal action is a critical step in the EE/CA and in the conduct of non-time-critical removal actions. At any release, regardless of whether the site is on the NPL, where the lead agency determines there is a threat to public health, welfare, or the environment, a removal action may be taken to abate, prevent, minimize, stabilize, mitigate, or eliminate the release or threat of release.

The following example illustrates this process at an NPL site with an ongoing RI/FS, and where an opportunity exists to conduct a non-time-critical removal action. The non-time-critical removal action will minimize migration of contaminated ground water and contaminants from subsurface soil but is considered an interim action because it is expected that the remedial action will ultimately address the area of concern.

In this example, the goal of the non-time-critical removal action is to minimize migration of contaminated ground water and to begin to reduce contaminants in the soil that are the source of ground water contamination. This goal corresponds to section 300.415(b)(2)(iv) of the NCP, which identifies "high levels of hazardous substances, pollutants, or contaminants in soils largely at or near the surface, that may migrate" as a factor to be considered in determining the appropriateness of a removal action.

Five specific objectives are then developed for the site:

- Minimize migration of contaminated ground water through installation of a containment system
- Initiate removal of volatile organic compounds from contaminated soils through in-situ treatment
- Dewater areas necessary to treat effectively the decontaminated soils
- Install and operate appropriate treatment systems for ground water and vapor generated by containment, dewatering, and soil treatment that will prevent unacceptable discharges or emissions.
- Dispose of waste streams from the removal action.

These objectives should be achieved by meeting specified cleanup levels while working within the statutory limits and attaining ARARs to the extent practicable. Exhibit 7 provides a checklist of factors to consider in developing EE/CA objectives.

Statutory Limits on Removal Actions

Because the EE/CA is a public document and readers may not be aware of the statutory limits on removal actions, the objectives section of the EE/CA should briefly explain the $2 million and 12-month statutory limits for Fund-financed removal actions pursuant to section 104(c)(1) of CERCLA. If the need for an exemption is determined early in the action, the details should be described in the EE/CA as well as in the Action Memorandum requesting the exemption.

2.5 IDENTIFICATION OF REMOVAL ACTION SCOPE, GOALS, AND OBJECTIVES (CONTINUED)

Determination of Removal Scope

The EE/CA should help define the scope of the removal action. The scope of the action could be, for example, total site cleanup, site stabilization, or surface cleanup of hazardous substances. It is critical that removal actions at non-NPL sites consider the potential for future listing to ensure the goals of the removal are consistent with any potential long-term remediation. When a non-time-critical removal action will be the only or last action taken to clean up a potential NPL site, the EE/CA should provide adequate documentation that activities performed at the site are sufficient to meet completion requirements.

Specific objectives vary with the type of removal. If cleanup levels are necessary as part of a specific objective, OSCs/RPMs employ several methods to determine these levels. Examples of current practice include applying an appropriate Federal or State ARAR, consulting a Regional risk assessor, or requesting support from ATSDR or ERT.

Specific objectives that clearly define the scope of the removal action are particularly important when the site poses multiple hazards and the response actions will be conducted in phases. OSCs/RPMs should always consider how the removal action would best contribute to the efficient performance of any remedial action to be taken, as required under CERCLA section 104(a)(2). OSWER Publication 9360.0-13, "Guidance on Implementation of the 'Contribute to Remedial Performance' Provision" (April 6, 1987), provides additional guidance on implementing CERCLA section 104(a)(2). For example, if EPA or the State plans to begin a long-term remedial action at the site in 2 years, the removal action should be designed to ensure that the site is stabilized until remedial action begins. The threats that meet the NCP removal criteria should be fully addressed, if possible, given the statutory limits on removal actions.

Determination of Removal Schedule

The general schedule for removal activities, including both the start and completion time for the non-time-critical removal action, should be part of the EE/CA. (A time-critical or emergency removal action may occur at any point from the planning phase to the completion of a non-time-critical removal action.) Although EE/CAs are only required when a planning period of at least 6 months is available, the nature of the threat may still dictate that action be initiated within 12 months or some other specific time period. The start date may also be influenced by weather, PRP negotiations, or Regional resources. For example, Regions should consult with Headquarters prior to taking any early action requiring funding beyond the Region's allowance. Also, weather can affect the schedule if the removal is to be implemented before winter. The time available before the removal action can be a significant factor in evaluating alternative technologies, since implementing technologies can necessitate considerable lead time.

The completion time should also be estimated for the removal action, considering the nature of the threat. It may be necessary to achieve beneficial results within a certain time frame to ensure adequate protection of public health and the environment. The time needed to sample treated wastes or other media prior to disposal should be factored into the schedule. Another important factor influencing the removal schedule is the statutory limit on Fund-financed removal actions. For Fund-lead sites not expected to qualify for either the emergency or consistency exemptions, the OSC/RPM should select a removal action alternative that can be implemented within the statutory limits. For Fund-lead sites expected to qualify for an exemption, the objective should be to select a

2.5 IDENTIFICATION OF REMOVAL ACTION SCOPE, GOALS, AND OBJECTIVES (CONTINUED)

removal action alternative that can be implemented within a reasonable time limit. Factors such as weather and the availability of Regional resources may also affect the completion time.

The flexibility in the removal schedule can vary greatly from site to site. Some sites may require a strict schedule, while others allow wider latitude in start and completion times. For a PRP-lead site the 1-year statutory restriction on removal actions is not applicable. In such cases, it may be advisable to establish a removal schedule in an administrative order. The schedule established for a site can be an important decision criterion to evaluate removal action alternatives based on their implementation times.

For More Information:

1. CERCLA:
   §104(a)(2), Removal Action
   §104(c)(1), Statutory Limits
2. NCP §300.415(b)(2)(i)-(viii), Appropriateness Factors
3. OSWER Publication 9360.0-13, "Guidance on Implementation of the 'Contribute to Remedial Performance' Provision" (April 6, 1987).

2.6 IDENTIFICATION AND ANALYSIS OF REMOVAL ACTION ALTERNATIVES

Based on the analysis of the nature and extent of contamination and on the cleanup objectives developed in the previous section, the OSC/RPM should identify and assess a limited number of alternatives appropriate for addressing the removal action objectives. If the information a Region typically uses to evaluate action alternatives is not sufficient, or if data quality is suspect, OSCs/RPMs should collect any additional technical information needed. If EPA is conducting oversight activities at the site, PRPs or State agencies may provide the information.

Treatment Technologies

Whenever practicable, the alternatives selection process should consider the CERCLA preference for treatment over conventional containment or land disposal approaches to address the principal threat at a site. Although CERCLA section 121(b) appears to apply only to remedial actions, the overall strategy scheme leads to the conclusion that this preference is also an appropriate goal for removal actions. Removal actions, however, cannot conform entirely to requirements for remedial actions because of site related time constraints and statutory limits on remedial actions. To identify alternatives, the OSC/RPM can draw from EPA experience with the particular technologies and contaminants involved, as well as technical advice from ERT, Office of Research and Development's (ORD)-START, the Technology Innovation Office (TIO), the Superfund Innovative Technology Evaluation program, EPA laboratories and task forces, technology vendors, and other sources.

2.6 IDENTIFICATION AND ANALYSIS OF REMOVAL ACTION ALTERNATIVES (CONTINUED)

While treatability studies often need not be performed for proven technologies, in many cases a study is necessary to assure the attainment of treatment objectives. An EE/CA often allows time to plan and conduct a treatability study.

OSCs/RPMs should refer to OSWER Publication 9380.0-17, "Furthering the Use of Innovative Treatment Technologies in OSWER Programs" (August 1991), EPA/540/2-90/004, PB91-921366, for further guidance on assessing treatment options.

Based on the available information, only the most qualified technologies that apply to the media or source of contamination should be discussed in the EE/CA. The use of presumptive remedy guidance can in many cases provide an immediate focus to the discussion and selection of alternatives, speeding the process by limiting the universe of effective alternatives for the non-time-critical removal action. Presumptive remedies involve the use of remedial technologies that have been selected in the past at similar sites or for similar contaminants. By evaluating technologies that have been consistently selected at similar sites, a presumption can be developed that a particular remedy or set of remedies is appropriate for a specific site type. EPA is developing several presumptive remedies for a variety of response situations. Currently, information is available for wood treater sites in OSWER Publications 9355.0-46FS and 9355.0-46, "Technology Selection Guide for Wood Treater Sites" (May 1993), PB93-963505. This information was previously cited as OSWER Publications 9360.0-46FS and 9360.0-46. OSWER guidance is under development for solvent and municipal landfill sites.

A limited number of alternatives, including any identified presumptive remedies, should be selected for detailed analysis. Each of the alternatives should be described with enough detail so that the entire treatment process can be understood. For example, if one of the alternatives is incineration, information on whether the incineration will occur on-site or off-site should be provided, as well as the volume of waste to be treated, the disposition of the treatment residuals, and any ARARs that would affect significantly the action, such as the land disposal restrictions. The technical implementability of this set of potentially applicable alternatives can then be evaluated based on readily available information from the site characterization phase. Specific technologies may not be applicable to the treatment of wastes in the concentration and form found at the site, and so may be disregarded. The OSC/RPM, however, must avoid even the appearance that a technology has been pre-selected. All selected technologies should be fully considered.

Treatment Technology Information Sources

Appendix D from OSWER Publication 9355.3-01, "Guidance for Conducting Remedial Investigations and Feasibility Studies (RI/FS) Under CERCLA" (October 1988), EPA/540/G-89/004, PB89-184626, provides a bibliography on various treatment technologies. In addition, EPA's Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing technology research, development, and demonstration programs. OSWER Publication 9380.3-03, "Inventory of Treatability Study Vendors" (March 1990), EPA/540/2-90/003a, PB91-228395, helps link the researcher and the user community.

Three additional databases can assist OSCs/RPMs in evaluating the effectiveness and availability of various treatment technologies. The Alternative Treatment Technology Information Center (ATTIC) is an on-line computer database that may be accessed with a personal computer and modem by calling 301-670-3808. ATTIC is a comprehensive, automated system that

integrates hazardous waste data into a centralized, searchable resource. Data about hazardous waste treatment technologies are found in many forms in this system, including:

- Literature search databases
- Expert lists
- Treatability databases
- Fate and transport databases
- Cost models
- Case histories
- Expert systems.

The central ATTIC database contains more than 1,400 technical documents collected in a key-word-searchable format. ORD Publication EPA/600/M-91/049, "Alternative Treatment Technology Information Center–ATTIC Brochure" (August 1991) provides additional information.

Another database operated by TIO is the Technology Vendor Information System for Innovative Treatment Technologies (VISITT). This database facilitates communication between technology vendors and government and private cleanup personnel and describes the capabilities and experience vendors have with innovative technologies. The database is useful in developing engineering studies and designs. The VISITT Hotline at 1-800-245-4505 can provide OSCs/RPMs with additional user information.

The Cleanup Information Bulletin Board (CLU-IN) provides electronic message capabilities, directories, on-line bulletins, and other cross-database files on innovative technologies. Special interest groups exist within the system specifically for OSCs/RPMs. CLU-IN can be accessed with a computer, modem line, and telecommunications software by calling 301-589-8366.

Defined alternatives are evaluated against the short- and long-term aspects of three broad criteria: effectiveness, implementability, and cost. Subcriteria to be evaluated under each of the criteria are identified in Exhibit 7 on the following page.

Effectiveness

The effectiveness of an alternative refers to its ability to meet the objective within the scope of the removal action. This section of the EE/CA should evaluate each alternative against the scope of the removal action and against each specific objective for final disposition of the wastes and the level of cleanup desired. These objectives should be discussed in terms of protectiveness of public health and the environment.

Overall Protection of Public Health and the Environment

How well each alternative protects public health and the environment should be discussed in a consistent manner. This discussion draws on assessments conducted under other evaluation criteria, including long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

EXHIBIT 7
Objectives/Criteria To Be Used In Comparative Analysis of Alternatives

- ❑ Effectiveness
  - ❑ Protectiveness
    - ❑ Protective of public health and community
    - ❑ Protective of workers during implementation
    - ❑ Protective of the environment
    - ❑ Complies with ARARs
  - ❑ Ability to Achieve Removal Objectives
    - ❑ Level of treatment/containment expected
    - ❑ No residual effect concerns
    - ❑ Will maintain control until long-term solution implemented
- ❑ Implementability
  - ❑ Technical Feasibility
    - ❑ Construction and operational considerations
    - ❑ Demonstrated performance/useful life
    - ❑ Adaptable to environmental conditions
    - ❑ Contributes to remedial performance
    - ❑ Can be implemented in 1 year
  - ❑ Availability
    - ❑ Equipment
    - ❑ Personnel and services
    - ❑ Outside laboratory testing capacity
    - ❑ Off-site treatment and disposal capacity
    - ❑ PRSC
  - ❑ Administrative Feasibility
    - ❑ Permits required
    - ❑ Easements or right-of-ways required
    - ❑ Impact on adjoining property
    - ❑ Ability to impose institutional controls
    - ❑ Likelihood of obtaining an exemption from statutory limits (if needed)
- ❑ Cost
  - ❑ Capital cost
  - ❑ PRSC cost
  - ❑ Present worth cost

2.6 IDENTIFICATION AND ANALYSIS OF REMOVAL ACTION ALTERNATIVES (CONTINUED)

The discussion should focus on how each alternative achieves adequate protection and describe how the alternative will reduce, control, or eliminate risks at the site through the use of treatment, engineering, or institutional controls. This evaluation should identify any unacceptable short-term impacts.

Compliance with ARARs and Other Criteria, Advisories, and Guidance

Section 300.415(i) of the NCP requires that Fund-financed removal actions under CERCLA section 104 and removal actions pursuant to CERCLA section 106 attain ARARs under Federal or State environmental laws or facility siting laws, to the extent practicable considering the urgency of the situation and the scope of the removal. At certain sites, ARARs may form the basis of the removal action objectives.

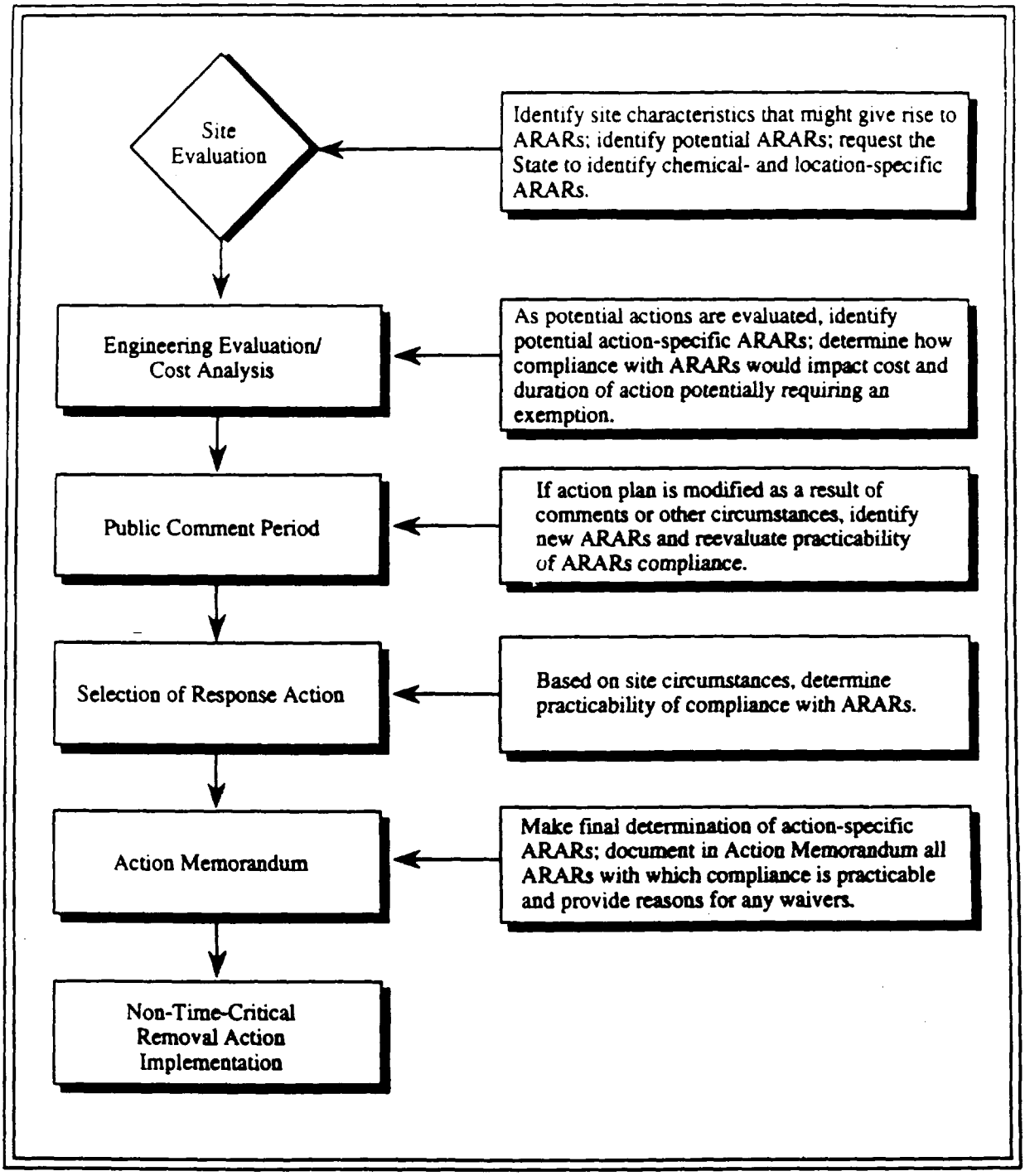
The detailed analysis should summarize which requirements are applicable or relevant and appropriate to an alternative and describe how the alternative meets those requirements. To ensure a full consideration of potential ARARs, OSCs/RPMs may choose to employ a summary table to list potential ARARs. OSCs/RPMs will then be able to quickly identify particular requirements in order to plan for compliance or eliminate requirements not of concern for a given site or alternative.

Since the evaluation of a site will produce data relatively quickly on the location of a release and on the chemical constituents of concern, chemical-specific ARARs and location-specific ARARs should be identified as promptly as possible upon request by the OSC/RPM. Therefore, only State standards that are promulgated, identified by the State in a timely manner, and more stringent than Federal requirements may be applicable or relevant and appropriate. Action-specific ARARs should be identified later in the process after qualified cleanup technologies are chosen for analysis in the EE/CA. The process for identifying and evaluating ARARs during non-time-critical removal actions is shown in Exhibit 8 on the following page.

In addition to ARARs, EPA may, as appropriate, identify other Federal or State advisories, criteria, or guidance to be considered (TBC) for a particular release. TBCs are not required by the NCP; rather, TBCs are meant to complement the use of ARARs. Because ARARs do not exist for every chemical or circumstance, TBCs may be very useful in determining what is protective of a site or how to carry out certain actions or requirements. A list of TBCs, such as the EPA Spill Cleanup Policy, Health Effects Assessments, EPA's Ground Water Protection Strategy, and advisories issued by the Fish and Wildlife Service and the National Marine Fisheries Service under the Fish and Wildlife Coordination Act, can be found in the NCP Proposed Rule Preamble, 53 FR 51449-51450 (December 21, 1988).

The EnviroText Retrieval System, a joint project of EPA, DOE, DOD, the Department of Justice, and the U.S. Army, will be a user-friendly, full-text library search system of multimedia environmental laws. On-line service as a pilot program is expected to start in Fall 1993, and should assist greatly in considering potential ARARs at any given site.

EXHIBIT 8
Identification and Evaluation of ARARs During Non-Time-Critical Removal Actions



2.6 IDENTIFICATION AND ANALYSIS OF REMOVAL ACTION ALTERNATIVES (CONTINUED)

Long-Term Effectiveness and Permanence

This evaluation assesses the extent and effectiveness of the controls that may be required to manage the risk posed by treatment residuals and/or untreated wastes at the site. The following components should be considered for each alternative:

- Magnitude of Risk. This criterion looks at the effectiveness of the alternative and assesses the risk from waste and residuals remaining at the conclusion of site activities. This component also evaluates whether the alternative contributes to future remedial objectives. If the non-time-critical removal action is an interim step and is expected to be followed by remedial action, this factor could be reduced in scope or deleted, if appropriate. If the non-time-critical action is the last action anticipated for a site or release, then the magnitude of risk should be fully evaluated for the action.

- Adequacy and Reliability of Controls. A completed removal action may require PRSC, those response activities necessary to sustain the integrity of a Fund-financed removal action following its conclusion (see Chapter 1). After the removal is completed, PRSC costs may be paid by the PRP, State or local government, or the remedial program.

Reduction of Toxicity, Mobility, or Volume Through Treatment

EPA's policy of preference for treatment (i.e., for technologies that will permanently and significantly reduce toxicity, mobility, or volume of the hazardous substances as their principal element) requires evaluation based upon the following subfactors for a particular alternative:

- The treatment process(es) employed and the material(s) it will treat
- The amount of the hazardous materials to be destroyed or treated
- The degree of reduction expected in toxicity, mobility, or volume
- The degree to which the treatment will be irreversible
- The type and quantity of residuals that will remain after treatment
- Whether the alternative will satisfy the preference for treatment.

The ability of the treatment technology to reduce the principal threats posed by the release, including the extent to which the toxicity, mobility, or volume of the contaminants are reduced (either alone or in combination) may be subject to time and applicability restraints, and may be beyond the scope of an interim removal action when remedial action is indicated.

Short-Term Effectiveness

The short-term effectiveness criterion addresses the effects of the alternative during implementation before the removal objectives have been met. Alternatives should also be evaluated with respect to their effects on human health and the environment following implementation. The following factors should be addressed as appropriate for each alternative:

- Protection of the Community. This factor addresses any risk to the affected community that results from implementation of the proposed action, whether from

air quality impacts, fugitive dusts, transportation of hazardous materials, or other sources.

- Protection of the Workers. This factor assesses any threats to site workers and the effectiveness and reliability of protective measures that would be taken.

- Environmental Impacts. This factor evaluates the potential adverse environmental impacts from the implementation of each alternative. The factor also assesses the reliability of mitigation measures in preventing or reducing the potential impacts.

- Time Until Response Objectives Are Achieved. This factor estimates the time needed to achieve protection for the site itself or for individual elements or threats associated with the site.

Implementability

The implementability criterion addresses the technical and administrative feasibility of implementing an alternative and the availability of various services and materials required during its implementation. The following factors should be considered under this criterion.

Technical Feasibility

The EE/CA must assess the ability of the technology to implement the remedy. Technical difficulties were initially identified during development of alternatives and should be addressed again in detail for the alternative as a whole. Each alternative should be evaluated for implementation factors such as assembling, staffing, and operating the alternative within the time frames in the removal schedule.

The reliability of the technology is also of concern, as technical problems associated with implementation may delay the schedule. Each alternative should be evaluated for technology maturity, prior use under similar conditions for similar wastes, and possible difficulty in operation once it is constructed. Operational difficulties could include the frequency or complexity of equipment maintenance or controls, the need for raw materials, or the need for a large technical staff. Potential impacts on the local community during construction operations should also be evaluated.

The EE/CA should consider environmental conditions not only with respect to the operation phase of the alternative, but also to the set-up and construction phase. Certain technologies may be difficult to construct or operate in remote locations. Climate or terrain may severely impact or eliminate specific alternatives from consideration. For example, an alternative that uses an oil/water separator or sedimentation tank may be unusable at freezing temperatures. Temperature and time of year may directly impact a technology's ability to reach a specific site. For example, a rainy season may make roads to the site inaccessible. Not only will local terrain affect the ability to locate an alternative, but it may also affect performance. For example, a site located in a valley may be susceptible to inversions or limited air currents, therefore making incineration unacceptable.

Potential future remedial actions should also be discussed. Remedial action or a non-time-critical removal action that completely cleans up an NPL site may trigger the five-year review

requirements of CERCLA section 121(c). This evaluation should also consider the operation of PRSC measures or operation and maintenance (O & M). This discussion should depict how difficult it would be for EPA to implement these future remedial actions. This is particularly applicable to an interim action where additional action is expected.

If the site will be receiving long-term remedial treatment, the EE/CA must determine if each alternative contributes to the efficient performance of any anticipated remedial activities. CERCLA section 104(a)(2) states that a removal action should, to the extent practicable, contribute to the efficient performance of any long-term remedial action with respect to the release or threatened release concerned. Removal actions that do contribute may be eligible for an exemption from the $2 million/12-month statutory limit on removal actions. OSWER Publication 9360.0-12A, "Final Guidance on Implementation of the 'Consistency' Exemption to the Statutory Limits on Removal Actions" (June 12, 1989), PB90-274465/CCE, states that removal actions should be designed to avoid wasteful, repetitive, short-term actions that do not contribute to the efficient, cost-effective performance of a long-term remedial action.

In some cases, it may not be easy to demonstrate removal action consistency with future remedial action. Remedial actions often cannot be anticipated when an EE/CA is being developed for a non-time-critical removal action. It may be difficult to show with reasonable certainty that a removal option would be consistent with a future remedial action. Section 104(a)(2) of CERCLA provides for discretion in using the practicability standard. Accordingly, OSCs/RPMs should avail themselves of this discretion when developing and evaluating removal action alternatives that would provide for partial cleanups of sites.

The ability to monitor the effectiveness of the alternative may also be considered in the EE/CA. These monitoring considerations would generally not be evaluated for Fund-lead non-time-critical removal actions where remedial work was planned.

Administrative Feasibility

The administrative feasibility factor evaluates those activities needed to coordinate with other offices and agencies. The administrative feasibility of each alternative should be evaluated, including the need for off-site permits, adherence to applicable nonenvironmental laws, and concerns of other regulatory agencies. Factors that should be considered include, but are not limited to, the following:

- Statutory Limits. Each alternative should be evaluated for its compliance with the statutory limits on removal actions. If an alternative requires a statutory exemption from the $2 million or 12-month limit, the EE/CA should evaluate whether the site qualifies. If the time or money needed to implement the alternative will exceed the statutory limit for removal actions, an exemption request, which is part of the Action Memorandum, should be submitted to Headquarters for review as soon as possible. Headquarters approval is only required for non-NPL consistency waivers and for emergency waivers (money, not time).

- Permits and Waivers. The EE/CA should evaluate whether each alternative will require off-site permits (e.g., building permits). Other factors that may affect the administrative feasibility include the need for easements, right-of-way agreements, or zoning variances.

2.6 IDENTIFICATION AND ANALYSIS OF REMOVAL ACTION ALTERNATIVES (CONTINUED)

Availability of Services and Materials

The EE/CA must determine if off-site treatment, storage, and disposal capacity, equipment, personnel, services and materials, and other resources necessary to implement an alternative will be available in time to maintain the removal schedule. Availability of funds to meet PRSC requirements is also a factor. Several important availability factors are:

- Personnel and Technology. Using the removal action schedule as a guide, the EE/CA should determine whether a specific alternative will be available from the manufacturer. Other technologies may require a large number of skilled laborers or specialists (e.g., welders, pipe fitters, chemical engineers) that may not be readily available if the site is remote, thus impacting the ability to assemble the removal action alternative.

- Off-Site Treatment, Storage, and Disposal. If off-site removal and treatment of the waste is being considered, the EE/CA should address the adequacy of off-site capacity. If the site is in a remote location, this type of service may not be available or may be extremely costly because of transportation expenses. OSCs/RPMs should review OSWER Publication 9834.11, "Revised Procedures for Implementing Off-Site Response Actions" (November 13, 1987), PB91-139282/CCE, before evaluating this option. The OSC/RPM and Regional off-site contact should discuss whether there are treatment facilities in compliance with the off-site policy that can accept the type of CERCLA waste at the site. [A final rule addressing this issue is expected in 1993.]

- Services and Materials. This factor involves considering such services as laboratory testing capacity and turnaround for chemical analyses, adequate supplies and equipment for on-site activities, or installation of extra utilities (e.g., power lines, sewer connections).

- Prospective Technologies. This factor assesses whether specific technologies are generally available for the site. Promising technologies sometimes require further development before they can be applied at full-scale. The EE/CA should indicate when a technology would be available for full-scale use. Also, if time allows, the OSC/RPM may be able to develop specifications to allow competitive bidding for a treatment contract. This would be of particular use in developing innovative technologies.

State (Support Agency) Acceptance

The State (or support agency in the case of State-lead sites) may have technical and administrative concerns. Since States may review the alternatives, their concerns should be considered in determining the recommended alternative in the EE/CA and in the final selection of the alternative in the Action Memorandum.

2.6 IDENTIFICATION AND ANALYSIS OF REMOVAL ACTION ALTERNATIVES (CONTINUED)

Community Acceptance

As with State acceptance, community acceptance of an alternative will be considered when making a recommendation in the EE/CA and in the final selection of the alternative in the Action Memorandum.

Cost

Each removal action alternative should be evaluated to determine its projected costs. The evaluation should compare each alternative's capital and PRSC costs. The present worth of alternatives that will last longer than 12 months should be calculated. In certain cases, OSCs/RPMs may conduct a sensitivity analysis of the present worth calculations.

To compare the cost of each alternative, the direct and indirect capital costs and the PRSC costs of each alternative should be projected. OSWER Publication 9360.0-02C, "Removal Cost Management System: Version 3.2" (May 1990), EPA/540/P-90/003, PB90-272691, provides guidance on performing cost projections and daily cost tracking. The following items are considered capital costs and PRSC costs:

- Direct capital costs
  - Construction costs
  - Equipment and material costs
  - Land and site acquisition costs
  - Buildings and services costs
  - Relocation expenses
  - Transport and disposal costs
  - Analytical costs
  - Contingency allowances
  - Treatment and operating costs

- Indirect capital costs
  - Engineering and design expenses
  - Legal fees and license or permit costs
  - Start-up and shakedown costs

- Annual PRSC costs
  - Operational costs
  - Maintenance costs
  - Auxiliary materials and energy
  - Disposal of residuals
  - Monitoring costs
  - Support costs.

Many sources of cost information exist, including the ERCS contract price list, vendor estimates, and estimates for similar projects. For items not currently on the ERCS list and for projects where outside bids are being considered, cost estimates more than 12 months old should be updated using an appropriate economic index, such as the Engineering News Record Construction Cost Index for construction costs, the Marshall and Stevens Index for treatment facility costs, the American City and County Municipal Cost Index for manpower costs, and the

Producer Price Index for Finished Goods, published by the U.S. Department of Labor in the Monthly Labor Review. All these information sources can be found in Regional and/or public libraries.

After identifying and estimating the costs, OSCs/RPMs should calculate the present worth for removal action alternatives that will last longer than 12 months. Present worth analysis evaluates expenditures that occur over different time periods by discounting all future costs, usually PRSC costs, to a common base year, usually the present year. Present worth analysis produces a single figure representing the amount of money that, if invested in the base year and dispersed as needed, would cover all costs associated with the alternative. This analysis is particularly important when comparing technologies with different operating lifetimes. The final present worth figure and the assumptions used in calculating that figure should be included in the EE/CA. The detailed computations should be attached as an appendix to the EE/CA.

For alternatives that include only PRSC after 1 year from the start of the removal action, the total cost of the option over the full life of the project should be calculated. In comparing alternatives, however, OSCs/RPMs should use the cost of the option to EPA for 1 year, provided that all PRSC costs will be assumed by another party after 1 year. OSWER Publication 9355.3-20 "Revisions to OMB Circular A-94 on Guidelines and Discount Rates for Benefit Cost Analysis" (June 25, 1993) provides information on discount rates for present worth calculations.

In addition, OSCs/RPMs should determine whether a sensitivity analysis is warranted. A sensitivity analysis assesses the effect that variations in specific assumptions associated with design, implementation, operation, discount rate, and effective life of an alternative can have on the present worth. The sensitivity of such costs to uncertainties can be observed by varying the cost assumptions and noting their effect on the present worth. A sensitivity analysis might be appropriate when uncertainties exist about the amount of waste present, how quickly a technology can perform, or the future price of cleanup services.

For More Information:

1. CERCLA:
   §104(a), Removal Action
   §121, Cleanup Standards
   §311(b), Alternative or Innovative Treatment Technology Research and Demonstration Programs
2. NCP §300.415(i), ARARs Attainment
3. Office of Policy Analysis (OPA) Publication, "Guidelines for Performing Regulatory Impact Analysis" (December 1983).
4. ORD Publication EPA/600/M-91/049, "Alternative Treatment Technology Information Center–ATTIC Brochure" (August 1991).
5. OSWER Publication 9234.1-01, "CERCLA Compliance with Other Laws Manual, Part 1 (Interim Final)" (August 1988), EPA/540/G-89/006, PB90-272535.
6. OSWER Publication 9234.1-02, "CERCLA Compliance with Other Laws Manual, Part 2: Clean Air Act and Other Environmental Statutes and State Requirements" (August 1989), EPA/540/G-89/009, PB90-148461.

2.6 IDENTIFICATION AND ANALYSIS OF REMOVAL ACTION ALTERNATIVES (CONTINUED)

7. OSWER Publications 9355.0-46FS and 9355.0-46, "Technology Selection Guide for Wood Treater Sites" (May 1993), PB93-963505, also previously cited as OSWER Publication 9360.0-46FS and 9360.0-46.
8. OSWER Publication 9355.3-01, "Guidance For Conducting Remedial Investigations and Feasibility Studies (RI/FS) Under CERCLA" (October 1988), EPA/540/G-89/004, PB89-184626.
9. OSWER Publication 9355.3-20, "Revisions to OMB Circular A-94 on Guidelines and Discount Rates for Benefit Cost Analysis" (June 25, 1993), PB93-963297.
10. OSWER Publication 9360.3-02, "Superfund Removal Procedures—Guidance on the Consideration of ARARs During Removal Actions" (August 1991), PB92-963401/CCE.
11. OSWER Publication 9360.0-02C, "Removal Cost Management System: Version 3.2" (May 1990), EPA/540/P-90/003, PB90-272691.
12. OSWER Publication 9360.0-12A, "Final Guidance on Implementation of the 'Consistency' Exemption to the Statutory Limits on Removal Actions" (June 12, 1989), PB90-274465/CCE.
13. OSWER Publication 9380.0-17, "Furthering the Use of Innovative Treatment Technologies in OSWER Programs" (August 1991), EPA/540/2-90/004, PB91-921366.
14. OSWER Publication 9380.3-03, "Inventory of Treatability Study Vendors" (March 1990), EPA/540/2-90/003a, PB91-228395.
15. OSWER Publication 9834.11, "Revised Procedures for Implementing Off-site Response Actions" (November 13, 1987), PB91-139287/CCE.*
16. OSWER Publication 9834.11a, "Off-Site Policy RFA or Equivalent Investigation Requirement at RCRA Treatment and Storage Facilities" (January 4, 1988), PB91-139295/CCE.*

* *A final rule addressing this issue is expected in 1993.*

2.7 COMPARATIVE ANALYSIS OF REMOVAL ACTION ALTERNATIVES

Once the alternatives have been described and individually assessed against the criteria, a comparative analysis should be conducted to evaluate the relative performance of each alternative in relation to each of the criteria. This is in contrast to the preceding analysis in which each alternative was analyzed independently without consideration of other alternatives. The purpose of the comparative analysis is to identify the advantages and disadvantages of each alternative relative to one another so that key tradeoffs that would affect the remedy selection can be identified.

2.8 RECOMMENDED REMOVAL ACTION ALTERNATIVE

The EE/CA should identify the action that best satisfies the evaluation criteria based on the comparative analysis in the previous section. This description should briefly describe the evaluation process used to develop the recommended action. For both Fund-lead and PRP-lead EE/CAs, EPA should determine the recommended action. This determination may be placed in the administrative record file concurrently with the EE/CA. This section of the EE/CA may enhance public involvement efforts by describing clearly why the alternative was recommended. Because the EE/CA is open to public comment and evaluation and because EPA is required to prepare

2.8 RECOMMENDED REMOVAL ACTION ALTERNATIVE (CONTINUED)

a written response to significant comments, the recommended alternative may not always be the final alternative selected in the Action Memorandum. The Action Memorandum and the administrative record should provide enough detail to justify the final alternative selected.

WEST CHICAGO INTERGOVERNMENTAL FORUM 10-22-93

On October 22, 1993, participants of the West Chicago Intergovernmental Forum (Forum) conducted the monthly meeting in the EPA Regional offices to discuss the status of the Kerr-McGee Superfund cleanup. Participants included City of West Chicago representatives Steve Lakics, Don Foster, Joe Karaganis, and Barbara Nagel; Scott Palmer of Congressman Hastert's Office; Dave Thomas with the West Chicago Park District; Francis Lyons, Doug Rathe and Bill Seith from the Illinois Attorney General's office; Dave Engel from Illinois EPA; Raymond Hansen of the DuPage County States Attorney office; Gordon Appel of IDNS; John Kelley, Bob Bowden and Ken Tindall representing the Office of Superfund; and Mary Canavan and Ken Westlake representing the Regional Administrator's Office.

John Kelley opened the meeting with a welcome and presentation of the agenda. It was decided that the six action items from the previous forum would be discussed and then new issues raised.

Concern was expressed over time frames for cleanup of all the Superfund sites in the city. The two main issues are: 1) the City wants to see major movement, moving waste in '94; and 2) a schedule, complete with back-end dates, for completion of the factory closure and all off factory site areas. The AG's office stressed that the schedule hinged on establishment of the cleanup criteria standards. City representatives elaborated that the Factory site closure application assumed the 5-15 pCi/g cleanup criteria in its design. Another concern was that the existing plan calls for screening of soils with ultimate dilution of dirty soils. This implies the 5-15 pCi/g standard. Once EPA sets the criteria, Kerr-McGee's closure design may need to change. EPA assured the forum that the criteria will be issued by EPA in November. As to the 5-15 pCi/g vs. the 5-5 pCi/g standard, EPA continues to represent that the 5-5 pCi/g standard is appropriate for residential areas and feels this standard has solid scientific support.

The AG's office stated that Kerr-McGee argues that 5-5 pCi/g is inappropriate. The key is for EPA to walk Kerr-McGee through their analysis to persuade them of its validity. This could be essential to getting them to do work. EPA stated that it would be meeting with Kerr-McGee once the cleanup criteria are final. The criteria are scheduled to be final within two weeks of Becky Frey's return from vacation on November 8, 1993. EPA has targeted the third week of November for meeting with Kerr-McGee. Not much further comment is anticipated by EPA from the final criteria review process. All final comments on the draft final are due on November 5.

The City stated that Kerr-McGee's cleanup threshold in the early 1980's was in uR/hr rather than pCi/g in soil. Apparently, Kerr-McGee claims they've cleaned up the properties to "background" using uR/hr. How will EPA apply the pCi/g standard to this

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action? The City stated that IDNS had argued to go to background. IDNS stressed not to confuse the discovery standard with the cleanup standard. IDNS thinks EPA will argue that 5 pCi/g is "background." The City wants to be able to tell the public that properties will be cleaned to background. IDNS maintained that DuPage County average soil concentration is likely less than 5 pCi/g, and that EPA is saying that 5-5 pCi/g is acceptable residual risk level. EPA is likely to excavate deeper than 5 pCi/g soils, such that residual is at 5 pCi/g or less. Region V will advise the Community Relations Staff of the importance of describing the cleanup standards to the public in understandable terms.

Congressman Hastert's office underscored that timing is critical. The factory site cleanup may be further along than residential areas. If the Kerr-McGee plan is good, the factory cleanup should be done by 1997. Hastert's office stated that if EPA takes three years to do a RI/FS, cleanup of the off factory site areas could stretch to the year 2000+. The AG's office interjected that the residential sites are being done as removals. Hastert's office asked what the overall cleanup time line is with or without Kerr-McGee.

Region V assured the forum that residential cleanups will be underway in the summer of 1994. Before removal work can start, EPA must prepare an Engineering Evaluation/Cost Analysis (EE/CA). The EE/CA must go out for public comment. This is a much shorter process than a RI/FS/ROD project. During the public comment period, Region V will prepare two action memos; 1) assumes Kerr-McGee does work under enforcement action, defines risk and need for action to support an AOC and; 2) if Kerr-McGee is unwilling to perform the removals, an action memo would commit EPA to do the project, with cost estimates. If Region V does the removals, partial funding is certain for 1994 with the project incrementally funded over following years. Region V stated that because the residential areas action will be performed as a non-time critical removal, the remedial budget can be used. The overall cost and time line for this sort of project depends on the number of properties identified for removal actions. The Region will attempt to shorten its procedures with 1997 as the target deadline for completion. This will involve taking some procedural risks. These risks would not jeopardize public health but would find ways to streamline and expedite the cleanup process.

The City questioned how long it would take to identify and cleanup residential properties. Could it be done by 1997? How many parcels will need to be screened? Region V responded that the work plan is currently being developed which will define the sampling and cleanup processes. The two processes will work in tandem. Once the work plan is completed, estimated schedules

will be available with the overall goal of 1997. Region V's removal program has had good success in meeting schedules.

Several parties expressed interest in EPA procedures for negotiating with Kerr-McGee for the removal actions and activities which must be completed before removals can start, again with an emphasis on schedules. Region V stated that the meeting with Kerr-McGee in November will address/explain/defend our standards in order to put that issue behind us before formal negotiations begin. If EPA gets a strong signal that Kerr-McGee won't agree to do the removals, EPA would begin working on the EE/CA. EPA has allocated 60 days for negotiations (finish by early February). Once the EE/CA has gone out for public comment and a cleanup decision has been reached, an action memo will be signed to commit EPA to do the work. Currently, Region V anticipates beginning removals in mid-May.

Congressman Hastert's office expressed concern that removals will begin by mid-May. Contractor problems have been a cause of great concern. EPA indicated that, because of the removal status of the project, it will have immediate access to construction contractor. Hastert's office stressed that realistic schedules need to be transmitted to the public. The City added that EPA needs to be able to tell the public when discovery and characterization will be done and when construction will be completed.

A discussion followed on Kerr-McGee's closure permit and potential modifications to encompass EPA's anticipated work. The AG's office pointed out that the factory transfer site will need adequate storage/shipment capacity and asked if Region V could provide an estimated maximum volume of wastes to be shipped. Further, if Kerr-McGee will not perform the removals, EPA will not be able to stage at plant site. This would require alternate staging areas. Region V responded that it will know early in negotiations if Kerr-McGee will be cooperative. Then EPA will pursue an alternative staging area. If the factory site was not accessible, Region V would need IDNS and City cooperation. The City indicated that flexibility in factory site design is required in the event transfer capacity needs to expand. Also, contamination extends beyond boundaries of plant site. Kerr-McGee doesn't want to clean up under the railroad tracks. The permit also proposes that retaining wall sheet pilings go only deep enough to accommodate a fourteen car train. More cars may be required to handle EPA's removal materials. Region V stated that the RPM and CH2M Hill have been speaking to the Kerr-McGee project manager on a number of issues related to these questions. The Mayor wants these design questions factored in to review of transfer station plans. The City also stated that Kerr-McGee proposes to replace one-half of the storm sewer leading from the factory site. The City needs to comment on what to do with the sewers. Region V responded that it will work with the City on this issue. There may be contamination in street rights of way.

The City will give EPA permission to go after parkway contamination.

IDNS stated that Kerr-McGee hasn't provided a cost estimate for the factory site closure, which it publicly committed to provide. Kerr-McGee's surety proposal has some deficiencies which need to be discussed. IDNS can't complete the surety analysis without a cost estimate on the cleanup. The surety portion of the permit is to guarantee that the site will be cleaned up even if Kerr-McGee walks or goes bankrupt.

The scoping meeting between Region V, CH2M Hill and IDNS during the first week of October was the next topic. Region V was very pleased with the outcome of the meetings. Scoping activities included settling issues on sampling protocols to have good statistical representation of site contamination, agency roles, and data management, among other things. A decision was made to use a system compatible with IDNS's geographical information system (GIS) to manage the large amount of data which will be generated during the project. This will allow data to be transferred back and forth between EPA and IDNS during the various phases of the project. Region V also will request the use of IDNS's laboratory for analysis of the discovery and characterization samples. Discovery and characterization work will be done by CH2M Hill, with EPA and IDNS oversight, not by Kerr-McGee. A great community relations effort will be required to deal with how individual residents are approached for access.

The AG's office asked what is the typical time for cleanup of a property -- a couple of days between excavation and verification sampling/analysis to conclusion of site work? Region V responded that each property is a separate engineering problem; discovery and mapping of utilities, documentation of initial landscape conditions to guide restoration and extent of contamination all factor into time frame. Congressman Hastert's office expressed concern that the cleanup (removal) people won't be ready once the characterization is done. Region V responded that it will know this winter if Kerr-McGee will do the work and will line up contractors, if necessary. The Park District asked if EPA could start planning actions on known hot spots. Region V answered that those properties will be the first to be characterized.

The next meeting of the governmental forum will be held on November 19 at 10:00 am in the Regional Administrator's conference room. Next month's issues include:

- How will rail tracks be addressed?
- What EPA issues are related to use of factory site for staging (retaining walls, etc.)? EPA should present these needs to Kerr-McGee.

- Fixed end date for completion of all projects. This issue is very important to the City.

West Chicago Intergovernmental Forum Sign-Up Sheet 10/22/93

ED WESTLAKE	USEPA	312-353-1327
ARY CANAVAN	USEPA	312-353-3018
avid Thomas	W.C. Park District	708-231-9474
ordon Appel	IDNS	217/524-4723
COTT Palmer	Cong Hastert	202/225-2976 708/406-1114
Francis Lyons	Ill. Atty Gen.	312/814-2500
Doug Rathe	IL Atty Gen	312 814 3094
Dave Engel	ILL EPA	217-782-5544
Bill Seith	Ill. Atty. Gen.	312-814-6987
John Kelley	USEPA	(312) 886-0538
STEVE LaKics	West Chicago	708-293-2211
Joe Karaganis	"	312 836-1177
Barbara Magel	"	"
Robert J Bowden	USEPA	312 ~~55~~ 353-[illegible]
en Tindall	U.S. EPA	312/886-9895
Raymond L. Hansen	Assistant DuPage County States Atty.	708/682-7054
Don Foster	West Chicago	708 293-2212

West Chicago Intergovernmental Forum
October 22, 1993

Agenda

10:00 Welcome, Discuss Agenda

10:15 Follow-up discussion from September 16 meeting

1. Need for an interim staging site if Kerr-McGee is not ready by mid-May.

2. EPA's ability/willingness to talk to Kerr-McGee before the negotiations, to explain the criteria and to persuade them to do the cleanup.

3. Status of EPA scoping meetings with the contractor, and IDNS participation.

4. Protocols for sampling and data verification, e.g. number of samples to be taken, spacing, etc.; need to discuss these with IDNS and the Forum before negotiating with Kerr-McGee.

5. Longer time-frames for cleaning up all four of the West Chicago sites; development of a time-frame for all West Chicago NPL sites with accompanying narrative.

6. Status of Kerr-McGee cost estimates and assurances with IDNS regarding the factory site.

_____ New Issues

_____ Wrap-up/Summary

11:30 Adjourn

MINUTES
WEST CHICAGO INTERGOVERNMENTAL FORUM
FEBRUARY 17, 1995

PARTICIPANTS

David Thomas, West Chicago Park District
Don Foster, City of West Chicago
Joe Karaganis, City of West Chicago
Cindy Pepple, TAG
Barb Guetler, TAG
Michael Kasiewicz, TAG
Carolyn Bay, Office of Senator Moseley-Braun
Scott Palmer, Office of Congressman Hastert
Raymond L. Hansen, DuPage County State's Atty. Office
Rich Allen, IDNS
Bill Seith, IAG
Douglas Rathe, IAG
Chuck Grigalauski, IEPA
Jodi Traub, U.S. EPA, OSF
David Seely, U.S. EPA, OSF
Mary J. Canavan, U.S. EPA-Congressional
Ken Westlake, U.S. EPA-RA Office
Mary Murphy, U.S. EPA, OSF
Ken Tindall, U.S. EPA, OSF
Rebecca Frey, U.S. EPA, OSF
Jack Barnett, U.S. EPA, OSF
Debra Klassman, U.S. EPA, OSF
Gail Ginsberg, U.S. EPA, OSF

GENERAL DISCUSSION

On February 17, 1995 the West Chicago Intergovernmental Forum (Forum) held its monthly meeting to discuss the status of the Kerr-McGee Superfund Sites cleanup. Jodi Traub opened the meeting by explaining a number of organizational changes which the Office of Superfund (OSF) is undergoing. The OSF has removed the Branch Chiefs over remedial response programs. OSF management hopes that this change will not only remove a layer but bring the Associate Division Director closer to individuals in the organization. Because OSF hopes to make optimum use of its staff, the Sections will no longer be divided geographically.

Three new Process Manager positions have recently been filled within OSF. These Managers are charged will moving the remedial process forward, and determining and eliminating roadblocks in the Superfund process. Wendy Carney is new Process Manager over the Remedial Investigation/Feasibility (RI/FS) through the Record of Decision (ROD) process. James Mayka is responsible for the ROD/ Remedial Design (RD)/Remedial Action (RA) through Operation & Maintenance (O&M) process. Tinka Hyde is the Process Manager over the Enforcement process. Jodi Traub also explained that

since Ken Tindall is Section Chief for the Federal Facilities Section, the Kerr-McGee sites would be removed from his Section. Margaret Guerriero is the new Section Chief with the responsibility for the Kerr-McGee sites.

SUMMARY OF EPA'S DISCUSSION WITH DOJ/EXPEDITED CLEANUP AT RKP, STP, AND KRESS CREEK

EPA's overall impression of the January 25, 1995 meeting with DOJ was very positive. DOJ agreed with EPA's overall enforcement approach on the other three Kerr-McGee sites. Technical/enforcement issues were discussed during the meeting. EPA feels that DOJ understands the need to move forward on a expedited basis.

Based on our review of the site information currently available and the draft schedules the Remedial Project Managers have developed, EPA believes that 2 (RKP and STP) of the 3 sites can be cleaned-up by the 1998 deadline. EPA currently does not feel confident that the 3rd site (Kress Creek) will meet the 1998 deadline, even with an expedited schedule, because EPA does not have enough data to make this decision. Cleanup standards for contaminated sediments at the site are presently an unknown. Although Kress Creek samples have been collected EPA hasn't received all of the analytical results from NAREL. Cleanup standards may depend heavily on risk assessment calculations and contaminant transport modeling.

During the course of this discussion a number of comments were made by Forum members. Joe Karaganis stressed the need to integrate activities with the City, U.S. Congressional representatives and State representatives and EPA when talking with Kerr-McGee. Scott Palmer stated that NAREL had failed to even respond to the December 1994 Congressional letter requesting that samples relating to the Kerr-McGee Residential Areas Site be expedited. Scott Palmer indicated that he thinks that NAREL is giving us the same excuses for its lack of performance that it has given in the past.

At this point, David Seely described some recent problems identified by NAREL in the analyses of the Kerr-McGee samples for Ra-226 and Ra-228. David Seely explained that NAREL identified that the Ra-226 analytical schedule incurred delays resulting from a NAREL requirement to re-calibrate their Ra-226 instruments every six months to ensure the quality of their data. This process takes about a month from start to finish for all of their Ra-226 instruments. Additionally, NAREL identified that the detectors for Ra-228 have experienced corrosion for a second time. The actual corrosion problems are with a goldplated screen inside the detectors . NAREL had not yet identified the reason for the corrosion and are investigating the problem fully.

Currently, NAREL theorizes that the problem may be related to a humidity problem in the lab and will take steps to minimize this problem in the future. In addition, NAREL has ordered replacement screens for all of the affected detectors and are awaiting delivery. NAREL anticipates receiving the screens shortly and expect to have them installed by the end of the month. Once the Ra-226 re-calibration effort is completed and the replacement Ra-228 screens are received/installed and the detectors are brought back on-line, NAREL will be able to determine the overall effect on the delivery schedules for Ra-226 and Ra-228.

David Seely explained that the effects of the recent NAREL delays on the overall analytical schedule is not currently known. However, after preliminary discussions it appears that the recent delays would mean an approximately one-month delay in receiving the radium data but that the uranium and thorium data will remain on schedule. NAREL is currently developing detailed delivery schedules for the results of all of the analyses for each Kerr-McGee site. The uranium and thorium schedules are expected next week. The Ra-226 and Ra-228 schedules will be developed after the re-calibration effort is completed and the detector problems are corrected. These schedules are currently expected by early March.

David Seely and Jack Barnett discussed the fact that the data quality is excellent and that NAREL has indeed made the processing of the Kerr-McGee samples a high priority. Five staff members from NAREL have been assigned to this project (two FTEs are funded by Region V). David Seely, Jack Barnett and Larry Jensen intend to visit the lab on February 21 to investigate the exact nature of the delays and what the Region can do to remove roadblocks, i.e., equipment, FTEs, etc. In answer to a comment from Scott Palmer about the possibility of using an outside lab instead of NAREL, Jodi Traub responded that this would cause major delays and raise a number of QA problems. Rebecca Frey stated that because of the high risk of litigation, the high quality data generated by NAREL will be critical to the Federal case.

Scott Palmer was very concerned about the delays and what they might mean to the April removal schedule for the Residential Areas Site. He asked that EPA keep him abreast of schedules, and provide him with updates rather than waiting till the next Forum meeting. David Seely mentioned that the unvalidated data is in for RKP. Following validation of the data, EPA should be able to sit down with CH2M Hill the latter part of March and go over the schedule for RKP.

Scott Palmer strongly encouraged EPA to talk with Kerr-McGee now about cleaning up the other 3 sites, keeping in mind the company's good faith interest in cleaning up all the sites by

1998. EPA agreed that we have nothing to lose by having a meeting with Kerr-McGee and agreed to pursue such a meeting at the appropriate time.

Richard Allen brought up the fact that it is important that Kerr-McGee understand the IDNS and NAREL processes. IDNS has had a number of discussions with Kerr-McGee to ensure that they understand the IDNS lab procedures, hopefully avoiding a challenge.

STATUS OF SCHEDULE AT RESIDENTIAL AREAS REMOVAL SITE

Rebecca Frey outlined for the Forum the Residential Areas Removal Site schedule to date. EPA received Kerr-McGee's draft Work Plan on December 30, 1994. Comments on the draft Work Plan were forwarded by EPA to Kerr-McGee on February 6, 1995. The UAO gave Kerr-McGee only 2 weeks to revise the documents. Kerr-McGee asked for a 1 week extension which EPA granted. The revised Work Plan is due to EPA by February 28, 1995. Kerr-McGee has solicited construction contract bids to 9 firms with 8 firms attending a pre-bid meeting at the REF. Assuming the revised Work Plan is approvable, a final Work Plan could be approved by mid-March. The April removal schedule could be impacted if the revised Work Plan is not approvable.

The City has met with Kerr-McGee to discuss what type of city permits would be required of Kerr-McGee during the residential cleanup. Erosion, stormwater drainage, and restoration of property were among some of issues discussed between Kerr-McGee and the City. Joe Karaganis stressed the importance of close coordination with the City's Public Works Department, Kerr-McGee and EPA/contractor. The City asked that EPA provide a contact for these discussions. Jack Barnett said that we might want to look at a couple of successful models of City/Federal coordination in the Region, i.e., Rockford, IL. and Elkart, IN.

The IAG asked if there were any substantive disputes with Kerr-McGee that might delay the schedule. EPA's response was that at the present time it appears that Kerr-McGee will make all the required changes to the Work Plan (even if they disagree with some of the changes) because otherwise they would be in violation of the UAO. Scott Palmer asked that if any delays and/or disputes arise that could impact the April schedule that he be notified so that he can intervene/facilitate a consensus or remove any stumbling blocks.

EPA is responsible for providing Kerr-McGee with information on the properties needing excavation work so they can put together individual work orders for the properties to enable the work to start in April. Rebecca Frey mentioned that she will be meeting with Kerr-McGee, IDNS and CH2M Hill during the week of March 6 to discuss the decision rules which establish field correlations

between soil concentrations and gamma readings (counts per minute) and the background data from uncontaminated properties. Once background and the decision rules correlations are finalized by EPA, EPA will be able to generate cleanup maps for Kerr-McGee. The gamma information allows for expedited activity during cleanup. Upon finalizing the decision rules document, CH2M Hill can provide property specific maps. Following the meeting with Kerr-McGee and IDNS, EPA will schedule a meeting with the City and TAG, to present the same information.

TAG members questioned why different cleanup levels might be used for the residential areas versus Reed-Keppler Park. David Seely responded that cleanup levels are determined based on exposure scenarios. TAG members stated that they want the Residential Areas cleanup levels used at Reed- Keppler Park. David Seely responded that EPA will consider the public's concerns, but it will need to calculate exposure and risks with appropriate site-specific assumptions made. TAG thinks that the decision rules developed for the Residential Areas Site should be used for the other three sites. Scott Palmer asked that EPA explore this possibility with Kerr-McGee. Jodi Traub stated that EPA will consider the public's concerns and future land use.

Joe Karaganis said that EPA's comments on Kerr-McGee's draft Work Plan reflected many of the City's concerns but that it is still unclear whether EPA will ensure ALARA during removal. Rebecca Frey stated that we cannot force Kerr-McGee to go beyond the established Cleanup Criteria. IDNS mentioned that digging up additional dirt costs more and requires additional time waiting at the excavation. IDNS stated that it expected that Kerr-McGee would remove additional soil if their field measurements indicate that they were very close to meeting the standards. EPA feels that Kerr-McGee will take professional pride when they do their verification, and they won't request a formal verification survey from EPA/IDNS until they are comfortable that they have met the cleanup standards.

Scott Palmer wants the political entities to discuss and put in writing what their expectations are regarding ALARA as a practical matter, and to investigate what incentive Kerr-McGee could be offered to cleanup to background levels. Scott Palmer added that the Forum needs to go beyond legal standards to get Kerr-McGee to agree to go to background whenever possible. Rebecca Frey stated that background numbers would be available by March 6, 1995.

Rebecca Frey reported to the Forum that another round of access letters was sent to West Chicago residents in February. Letters were sent to residents who had previously given us only outside access, and property owners EPA hadn't contacted previously. In addition, certified return receipt letters were sent to nonrespondents from previous mailings. EPA also sent Spanish

language letters to all residents with Spanish surnames. CH2M Hill has a Spanish-speaking employee available to assist with setting up appointments for indoor scans and notification of soil sampling. Indoor gamma scans are currently being conducted at West Chicago properties. A letter is being prepared by EPA which will provide property owners with their results. Scott Palmer sees two impediments to the mid-April removal schedule. The first impediment being the need to resolve the decision rules/correlation and the second being the need to properly notify the community before work starts. Rebecca Frey stated that on February 21 she will get a prototype of CH2M Hill's results, and will then work on drafting the letter to residents. EPA again stated that it would work with TAG to make sure the information provided to property owners is understandable. Jodi Traub also mentioned that EPA is considering availability sessions after we send the results to the residents. TAG indicated its willingness to participate in such sessions. TAG also suggested printing a sample of the letter in the local newspaper.

UPDATE ON THE SCHEDULE FOR THE 15 SAMPLES FROM THE RESIDENTIAL AREAS/SECULAR EQUILIBRIUM

Rebecca Frey stated that as of our last Forum meeting (January 20, 1995) EPA believed the schedule for receiving the data from NAREL to be on target. A few days after the Forum, EPA was informed by NAREL that there were delays affecting the radium tests. Uranium and thorium are still on target. EPA reported that a preliminary review of the unvalidated uranium and thorium data shows that the thorium decay chain is in equilibrium. The preliminary review of the uranium shows that it is not totally in equilibrium, but EPA does not believe the levels to be of concern. The City expressed some concerns that it did not feel that the 15 samples were representative of all the wastes from the REF. Scott Palmer asked what regulatory power EPA had over uranium. Rich Allen mentioned that neither the State nor Federal government have regulatory standards for uranium (standards are in terms of radium) but the waste we are dealing with in West Chicago is all 11(e)(2) by-product material. Kerr-McGee has acknowledged that uranium needs to be examined separately at the factory site. By way of giving further assurances to the residents, Rebecca Frey offered the possibility of taking some extra samples at approximately 10% of the sites (just before backfilling with clean soil) and sample them for uranium. EPA also reminded the Forum that the data from the other 3 Kerr-McGee sites will also provide an excellent information source for what wastes may have left the REF. EPA also mentioned that the technical meeting with the City (mid-March) will hopefully resolve the issue of secular equilibrium. The City mentioned that they are looking for solutions too and would have its consultant available for these discussions.

UPDATE OF THE SCHEDULE FOR NAREL SAMPLE ANALYSIS

SEE PREVIOUS DISCUSSION UNDER **EXPEDITED CLEANUP AT RKP, STP AND KRESS CREEK.**

UPDATE ON SCANNER VAN

Since the last Forum EPA staff have had funding discussions with the Las Vegas lab. Rebecca Frey feels that in order to keep the focus on the April removal, she does not want to proceed with the Scanner Van surveys until June or July. If we wait until summer we will also have longer daylight hours and less down time due to rain. The Las Vegas lab has indicated that its personnel will be willing to work 10 hour days. EPA is outlining the Scanner Van study area in order to determine the total area the Scanner Van will need to cover. Region V will be forwarding this information to the Las Vegas lab shortly so it can access the amount of time needed for the project. EPA will develop a fact sheet on the Scanner Van and prepare a community outreach/education session prior to sending the Scanner Van out to the neighborhoods.

JANUARY ACTION ITEMS

* EPA (David Seely) provided electronic data to the City and IDNS.

* EPA is prepared to schedule a meeting between the Regional Administrator and Congressional entities in March to discuss how EPA plans to achieve 1998 cleanup for the other 3 Kerr-McGee sites. EPA (Mary Canavan) will coordinate with the parties involved.

CITY STREET CONSTRUCTION

Don Foster informed the Forum that the City has applied for block grants for limited street restoration. The City would like EPA to get Kerr-McGee to remove contamination from parkways, and under some streets. Rebecca Frey will request CH2M Hill to collect data from the 2 streets early in the Spring survey season. EPA will determine if the existing street materials are contaminated. If contamination is found EPA will direct Kerr-McGee to remove the contamination.

The following list of action items were identified for the next Intergovernmental Forum:

1. EPA (David Seely and Larry Jensen) will report to the Forum

on the status of the NAREL delays.

2. **EPA** needs to provide Congressman Dennis Hastert (Scott Palmer) with regular updates on the removal schedules and any potential delays. Scott Palmer would like to be kept informed of any disputes arising among the parties that could impact the April removal schedules.

3. **EPA** (Rebecca Frey and Larry Jensen) will meet with Kerr-McGee and **IDNS** the week of March 6, 1995 to discuss the decision rules/correlations developed for the Residential Areas Removal Site. Following that meeting, **EPA** will schedule a technical meeting with the City and TAG to explain the decision rules.

4. **EPA** (Rebecca Frey) will direct CH2M Hill to collect data from the two streets identified by the City. **EPA** will determine if there is any contamination prior to street restoration.

The next West Chicago Intergovernmental Forum is scheduled for 10:00 am on March 24, 1995. It will be held in the Lake Superior Room on the 12th floor of the Metcalfe Building.

WEST CHICAGO INTERGOVERNMENTAL FORUM

FEBRUARY 17, 1995

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David Thomas	W.C. Park District	708 231-9474
Jodi Traub	USEPA/OSF	(312) 886-0537
Raymond L. Hansen	DuPage County State's Atty. Office	(708) 682-6456
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Jacie Barnette	Radiation U.S. EPA	(312) 886-6175
KEN WESTLAKE	USEPA, OFC OF RA	312-353-1327
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MARK J. CANAVAN	USEPA CONGRESSIONAL	(312) 353-3016
Richard Allen	IL Dept Nuc. Saf.	(217) 782-1322
Chuck Grigalauski	Illinois EPA	(708) 338-7933
Ken Tindall	U.S. EPA	(312) 886-9895
Debra Klassman	US EPA/ORC	312/886-6742
Becky Frey	U.S. EPA/OSF	312-886-4760
DAVID SEELY	U.S. EPA/OSF	312-886-7058
Douglas Bruce	U.S. EPA Office	312 814-5084

AGENDA

WEST CHICAGO INTERGOVERNMENTAL FORUM

February 17, 1995, 10:00 am
RA's Conference Room

Opening Remarks Management Transitions	J. Traub
DOJ Response to EPA's Proposed Strategy to Expedite Cleanup at RKP, STP and Kress Creek	J. Traub
Status of Schedule at Residential Areas Removal Site	R. Frey
Update on the Schedule for NAREL Sample Analysis -RKP, STP and Kress Creek Samples	D. Seely
Update on the Schedule for the 15 Samples from the Residential Areas	R. Frey
NAREL Analytical Results to Date from RKP, STP, and Kress Creek Sites	D. Seely
Update on Scanner Van	R. Frey
Review of the 1/20/95 Action Items and General Discussion	Forum
Other Issues -City Street Construction	City

EPA 520/4/82/013-1
October 1982

Final
Environmental Impact Statement
for
Remedial Action Standards
for
Inactive Uranium Processing Sites
(40 CFR 192)

Volume I

Office of Radiation Programs
Environmental Protection Agency
Washington D.C. 20460

cleanup costs, and health benefits. For B3 and B4, which include a range over which remedial action is optional, the cost estimates were derived by assuming a value within the range which would typically be achieved and costing controls to reach this level. For B3, we assumed that at least 0.015 WL (including background) would be achieved. For B4, we assumed that at least 0.03 WL would be achieved.

The extent of contamination of buildings as well as the cleanup costs will not be known in detail until the cleanup program is well underway. Therefore, we used the Grand Junction remedial action program as the basis for our estimates. Appendix B contains a summary of the Grand Junction experience and the cost calculations which support the estimates in Table 7-1.

The cost estimates for each alternative standard are determined by the number of buildings requiring remedial work and the cost per building. As the remedial action criterion is lowered, more buildings will need to be cleaned up, increasing costs. A lower criterion also increases the cleanup costs per building since this requires more complete tailings removal. In many cases, successive actions are needed when the first remedial action does not meet the cleanup criterion. Using active measures to meet a cleanup criterion when the level is only slightly exceeded is much cheaper than tailings removal, roughly one-tenth as costly.

The benefit of cleaning up contaminated buildings is expresed by the number of lung cancer deaths avoided. This is estimated by assuming the risk factors discussed in Chapter 4 are appropriate, an initial distribution of decay product levels in contaminated buildings identical to that for the buildings monitored in Grand Junction, a 50-year average useful life remaining for the stock of contaminated buildings, and a 3-person household size. Also, benefits of cleanup are expressed by the maximum residual risks to people living in the buildings. This risk to an individual is calculated assuming lifetime exposure to radon decay products at the highest level each alternative standard allows.

7.2 Alternative Cleanup Standards for Near-site Contaminated Land

We have analyzed four alternative cleanup standards for near-site (on the site or adjacent to the site) contaminated lands. All have requirements that limit the amount of radium contamination because the presence of radium is a reasonable index of the health hazard, including that due to toxic chemicals as well as other radionuclides.

Alternative L1 approaches a high-cost nondegradation alternative; below this proposed radium limit it is usually not possible, using conventional survey equipment, to accurately distinguish between contaminated land and land with high naturally-occuring levels of radium. Alternatives L2 and L3 approximate optimized cost-benefit standards, but L2 demands a more rigorous cleanup of the soil

TABLE 7-1. COSTS AND BENEFITS OF ALTERNATIVE CLEANUP STANDARDS FOR BUILDINGS
(in 1981 dollars)

Alternative Standards	Radon Decay Product Limit (WL)[a]	Number of Buildings Requiring Cleanup[b]	Total Cost (millions of dollars)	Deaths Avoided (in first 50y)[c]	Estimated Residual Risk of Lung Cancer[d]
B1	0.015	370	11.5	65	0.8 in 100
B2	0.02	330	8.5	60	1.3 in 100
B3	0.005 (above background) to 0.02	420	9.0	65	1.3 in 100
B4	0.01 (above background) to 0.05 (above background)	350	9.5	55	5 in 100

[a] The specified value includes background unless otherwise noted. Background in Grand Junction is approximately 0.007 WL.

[b] See Section 3.4. For Alternative B4, which is identical to the Grand Junction criteria for action, we assumed the geometric mean of our two extreme estimates for the number of buildings requiring remedial action. Assuming the distribution of radon decay product levels will be the same as in Grand Junction, the number of buildings in the United States requiring action was adjusted for the other options.

[c] Based upon the relative risk model. Estimates based upon the absolute risk model are a factor of two lower. Health benefits attributable to reductions in gamma radiation levels are much smaller and have not been quantified.

[d] Lifetime risk to the individual living in a house at the radon decay product concentration limit. This risk is calculated after subtracting background from the level permitted by the standard.

surface. Standard L4 is a least-cost alternative that allows high radiation levels that are close to Federal Guidance recommendations for exposure of individuals to all sources of radiation excepting natural background and medical uses.

The four alternative standards are:

Standard L1. (The standard proposed in April 1980). Land should be cleaned up to levels not exceeding an average 5 pCi/g of radium-226 in any 5-cm layer within 1 foot of the surface and in any 15-cm layer below 1 foot of the surface.

Standard L2. Land should be cleaned up to levels not exceeding an average of 5 pCi/g in the 15-cm surface layer of soil, and an average of 15 pCi/g over any 15-cm depth for buried contaminated materials.

Standard L3. Land should be cleaned up to levels not exceeding an average of 15 pCi/g in any 15-cm depth of soil.

Standard L4. Land should be cleaned up to levels not exceeding an average of 30 pCi/g in any 15-cm depth of soil.

In Table 7-2 we list the estimates of the costs and benefits of each alternative standard for near-site contamination around inactive tailing piles. In each standard, the only remedial method for which we estimated cost was the removal and disposal of contaminated soil, since this is generally less costly than placing earth cover and vegetation over contaminated areas and excluding access by fencing. The benefits are expressed by (1) the number of acres of land that are cleaned up and returned to productive use, and (2) the typical maximum residual risk to individuals living in houses that might then be built on this land.

The number of acres requiring cleanup under each option was based upon the results of the EPA gamma radiation survey of twenty inactive mill sites (Table 3-4). By assuming a typical depth profile of the radium contamination, it is possible to relate the gamma radiation levels measured by the survey to the areas of land contaminated above a specific concentration level of radium. If the top 15-cm layer of earth is uniformly contaminated with 30 pCi/g of radium, the gamma field at the surface would be 63 percent of the gamma flux from an infinitely thick layer, or 34 microroentgens/hr (He78). However, if the 30-pCi/g average in the top 15 cm of earth is due to a thin surface layer of nearly pure tailings of a few hundred pCi/g, the resulting gamma radiation at the surface would be about 54 microroentgens/hr. Since we expect windblown contamination profiles to be somewhere in between these extremes, we estimate that, on the average, 44 microroentgens/hr above background (385 mrem/y) implies 30 pCi/g radium contamination in the top 15 cm of soil (Standard L4). Similar analyses for Alternative Standards L1, L2, and L3 result in 3. 7 and

TABLE 7-2. COSTS AND BENEFITS OF ALTERNATIVE CLEANUP STANDARDS FOR LAND
(in 1981 dollars)

Alternative	Radium-226 Soil Concentration Limit (pCi/g)	Number of Acres Requiring Cleanup[a]	Total Cost (millions of) dollars)	Estimated Residual risk of Lung Cancer[b]
L1	5	2700	21	2 in 100
L2	5 to 15	1900	14	2 in 100
L3	15	900	7	6 in 100
L4	30	250	2	10 in 100

[a] Areas of land near inactive tailings piles that have radium contamination in excess of the soil concentration limit.

[b] The lifetime risk of lung cancer to the individual living in a house built on land contaminated to the limits allowed by the alternative standards. This is based on the relative-risk model; use of the absolute-risk model gives risks which are about a factor of two lower.

22 microroentgens/hr, respectively (or 26, 61, and 193 mrem/y, respectively). Additional deeper contamination would yield only slightly higher gamma values because of shielding by the surface layer.

Using these correlations between radium contamination levels and gamma radiation levels, the areas requiring cleanup under each standard were estimated based on the EPA survey data. The total costs of cleanup were then calculated assuming a cleanup cost of $7650 (1981 dollars) per acre. This cost was estimated from EPA field experience (a cleanup program at the Shiprock mill site) and is in agreement with cost estimates of DOE contractors. Areas of heaviest contamination, such as the ore storage area and mill buildings, are excluded from this analysis since we have included them in the analysis of disposal costs for the piles.

The highest risk to people living in houses built upon contaminated land is due to the inhalation of radon decay products from radon that seeps into the house. In the worst case, Standards L1 and L2 would allow thick-surface earth layers with 5 pCi/g contamination, while Standards L3 and L4 would allow thick layers of contaminated soil at 15 pCi/g and 30 pCi/g, respectively. On the average, houses built on such 5 pCi/g earth would be expected to have indoor radon decay product levels of about 0.02 WL. Houses with poorer-than-average ventilation would have higher levels, while well-ventilated houses would have lower levels. Houses built on land more heavily contaminated than 5 pCi/g would have higher average indoor decay product levels in proportion to the contamination. The estimated risks due to lifetime exposure from these levels are listed in Table 7-2. These are maximum estimates since most contaminated land away from the immediate mill sites (where houses might be built) has only thin layers (a few tens of centimeters) of contaminated material.

The gamma radiation levels to individuals permitted under the four alternative standards are 80 mrem/yr for L1 and L2, 240 mrem/yr for L3, and 470 mrem/yr for L4. This assumes a thick layer of contaminated material over a large area at the maximum permitted levels of radium concentrations. These doses would lead to increased risk of many kinds of cancer, but this increase would be small compared to the lung cancer risks due to radon decay products.

7.3 Alternative Cleanup Standards for Offsite Properties

Tailings on offsite properties which are not associated with building construction are usually there because someone transported them from a tailings pile. Examples of this kind of misuse are tailings used as fill around fence posts and sewer lines, as the basis for sidewalks and driveways, and as conditioners for soil in gardens. Most tailings misused in this way are still concentrated; they are not diluted by large quantities of earth or spread thinly over large areas.

The major hazard stems from the chance that indoor radon levels will be high in new buildings constructed on contaminated offsite properties. There could also be a significant gamma radiation hazard if people spend a lot of time close to the tailings.

We expect that offsite properties where tailings were misused will typically exceed all the radium concentration limits specified for land contamination in Alternative Standards L1 through L4. Therefore, virtually all of the 6500 contaminated sites identified in Chapter 3 would require cleanup under any standard. Based on engineering assessments and similar cleanup work near a mill site in Edgemont, South Dakota, we estimate it would cost $6,000 to clean up each of these properties. This implies a total cleanup cost of $39 million. However, many of these sites are unlikely to cause a significant present or future hazard, either because of their location or because the quantity of tailings involved is so small. Cleaning up such sites implies high cost without significant benefits.

It is consistent and simple to use the same numerical cleanup criteria for offsite contamination of properties as for near-site land contamination. Since some offsite contaminated properties present a minimal hazard and would cost a great deal to clean up to any reasonable radium concentration criterion, additional criteria are considered in one of the following alternative standards for contaminated offsite properties:

Standard P1: Offsite properties should be cleaned up to the same levels as near-site land,[1] with no exceptions.

Standard P2: Offsite properties should be cleaned up to the same levels as near-site land, with the following exceptions:

a. When contamination levels averaged over 100 m^2 are less than the action levels required for near-site lands.
b. When the hazard from the tailings is judged to be insignificant because of location.

Small amounts of tailings will be eliminated from consideration if levels are averaged over an appropriate area. For Standard P2 we have selected 100 m^2 as a reasonable area for this purpose since this is the typical area of the foundation of a House. Thus, risk levels allowed under Standard P2 should be no higher than the risks allowed under the corresponding near-site land cleanup standard. Additional sites will be eliminated under Standard P2 because of their location.

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[1] Alternative Standards L1, L2, L3, or L4; whichever is selected as a land cleanup standard.

Based on an analysis of misused tailings that are not associated with buildings (Section 3.4), we estimate that, because of location or small quantity, Standard P2 would not require the cleanup of minor locations such as under sidewalks or around fence posts. Also, we estimate that half of the garden beds, yards, and detached buildings in which tailings were used and one-fourth of all driveways with tailings under them would not require cleanup. This would eliminate approximately 4,000 sites and save about $24 million, for a total cost of about $15 million.

EPA 520/1-83-008-1

Final
Environmental Impact Statement
for
Standards for the Control
of
Byproduct Materials from
Uranium Ore Processing
(40 CFR 192)

Volume I

September 1983

Office of Radiation Programs
U.S. Environmental Protection Agency
Washington, D.C. 20460

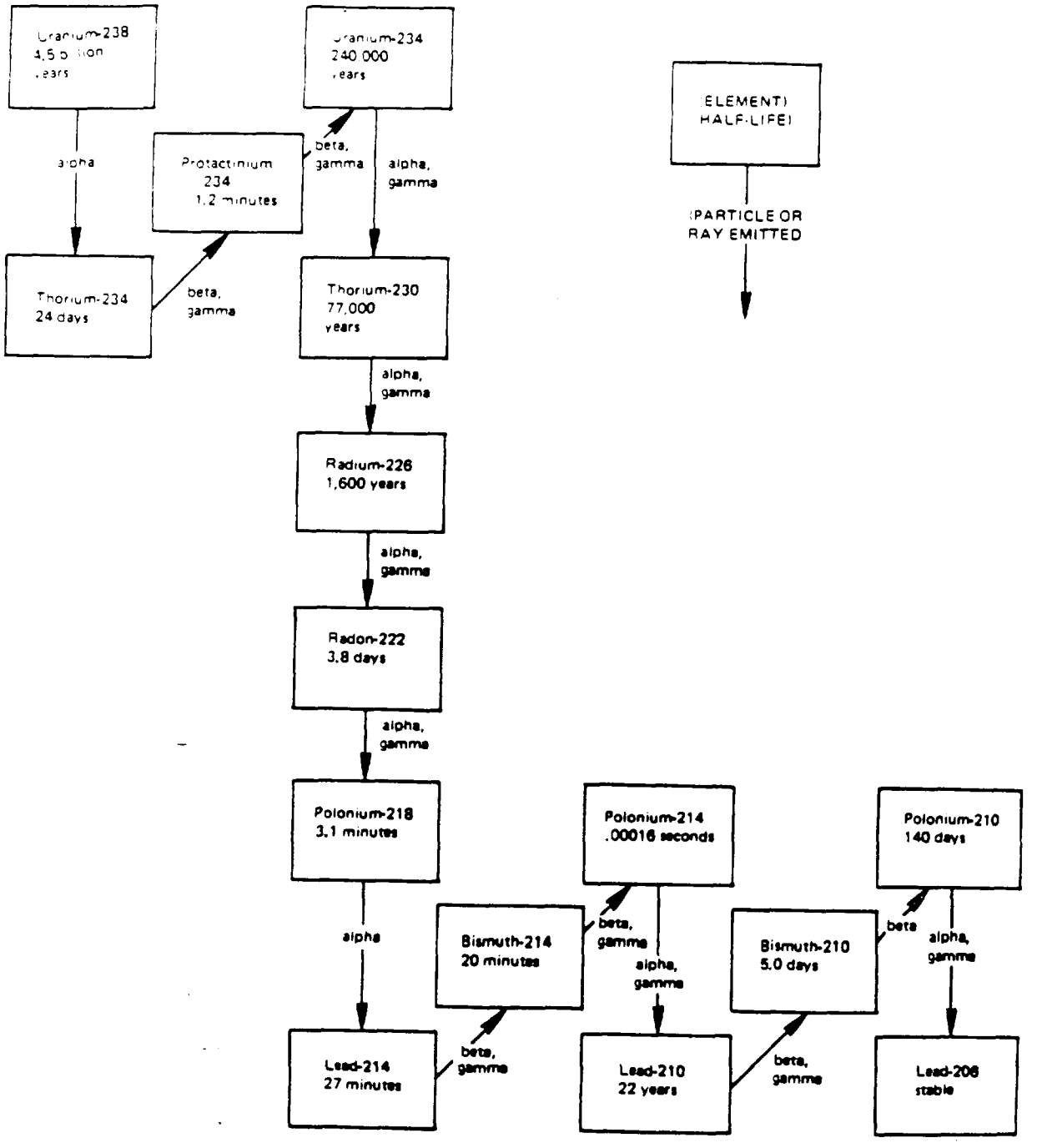

Figure 3-1. The Uranium-238 Decay Series.

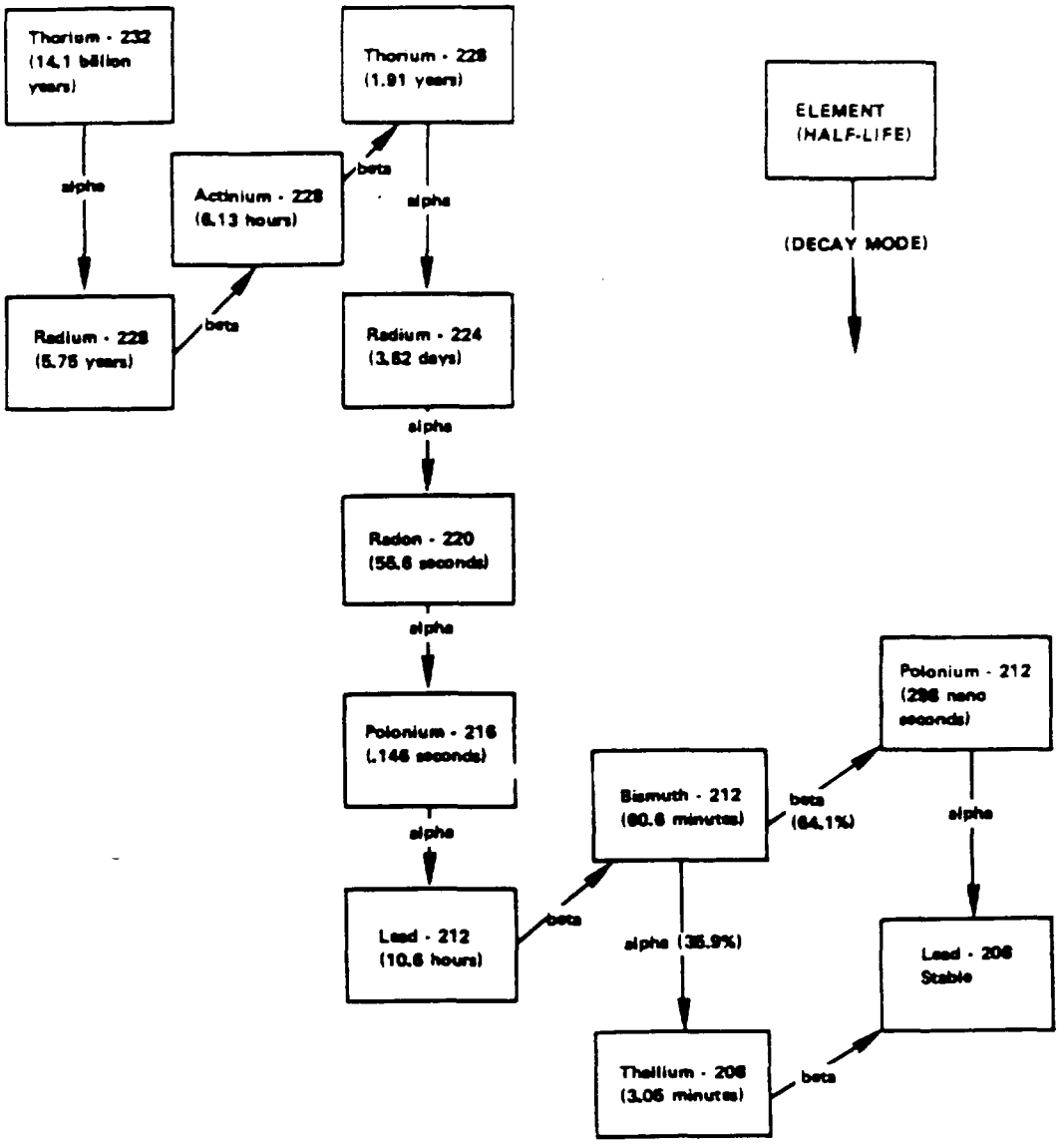

Figure G-1. Thorium-232 Decay Series.

U.S. NUCLEAR REGULATORY COMMISSION July 1993

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 8.37
(Draft issued as DG-8013)

ALARA LEVELS FOR EFFLUENTS FROM MATERIALS FACILITIES

A. INTRODUCTION

In 10 CFR Part 20, "Standards for Protection Against Radiation," § 20.1302(b) requires that:

> "A licensee shall show compliance with the annual dose limit in § 20.1301 by (1) Demonstrating by measurement or calculation that the total effective dose equivalent to the individual likely to receive the highest dose from the licensed operation does not exceed the annual dose limit; or (2) Demonstrating that (i) The annual average concentrations of radioactive material released in gaseous and liquid effluents at the boundary of the unrestricted area do not exceed the values specified in Table 2 of Appendix B to §§ 20.1001—20.2401; and (ii) If an individual were continually present in an unrestricted area, the dose from external sources would not exceed 0.002 rem (0.02 mSv) in an hour and 0.05 rem (0.5 mSv) in a year."

In addition, 10 CFR 20.1101(b) requires that:

> "The licensee shall use, to the extent practicable, procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (ALARA)."

This regulatory guide provides guidance on designing an acceptable program for establishing and maintaining ALARA levels for gaseous and liquid effluents at materials facilities. Materials facilities are those facilities at which the possession or use of source, byproduct, or special nuclear material is licensed under 10 CFR Parts 30, 40, 60, 61, and 70.

Additional guidance on ALARA programs can be found in other regulatory guides. While these guides deal primarily with occupational exposure and may be specific to one type of licensee, they contain programmatic information that may be useful to all licensees. They are as follows:

- Regulatory Guide 8.10, "Operating Philosophy for Maintaining Occupational Radiation Exposures As Low As Is Reasonably Achievable." This guide delineates the components of an ALARA program.
- Regulatory Guide 8.18, "Information Relevant to Ensuring that Occupational Radiation Exposures at Medical Institutions Will Be As Low As Reasonably Achievable."
- Regulatory Guide 8.31, "Information Relevant to Ensuring that Occupational Radiation Exposures at Uranium Mills Will Be As Low As Is Reasonably Achievable."

- Regulatory Guide 10.8, "Guide for the Preparation of Applications for Medical Use Programs." Section 1.3 and Appendix G deal specifically with ALARA programs for medical facilities.

In addition, further information can be found in Revision 1 to NUREG-0267,[1] "Principles and Practices for Keeping Occupational Radiation Exposures at Medical Institutions As Low As Reasonably Achievable" (October 1982).

Any information collection activities mentioned in this regulatory guide are contained as requirements in 10 CFR Part 20, which provides the regulatory basis for this guide. The information collection requirements in 10 CFR Part 20 have been approved by the Office of Management and Budget, Approval No. 3150-0014.

B. DISCUSSION

At the relatively low levels of radiation exposure in the United States, it is difficult to demonstrate a relation between exposure and any health effects. The dose limits in 10 CFR Part 20 are based on limiting dose to what is considered to be an acceptable level of risk to the exposed individual. Still, any radiation exposure may carry some risk. Thus, the NRC requires licensees to take actions, to the extent practicable, utilizing procedures and engineering controls to further reduce risk below the levels implicit in the dose limits in keeping with the principle that exposures should be as low as is reasonably achievable. This is the goal and purpose for radiation protection programs. In order to achieve this goal, licensees must control the way radioactive material is handled from receipt through disposal.

NRC licensees have traditionally reduced exposures and effluents to small fractions of the dose limits using the ALARA process. Recently, the Environmental Protection Agency (EPA) conducted 2 studies of materials facilities. The first was a survey of 367 randomly selected nuclear materials licensees. The highest estimated dose to a member of the public from effluents was 8 mrem/yr, based on very conservative modeling. In addition, 98% of the facilities examined had doses to members of the public resulting from effluents less than 1 mrem/yr. The second study evaluated effluents from 43 additional facilities that were selected because of their potential for effluent releases resulting in significant public exposures. Of these, none exceeded 10 mrem/yr to a member of the public, and 75% of them were less than 1 mrem/yr to a member of the public. Based upon this information, and the ongoing NRC program of licensing and inspection, the NRC expects that the goals suggested in this guide will be easily achievable by all NRC materials licensees.

The NRC staff will be examining licensee programs to determine compliance with the requirements of 10 CFR Part 20. In the event that a particular materials facility licensee establishes ALARA goals that are less stringent than the goals identified in this guide, or consistently fails to achieve ALARA goals it has established pursuant to this guide, the NRC staff will conduct a more detailed review of that licensee's program to determine the rationale for the greater levels. In such circumstances, the NRC will evaluate the rationale provided by the licensee, as well as the licensee's operations, to determine whether the licensee has established an adequate ALARA program and is operating that program in compliance with 10 CFR 20.1101(b).

This guide deals with only a part of a licensee's overall radiation protection program. Specifically, it deals with the application of ALARA in controlling gaseous and liquid effluents. In addition to controlling doses resulting from the release of effluents, licensees must implement a radiation protection program that controls dose rates in unrestricted areas to maintain overall doses to workers and members of the public ALARA and below the limits in 10 CFR Part 20. Licensees may choose to focus their evaluation of public dose to members of a critical group as suggested by the International Commission on Radiological Protection (ICRP) as a means of identifying and controlling the exposure to the individual member of the public likely to receive the highest exposure.

NRC licensees have taken actions to maintain doses to both workers and members of the public ALARA under the admonition contained in 10 CFR 20.1(c),[2] which requires that licensees "make every reasonable effort" to maintain doses and effluents ALARA. NRC licensees have generally reduced doses to relatively small fractions of the dose limits. Therefore, the NRC staff does not expect that most licensees will need to make significant changes to procedures, operations, and equipment in order to be in compliance with the requirements of 10 CFR 20.1101(b).[2] However, for those licensees who have not previously developed a radiation protection program that includes written procedures and policies as well as a commitment to ALARA, additional steps may be necessary to demonstrate compliance with requirements now explicit in 10 CFR Part 20 to maintain doses ALARA.

Components of an effective radiation protection program, as required by 10 CFR 20.1101(b), include radiation exposure control, written procedures and

[1] Copies are available for purchase from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082, telephone (202) 512-2249 or (202) 512-2171.

[2] In June 1991, 10 CFR Part 20 §§ 20.1001 through 20.2401 became effective, and compliance with these sections becomes mandatory on January 1, 1994. However, 10 CFR Part 20 §§ 20.1 through 20.601 became effective in 1957 and remains in effect until January 1, 1994, or when licensees voluntarily implement the requirements of 10 CFR Part 20 §§ 20.1001 through 20.2401, whichever is earlier.

policies, control of radioactive materials, radioactive contamination control, radioactive waste management, training, program reviews, and audits. Guidance on other facets of a radiation protection program for materials facilities is currently under development.

C. REGULATORY POSITION

An ALARA program for effluent control to control doses to members of the public should contain the following program elements:

1. Management commitment to ALARA, including goals,
2. Procedures, engineering controls, and process controls,
3. Surveys and effluent monitoring,
4. ALARA reviews,
5. Worker training.

These program elements, while given specifically for effluents in this guide, are also applicable to the control of direct exposure.

1. MANAGEMENT COMMITMENT TO ALARA, INCLUDING GOALS

The single most critical aspect of successfully achieving ALARA in the radiation safety program is the commitment of management to maintain doses ALARA, both occupational and to the public. The licensee's radiation protection program (including ALARA elements) should be commensurate with the potential hazards associated with the licensed activity.

1.1 ALARA Policy

The licensee should establish an ALARA policy that is issued and supported by the highest level of management. All employees should be made aware of the ALARA policy through training. This policy should make clear that all personnel will be responsible for ensuring that work they perform is in accordance with ALARA procedures.

1.2 ALARA Goals

To assist in demonstrating compliance with the requirements of 10 CFR Part 20, the licensee should set ALARA goals for effluents at a modest fraction of the values in Appendix B, Table 2, Columns 1 and 2, to §§ 20.1001—20.2401. These goals may be set independently for gaseous and liquid effluents. Past experience and effluent information reported to the NRC staff indicate that goals within a range of 10 to 20% of Appendix B values or less can be achieved by almost all materials facility licensees. However, establishing a goal is not intended as setting a precedent or a de facto limit. Goals may need to be adjusted up or down on the basis of the annual review of what may be ALARA for the particular circumstance.

If the licensee chooses to demonstrate compliance with 10 CFR 20.1301 through a calculation of the total effective dose equivalent (TEDE) to the individual likely to receive the highest dose, the licensee should set the ALARA goal at a modest fraction of the dose limit for members of the public. Experience indicates that values of about 0.1 mSv/yr (10 mrems/yr) or less should be practicable for almost all materials facility licensees. Licensees need not assume worst case models when calculating dose but rather should make assumptions that will result in realistic esumates of actual dose received by the member of the public likely to receive the highest dose.

If the circumstances of a particular case are such that the licensee cannot achieve effluent concentrations less than 20% of the Appendix B values or demonstrate by calculauon that the TEDE to the individual likely to receive the highest dose is less than 0.1 mSv/year (10 mrems/year), the ALARA philosophy continues to apply, and the licensee should demonstrate compliance with the requirements of 10 CFR 20.1101(b) by evaluating procedures, engineering controls, and process controls as described in Regulatory Position 2 below.

1.3 Investigation Levels

In addition to ALARA goals, the licensee should establish investigation levels at effluent values that are close to normal or anticipated release levels. If exceeded, an investigation should be initiated and corrective actions should be taken, as appropriate.

1.4 Radiation Safety Committee

For licensees that have a radiation safety committee, one responsibility of that committee should be to establish ALARA goals. The committee must meet at least annually to review the radiation protection program content. The committee should also review ALARA goals and discuss ways to further reduce doses if necessary. Goals may need to be adjusted on the basis of the committee's review. The committee should assess short-term and long-term performance in terms of achieving the ALARA goals. ALARA goals and the results of reviews should be reported at least annually to senior management with recommendations for changes in procedures or equipment needed to accomplish the requirements of the ALARA policy as appropriate.

For licensees with no radiation safety committee, the radiation safety officer should be responsible for setting, adjusting, and periodically reviewing the radiation protection program and the ALARA goals.

2. PROCEDURES, ENGINEERING CONTROLS, AND PROCESS CONTROLS

Licensees should consider available engineering options to control the release of effluents to the

environment. Examples of the available options include filtration, encapsulation, adsorption, containment, and the storage of liquids for decay. If further reductions in effluents are needed to achieve ALARA goals, the recycling of process fluids, leakage reduction, and modifications to facilities, operations, or procedures should be considered. These modifications should be implemented unless an analysis indicates that a substantial reduction in collective dose would not result or costs are considered unreasonable. A determination of reasonableness may be based on a qualitative analysis requiring the exercise of judgment and consideration of factors that may be difficult to quantify. These factors could include nonradiological social or environmental impacts, the availability and practicality of alternative technologies, and the potential for unnecessarily increasing occupational exposures.

Alternatively, reasonableness may be based on a quantitative cost/benefit analysis. Preparation of an ALARA cost/benefit analysis requires the use of a dollar value per unit dose averted. The NRC staff is conducting a review and analysis of various methodological approaches to setting dollar values, and the staff recognizes that varying degrees of justification exist for a wide range of dollar values. However, the value of $1000 per person-cSv (man-rem) is acceptable to the NRC staff and may be used pending completion of that reassessment.

3. SURVEYS AND EFFLUENT MONITORING

Licensees must perform surveys and monitoring sufficient to demonstrate compliance with the requirements of 10 CFR 20.1302. This includes the monitoring and surveys that may be necessary to determine whether radiation levels and effluents meet the licensee's established ALARA goals. These surveys should include air and liquid effluent monitoring, as appropriate, as well as surveys of dose rates in unrestricted areas.

If the licensee chooses to demonstrate compliance with dose limits to the member of the public likely to receive the highest dose by calculating the TEDE, all significant environmental pathways should be evaluated. Some of the equations included in Regulatory Guide 1.109, "Calculation of Annual Doses to Man From Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I," and Regulatory Guide 3.51, "Calculational Models For Estimating Radiation Doses to Man from Airborne Radioactive Materials Resulting from Uranium Milling Operations," may be useful in performing dose assessments. However, pending the anticipated revision of these regulatory guides, the dose conversion factors should be based on the methodology described in ICRP 30, "Limits for Intakes of Radionuclides by Workers."[3]

3.1 Airborne Radioactive Effluent Monitoring

When practicable, releases of airborne radioactive effluents should be from monitored release points (e.g., monitored stacks, discharges, vents) to ensure that the magnitude of such effluents is known with a sufficient degree of confidence to estimate public exposure. Licensees should verify the performance of effluent monitoring systems by regular calibration (at least annually) to ensure that these monitors provide reliable indications of actual effluents. Further guidance can be found in Regulatory Guide 4.15, "Quality Assurance for Radiological Monitoring Programs (Normal Operations)—Effluent Streams and the Environment."

Effluent monitoring systems should be designed in accordance with ANSI N13.1 (1969), "Guide to Sampling Airborne Radioactive Materials in Nuclear Facilities,"[4] and ANSI N42.18, "Specification and Performance of On-site Instrumentation for Continuously Monitoring Radioactive Effluents."[4]

NCRP Commentary No. 3, "Screening Techniques for Determining Compliance with Environmental Standards,"[5] published in January 1989 and the addendum published in October 1989 provide acceptable methods for calculating dose from airborne radioactive effluents. In addition, there are several computer codes available that perform these calculations. Licensees may use such computer codes as long as they can demonstrate that the code uses approved methods.

3.2 Liquid Effluent Monitoring

When practicable, releases of liquid radioactive effluents should be monitored.[6] Methods for calculating doses from liquid effluents similar to those described in NCRP Commentary No. 3 are currently under development by the NCRP. In the interim, guidance available in Regulatory Guide 4.14, "Radiological Effluent and Environmental Monitoring at Uranium Mills," and Regulatory Guide 4.16, "Monitoring and Reporting Radioactivity in Releases of Radioactive Materials in Liquid and Gaseous Effluents from Nuclear Fuel Processing and Fabrication Plants and

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[3]Copies are available from Pergamon Press, Inc., 660 White Plains Road, Tarrytown, NY 10591-5153, phone (914) 594-9200.

[4]Copies of ANSI standards may be obtained from the American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.

[5]Copies may be purchased from the National Council on Radiation Protection and Measurements, NCRP Publications, 7910 Woodmont Avenue, Bethesda, MD 20814.

[6]Liquid effluents do not include releases into sanitary sewerage in accordance with 10 CFR 20.2003(a) or excreta from patients in accordance with 10 CFR 20.2003(b).

Uranium Hexafluoride Production Plants," may be useful to materials licensees in calculating doses from liquid effluents.

3.3 Unmonitored Effluents

If a licensee has release points for which monitoring is not practicable, the licensee should estimate the magnitude of the unmonitored effluents. For instance, a research hospital or university broad scope licensee might have dozens of locations where radioactive material could be released. The licensee should estimate the magnitude of unmonitored releases and include those estimated amounts when demonstrating compliance with dose limits and the licensee's ALARA goals. Unmonitored releases may be estimated based on the quantity of material used in these areas or the number of procedures performed or other appropriate methods. When practicable, unmonitored effluents should not exceed 30% of the total estimated effluent releases.

4. ALARA REVIEWS

According to 10 CFR 20.1101(c), the content and implementation of the radiation protection programs, which would include the ALARA effluent control program, must be reviewed at least annually. This review should include analysis of trends in release concentrations and radionuclide usage as well as other available monitoring data. The review should provide a documented basis for determining whether changes are needed in systems or practices to achieve ALARA effluent goals. In addition, the licensee should review all designs for system installations or modifications to ensure compliance with 10 CFR 20.1101(b). The results of ALARA reviews should be reported to senior management along with recommendations for changes in facilities or procedures that are deemed necessary to achieve ALARA goals.

5. WORKER TRAINING

Specific training on ALARA should be provided as a part of the annual employee radiation protection training (see 10 CFR 19.12). For an ALARA program to be successful, employees must understand the ALARA program's goals and principles. The radiation protection staff should be available to help clarify the ALARA policy and its goals and to assist employees both during training and throughout the year.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this guide.

Except in those cases in which an applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the methods described in this guide will be used in the evaluation of applications for new licenses, license renewals, or license amendments and for evaluating compliance with 10 CFR 20.1001–20.2401.

REGULATORY ANALYSIS

A separate regulatory analysis was not prepared for this regulatory guide. The regulatory analysis prepared for 10 CFR Part 20, "Standards for Protection Against Radiation" (56 FR 23360), provides the regulatory basis for this guide. A copy of the "Regulatory Analysis for the Revision of 10 CFR Part 20" (PNL-6712, November 1983) is available for inspection and copying for a fee at the NRC Public Document Room, 2120 L Street NW., Washington, DC, as an enclosure to Part 20.

United States
Nuclear Regulatory Commission

Variability of Natural Background Radiation

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Advisory Committee on Reactor Safeguards

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TABLE OF CONTENTS

		PAGE
VARIABILITY OF NATURAL BACKGROUND RADIATION		1
I.	NATURAL BACKGROUND	1
	i Cosmic Rays	1-3
	ii External Terrestrial	3-6
	iii Internal	6-11
II.	CELEBRATED HOT SPOTS	11-14
III.	SOME LOCAL SURVEYS	15
	i EML Data	15-16
	ii NRC Survey of Nuclear Power Plant Sites	16-18
	iii The Los Alamos Survey	18-19
	iv Washington DC	19-20
	v Variability	20-21
IV.	OBSERVATIONS AND COMMENTS	21-25
V.	CONCLUSION	25-26
	Note Concerning Radiation Units	26-27
	Bibliographical Note	27-29

VARIABILITY OF NATURAL BACKGROUND RADIATION

The average annual exposure of persons in the United States to radiation from natural background sources is often said to be "about 100 millirem" whole-body dose equivalent. Though it is usually pointed out that actual exposures differ from one region of the country to another, and that the 100 mrem value is an estimate of a population-weighted average, many references include little to indicate the extent of the variations actually encountered. As a result, there is some room for the impression that this nominal 100 mrem is a sort of natural constant -- much like that of normal body temperature (37°C) -- and that any appreciable departure above this norm is associated with seriously undesirable consequences. In the present discussion it is intended, first, to describe the generally familiar range of natural background (particularly as experienced in the U.S.), and then to bring to attention some of the more fine-grained aspects of its variability. These naturally-occurring variations warrant consideration in assessing the significance of incremental perturbations of the radiation levels to which people may be exposed.

I. Natural Background

This consists of three major components: (i) Cosmic Rays, (ii) External Terrestrial, and (iii) Internal. These are described separately.

(i) Cosmic Rays

In the lower atmosphere (altitudes less than a few km) the radiation from this source is mostly provided by muons and high energy (very penetrating) electrons. There are other particles in the flux, including neutrons. The number of neutrons (at low altitudes) is small compared to the number of muons and electrons, but because of their large quality factor (Q) or relative biological effectiveness (RBE), which -- at least in UNSCEAR-1982 -- has been taken to be 10 for neutrons as compared with unity for muons or electrons, the neutrons contribute appreciably (about 10%) to the dose equivalent in tissue, even at sea level. This contribution increases with altitude, and at 3 km (9,850 ft) the neutron component contributes about 25% of the total biological dose. (More recently, the NCRP has decided that the value of Q for neutrons might lie between 5 and 20. The total level of the cosmic radiation (in rems) may, then, finally be rated somewhat differently than in some of the values used below.*)

At high altitudes (altitudes greater than about 10 km, which are accessible only to high-flying aircraft or space vehicles) there is a strong dependence of the cosmic ray flux (or dose) on the geomagnetic latitude -- the flux being many times larger at the magnetic pole than at the equator. However, on the inhabited portions of the earth's surface (altitudes less than ~5 km) the variation with geomagnetic latitude is much smaller; and for the continental U.S. (essentially all lying between 40° and 60° N geomagnetic latitude) the variation with latitude is only a percent or so. This will be ignored in the sequel.

*See Appended Note Concerning Radiation Units, (p. 26).

At any particular location on the surface of the continental U.S., the cosmic radiation may be considered as uniform in time. Though there are temporal variations associated with the 11-year sunspot cycle, with solar flares, and with changes in atmospheric pressure and temperature, these are either of limited extent (near the surface at U.S. latitudes) or are of short duration. They may consequently be incorporated in some average value, and will not be further considered.

The significant variation in cosmic ray exposure is the variation with altitude. This results from the difference in thickness of the atmospheric blanket. On this account the tissue dose equivalent from cosmic rays at altitudes of 1, 2, or 3 km above sea level are larger than the exposure at sea level by factors of about 1.35, 2.2, and 4.0, respectively. The average cosmic ray dose rate out-of-doors at sea level is 29 mrem/yr. Since people spend a considerable fraction of their time indoors, and since structures provide at least some shielding, it has been estimated that for the U.S. the average exposure received by the population is about 10% smaller than the exposure out-of-doors. The average exposure rate at sea level has thus been taken to be 26 mrem/yr. Taking into account the distribution in altitude of the U.S. population, the average dose equivalent rate from cosmic rays has been estimated to be 28 mrem/yr. This is the number included in the assessment that the average annual exposure in the U.S. is about 100 mrem/yr.

More than 80% of the U.S. population lives at altitudes less than 0.3 km (~1,000 ft), and for these the cosmic ray dose rate is within a mrem/yr, or so, of the countrywide average. About 10 million live at altitudes $\geq$ 1 km, where the cosmic ray dose rate (out-of-doors) exceeds 40 mrem/yr. More than five million live at altitudes > 1.3 km for whom the cosmic ray dose rate exceeds 45 mrem/yr. Cities included in this group are: Salt Lake City, Albuquerque, Reno, Colorado Springs, and Denver. (For Denver, altitude 1.6 km, population 1.5 million, the cosmic ray dose rate is 50 mrem/yr). More than 100,000 live in cities -- such as Durango, Gallup, Flagstaff, and Santa Fe -- at altitudes $\geq$ 2 km, for whom the out-of-doors cosmic ray dose exceeds 60 mrem/yr. There are many small settlements in the Rockies (e.g., Silverton, Colorado, 2.8 km) at altitudes of about 3 km. In particular, for Leadville, Colorado (altitude 3.1 km) and nearby Climax (altitude 3.4 km), in or near which a total of about 10,000 persons reside, the cosmic ray dose rate would be 120-150 mrem/yr (out-of-doors).

In this same general connection, outside the U.S. there are a number of cities with large populations at quite high altitudes. These are at lower geomagnetic latitudes than apply in the U.S. As a rough allowance, in designating cosmic ray dose rates for these cities, the doses from the detailed dose-altitude curve drawn for the U.S. have been reduced by the same fraction as the sea-level doses for the relevant geomagnetic latitude. The particular dose-altitude curve used is that presented in NCRP-45 (1975). These high-altitude cities include: Johannesburg, alt. 1.8 km, population ~2 million, dose rate ~60 mrem/yr; Mexico City, alt. 2.5 km, population ~18 million, dose rate ~80 mrem/yr; Bogota, alt. 2.6 km, population ~4 million, dose rate ~85 mrem/yr; and Quito, alt. 2.85 km, population ~.75 million, dose rate ~100 mrem/yr. There is also La Paz and the Altiplano region of Bolivia.

In the Altiplano the altitude ranges from 3.6 to 4 km, and about 75% of Bolivia's total population of 6 million live in this region. In addition to La Paz at 3.6 km, population (La Paz Department -- that is, the city, plus the surrounding administrative area) 1.8 million, there is the city of Oruro at 3.7 km, Lake Titicaca and its surrounding settlements at 3.8 km, and the city of Potosi at 3.9 km, population (Potosi Department) ~0.8 million. Thus, in the Altiplano region there are 4 million, or so, people for whom the cosmic ray dose rate is in the range 150 to 200 mrem/yr.

(**) External Terrestrial

At any location on the earth's surface persons are exposed to some flux of radiation (mostly photons) from the decay of radioactive elements contained in the soil and rocks. The main primordial sources are K-40, Th-232, and U-238; though, in the case of Th and U, the major part of the radiation encountered is provided by the radioactive daughters in their decay chains. The radiation flux at any location will vary depending on whether the soil is wet or dry, covered with snow or not, subjected to changing barometric pressure, and so forth; but these fluctuations will average out over the year. The significant variation is that applying from place to place due to differences in the local abundance of the primordial elements. Most of the radiation to which people are exposed is transmitted directly into the air from the near-surface rocks and soil as they reside in place. Almost all the radiation reaching the atmosphere originates in the topmost 25 or 30 centimeters of the soil.

On a mass basis the elements potassium, thorium, and uranium in the materials of the earth's crust are, respectively, something like two percent, and 12 and 4 parts per million. The number of atoms per gram of potassium (atomic mass ~40) is six times larger than that of thorium or uranium (atomic mass ~240). The isotopic abundance of K-40 (the only radioactive isotope of potassium) is 1.2×10^{-4}. The atomic ratios of K-40, Th-232, and U-238 in the earth's crust are, consequently, about as 4:3:1. With half-lives of 1.26×10^{9}, 1.4×10^{10}, and 4.5×10^{9} years, the number of disintegrations per unit time of K-40, Th-232, and U-238 are about in the ratio of 15:1:1. In ninety percent of the disintegrations of K-40 a β-particle (maximum energy ~1.3 MeV) is emitted, and almost all of these are absorbed in the soil close to the source. However, in the remaining 10% a γ-ray (energy 1.46 MeV) is emitted, and some of these will penetrate to the atmosphere. From the above it can be seen that in material having the average composition of the earth's crust there are about 1.5 γ-ray-emitting disintegrations of K-40 per disintegration of Th-232 or U-238 -- which are essentially equal. Th-232 and U-238 are the parent nuclei of decay series with ten or a dozen daughters having relatively short half-lives. Assuming a state of radioactive equilibrium (which doesn't always apply) each of the daughters in the series will disintegrate at the same rate as the parent nucleus. These series disintegrations release about 40 or 50 MeV of energy, but all but about 2 MeV of this energy is carried by α and β particles and deposited in the immediate vicinity of the source. About 30% of the energy carried by γ-rays is in low energy quanta (less than 1 MeV) which are strongly attenuated in the soil. In the thorium series there is a 2.6 MeV γ-ray emitted about 36% of the time, but in the uranium series there are no γ-rays with such a high energy. Thus, thorium contributes more than uranium to the terrestrial background radiation. The average concentrations of these elements in near-surface soil is somewhat lower than in the earth's crust; but in UNSCEAR-77 it is estimated that the world average radiation level at one meter above the

surface is about 40 mrad/yr: 15 from potassium, 15 from thorium, and 10 from uranium. As already suggested the actual background radiation rate from one location to another may vary considerably from this average depending on the composition of the soil or rocks nearby.

On the basis of extensive surveys the U.S. has been divided into three distinguishable regions with respect to terrestrial radiation backgrounds. These are: (i) The Atlantic and Gulf Coastal Plains Area -- a coastal belt of from one to a few hundred miles in width extending south and west from Long Island to Texas, including between 15 and 20% of the U.S. population, and within which the terrestrial radiation is said to provide an absorbed dose rate in outdoor air of between 15 and 35 mrad/yr, with a population-weighted average taken to be 23 mrad/yr; and (ii) Middle America, or The Noncoastal Plain Area, the region extending north and west from the Coastal Plains Area to the Pacific coast (except for a relatively small island around Denver and the Colorado Plateau). In this region, which includes about 80% of the U.S. population, the natural terrestrial background exposure rates range from 35 to 75 mrad, with the average taken to be 46 mrad/yr; and (iii), the Denver, Colorado Area, including some part of the East Front of the Rockies and the Colorado Plateau, in which the terrestrial exposure ranges from 75 to 140, and for which the average is taken to be 90 mrad/yr.

Much of the support for this regional breakdown is provided by the ARMS survey. ARMS refers to the Aerial Radiological Measurements Surveys of the radioactivity in the vicinity of government-sponsored nuclear facilities, conducted for the AEC between 1958 and 1963. Areas about 100 miles on a side around each of 25 locations were surveyed on a one-mile grid to map the terrestrial radiation background. About 30% of the population of the U.S. was comprised within these areas.

A range of radiation rates was observed in each area. For some of the locations, half or more of the area was noted as having rates more than ±15 mrad/yr from the mean for the area. For each area, the mean rate was taken to be applicable to the population of that area. For these portions of the country not covered by ARMS, the regional average exposures noted above were used to determine a population-weighted average of ~40 mrad/yr for the outdoor absorbed dose rate in air for the U.S.

This terrestrial radiation is mainly composed of γ-rays with an energy of one to two MeV. This radiation is attenuated by the materials in structures, and, since people spend more than two-thirds of their time indoors, and even though there may be some external dose from the building materials themselves, a factor of 0.8 has been applied to the outdoor dose in estimating the actual average exposure people receive. In addition, because of the shielding provided to the vital organs (gonads, bone marrow, etc.) by the outer tissues of the body, a further factor of 0.8 has been used in converting the terrestrial dose in air to the equivalent biological whole-body dose rate. With these factors, the population-weighted countrywide average dose equivalent from terrestrial radiation to persons in the U.S. has been taken to be 26 mrem/yr. This is the number used in the assessment that the background radiation dose in the U.S. is ~100 mrem/yr.

Surveys of background terrestrial radiation levels have also been made in other countries. Because of differences in instrumentation and procedures, not all

of these survey results are directly comparable, and not all have been carried through to the point of developing a population-weighted average. From having smaller areas the surveys of some of the countries are geographically more complete than present U.S. surveys, and, in addition, at least some have been conducted more systematically. Notwithstanding these differences, some of the values listed in UNSCEAR-82 showing the results of the surveys of about fifteen countries are indicated below. The values quoted are for absorbed dose in outdoor air in mrad/yr, which may be compared with the U.S. average of 40, already noted. The lowest average values (32-33) are for Canada, Denmark, Poland; the highest (70-80) for France, Romania, Switzerland, East Germany (GDR). In most cases ranges are given. The highest of the high range values are: Norway, 950; Italy, 415; West Germany (FRG), 315; France, 250; GDR, 225. For bottom of the range values, several were less than 10, including: Japan, Italy, FRG, France, Austria. Not to be cheated out of having something special about it, the bottom of the range for Ireland is listed as zero -- which could, of course, actually apply to a peat bog.

In a few cases, population-weighted indoor to outdoor ratios are listed. With the exception of the GDR which lists 0.8 (the same value assumed for the U.S.), these ratios are all larger than unity -- ranging from 1.65 for Austria to 1.08 for Canada. (The values for Canada are not from UNSCEAR, but from the report of an extensive Canadian survey completed in 1984.) At least on the basis of the data shown in UNSCEAR-1982, the U.S. value for indoor-outdoor ratio would appear to be one of the least well supported, being based on results from only about 270 dwellings as compared with the Norway value of 1.12 (2000 dwellings), or the FRG value of 1.36 (30,000 dwellings). Indeed, the value for this factor for the U.S. may well deserve further consideration. (In its forthcoming report, NCRP proposes to change this factor from 0.8 to 1.0.)

From this welter of data, along with data concerning the worldwide distribution of the primordial elements, UNSCEAR-82 concluded that, for external terrestrial background, a reasonable value for the global average of the absorbed dose rate in outdoor air would be about 44 mrad/yr, and that a value of 1.2 would be a suitable global average for the indoor-outdoor ratio.

The total environmental exposure to external radiation consists of the sum of the cosmic ray and the terrestrial components. For the Continental U.S., as already indicated, the population-weighted average of this sum is 28 + 26 = 54 mrem/yr. In a survey conducted in 1971 by the Lawrence Livermore Laboratory at 107 weather stations throughout the U.S. (but not including any locations at altitudes higher than that of Flagstaff, Arizona ~7000 ft), the range in this quantity was from a low of about 35 mrem/yr to a high of about 150 mrem/yr. The low values applied in southern Florida, where the cosmic component was small (sea level, less than 40° N. geomagnetic latitude), and the terrestrial component was also very low. The high values applied at Colorado Springs, Colorado (alt. ~6150 ft) which has fairly high components, both cosmic and terrestrial; and Bishop, California (alt. ~4150 ft) with a moderate cosmic component, but very high terrestrial. Flagstaff, Arizona, with the highest cosmic component of the locations included in this survey, had a rather low terrestrial component, and a total exposure to external radiation of only about 90 mrem/yr. In Hawaii (near sea level, and only 20° N geomagnetic latitude) the cosmic component was smaller than in Florida and the terrestrial components were also very low; so that external radiation provided about 30 mrem/yr for the locations monitored. In the reports examined, no measurements were given

of the terrestrial component of external radiation for the high-lying settlements in Colorado (>7000 ft altitude). There is, however, a general tendency for the external terrestrial radiation at such locations to be high -- in part, no doubt, because of the presence of rock near the surface, or of the exposure of bare rock. It therefore seems likely that among these settlements, which already have a cosmic ray exposure in excess of 100 mrem/yr, there will be some for which the total environmental exposure is >200 mrem/yr.

(iii) Internal

The exposures from internal sources of radiation may conveniently be considered in three classes: (a) that from normal constituents of the body (principally potassium); (b) that from radionuclides lodged in the body (uranium, etc.); and (c) exposures from inhaled radionuclides (radon and its daughters).

(a) The concentrations of the normal constituents of the body (such as H, C, or K) are maintained at fairly constant levels by the body's state of physiological equilibrium. They are consequently largely independent of such factors as diet or geographical location. In the absence of temporary man-made perturbations -- such as tritium releases, nuclear explosions, and so forth -- the isotopic composition of such elements in the body will be the same as that in the biosphere.

Cosmic rays provide a steady source of a large variety of radionuclides -- mostly produced at high altitudes. These mix with the lower atmosphere and other components of the biosphere and the deep ocean reservoir, and have established and maintained for a very long time a stable concentration in the various parts of the environment. The concentration of any particular cosmogenic radionuclide in any particular component of the environment depends strongly on the half-life of the nuclide (along with other factors, such as solubility).

In the biosphere (the lower atmosphere, surface waters, plant life, etc.), the four most abundant cosmogenic radionuclides are C-14, Na-22, Be-7, and H-3. Except for Be, these elements are essential constituents of the body. The total internal dose delivered by these radionuclides is about 1 mrem/yr, and is almost all provided by C-14; being, in particular: C-14, ~1; Na-22, ~0.02; and H-3, 0.001 mrem/yr. (Though not a body constituent, Be-7 may be ingested or inhaled, and is estimated to provide an internal dose of about 0.008 mrem/yr.) The total dose from all other cosmogenic nuclides is thought to be less than .001 mrem/yr.

Potassium is an essential constituent of the body, with an abundance of about 2 grams per kilogram of total body weight. Strictly speaking, the 2 gm level applies only to young males (age ~20) and falls essentially linearly with time over the next 60 years to about 1.6 gm. In females, after age 20, the potassium concentration at all ages is only about 75 to 80% of that in males -- in part, possibly, because of the difference in proportion of adipose tissue in which the potassium concentration is relatively low (only about 0.5 gm/kg). There is an appreciable variation in potassium concentration from one organ of the body to another (~4 gm/kg in red marrow, 2 in testes, 0.5 in bone) and a corresponding variation in doses to the different organs. However, for an assumed average concentration of 2 gm/kg body weight, the whole-body dose equivalent has been estimated to be ~18 mrem/yr.

Essentially all the β-particles from the decay of K-40 will be absorbed in the body; but more than half of the γ's will escape. Because of this, each person carries a small radiation field around with him. This, no doubt, is the basis for the jocular comment that there is some hazard (from radiation) in sharing a double bed. The hazard, of course, is not very great, being on the order of only a tenth of a mrem/yr in bed. However, since a nearby body would screen about 10% of the solid angle from the normal external terrestrial radiation of ~30 mrem/yr, it might better be said that sharing a double bed has a favorable effect.

After K-40 the most prominent nonseries primordial radionuclide is Rb-87. This nuclide emits only β-particles (maximum energy 0.27 MeV) so it is significant (if at all) only as a source of internal dose. Considering the factors of elemental abundance in the earths crust, isotopic fractions, half-lives, and energy per disintegration, the dose from Rb-87 would be about fifteen times smaller than that from K-40 -- provided the concentration in the body relative to that in the earth's crust should be the same. From measurements of rubidium in the body it has been concluded (UNSCEAR-77) that the dose rate from Rb-87 is about 0.4 mrem/yr. This is about forty times smaller than that from K-40.

In addition to K-40 and Rb-87, there are about twenty other nonseries primordial radionuclides in the material of the earth's crust. Considering their elemental abundances, isotopic fractions, etc., their rates of energy release per gram of terrestrial material range from a few percent down to many orders of magnitude smaller than that from Rb-87. The contribution of these to internal dose may consequently be ignored.

In summary, the dose rate from radioactive constituents of the body (K-40, C-14, H-3, etc.), is from 18 to 20 mrem/yr.

Finally, in this discussion of natural backgrounds, it is not intended to discuss the effects of the testing of nuclear explosives except as these may have affected items in the natural background. The immediate effect of nuclear testing (from the mid-1950s to 1963) was to release in the atmosphere large quantities of radioactive fission fragments (such as Sr-90 and Cs-137) which were not otherwise present in the environment. These will decay (or have decayed) to inconspicuous levels providing the present ban on testing in the atmosphere continues. As to the isotopes already considered in connection with natural background, the effects were as follows: for Rb-87 -- even though this is a direct fission product -- the amount added was much less than one percent of the natural abundance of this nucleus in the upper millimeter of the earth's crust. Eight of the other primordial radioisotopes are also direct fission fragments. For these, also, the contribution from testing was a very small fraction of the abundance of these isotopes in the topmost layer of the earth's crust. K-40 is not a fission product, so there was no effect on that.

C-14 is not a fission fragment, but it is formed by the capture of neutrons in the nitrogen of the atmosphere. H-3 (tritium) is also not a fission fragment, but is a residue of the burning of thermonuclear fuel. The inventory of C-14 in the biosphere was approximately doubled as a consequence of weapons' testing. The previously ascribed one mrem/yr from this source could have been raised to something between 1.5 and 2 mrem/yr. This incremental effect will decrease much more rapidly than it would merely as a result of the radioactive decay of C-14

(half-life about 5,700 years) because of the process of equilibration with the contents of the deep ocean reservoir. This process is believed to proceed with a mean life of about 7 years, or so. The present (1986) level of C-14 in the biosphere is about 20% larger than the "natural" level of C-14.

It has been estimated that the global inventory of tritium (H-3) was increased by a factor of between several hundred and a thousand by the nuclear explosions conducted in the atmosphere prior to 1963. With a half-life of 12.3 years, the amount of injected tritium will by now have been reduced by a factor like 5; but, it still completely masks the effect of "natural" tritium, and will continue to dominate for the next hundred years or so. Even at that, of course, it is a rather small term in the total exposure to natural radiation.

(b) Apart from the radioactivity associated with essential constituents of the body, there is some internal dose resulting from the ingestion of "foreign" radionuclides in the environment. The amount of these is not homeostatically controlled, but depends on their concentration in materials (air, water, and food) taken into the body. The items of particular concern here are the parental thorium and uranium and some of their daughters, such as radium. Their gaseous daughter, radon, will be discussed separately later.

Though the amount of these elements taken up in the body was once, no doubt, rather directly related to the concentration of these elements in the local environment, that is no longer so much the case. It is still true that some of the underground water in Iowa and Illinois, as well as at other locations in the country, has an unusually high radium content; but an increasing fraction of such water is now treated before it reaches a consumer. More significantly, with the greatly increased use of canned and packaged foods (which may be processed anywhere in the country) and the countrywide distribution system for produce of all sorts, the U.S. food supply has become homogenized to a very large extent. Consequently, in discussing the uptake by ingestion of the series radionuclides it seems appropriate to use the average values estimated for the U.S. Quite apart from the (relatively) straightforward matter of assessing the average uptake of uranium and thorium (and daughters), the matter of correlating this with a whole-body equivalent dose requires composing a number of radically different effects: the ingested radionuclides spend some time in the stomach, some time in the bloodstream, and some end up deposited in the gonads and on the bone surfaces. The amount of thorium ingested is probably about the same as that of uranium; but the retention of thorium in the body is very much smaller. As a consequence, most (80 or 90%) of the internal dose from the series radionuclides is provided by uranium and its daughters.

In the following discussion the estimates compiled in the 1975 report, NCRP-45, will be presented; but at the end of this section on internal exposure some comparison will be made between these estimates and the newer (1986-87) estimates being considered by the NCRP. From NCRP-45, then, the ingestion of the primordial series radionuclides results in a whole-body equivalent dose rate of about 7 mrem/yr. Uncertainties and differences which could readily affect this estimate would not greatly affect the estimate of the total dose from internal sources since this is dominated by the dose from K-40, which is about twice as large as that from uranium. Thus, with the exception of the dose resulting from inhaled radon (and daughters), the dose equivalent rate from internal sources is about 25 mrem/yr -- ~20 from K-40, and 7, or so, from

uranium, etc. This is the number assumed in the assessment that the average dose to persons in the U.S. is about 100 mrem/yr.

(c) The main additional source of internal radiation is that resulting from the inhalation of radon and its short-lived daughters. Radon appears at nearly the same rate in both the uranium and thorium decay series, and is the only gaseous element in these series. In the uranium series, the isotope Rn-222 is an alpha-emitter with a half-life of 3.8 days. This allows time for an appreciable fraction of the radon formed near the surface to migrate into the atmosphere and to be carried about by the wind. In contrast, the isotope Rn-220, which appears in the thorium series, has a half-life of only 55 sec, so that it does not succeed in migrating from the soil to an extent which warrants consideration in comparison with the 3.8-day Rn-222.

Radon is an inert monatomic gas -- one of the "noble" gases, which engage in few, if any, chemical reactions. Once released to the atmosphere these atoms move freely about and the products of their decay appear as single atoms and attach themselves either to some molecule in the air or to an aerosol particle and thus remain suspended in the air for a considerable time. Radon decays by α-emission; and if this occurs while the radon atom is still suspended in air there is no direct effect on human exposure. The immediate daughters of Rn-222 (Po-218, Pb-214, Bi-214, Po-214) have short half-lives (from 0.16 msec, to 27 min) and their decays are also likely to occur while the atoms are still suspended in the air. The first and last of these decays are by α-emission; so that, again, there will be no direct effects on exposure to humans -- unless, of course, the original radon atom, or one of these daughters had been taken into the body by inhalation and the energy of the subsequent decay were deposited there. However, the second and third daughters are β-emitters, and their disintegrations are accompanied by a large fraction of the gamma-ray energy appearing in the uranium decay series. Thus, even if these disintegrations occur while the daughters are still suspended in the air they would provide some external exposure to humans -- though not a very important component from radon concentrations normally encountered in outdoor air. The (temporary) end-product of this group of decays is the (relatively) long-lived Pb-210 (21 years). This undergoes two β-decays followed by the emission of an α-particle, which terminates the uranium series in the stable isotope Pb-206. There are essentially no gammas associated with the decay of Pb-210; so this isotope contributes only to internal exposure. That could result either from the inhalation of air in which Pb-210 were still present after the decay of Rn-222, with some fraction of the Pb-210 being lodged in the body, or from the ingestion of plant-life growing on soil in which the Pb-210 had been deposited. The former is by far the more important route for exposure to radiation from Pb-210.

Very little radon is emanated from the surface of the ocean, and on this account the concentration in coastal air is low and variable -- depending on whether the air is moving from inland or from the sea. In the continental air mass, the level of radioactivity is about 150 pCi (pico-curies: 10^{-12} Ci) per cubic meter. A large fraction (>2/3) of the radon inhaled is exhaled before it decays, but the solid radon daughters (the 21-year Pb-210 and the 140-day Po-210) attach to the surfaces of the pulmonary tract -- and particularly to the walls of the hair-like passages in the segmental bronchioles. The dose rate to the tissues of the lung from this cause has (in NCRP-45) been estimated as being about 90 mrem/yr, and to the bronchial epithelium about 450 mrem/yr.

Using the weighting factor recommended by the ICRP (whole-body dose equivalent at 0.12 times the dose to the lung tissue), the whole-body equivalent dose from exposure of the lung tissue would be about 11 mrem/yr. If one applies the ICRP-recommended weighting factor of 0.08 to the dose to the bronchial epithelium, this would add an additional 36 mrem/yr to the whole-body dose equivalent. Adding to the 80 mrem/yr already identified (28 cosmic, 26 external and 26 internal), we have an average natural background exposure for persons in the U.S. of rather more than 100 mrem/yr, without taking into account the proposed revision of the indoor/outdoor factor from 0.8 to 1.0, which would raise the external component from 26 to 32 mrem/yr.

Up to this point the exposure to inhaled radionuclides (radon, etc.), has been described only in terms of persons breathing outdoor air. In fact, of course, people spend a major fraction of their time indoors, and the radon levels in dwellings may be quite different (usually higher) than the radon levels out-of-doors. Radon seeps into dwellings from the soil in which the basement is embedded, from the materials of construction -- such as cinder blocks -- and, because the rate of exchange of air in dwellings is intentionally much smaller than the rate of exchange of air outdoors (in houses weatherproofed for energy conservation, a great deal smaller), the radon concentration in indoor air may run much higher than in the ambient air outside. The effects of this have not been considered here as part of the "natural background," since they are, in fact, technologically enhanced and could (in principle, at least) be controlled. They do, nevertheless, provide an additional source of radiation to which the population is exposed. Some (quite partial) surveys have been conducted. These do not yet begin to be adequate to establish an average level for indoor radon exposure for the U.S. From the surveys which have been made examples have been found in which the indoor radon levels were ten, or more, times larger than the continental outdoor average. Such a level would imply an equivalent whole-body dose larger than the average already identified by a hundred -- or even more -- mrem/yr.

As stated earlier, the components of the dose equivalent rates from natural background radiation as given above are derived from the data provided in NCRP-45. In its 1982 report the UNSCEAR directed much more attention to radon than it had in previous reports; saying, in particular: "Inhalation is now recognized to be the most important pathway," -- and "on average about one-half the effective dose equivalent from natural sources of radiation is now calculated to be due to the presence of radon in the air inside buildings."

In the January 1987 draft of a forthcoming NRCP report, the dose equivalent values for cosmic radiation, terrestrial gamma radiation, and the internal dose from cosmogenic radionuclides and K-40 are changed very little. But there are marked changes in the components where the exposure is provided primarily by α-radiation: the uranium contribution to internal radiation, and, most particularly, the dose attributed to inhaled radon. These changes were in part occasioned by the increase from Q=10 to Q=20 for α-radiation; but they were also affected by new data showing higher concentrations of Pb and Po-210 in bone, by higher estimates for the tissue dose from radon decaying in the body, and particularly by including some allowance for the higher level of radon indoors as compared to outdoors. More specifically, the contribution of uranium to the internal exposure is now being rated as about 10 to 15 mrem/yr whole-body dose equivalent (rather than the value of about 7 noted above); and the dose rate proposed for the bronchial epithelium is 2,450 mrem/yr (rather

than the 450 suggested in NCRP-45). Applying the weighting factor of 0.08 to the dose to the bronchial epithelium would add about 200 mrem/yr to the whole-body dose equivalent. In summary, the draft version of the forthcoming report provides an estimate of the total average annual exposure to a member of the population of the U.S. from sources of natural background radiation of 300 mrem.

It should be noted that there is some continuing controversy about the proper weighting factor for the whole-body equivalent of dose to the bronchial epithelium. In addition, as already mentioned, the data to establish a country-wide average of indoor radon concentration is still far from complete -- though additional surveys on this point are in progress. For both of these reasons the estimate of the contribution from the bronchial epithelium to the total dose must be regarded as still in question.

II. Celebrated Hot Spots

There are locations in which the natural background of terrestrial radiation is much higher than those so far referred to. A particularly notable one is the Kerala Coast. (The state of Kerala is on the west coast of India near the southern tip.) In a narrow strip, extending 100 miles, or so, along the beach, numerous patches of monazite sand are exposed. (The mineral monazite consists of highly insoluble phosphates of cerium and other rare earth elements in various proportions, usually accompanied by some thorium and, on occasion, small amounts of uranium, and their daughters.) The most concentrated deposits are found in a 30-mile section of the strip; and there the monazite contains from 8 to 10.5 percent thorium by weight -- the highest known in the world. About 70,000 persons live in this section. There is, of course, considerable variation in the external terrestrial exposure received by the people residing in this region (some of the dwellings -- which are mostly made of coconut straw and wood -- being located directly on patches of monazite, and some not; some residents being employed outside the high background area, while others spend most of their time near home). However, on the basis of radiometric surveys, the average exposure to terrestrial radiation for the 70,000 persons in the region has been estimated to be about 380 mrem/yr. For about 17,000 persons the exposure has been estimated to exceed 500 mrem/yr. It exceeded 1,000 mrem/yr for more than 4,000 persons; and it exceeded 2,000 mrem/yr for about 500. People have been living in this part of India for hundreds of years. It is very densely populated, and it would seem unlikely that there has been any large influx of people from outside for a long time. In all probability most of the present residents have generations of ancestors who also lived in this region. Some preliminary epidemiological studies have been made, and more are planned. Still -- at least as reported up through about 1980 -- no statistically significant evidence has been found of effects resulting from the unusually high background radiation to which the population of the Kerala Coast has been exposed.

Impressive deposits of monazite sands also occur on some of the beaches of Brazil, about 200 miles northeast of Rio de Janeiro. In particular, in the town of Guarapari -- which has a resident population of 12,000 persons, and a summer tourist population of 30 to 40 thousand -- it has been estimated that the average annual exposure rate to external terrestrial radiation in the town is about 550 mrem/yr. Along the beach of this health resort there are patches

of "black sand" (particularly favored by the tourists) on which the radiation levels are from five to ten times higher than in the streets of the town.

There is a small agricultural area in China about 100 miles southwest of Canton in which an appreciable concentration of monazite has been deposited by alluvial action. About 80,000 persons reside in the high-radiation area, and over 90% of these have had six or more generations of forebears who lived in the same area. There are similar long-established villages at distances of only 10, or so, km where the concentrations of U and Th in the soil are from 3 to 10 times smaller; and these have provided a control group. Though the external terrestrial radiation level is four times greater in the high-radiation area than in the control area the total whole-body exposure (including cosmic and internal components) is only 2.4 times greater, being about 230 and 95 mrem/yr, respectively. Extensive medical surveys have been made of the two population groups to obtain data concerning such factors as morbidity and mortality rates from malignancies, spontaneous abortion rates, and the incidence of hereditary and congenital diseases. In addition, more than 20,000 individuals from each group were examined to check for differences in chromosomal aberrations, leukemia, and measures of growth and development. In a number of instances the results for the two groups were essentially identical, and in no case was a statistically significant difference observed. Although no appreciable effect was found the Chinese Radiation Research Group which conducted the studies concluded that the size of the population group was too small to show minor increments of detrimental effects at such low doses.

In addition to the monazite beaches there is a region in Brazil with very high terrestrial background radiation in a distinctly different geological setting. This is a volcanic area about 200 miles west (inland) from Rio and extending north-from the city of Pocos de Caldas to Araxá where there are intrusions containing minerals having close to two percent thorium oxide and over one percent uranium oxide. Radiation levels up to twice those noted in the streets of Guarapari have been measured near Araxá, and on a small uninhabited hill -- the Morro do Ferro -- near Pocos de Caldas absorbed dose rates in air up to 24 rads/yr have been reported. No large population groups appear to be exposed continually to the very high radiation background in this region.

In France locations providing absorbed dose rates in air of about 1.75 rads/yr are not uncommon, and the discovery of a quite small area providing a rate of over 80 rad/yr has been reported. There are also locations in Paris where one may receive a biological dose of up to 350 mrem/yr. Though no one actually lives in St. Peter's Square in Rome, many people spend appreciable time there, where it is reported that the paving stones provide up to something like 400 mrem/yr. The Fichtelgebirge is a granitic mountain near the northeast border of Bavaria. There are several towns or villages on the slopes of this mountain. On the streets of these villages the terrestrial γ-ray exposure ranges up to more than 500 mrem/yr -- the highest known in the FRG.

In Grand Central Station in New York City -- which was built with granite from the Millstone Quarry in Connecticut -- there are locations where the external terrestrial dose rate is about 525 mrem/yr. Stone from the same source was used in constructing the foundation for the Statue of Liberty in New York harbor, and this also provides a high radiation exposure. (While it was operating -- from about 1740 to 1960 -- the Millstone Quarry was a favored source of building material since it was immediately adjacent to the shore, and rock could be

transported readily to locations on the East Coast. The radiation exposure of persons working in this quarry must have been quite high.) High radiation levels (absorbed dose rates in air up to 150 mrad/yr, or so) can also be found in other granitic regions of New England, and, indeed, wherever else similar rock may be found at the surface. A different setting for high terrestrial background radiation is presented by the phosphate deposits in Florida. From this appreciably uraniferous material terrestrial background radiation levels of absorbed dose rates in air up to 150 mrad/yr have been observed. Deposits of phosphate rock occur throughout the world. Among the major phosphate-producing areas the deposits in South Carolina, Wyoming, and some of those in Brazil have higher concentrations of uranium than those in Florida, while a number of others are comparable to the ones in Florida.

The remaining type of situation resulting in unusually high exposures to natural background radiation (excluding the circumstances affecting underground miners) has to do with water. In the ionization states most usually occurring in natural settings, radium is much more soluble and mobile than either uranium or thorium. On this account water -- and particularly warm water -- flowing through beds of sandstone or fractured granitic rock may accumulate concentrations of radium very much higher than the concentration in the material through which the water has been flowing. At locations where such water may emerge to the surface one has the makings of a "radium spring," or -- where the neighboring population is sufficient to support it -- a "spa."

Locally notable "hot springs" occur in all parts of the world. Many of these became famous as "health resorts" long before the existance of radium was known, and before measurements of levels of radioactivity were ever considered. Of interest here is the fact that not only do some of the "waters" carry a level of radioactivity which would now be regarded as distinctly unhealthy, but the radon decay product of the radium in the water is released to the atmosphere and provides an unusually high level of exposure to the population in the neighborhood.

There are reports concerning a few notable radioactive hot springs. For example, the springs at Tuwa, a village in India about 200 miles north of Bombay, have a high concentration of Ra-226. In the air close to the main spring at Tuwa, the γ-ray dose (from the short-lived radon daughters) has been reported to be about 10, or more, rad/yr. At a distance of about a dozen kilometers (and several villages) downwind, this exposure rate falls to ~750 mrad/yr. Similarly, in the city of Ramsar, a resort on the Caspian coast of Iran, population >10,000, there is an area of a few square kilometers around the radium-bearing springs (which emerge in downtown Ramsar) within which levels of absorbed dose in air have been measured ranging from 1.75 to over 40 rads/yr.

The springs at Badgastein, Austria (about 50 miles south of Salzburg) have received the most extensive and detailed studies of radioactivity, both as to the "waters," and as to the surrounding neighborhood. This famous spa has been known as a "watering place" for more than six hundred years. Already in the 18th century several thousand persons travelled there each year for treatment. Over the centuries many accounts have been written (including one by Paracelsus, printed in 1562) describing the therapeutic effects of the baths at Badgastein. Badgastein gained in popularity, so that by 1940, 30,000 visitors were reported, and by 1970, about a million baths per year were administered. By this time, also, about 300 hotels were said to be operating in the region to accommodate

visitors, and the permanent population of Badgastein and environs was about 12,000.

In 1904 the presence at Badgastein of "emanation" (as radon was then known) was established by P. Curie and colleagues. Subsequent studies have determined that, although the amounts of U, Th, and Ra in the spring water are not exceptionally high, the Rn-222 content is outstanding. For most of the visitors, or spa patients taking only a few treatments, the dose received is low (from a few, to a few tens, of mrem). For patients taking a "whole cure" (a dozen 2-hour sessions in the "thermal gallery" in which the Rn-222 concentration is 3,000 pCi/l), the dose to the lung tissue is about 900 mrem -- and several times more to the bronchioles. By inhalation of Rn-222 the 5 or 6,000 permanent inhabitants of Badgastein proper -- where the springs are located -- receive from 0.7 to 1.5 rems/yr (in lung tissue). The bath attendants, other personnel connected with the treatment facilities, and, particularly, the doctors attending patients in the "thermal gallery" (a group of only a few hundred persons) receive from about two, up to several tens, of rem/yr (to lung tissue) -- or did receive such exposure until about 1970 when some corrective measures are said to have been placed in effect. (The dose levels reported in this and previous paragraphs are all in the "old scale" using Q=10 for alpha particles.) Surveys have been made to compare the general health of residents of Badgastein with that of groups living in similar circumstances -- but not having any enhanced radiation exposure. These resulted in the conclusion that the longevity of the Badgastein residents was not less, and the incidence of cancer was not greater, than that for the other population groups. As of 1972 studies to identify possible radiation-induced anomalies in cells had led to the tentative conclusion that at dose levels up to somewhere between 0.3 and 1.0 rem/yr, there was no clear evidence of cell damage. For doses larger than somewhere between 0.3 and 1.0 rem/yr, there was an increasing incidence of (for example) broken chromosomes. Presumably, such studies at Badgastein have by now been extended.

There are many other well-known hot springs, or mineral springs, which have not been discussed at recent symposia on high natural environmental radiation. This could be because they have been studied, and found not to have radiological features of interest; or because specific studies have not yet been made.

Among these are the springs at Bath, in southwest England -- a spa well-known and used since Roman days. At about the same time as Curie made his findings at Badgastein, J.J. Thomson (who discovered the electron in 1897) reported the existance of copious amounts of "emanation" at Bath, and suggested that the salubrious properties of the waters there might be due to their radioactivity. With respect to the waters at Saratoga Springs, New York -- though it has been pointed out that the waters bottled and distributed from there come from a spring having low to moderate radioactive content -- some of the long-time residents, preferring the water from a different spring having several hundred times the radium content recommended (since 1962) by the NCRP as "maximum permissible," have been making regular use of this more radioactive water for periods up to 50 or 60 years without any apparent deleterious effects. Reports concerning the radioactive properties (if any) of the springs in Vichy, France (famous since Roman times) or at Hot Springs, Arkansas, or Warm Springs, Georgia, and many other locations could also be interesting.

III. Some Local Surveys

Partial results from four sets of observations of environmental radiation are described. The measurements reported are the sum of contributions from terrestrial gammas and cosmic radiation to the exposure in air -- mostly in outdoor air. The data considered were drawn from: (i) reports of EML -- the Environmental Measurements Laboratory of the U.S. DOE; (ii) NUREG-0837, the quarterly reports of the NRC TLD Direct Radiation Monitoring Network; (iii) the annual reports of the Los Alamos Environmental Surveillance Group; and (iv) readings taken in the course of a mini-survey made by the author in downtown Washington, DC, in the early summer of 1988.

(i) EML Data

Over many years members of the staff of the EML (initially the AEC's Health and Safety Laboratory -- HASL) have studied a very wide range of aspects of environmental radiation. Here, only three particular projects are referred to. The first of these is a program initiated in the fall of 1971 to monitor continuously the exposure level in outdoor air. Thermoluminescent dosimeters (TLD's) were set up near four residential locations in the suburbs of New York City, and were monitored on a monthly basis. The sites were (roughly) in directions west, north, and east, and at distances between about 15 and 30 miles, from Central Park. These locations are all close to sea level (cosmic radiation exposure about 29 mrad/yr in outdoor air) and in the Coastal Plain region (average exposure to terrestrial radiation previously said to be 23 mrad/yr). On this basis the exposure at these locations would be about 52 mrad/yr.

The 10-year average exposures measured ranged from 53 to 60 mrad/yr -- in acceptable conformance with the nominal regional value. The annual averages at a given site were observed to fall in the range (maximum-minimum/minimum) of only about 10%, but the measurements for a given month showed differences of as much as 40% from one year to another at a given site. Such differences were attributed mainly to differences in the annual snow cover and rainfall.

One consequence of such variability is that it may be difficult to obtain a precise measurement of the size of some increment in exposure level (such as might result from reactor operation or other non-natural source of radioactivity) -- at least on the basis of TLD readings, and particularly if the increment is small compared to the background. The TLD registers the sum of the incremental and background exposures integrated over some period of time. To assess the increment it is necessary to subtract the background contribution from the total reading. Since the background may vary, and cannot be read separately, the background contribution will have to be assumed on some basis, and this may leave room for considerable uncertainty in the actual size of the increment. This could, of course, be greatly improved by the use of more elaborate detectors, such as a spectrometer which could identify source isotopes; but such equipment is not attractive for use in field monitoring.

The second EML project to be mentioned here is their continuous monitoring over several years of the natural radiation exposure rates at Shoreham, NY, and the EML station at Chester, NJ. The Shoreham site is on the North Shore of Long Island, at sea level, and in the Coastal Plain region for terrestrial radiation. Chester, NJ is a little more than 90 miles west of Shoreham, at an altitude of

about 750 ft, and near the eastern fringe of the Middle America terrestrial region. The annual average exposure rates measured by EML were 59 mrad/yr at Shorenam and about 109 mrad/yr at Chester. The cosmic ray components will have been 29 and about 31 mrad/yr, respectively, so that the terrestrial components were about 30 and 78 mrad/yr. The terrestrial level at Shorenam is well within the range (15 to 35) previously ascribed to the Coastal Plain region, but the level at Chester is just above the range (35 to 75) ascribed to the Middle America region. The 50 mrad/yr difference in exposure rates is smaller than many of the variations identified earlier, but it is of interest to find that it applied between locations which would not normally be thought of as widely separated nor in different geographical provinces of the country. Actually the 50 mrad transition is much sharper than indicated by the Chester-Shorenam comparison since two of the residential sites discussed above, for which the average annual exposures measured by EML were within one mrad of that reported for Shorenam, are less than 25 miles east of Chester.

The third EML project considered is their sponsorship of a series of International Intercomparisons of Environmental Dosimeters. Eight such exercises were held between 1974 and 1986 with participants from 130, or so, laboratories from over 30 countries. The TLD exposure readings were compared with each other and with control readings on continuously monitoring high pressure ionization chambers. Many factors contributed to differences in the results obtained in the intercomparison. These included effects from differences in packaging -- where both wall thickness and ambient temperature of the luminescent element affected the readings; differences in calibration methods; in spectral response -- as for example between terrestrial gammas and cosmic radiation; problems with signal loss, or "fading," for some phosphor types; and a few others.

The conclusion from the intercomparison series was that over 85% of the participants obtained results within ±30% of the delivered exposures and that about half the results were within ±10%. Some of the test exposures included in this observation were at higher levels than typical environmental levels, and in general the percentage spreads in the readings are somewhat larger at lower exposure levels. This is partly because the corrections which must be applied for exposure during transportation and storage of the TLD's constitute a larger fraction of the total. For this reason, also, TLD readings of background over short periods -- much less than a month, say -- will not be very accurate. It follows that exposures reported from different countries or different laboratories may not be fully comparable. However, it may be expected that surveys made by a single organization using standard procedures and equipment will provide fairly good data on the differences in exposure levels from place to place or from time to time.

(ii) NRC Survey of Nuclear Power Plant Sites

Since August 1979 (a few months after the accident at TMI-2); the NRC has maintained a network of TLD's around every licensed nuclear power plant site in the country, both those under construction and those in operation. In each case about 40 detectors are emplaced in a reasonably uniform azimuthal distribution at various distances from the plant -- nominally, 16 within 2 miles of the plant, but outside the plant boundary, 16 between 2 and 5 miles, and 8 between 5 and 20 miles from the plant. The detectors are collected every three months and

replaced with fresh ones, and the readings from the exposed detectors are reported in the quarterly series NUREG-0837.

The cosmic component is uniform over the extent of the array at any particular site, so that any variation in a single array will be entirely due to differences in the terrestrial background -- unless effluents from an operating plant should lead to higher readings on detectors close to the plant in the downwind direction. However, there is little evidence of a general pattern of this sort in the data collected, and for plants still under construction there is no such consideration. Indeed, there are twice as many instances in which the highest zonal average is for one of the two outer zones rather than for the innermost zone. At two of the sites detectors unusually close to the plant also had the highest readings in the array. The data from these stations has been ignored in the following, as has the data from a few other stations which provided readings which were obviously erroneous -- such as indicating levels smaller than that of the cosmic component alone, or levels which, for one particular quarter, were much higher than that for any other station in the array while, for other quarters, the level at the same station was not outstanding. In NUREG-0837 the exposure rates for the absorbed dose in outdoor air are listed in terms of mR/quarter; but these are converted below to mrad/yr.

In the 4th quarter of 1983 arrays were operated at 69 sites, but from trouble in collecting the data needed to normalize the detector readings at 12 of these sites corrected data are available for only 57 sites. The average exposure rate for the 57 sites during this quarter was about 66 mrad/yr -- in reasonable agreement with the 70 mrad/yr (30 cosmic plus 40 terrestrial) previously identified as the country-wide population-weighted average value for the exposure rate in outdoor air. The site average rates ranged from a high of 108 mrad/yr (Fort St. Vrain) to a low of 42 mrad/yr (Catawba). The highest (non-anomalous) reading for a single station was 135 mrad/yr at a location 13 mi from Fort St. Vrain.

Of particular interest in the present discussion is the range of readings among the various detector stations within the limited extent of a single array. In the 4th quarter of 1983 the average over the 57 sites of the difference between the highest and lowest exposure rates recorded at each site was 34 mrad/yr. Amongst the sites this difference ranged from a low value of 16 mrad/yr to a high of 59 mrad/yr. This maximum spread was between two stations in the Surry array where one station, 3.7 mi from the plant, recorded a rate of 39 mrad/yr, while the other, 11 mi from the plant and 13 mi from the first, recorded a rate of 98 mrad/yr. Of course, the rates recorded at these stations -- as for almost all stations -- change from one quarter to the next as do the differences between them; but during the whole of 1983 the difference in exposure at these two stations was 42 mrad. This same difference in exposure for the year also occurred between two stations, only 1.5 mi apart, in the array at North Anna. While the maximum spread within an array was found at Surry in the 4th quarter of 1983, for the other quarters of the year (first through third) the maximum spreads were as follows: McGuire (56), Surry (57), and North Anna (54). Along with these maximum spreads, in the NUREG-0837 data for 1983 differences in exposure rates of more than 40 mrad/yr between stations in a single array were recorded at more than two dozen sites. In half of these instances the stations involved were less than 10 mi apart. Except for the Far South East (as in Florida, for example, where the terrestrial background on undisturbed land is generally too small to allow room for variations as large as 40 mrad/yr) these arrays had an

essentially country-wide distribution from the Pacific coast, through the mid-continental region, to the Atlantic.

Finally, considering that in the NUREG-0837 survey there were nominally 8 stations between the 5 and 20 mile circles around the plant, on the average each station reported on an area of about 145 square miles. There is no reason to suppose that the extremes in the naturally-occurring exposure rates within the arrays would necessarily be picked up in this survey.

(iii) The Los Alamos Survey

For many years the Environmental Surveillance Group of the Los Alamos Laboratory has monitored a large number of locations in the technical areas of the Laboratory, and also in the surrounding neighborhood, for the presence of a long list of possible radioactive and chemical contaminants in the air, soil, and water. As a part of this operation they have maintained an array of TLDs to monitor the cosmic ray and terrestrial radiation background. A number of these TLD stations are outside the perimeter of the technical area at locations where normal Laboratory operations would not affect the readings of the dosimeters. Seven of these outside stations are deployed in the townsite; and these are all in generally similar (mesa-top) terrain, and are all at an altitude close to 7250 ft (2,200 m). They are all located within an area somewhat less than 7 square miles, and the extreme distance between any two of these stations is only 3.5 miles. These seven stations thus constitute a rather compact array. The measurements reported are believed to be within 4 percent of actual levels.

The TLDs register the sum of the absorbed dose in outdoor air from the cosmic and terrestrial backgrounds -- with the exception of the cosmic ray neutrons, to which the particular detectors used are not sensitive. To obtain the total background exposure it is necessary to add 11 mrem/yr to the TLD readings to allow for the neutron component (as taken from the dose-altitude curve of NCRP-45 at 2,200 m). The total exposures for the calendar year recorded by the TLDs at each station are listed in the annual reports of the Surveillance Group. Again from NCRP-45, the average exposure rate to cosmic radiation (excluding neutrons) at 2,200 m altitude is 60 mrad/yr. The average of the TLD readings for all seven stations over the six-year period from 1980 through 1985 is 116 mrad/yr. The average exposure from terrestrial radiation is, then, 56 mrad/yr.

Over any particular time period the cosmic background will, of course, be uniform across this compact array, though over a six-year period the level will change somewhat as a consequence of the 11-year solar activity cycle. At the geomagnetic latitude of the Continental U.S., this variation has a maximum amplitude of less than 10% of the mean level. Changes in the array average such as that between 1980 and 1981 (from 123 to 100 mrad/yr.), or that between 1982 and 1983 (from 109 to 131 mrad/yr.) will have resulted from changes in the terrestrial background. Presumably such shifts are to be accounted for by differences in precipitation, snow cover, and so forth -- and, indeed, there was 30% more precipitation in 1982 than in 1983: 21.7" vs. 16.7." However, the size of the changes from 1982 to 1983 was by no means the same at each station, ranging from +11 mrad/yr. to +35 mrad/yr. Another curious example of a station-to-station variation occurred between 1984 and 1985. The array average exposure was 116 mrad/yr. for each of these years; but, while the exposure at one station dropped from 135 to 120, that at another, only 1.2 miles away, increased from 115 to 136 mrad/yr.

The spread between the highest and lowest readings in 1980 was only 25 mrad/yr; but for each of the other annual periods this spread ranged between 30 and 40 mrad/yr -- even within the very limited extent of this array. During the six annual intervals considered, the lowest exposure was recorded at one or the other of two stations, while three different stations were involved in providing the highest reading of the year.

These examples, culled from the results of the Los Alamos survey, point up the fact that there is much more variability in the natural background radiation -- both over time, and in space -- than is brought to mind by references to countrywide, or even regional, averages.

(iv) Washington, DC

Being at sea level, Washington has a cosmic ray dose rate (including neutrons) close to 30 mrem/yr. Since the neutron component in this cosmic ray flux is quite small the difference between rads and rems is also small, and may be ignored. Washington is in the Coastal Plains Region for which the outdoor exposure rate to terrestrial radiation is said to be between 15 and 35 mrad/yr. The natural background dose rate in Washington should, then, be between 45 and 65 mrad/yr. Still, some question on this point is suggested by Alvin Weinberg's measurement in May 1979 of a dose rate of 250 mrem/yr during a hearing in the Dirksen Senate Office Building.

Having this in mind, a hand-portable radiation rate-meter was taken on several short excursions during May, June, and July of 1986. The resulting observations cannot be considered to constitute a survey, since they were made in the course of visits to a somewhat random selection of targets. The rapid time-response of the rate-meter made it attractive to take many of the readings en passant, so the precision of the readings was not impressive -- something like ±1 μR/hr. Still, the measurements were probably sufficiently accurate to permit the grouping into the rather broad exposure ranges indicated below. The rate-meter was calibrated in μR/hr; but that has been converted to mrad/yr using 1 μR/hr = 8.76 mR/yr = 7.6 mrad/yr.

The following is a summary of the results of this mini-survey. The numbers given refer to exposure rates in ambient air in mrad/yr.:

- 60-75. The lowest rate observed was about 60. This was found in a variety of locations: the doorway of the older World Bank Building at 18th and G; the 5th floor of the Hart Senate Office Building; at street level inside the new Presidential Plaza at 19th & I. Rates close to 75 were found along First Street, SE.; on the steps and among the columns in front of the Supreme Court; the northwest doorway of the Russell Senate Office Building; the interior of the Lincoln Memorial; and the street in front of 1717 H Street, as well as in the lobby and the large conference room on the 10th floor.

- 75-90. Examples were found along a number of streets (18th Street, I Street, Pennsylvania, and 20th); the lobby of the Lombardy Hotel; the

lobby of the National Science Foundation Building; and both on the street level and the lower level of the Farragut west Metro station.

- 90-115. Rates in this range were found on upper floors of both the Dirksen and the Russell Senate Office Buildings; on the street level of the new world Bank Building at 18th and Pennsylvania (then under construction) except that the rate of about 90 increased to about 115 on walking past the concrete structural columns; outside the base of the Washington Monument; the lobby of the Hay Adams; lobby of the New Executive Office Building; upper floors of the Lombardy Hotel; the men's rooms and corridors on the 10th and 11th floors of 1717 H Street (about 15 higher when passing concrete columns); the roadway of East Capitol near the foot of the steps to the Capitol; the sidewalk along Pennsylvania Avenue near the White House fence.

- 115-150. Inside the Washington Monument at ground level; beside the Reflecting Pool; in Lafayette Square (about 30 higher than on the other side of Pennsylvania Avenue); the street in front of the New Executive Office Building; on some sections of sidewalk such as that paved with bricks on Madison Place, and the section paved with ornamental stone slabs at 17th and H -- both being about 30 higher than nearby sections with concrete walks.

- 150-200. In this range were the entryway at the southeast corner of the Presidential Plaza; the porte-cochere on the east side of the Capitol; the walk by the Viet Nam Memorial; and the steps from the Reflecting Pool up to the Lincoln Memorial.

- >200. On crossing Madison Place from the east side of Lafayette Square (rate ~150) one can go through the porch of the Law Courts Building (rate ~265) into a delightful patio (rate ~240) and on into the lobby (rate ~120). On starting up the steps to the Library of Congress from First Street, SE. (rate ~75) one comes to the first landing (rate ~150), then the second landing (rate ~225), and then the doorway (rate ~380) and on into the lobby (rate ~115). On approaching the north entrance of the Old Executive Office Building one leaves the sidewalk on Pennsylvania Avenue (rate ~115), goes through a gateway in the fence (rate ~165), crosses a flagstone-paved patio (rate ~190) and up to the top of the steps (rate ~400) and into the lobby (rate ~135). Apart from these observations there is Weinberg's Senate Hearing room (rate ~250).

(v) Variability

Differences in natural background exposure rates of 50 to more than 100 mrad/yr have already been identified in earlier sections of this discussion. Such, for example, as that in the cosmic radiation background between locations at sea-level and locations at an altitude of 3 or 4 km., and as, also, that in the terrestrial background between the Coastal Plain and the Denver, Colorado Regions. Reference to these instances suggests broad, sweeping changes as between some location and another location a continent or part of a continent away.

however, the variations noted in the local surveys just described make it clear that the broad contours of the radiation intensity surface are overlaid by an irregular, fine-textured network of variations of appreciable size. It is not necessary for an individual to travel from the East Coast to Denver in order to encounter large changes in his rate of exposure to background radiation. Considerable variations will be experienced by a stationary individual in many locations, by individuals traveling a few miles to the store in many parts of the country (as evidenced by the NRC survey), by individuals residing in one house or in another house a few blocks away (as from the Los Alamos survey), or by individuals crossing from one side of the street to the other (as in Washington). Of course, the 'countrywide, population-weighted, average annual exposure' is a perfectly well-defined concept which is useful for some purposes, even if there should not be an individual anywhere who actually receives just that exposure for one year, let alone two years running.

IV. Observations and Comments

We know that extreme exposures to radiation can be fatal, and we know a fair amount about the levels which produce lethal effects in a short time. We even know that there is some risk that an exposure about twenty times smaller than one resulting in a prompt fatality -- a whole-body exposure, that is, of something like 20 or 30 rem of low-LET radiation delivered in a short time -- may, with a rather poorly known probability, initiate processes which result in fatality years later. However, there is a gap of about two orders of magnitude between the dose levels for which observational data are available and the levels provided by natural sources. As stated in UNSCEAR-77, "It must be emphasized, however, that such estimates" (referring to their estimate of $\sim 10^{-4}$ fatal malignancies/person-rad) "are derived predominantly from rates observed following absorbed doses of over 100 rads," and "In particular, at low doses in the region of those received annually from natural sources, no direct information is available as to the level of induction of malignancies that might apply."

The human species has, of course, been receiving this natural background radiation, including variations of the sort already described, through the whole period of evolutionary time. Over that period it has evolved from primitive life forms, through the earliest hominids, and on to modern man. In the course of this it will have experienced a large number of mutations, of which some fraction will have been induced by natural background radiation. It seems to be generally felt that the outcome of this process has been favorable.

In its development the species has accommodated to the factors found in its environment; and for many of these factors there is a range of exposure levels which appear to be optimal for the well-being of the organism. Frequently this range is in the neighborhood of the levels usually encountered. Exposures (or supplies) at levels within this range may be either neutral, or beneficial, or essential to the organism's well-being; whereas great deficiencies may be detrimental or fatal, as may great excesses. Such is the case, for example, for the physical factors of heat, light, sound, and moisture. It is also the case for many chemical substances such as Vitamin A, and even materials containing arsenic and selenium. These, and many other substances, are essential in trace amounts but are deleterious or lethal at even moderate doses.

An agent having beneficial effects at low levels which would not be indicated by interpolation from its known deleterious effects at high levels is sometimes referred to as "hormetic." It is not known whether low-LET radiation is hormetic for the human organism, but it would not be greatly surprising if such should be the case. A large number of examples of radiation hormesis have been observed in a wide range of plant and animal species -- at least as gauged by such factors as growth rate, fertility, and longevity. Included in these observations is a series in which the rate of proliferation of a colony of bacteria increased as the radiation level was raised to fourteen times the natural background, but decreased both as the radiation level was raised still further, and as it was reduced by a factor of six below natural background by 10 cm of lead shielding. Suggestive as such observations may be, they are, of course, by no means conclusive as to an hormetic effect of radiation on the specific and complex system constituting human tissue.

In contrast with this there is no doubt that a single quantum can damage a cell or induce a mutation. A quite enormous number of experiments have been conducted on cell colonies and various types of animals showing deleterious effects of exposures of ~10 rads, or more. Such observations are also suggestive; but, as pointed out in UNSCEAR 77, they do not yet provide any direct information concerning the incidence of carcinogenesis in man resulting from exposures in the general range of natural background levels.

There are many cautionary statements by many authorities calling attention to the lack of actual knowledge on this last point. Those which appear in BEIR III include the following:

- "The Committee does not know whether dose rates of gamma or X-rays of about 100 mrad/yr are detrimental to man."
- "The quantitative estimation of the carcinogenic risk of low-dose, low-LET radiation is subject to numerous uncertainties. The greatest of these concerns the shape of the dose-response curve."
- "For the most part, the available human data fail to suggest any specific dose-response model."
- The collective influence of the uncertainties which apply "is such as to deny great credibility to any estimates that can now be made for low-dose, low-LET radiation."
- For its illustrative computations of the lifetime risk from whole-body exposure the Committee chose the situations of a single exposure to 10 rads, and a continuous lifetime exposure to 1 rad/yr, and then said: "Below these doses, the uncertainties of extrapolation of risk were believed by some members of the Committee to be too great to justify calculation."

In the face of these and other similar warnings that there is no factual basis for any particular estimate of the risk which might apply as a result of an exposure in the range of one to a few hundred mrad, precise values are routinely asserted for such quantities by regulators (and others) on the basis of the

no-threshold linear hypothesis. Of course, different precise values are equally firmly asserted by different estimators since the slope of the line employed is open to some choice. For example, the average risk of inducing a fatal malignancy was taken as being "in the region of 10^{-4}/rad" in UNSCEAR-77; but the coefficient multiplying 10^{-4} in the estimate of the number of fatalities per man-rem has been variously taken to be: 1.25 (ICRP-26, 1977), 1.7 (BEIR 1972, 1980, and 10 CFR 20, NRC, 1985), 2.3 (NUREG-1150, 1987), 2.7 (40 CFR 191, EPA, 1985), and 3.75 (40 CFR 193, EPA, 1987).

Though these assorted values display the lack of any absolute technical basis for the assumptions, to a very large extent the no-threshold linear hypothesis has been accorded the status of an axiom. Two important corollaries follow from this hypothesis. The first is that the risk to the individual is directly proportional to the dose (that is, the increment in exposure over natural background plus radiation received for medical purposes) independently of the size of the incremental exposure or the level of the background. (The medical component, incidentally, though highly variable from person to person, is estimated (NCRP, 1987) to add 53 mrem/yr to the average exposure of the population of the U.S.). The second corollary is that the collective consequences of an incremental exposure of a population are directly proportional to the integral of the incremental number of man-rem delivered, independently of the size of the incremental exposures. For hypothetical incidents, at least, the incremental total of man-rem is itself the endpoint of a chain of assumptions concerning meteorological factors, individual behavior, and so forth.

Not everyone subscribes to the linear hypothesis. There are those who hold that at low exposures the dose-response curve is concave downwards and lies above a straight line from the origin so that the effects at low doses will be larger -- possibly much larger -- than indicated by the linear hypothesis. There are also those -- including the majority of the BEIR III Committee -- who consider it probable that the true response curve is concave upwards, lies below a straight line through the origin, and that the effects at low doses will be less -- possibly considerably less -- than indicated by the linear hypothesis. And then, as mentioned above, there are those who hold that radiation may be hormetic. For those, exposures in some range of low doses would not necessarily constitute any risk at all. Arguments can be (and have been) adduced in support of each of these dose-response models; but, as already noted, the BEIR III Committee concluded "the available human data fail to suggest any specific dose-response model."

Whether the fashionable linear hypothesis represents any biological reality or not, it does have two features in its favor. One (for which few public claims are made) is that it is wonderfully economical of regulatory thought. The other (that most commonly urged in its defense) is that it is said to be "prudent." This neo-technical term -- like its sister regulatory term "conservative" -- is frequently invoked to provide an unassailable license to make mistakes, as long as they are made in the right direction, i.e., to overstate the negative aspects. However, other considerations must also be taken into account, and a "prudent" estimate on one side of an equation is unlikely to be of assistance in striking a (truly) prudent balance between conflicting considerations -- a balance, that is, reflecting the exercise of good judgment.

The ALARA principle may be taken as an example. Here the intention is to reduce risk, but the quantity which can be directly affected by actions taken is potential radiation exposure. It becomes progressively harder (and more expensive) to reduce the potential exposure the lower the level at the start. The resources devoted to the exercise of ALARA are themselves of interest to the public; but the ALARA principle is open-ended. To avoid the indefinite and ultimately pointless iteration of cost-benefit analyses along with efforts to devise means of reducing potential exposures to ever lower levels, there is an obvious need for some sort of floor for the further imposition of ALARA. Of course, along with ALARA and the linear hypothesis we do have the $1,000 per man-rem convention; but this merely intercalibrates the scales for risk estimates and costs, albeit in a somewhat arbitrary fashion. It enables cost-benefit analysis, and may serve to support a decision that some particular mechanical measure estimated to reduce exposures by such and such an amount is not "worthwhile." But it goes no way towards saying when further study may be laid aside. Neither the linear hypothesis -- and particularly not the presumed prudence of the risk estimates derived from it -- nor the $1,000 per man-rem convention provide any logical assistance in specifying a reasonable floor for ALARA.

Similar conditions apply to attempts to establish a de minimis dose. While this and a floor for ALARA have much in common they are by no means identical. The one refers to a level at which further efforts at reduction would not be mandatory. The other refers to a dose level at which the consequences (if any) would be deemed trifling and would not warrant consideration -- either by regulators, individuals, or society. It has been urged that the establishment of a de minimis level would serve a number of useful purposes, such as providing a cut-off for regulatory efforts (presumably including estimation of collective doses), providing limits for control programs, and, conceivably, assisting in developing a better public understanding of the significance of radiation exposure. Any level selected will have to meet a number of conditions, among them that it can be adequately measured, but also that it be capable of gaining public acceptance.

The desirability of an official de minimis dose has been discussed for many years among many groups. Most frequently such discussions have started (and often ended) with attempts to decide on an "acceptable risk." Levels for the risk of premature death in the range of 10^{-6} to 10^{-3}/yr have been mentioned in this connection and, with the help of the linear hypothesis, a corresponding range of dose levels: from less than one to over a hundred mrem/yr. It is, of course, far from clear what an "acceptable" risk level may be, or even if there is one. Much has been made of the fact that even in so-called "safe" industrial settings the (occupational) risk may run as high as 10^{-4}/yr; and, since this appears to be acceptable, presumably any risk appreciably smaller -- such as 10^{-6}, say -- ought to be acceptable too? However, this may not cover the situation. For one thing, the risks in familiar settings have not been so flamboyantly identified, debated, and belabored as they have for radiation, and may to a large extent be accepted unknowingly. For another, there is nothing to say that risks similar to or even smaller than those applying to more familiar activities would be deemed acceptable for radiation -- partly in view of its being pictured as more mysterious, but at least partly because the official assumptions have tended to endorse an unlimited and unreasoning fear. Such psychological factors could well interpose great difficulties for any risk-based

approach to settling on a reasonable prescription for a de minimis dose. There is also the more basic point that to proceed from a pre-assigned risk to an associated dose in a logical way one really needs a fairly well-founded dose-response correlation; but, as BEIR III has timelessly told us, we do not have one.

V. Conclusion

Confronted with a zone of ignorance a few decades wide we have adopted the simplest possible hypothesis for use as a convenient bridge. A priori it would seem rather unlikely that a linear dose-response function would actually provide a very good description of such a complex biological relationship as that between carcinogenesis and radiation exposure. Perhaps the best that can be said of it is that there is a majority opinion that it provides a "prudent" description. This cannot be regarded as an intellectually satisfactory basis for important decisions, particularly when there are some quite relevant facts which are known with certainty. Amongst these is the wide variation in the exposures people receive naturally

As a sufficient gesture towards "prudence" one can leave aside the most extreme situations -- such as the Ances, the Kerala Coast, or even the hearing rooms in the Dirksen Senate Office Building -- and still find that millions of people dwell in low-LET radiation fields with levels from 50 to more than 100 mrem/yr larger than the averages usually assigned to the natural background of low-LET radiation. There is no evidence that the variations encountered by these quite large contingents of the species are detrimental in any way. Such variations are similar in nature to the other inhomogeneities which mark the planet we inhabit: differences in weather and climate, sunlight, altitude, water, ice, and so forth. They are features of the environment in which we have developed, and in which we will continue to live. For the particular factor of exposure to radiation the natural background, and its variations, provide the most certain guide and basis we have (and, quite possibly, the most certain guide we ever may have) for consideration of such matters as appropriate levels for a floor to ALARA and for a de minimis dose. (These, of course, need not be the same.) Though the guidance which might be drawn from observation of the broad spectrum of natural variations would have a real basis, that would not point clearly at any precise value that should be used for the purposes we are considering. It is not proposed to try to specify such a value here. However, from the evidence which has been presented it would appear that any attempt to argue for a smaller level than 50 or 100 mrem/yr would have to construct its support on the mystical basis of the linear hypothesis.

The main intent of this discussion is to urge that we base our actions and decisions to the extent possible on things known. Quantitative statements concerning risk do not fall in that category. Particularly offensive in this respect are the statements frequently emitted by regulators to the effect that so and so many "excess fatalities" will result from such and such an incremental exposure, or be saved by this or that proposed new procedure. Such statements are not only without foundation -- derived, as they are, by the application of some simple scale factor of unknown validity -- but they also tend to give the unwarranted and revolting impression that fatalities are the coin of the realm in nuclear affairs. It is really of great importance that comments concerning risks, fatalities, and so forth should be as factual as possible. They should leave no room for doubt as to what the real situation is, namely: that neither we, nor anyone else, knows the precise relationship

between dose and response at low doses; but that, at least within the range of exposures discussed above, there is as yet no evidence of any detrimental effects on man.

NOTE CONCERNING RADIATION UNITS

The units used throughout this discussion are the "rad" and the "rem."

The rad is the unit for energy deposited by ionizing radiation of any type in any material. One rad refers to an exposure resulting in an absorbed energy (or "dose") of 100 ergs/gm. To provide a correlation between the radiation flux and the dose, it is necessary to specify the material considered. Thus, one speaks of "an absorbed dose in air" of so many rads. Since there are more electrons per gram in biological tissue than in air (resulting from the larger proportion of hydrogen in tissue) a given flux of radiation will deposit somewhat more energy per gram in tissue than in air. This difference, however, is rather small (only 7%) and is usually ignored; so that, to a reasonable approximation, a radiation exposure providing an absorbed dose in air of one rad would be said to provide one rad of absorbed dose in tissue.

The rem is the unit used to calibrate biological effects in human tissue. One rem is the dose from any radiation that produces biological effects in the body equivalent to those from one rad of X-rays within a given energy range. One rad delivered by α-particles is more damaging than one rad from X-rays, even though the amount of ionization per gram produced by the two would be the same. In the case of the α-particle most of its energy is deposited in a very short distance at the end of its path, resulting in a very high level of ionization within a quite small volume. On this account an α-particle is said to have a high Linear Energy Transfer (LET), and the radiation it provides is referred to as high-LET radiation. By contrast, an X-ray deposits its energy more uniformly along the length of its (longer) path, and X-rays (as well as γ-rays and β-particles) provide what is called low-LET radiation. To take account of the differences in biological effects, a factor -- variously referred to as the Relative Biological Effectiveness (RBE) or Quality Factor -- and, in current writing, usually designated Q -- is introduced, by which the dose in rads is multiplied to obtain the dose in rems. By definition, Q=1 for X-rays; and is also taken to be unity for γ-rays and β-particles. However, for α-particles, it is now officially agreed to take Q=20. A value of Q between 5 and 20 is currently assigned to neutrons.

One further convention is necessary. α-particles as well as β-particles, deposit their energy in a quite thin layer of tissue immediately adjacent to their source. Thus, they do not provide a "whole-body" dose, but only a dose to the organ (or small portion thereof) in which the source of such radioactivity may be located. In order to assess the relative biological hazards of the effects of radiation delivered by various means to various parts of the body, one needs some way of translating any particular organ dose onto a common scale at a level judged to represent an equivalent overall effect. The ICRP has devoted extensive efforts to developing a system of "weighting factors" whereby the dose to any particular region of the body can be converted to an appropriate value of whole-body dose equivalent (D.E.). This is called the "effective" D.E. Thus, for example, the effects of a dose of x rem to the lung tissue is taken to be adequately represented by 0.12 x rem of whole-body D.E. Obviously, the sum of all the weighting factors for the different organs, or

regions of the body judged to be significant, must equal unity -- so that a dose of x rem to each significant center will, when added up, equate to a whole-body D.E. of x rem.

As an additional comment, it may be noted that the classical unit for radiation exposure -- the Roentgen (R) -- is no longer in use, though it appears in many older and even recent reports. The Roentgen was defined in terms of the amount of ionization produced: in particular: one esu of charge in one cubic centimeter of air at standard temperature and pressure. This is equivalent to an absorbed dose in air of 87 ergs/gm (0.87 rad), or of 93 ergs/gm in tissue. At least in discussions of natural background radiation (where air and tissue are the media of interest) the rough approximation 1 R = 1 rad is frequently used. Today, there is the newer SI unit for energy deposited -- the Gray (Gy). One Gray is the exposure resulting in the deposition of one joule/kilogram (rather than 100 ergs/gm) so that 1 Gy = 100 rads. Similarly, the SI unit for dose equivalent in biological tissue -- the Sievert (Sv) -- is such that 1 Sv = 0 Gy = 100 rems.

Finally, just as one could (if one chose) calibrate velocity in terms of furlongs per fortnight, there is the unit of the Working Level (WL) to calibrate α-activity in air, and the Working Level Month (WLM) for the integrated exposure to such radioactivity. The WL is defined as a concentration of short-lived radon daughters which would result in the release of 1.3×10^5 Mev of α-energy per liter of air. The population of the radon daughters Po-218, Pb-214, Bi-214, and Po-214 in radioactive equilibrium with 100pCi/l of Rn-222 would release 1.3×10^5 Mev of α-energy per liter, and would thus provide one WL. The WLM is defined as the exposure to one WL for 170 hours. As with any attempt to correlate the concentration of airborne radioactivity with the dose delivered to any particular organ (such as the lung) resulting from inhalation, the steps are more than a little complicated; requiring, as they do, either knowledge or assumptions concerning breathing rate, departures from radioactive equilibrium (which essentially always apply except in situations where the air is quite stagnant), the particle sizes of the aerosols involved, and the extent to which the individual radon decay products are attached (or not attached) to the dust particles within the air, as well as the physiological distribution and retention of the materials inhaled. On the basis of averaging assumptions on each of these points it has been taken that one WLM corresponds to a dose of about 12-14 rem to the segmental bronchioles. With the ICRP weighting factor of 0.08, one WLM corresponds to a whole-body dose equivalent of about 1 rem.

BIBLIOGRAPHICAL NOTE

1. General references.

The following are noted in the text:

- NCRP-45, "Natural Background Radiation in the United States." National Council on Radiation Protection and Measurements. Report No. 45, Washington D.C. (1975).

- UNSCEAR. United Nations Scientific Committee on Effects of Atomic Radiation. Report on "Sources and Effects of Ionizing Radiation." New York:United Nations. (1972, 1977, 1982).

- BEIR. National Research Council, Committee on the Biological Effects of Ionizing Radiations. "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation." 1972 (BEIR-I), 1980 (BEIR-III). Washington, D.C. National Academy Press.

- ICRP-26. Recommendations of the International Commission on Radiological Protection. Publication No. 26. Pergamon. (1977).

- Though not noted in the text, an excellent discussion of this whole field is presented in:
  Eisenbud, M. "Environmental Radioactivity." 2nd Ed., 1973; 3rd Ed., 1987 Academic Press.

2. Particular Topics. Details may be found in the following.

For Section I:

- Beck, H.L., de Planque, G. "The Radiation Field in Air Due to Distributed Gamma-Ray Sources in the Ground." USAEC Report HASL-195 (1968).

- Oakley, D.T. "Natural Radiation Exposure in the United States." USEPA report ORP/SID 72-1 (1972).

- Grasty, R.L., et al. "Natural Background Radiation in Canada." Bulletin 360, Geological Survey of Canada (1984).

- Report of the Minister of the Interior of the Federal Republic of Germany presenting the results of a survey of the background radiation (both outdoors and indoors) in the FRG. (1977).
  ["Die Strahlenexposition von Aussen in der Bundesrepublik Deutschland Durch Natürliche Radioaktive Stoffe im Freien und in Wohnungen."]

For Section II:

- Papers in: the Proceedings of the First (and Second and Third) International Symposium on the Natural Radiation Environment. Three symposia were held in Houston, Tx.; in Apr. 1963, Aug. 1972, and Apr. 1978. The Proceedings were published under the titles:
  "The Natural Radiation Environment," J.A.S. Adams and W.M. Lowder (editors), Univ. Chicago Press (1964).
  "The Natural Radiation Environment - II," J.A.S. Adams, W.M. Lowder, and T.F. Gesell (editors), USERDA CONF - 720805 (1972).
  "The Natural Radiation Environment - III," T.F. Gesell and W.M. Lowder (editors) US DOE CONF - 780422 (1978).

- Papers in: Natural Radiation Environment, Proc. Second Special Symposium on Natural Radiation Environments, Bombay, Jan. 1981, K.G. Vohra, U.C. Mishra, K.C. Pillai and S. Sadasivan (editors). John Wiley & Sons. (1982).

- Muller, R, "Natural Radiation Background vs. Radiation from Nuclear Power Plants." Journal of Environmental Sciences, July/August 1972.

For Section III:

- Gulbin, J. and de Planque, G., "Ten Years of Residential TLD Monitoring." Rad. Prot. Dosimetry, 6, 299-303. (1984).
- de Planque, G., and Gesell, T.F., "Environmental Measurements with Thermoluminescence Dosemeters -- Trends and Issues." Rad. Prot. Dosimetry, 17, 193-200. (1986).
- High Background Radiation Research Group. "Health Survey in High Background Radiation Areas in China." Science, 209, 877-880, 1980.
- NUREG-0837. NRC TLD Direct Radiation Monitoring Network. (Quarterly Reports) Vol. 2, 1982; Vol. 3, 1983.
- Annual Reports of the Environmental Surveillance Group, Los Alamos National Laboratory. (1980-1985).

For Section IV:

- Special Issue on Radiation Hormesis. Health Physics, 52,5. (1987).
- Adams, J.A.S., in Natural Radiation Environment, Special Second Symposium. (1981).
- Schiager, K.J. et al. Special Report "De Minimis Environmental Levels: Concepts and Consequences." Health Physics, 50, No. 5, 569-579, 1986.

Backfill Sample Analysis Report

Sample Date: 9/16/96 **Location: Wheaton, ILL.**

As Recieved Basis **Dry Weight Basis**

Sample Number	Sample Moisture in percent	U-238 in pCi/g	2 sigma uncertainty in pCi/g	Ra-226 in pCi/g	2 sigma uncertainty in pCi/g	Ra-228 in pCi/g	2 sigma uncertainty in pCi/g	U-238 in pCi/g	2 sigma uncertainty in pCi/g	Ra-226 in pCi/g	2 sigma uncertainty in pCi/g	Ra-228 in pCi/g	2 sigma uncertainty in pCi/g	Total Radium in pCi/g
WTS-1B	16.5	<MDA	na	1.5	0.3	1.2	0.4	<MDA	na	1.7	0.3	1.4	0.4	3.2
WTS-2B	13.5	<MDA	na	1.2	0.2	1.5	0.3	<MDA	na	1.4	0.2	1.7	0.3	3.1
WTS-4B	15.9	<MDA	na	1.3	0.3	1.5	0.4	<MDA	na	1.5	0.3	1.8	0.4	3.4
WTS-7B	16.2	<MDA	na	1.1	0.2	1.3	0.3	<MDA	na	1.3	0.2	1.6	0.3	2.8
WTS-8B	17.5	1.9	0.9	1.1	0.2	1.3	0.3	2.3	0.9	1.3	0.2	1.6	0.3	2.9
WTS-11B	17.0	<MDA	na	1.3	0.3	1.6	0.4	<MDA	na	1.5	0.3	2.1	0.4	3.7
WTS-14B	9.7	<MDA	na	1.3	0.3	1.7	0.4	<MDA	na	1.4	0.3	1.9	0.4	3.3
WTS-15B	13.8	<MDA	na	1.2	0.3	1.9	0.4	<MDA	na	1.4	0.3	2.2	0.4	3.7
WTS-QC1B	16.1	<MDA	na	1.4	0.3	1.9	0.4	<MDA	na	1.6	0.3	2.3	0.4	3.9
WTS-QC2B	20.2	<MDA	na	1.0	0.3	1.5	0.4	<MDA	na	1.2	0.3	1.9	0.4	3.1

The MDA values are: U-238 1.47 pCi/g; Ra-226 0.43 pCi/g; and Ra-228 0.67 pCi/g.

Samples analyzed using method SOP-RAR 366.

Samples counted for ten minutes.

9/18/96

9/19/96

9-19-96

F.U RAR-6.2-1

Backfill Sample Analysis Report

Sample Date: 9/10/96

Location: South Elgin, ILL.

As Recieved Basis **Dry Weight Basis**

Sample Number	Sample Moisture in percent	U-238 in pCi/g	2 sigma uncertainty in pCi/g	Ra-228 in pCi/g	2 sigma uncertainty in pCi/g	Ra-226 in pCi/g	2 sigma uncertainty in pCi/g	U-238 in pCi/g	2 sigma uncertainty in pCi/g	Ra-228 in pCi/g	2 sigma uncertainty in pCi/g	Ra-226 in pCi/g	2 sigma uncertainty in pCi/g	Total Radium in pCi/g
LEC - 3B	8.2	<MDA	na	2.1	0.3	0.9	0.4	<MDA	na	2.3	0.3	1.0	0.4	3.3
LEC - 5B	5.8	<MDA	na	1.9	0.3	1.2	0.4	<MDA	na	2.0	0.3	1.3	0.4	3.2
LEC - 6B	6.7	1.4	0.7	2.6	0.2	0.8	0.3	1.5	0.7	2.8	0.2	0.9	0.3	3.7
LEC - 10B	8.2	<MDA	na	1.0	0.3	1.3	0.4	<MDA	na	1.1	0.3	1.4	0.4	2.5
LEC - 11B	10.6	<MDA	na	2.0	0.2	1.3	0.3	<MDA	na	2.2	0.2	1.4	0.3	3.6
LEC - 12B	6.4	<MDA	na	2.0	0.2	1.2	0.3	<MDA	na	2.1	0.2	1.3	0.3	3.5
LEC - 13B	8.5	<MDA	na	2.4	0.3	1.2	0.4	<MDA	na	2.6	0.3	1.3	0.4	3.9
LEC - 16B	7.2	<MDA	na	3.3	0.3	<MDA	na	<MDA	na	3.5	0.3	<MDA	na	3.5
QC1B	9.7	<MDA	na	1.7	0.2	1.3	0.3	<MDA	na	1.9	0.2	1.4	0.3	3.3
QC2B	6.3	<MDA	na	2.0	0.2	0.9	0.3	<MDA	na	2.2	0.2	0.9	0.3	3.1

The MDA values are: U-238 1.41 pCi/g; Ra-228 0.41 pCi/g; and Ra-226 0.62 pCi/g.

Samples analyzed using method SOP-RAR 366.

Samples counted for ten minutes.

RAR 6.2.1

Revised Data Quality Evaluation of Kerr McGee West Chicago Samples

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DATE: September 7, 1998

Introduction

This technical memorandum (TM) is a revision of the TM prepared on May 28, 1998 and describes the results of the CH2M HILL data quality evaluation process (DQEP) used to review and validate data generated as part of the Kerr-McGee West Chicago RI/FS. In addition to the results reported in May, this TM also presents the results of the DQEP for Radium-226 and Radium-228 data reported by NAREL in June and August 1998, respectively.

Samples were collected for the analysis of radiochemical and conventional parameters. Field samples were submitted to NAREL for radiochemical analyses of Uranium (U-234, U-235, U-238), Thorium (Th-227, Th-228, Th-230, Th-232), Radium-226 (Ra-226) and Radium-228 (Ra-228). These samples were also characterized for gross alpha and gross beta activities. In addition, samples were submitted to Katalyst ATI Laboratories for the analysis of total and dissolved metals, volatile and semivolatile organics.

The DQEP consisted of review and evaluation of the following (as applicable to the method):

- data package completeness
- holding times
- instrument tuning
- initial and continuing calibration
- instrumental efficiencies and background
- surrogate recoveries
- internal standard areas
- serial dilution results
- interference check standard results
- matrix-spike / matrix spike duplicate precision and accuracy
- chemical yield
- laboratory and field blank contamination

- duplicate/replicate sample results

The DQEP for the subset of samples characterized for gross alpha/beta activities was limited to an evaluation of package completeness.

This report consists of six sections. Section 1.0 summarizes the body of samples validated. Section 2.0 summarizes the analytical methods and targeted analytes for all analyses. Section 3.0 describes the individual steps in the review and validation of laboratory data. Section 4.0 summarizes results from the validation procedures for both laboratory performance factors (Section 4.1) and multiple measures (Section 4.2). Section 5.0 provides a bulleted summary of the overall usability of the data, as determined through the validation process.

1.0 Summary of Samples Collected

The field samples, including field QC, validated as part of the DQEP process are summarized in Table 1.

Table 1 – Summary of Samples Reviewed

Field Sample ID	Parameter List
GW-RKP-1 Total	Isotopic U and Th, Ra 226, Ra-228[a], Tot Metals, VOC's, SVOC's
GW-RKP-1 Dissolved	Isotopic U and Th, Ra 226, Ra-228[a], D Metals
GW-RKP-2 Total	Isotopic U and Th, Ra 226, Ra-228[a], Tot Metals, VOC's, SVOC's
GW-RKP-2 Dissolved	Isotopic U and Th, Ra 226, Ra-228[a], D Metals
GW-RKP-3 Total	Isotopic U and Th, Ra 226, Ra-228[a], Tot Metals, VOC's, SVOC's
GW-RKP-3 Dissolved	Isotopic U and Th, Ra 226, Ra-228[a], D Metals
GW-RKP-4 Total	Isotopic U and Th, Ra 226, Ra-228[a], Tot Metals, VOC's, SVOC's
GW-RKP-4 Dissolved	Isotopic U and Th, Ra 226, Ra-228[a], D Metals
GW-MW-2 Total	Isotopic U and Th, Ra 226, Ra-228[a], Tot Metals, VOC's, SVOC's
GW-MW-2 Dissolved	Isotopic U and Th, Ra 226, Ra-228[a], D Metals
GW-MW-1 Total	Isotopic U and Th, Ra 226, Ra-228[a], Tot Metals, VOC's, SVOC's
GW-MW-1 Dissolved	Isotopic U and Th, Ra 226, Ra-228[a], D Metals
GW-MW-6 Total	Isotopic U and Th, Ra-226[b], Ra-228[a], Tot Metals, VOC's, SVOC's
GW-MW-6 Dissolved	Isotopic U and Th, Ra-226, Ra-228[a], D Metals

Field Sample ID	Parameter List
GW-MW-5 Total	Isotopic U and Th, Ra 226, Ra-228[a] Tot Metals, VOC's, SVOC's
GW-MW-5 Dissolved	Isotopic U and Th, Ra 226[b], Ra-228[a] D Metals
GW-RKP-5 Total	Isotopic U and Th, Ra 226, Ra-228[a] Tot Metals, VOC's, SVOC's
GW-RKP-5 Dissolved	Isotopic U and Th, Ra-226, Ra-228[a] Diss Metals
FB012798 Total (FB121797)	Isotopic U and Th, Ra-226 [b], Ra-228[a] Tot Metals, VOC's, SVOC's)
TB121797	VOC's only

[a] Indicates results reported in August, 1998
[b] Indicates results reported in June, 1998

Validated nuclide specific groundwater results including uranium, thorium and radium-226 and radium-228 are presented in Tables 2, 3, 4 and 5, respectively. Corresponding unvalidated gross alpha and gross beta results are shown in Table 6. Validated results for volatile organics, semi-volatile organics and total and dissolved metals are summarized in Table 7, 8 and 9, respectively.

2.0 Summary of Analytical Methodologies

Samples collected as part of the RI/FS activities were analyzed by a number of radiochemical methods for both gross radiation characterization as well as quantitation of individual target radionuclides. Samples were also analyzed for conventional chemistry parameters. Table 10 below summarizes analytical methods in terms of targeted analytes.

Table 10 – Target Analytes and Methods

Target Analyte(s)	Method
Uranium and Thorium Isotopes	Alpha Spectroscopy
Radium-226	Radon Emanation/Scintillation Counting
Radium-228	Beta counting
Volatiles	CLP SOW OLM03
Semivolatiles	CLP SOW OLM03
Total and Dissolved Metals	CLP SOW ILM04

3.0 Data Review and Validation

The project chemists using the process outlined in the site-specific QAPP reviewed radiological data packages. Conventional organic and inorganic data were validated in accordance with EPA's *National Functional Guidelines for Inorganic and Organic Data Review.* The data review and validation process, which is independent of the laboratory's checks, focused on the usability of the data to support the project data interpretation and decision-making process. Areas of review included (as applicable to the method):

- Data package completeness
- Sample holding times
- Initial and continuing calibration
- Instrument tuning
- Matrix spike /matrix spike duplicate recoveries and precision
- Surrogate recoveries
- Internal standard areas
- Chemical yields, efficiency and background measurements
- Laboratory method and field blank contamination
- Duplicate/replicate sample results

In the event that certain data were determined not to meet the specified acceptance criteria, a data qualification flag and subflag were entered into the DQEP database. The data qualification flags used for radiological sample results are shown below:

- J - Indicates the analyte is present, but the reported value may not be accurate or precise because the associated QA/QC did not meet acceptance criteria. The result is considered "estimated."

- R - Indicates the data are unusable. This flag is used when the result should not be used to support project decisions. The result is considered "rejected."

- U - Indicates that the sample was analyzed, but the analyte was not detected above the stated concentration. The result is considered "undetected."

The following subqualifiers give further detail on the type and amount of qualification a given radiochemical result has received:

- D - Qualified because laboratory duplicate control limits were exceeded.

- S - Qualified because recovery control limits were exceeded.

- C - Qualified because of instrument calibration problems.

- Q - Qualified because of blank contamination problems.
- M - Qualified because laboratory spike control limits were exceeded.
- Q - Qualified for reasons not stated above, references reader to the validation worksheet for additional details.

Samples analyzed for conventional inorganics and organics that were not within the acceptance limits were appended with a qualifying flag, which consists of a single or double-letter abbreviation that indicates a problem with the data. Although the qualifying flags originate during the data review and validation process, they are included in the data summary tables so that the data will not be used indiscriminately. The following flags were used in this text:

- U - Undetected. Analyte was analyzed for but not detected above the method detection limit.
- UJ -Detection limit estimated. Analyte was analyzed for, and qualified as not detected. The result is estimated.
- J - Estimated. The analyte was present, but the reported value may not be accurate or precise.
- R - Rejected. The data are unusable. (NOTE: Analyte/compound may or may not be present.)

Numerical sample results that are greater than the method or instrument detection limit (MDL or IDL) but less than the EPA CLP Contract Required Reporting Limit (CRDL) are qualified with a "J" for estimated as required by the EPA's *National Functional Guidelines for Inorganic and Organic Data Review.*

Once each of the data packages was reviewed and the data review worksheets were completed, then the entire data set was evaluated for overall trends in data quality and usability. The data were also evaluated to identify potential data limitations or uncertainties in the laboratory.

4.0 Results of the Data Quality Evaluation Process

4.1 Laboratory Performance

The DQEP resulted in the qualification of some results; however, no data were rejected. Overall, the data completeness goal of 95 percent stated in the associated site QAPPs was exceeded, with 100 percent of the data accepted as usable.

Holding Times: The required sample holding times were meet for all samples/analytes except 18 of the 20 samples submitted for Ra-228 analysis. The exceedences of the 180-day holding time ranged from 2 to 44 days. Positive sample results were qualified as estimated, holding time exceeded, "JQ" and non-detects were qualified as "UJQ".

Laboratory Replicates: Results for a laboratory replicate with this analytical batch for all methods. This lab replicate (LR) was prepared by taking a second aliquot of the selected field sample and preparing and analyzing it in parallel with its parent sample. Replicate results provided information about analytical precision independent of the field sampling efforts. Specific acceptance criteria were established in the QAPPs, as follows:

- Control limits of 20 percent RPD for water samples were used for sample concentrations or activities greater than 5 times the MDA or CRDL

- Control limits of 1 times the MDA (or CRDL) for water samples were used for the situation where either or both sample activities or concentrations were less than 5 times the MDA (or CRDL)

All laboratory replicate precision requirements were met for the radiological and conventional methods of analysis.

Field and Laboratory Contamination: Laboratory reagent blanks (LRB) were used to determine background activities that result from environmental and reagent radiation sources and to monitor instrument background contributions. NAREL prepared and analyzed LRBs at a frequency of 1 LRB per analytical batch per analysis type (alpha isotopic, beta, etc.). Method blanks were prepared and analyzed in the same manner as the field samples for the conventional analyses. Method blanks were analyzed at a frequency of 1 per 20 samples or 1 per batch, whichever was most frequent. Two field blanks were submitted and analyzed.

The LRBs were evaluated to ascertain whether determined concentrations were quantitated at levels greater than the MDA, indicative of contamination. Sample nuclide activities found to be less than five times the associated blank activity were qualified as UB (non-detect associated with blank contamination).

According to the EPA's *Functional Guidelines for the Review of Inorganic and Organic Data*, concentrations of common organic contaminants detected in samples at less

than ten times the maximum concentration in the blanks can be attributed to field sampling and laboratory contamination rather than environmental contamination from site activities. Common contaminants include acetone, methylene chloride, and phthalates. For less common contaminants, concentrations of contaminants detected in samples at less than five times the maximum concentration in the blanks can be attributed to field sampling and/or laboratory. One trip blank and two field blanks were submitted to the laboratory with the samples.

Data qualified as UB due to blank levels greater than the MDA consisted of 15 Ra-226 samples, 20 Ra-228, 3 of Th-230, 4 of Th-232, 1 of U-234, 4 of U-235, and 10 of U-238. All blank results were at or near the MDA and are indicative of instrument noise rather than actual nuclide contamination.

There were no metals detected above the CRDL. However, arsenic, magnesium, mercury, silver, selenium, thallium, and lead were detected just above the IDL indicative of false positives due to instrument noise. Barium, calcium, copper, iron, sodium, and zinc were detected at levels indicative of low level contamination. Many of these metals are ubiquitous at low levels. Zinc is used in the galvanization of steel and as a catalyst in many chemical and/or manufacturing processes. Copper is the primary metal used in water pipes and electrical wiring. Chromium, iron, copper, and nickel are associated with many alloys or solder combinations. Barium, calcium, and sodium are common cations associated with various salts. Additionally, all of these elements can be found as trace level contaminants in acids utilized for digestion in the laboratory.

Several common laboratory contaminants were quantified in the volatile fraction. Method blanks contained 2-Butanone, 2-Hexanone, and Xylene. The field blanks contained Methylene choride, 2-Butanone, and Acetone. The trip blank was reported with Acetone as the only contaminant. Methylene chloride and acetone are used as extraction solvents in the laboratory and are common laboratory contaminants. 2-Butanone and 2-Hexanone, as ketones, are significant contaminants in rinsate solvents, such as methanol. Data qualified as non-detect due to the 5X or 10X rule included 4 samples for Acetone and 2-Butanons, and 1 for Xylene.

Phthalates are used as plasticizers. The most common phthalate is bis(2-ethylhexyl)phthalate (BEHP). Phthalates are often introduced into samples during handling. Latex gloves are generally used when handling groundwater sampling equipment such as pumps, hoses, and bailers. Additionally, laboratory chemists use gloves when performing separatory funnel extractions or setting up continuous extraction equipment. The latex gloves are coated with plasticizers such as BEHP to facilitate release of the gloves from the skin. Diethylphthalate and BEHP were reported in laboratory method blanks. BEHP and di-n-Butylphthalate were detected in the field blank. Eight samples were qualified as non-detect due to blank

contamination for BEHP and di-n-Butylphthalate. A single sample was similarly qualified for diethylphthalate.

Summary of Matrix Effects: Matrix spike / matrix spike duplicates (MS/MSD) were performed for the radiochemical and organic analyses. For the MS/MSD, three aliquots of a single field sample were analyzed: one native and two spiked with the same concentration of the target nuclides or compounds. These samples were analyzed at a frequency of one MS/MSD pair in 20 samples or one set per analytical batch, whichever was most frequent. Accuracy for the set of samples (as influenced by the matrix) was evaluated by calculating the percent recovery in the MS and MSD sample. Matrix precision is a measurement of the reproducibility of analytical results under a standard set of conditions. Comparison of the MS and MSD recoveries were utilized with these data in order to calculate relative percent difference (RPD). For the metals analysis, both MS/MSD pairs and native duplicates were prepared and analyzed.

Accuracy and precision criteria for uranium and thorium isotopic analyses met all accuracy and precision requirements. The radium-226 measurements were all within control limits. For Ra-228, MS/MSD recoveries were above the 125% criterion at 146% and 149%, respectively. All the associated Ra-228 results were qualified as estimated, "JS".

Organic results are not qualified upon the results of MS/MSD samples alone. Evaluation is in conjunction with surrogate and internal standard (if applicable) results. All MS/MSD results for SVOC's and all but 1 compound in the VOC MS/MSD were within criteria. All of the VOC surrogate and internal standard requirements were met and thus no flags were applied. This indicates that the specific sample matrix did not influence the overall analytical process or the final numerical sample result.

All MS/MSD accuracy and precision requirements were met for the total and dissolved metals samples. Additionally, all precision criteria (with the exception of total manganese) were met. All total metals samples were flagged as "J or UJ". All field samples were postspiked as per the SOW for the GFAA metals of arsenic, lead, selenium, and thallium. Several postspikes were found to be outside criteria and were flagged as "J or UJ".

4.2 Field Duplicate Results

The sampling activities generated blind field duplicate samples that were submitted to the laboratories for analyses. These data were reviewed and the RPDs between parent and field duplicate activities (or concentrations) were calculated as a measure of assessing precision of field sampling techniques. Additionally, matrix

homogeneity is assessed by this measurement. Since no performance standards were developed in the QAPPs, analytical results were not qualified based on field duplicate RPDs.

One dissolved and one total groundwater field duplicate set were collected for this suite of radiological and chemical analyses. All field duplicate precision requirements were met.

5.0 Summary and Conclusions

The following conclusions can be drawn from the DQEP:

- The laboratories analyzed the samples in accordance with the site specific work plans as demonstrated by acceptable instrument calibrations and tracer recoveries

- Results of the reagent blank (LRB) analyses indicated that field sample results are not biased by laboratory-related contamination

- Holding time for 18 of the 20 samples submitted for Ra-228 analysis was exceeded and resulted in the qualification of associated sample results as estimated

- The conventional parameter method blank results indicated some laboratory contamination from common laboratory/field contaminants. All affected samples were qualified as "U", non-detect due to blank contamination

- Matrix spike recoveries and duplicate sample results indicate that specific sample matrix did not significantly interfere with the analytical process

- The evaluation process resulted in the acceptance of all data (100% completeness)

These radiochemical and conventional data can be used in the project decision-making process without further qualification.

Table 2 U-Isotopic
Kerr McGee West Chicago

NAREL Sample ID	Client Sample ID	UNITS	TOT/DISS	U234 Activity	PQ	Uncertainty	MDC	U235 Activity	PQ	Uncertainty	MDC	U238 Activity	PQ	Uncertainty	MDC
98.00081P	GW-RKP-1	PCI/L	TOT	2.14E-01	=	4.40E-02	1.10E-02	1.27E-02	UB	1.10E-02	7.60E-03	1.53E-01	=	3.70E-02	6.40E-03
98.00082Q	GW-RKP-1	PCI/L	DISS	1.36E-01	UB	3.80E-02	1.70E-02	1.48E-02	UB	1.30E-02	8.90E-03	2.01E-01	=	4.60E-02	1.50E-02
98.00083R	GW-RKP-2	PCI/L	TOT	2.96E-01	=	5.60E-02	1.90E-02	2.30E-02	UB	1.80E-02	2.00E-02	2.41E-01	=	5.00E-02	1.50E-02
98.00084T	GW-RKP-2	PCI/L	DISS	3.57E-01	=	6.50E-02	3.00E-02	1.31E-02	=	1.50E-02	2.40E-02	2.66E-01	=	5.50E-02	2.50E-02
98.00085U	GW-RKP-3	PCI/L	TOT	5.16E-01	=	1.00E-01	3.40E-02	5.53E-02	=	3.50E-02	1.70E-02	4.88E-01	=	9.90E-02	2.40E-02
98.00086V	GW-RKP-3	PCI/L	DISS	6.11E-01	=	1.10E-01	4.50E-02	2.05E-02	=	2.40E-02	3.50E-02	5.14E-01	=	9.90E-02	2.60E-02
98.00087W	GW-RKP-4	PCI/L	TOT	3.33E+00	=	3.90E-01	6.40E-02	1.48E-01	=	8.10E-02	6.30E-02	3.21E+00	=	3.80E-01	7.20E-02
98.00088X	GW-RKP-4	PCI/L	DISS	2.77E+00	=	3.70E-01	6.80E-02	1.03E-01	=	7.30E-02	6.50E-02	2.62E+00	=	3.60E-01	6.10E-02
98.00089Y	GW-MW-2	PCI/L	TOT	9.89E-02	UB	3.10E-02	1.60E-02	2.75E-02	UB	1.70E-02	8.30E-03	7.82E-02	UB	2.80E-02	1.60E-02
98.00090Q	GW-MW-2	PCI/L	DISS	9.68E-02	=	4.80E-02	3.70E-02	1.50E-02	=	2.80E-02	5.10E-02	1.15E-01	=	5.10E-02	3.30E-02
98.00090Q	GW-MW-2 DUP	PCI/L	DISS	1.52E-01	=	6.70E-02	6.80E-02	1.78E-02	=	2.40E-02	3.50E-02	1.00E-01	=	4.90E-02	3.80E-02
98.00091R	GW-MW-1	PCI/L	TOT	2.33E+00	=	3.10E-01	5.40E-02	3.18E+01	=	1.20E-01	8.90E-02	1.75E+00	=	2.70E-01	9.50E-02
98.00092T	GW-MW-1	PCI/L	DISS	2.18E+00	=	2.18E-01	2.70E-02	9.10E-02	=	4.20E-02	3.00E-02	1.36E+00	=	1.60E-01	2.80E-02
98.00093U	GW-MW-6	PCI/L	TOT	2.43E-01	=	7.20E-02	4.10E-02	1.19E-01	=	5.40E-02	3.60E-02	1.40E-01	=	5.40E-02	3.60E-02
98.00094V	GW-MW-6	PCI/L	DISS	1.06E-01	UB	3.40E-02	2.10E-02	1.84E-02	UB	1.60E-02	1.80E-02	8.16E-02	=	2.90E-02	1.30E-02
98.00610T	GW-MW5	PCI/L	TOT	1.50E+01	=	1.50E+00	1.70E-01	1.43E+00	=	4.10E-01	8.40E-02	1.46E+01	=	1.50E+00	7.00E-02
98.00611U	GW-MW5	PCI/L	DISS	1.64E+01	=	1.70E+00	1.60E-01	1.06E+00	=	3.70E-01	1.60E-01	1.51E+01	=	1.60E+00	1.90E-01
98.00612V	FB121797	PCI/L	TOT	1.69E-01	=	6.50E-02	4.00E-02	9.76E-02	=	5.20E-02	2.10E-02	9.51E-02	=	4.90E-02	3.60E-02
98.00613W	GW-RKP-5	PCI/L	TOT	3.07E+00	=	3.80E-01	1.00E-01	2.77E-01	=	1.10E-01	7.00E-02	3.17E+00	=	3.80E-01	4.50E-02
98.00614X	GW-RKP-5	PCI/L	DISS	3.72E+00	=	4.40E-01	8.20E-02	4.22E-01	=	1.50E-01	8.00E-02	3.29E+00	=	4.00E-01	5.10E-02
98.00615Y	FB121798	PCI/L	TOT	6.57E-02	UB	4.50E-02	5.50E-02	6.77E-02	=	4.50E-02	3.60E-02	4.09E-02	UB	3.40E-02	4.00E-02

Notes
TOT - Total
DISS - Dissolved
pCi/L - picoCurie per Liter
MDC - Minimum Detectable Concentration
PQ - Project Qualifier
U - Indicates that the samplewas analyzed,but the analyte was not detected above the stated concentration.The result is considered "undetected." Qualified for reasons not stated above refe to the text of the validation worksheet.
= - Indictes no qualification flag was assigned (placeholder).

Table 3 Th-Isotopic
Kerr McGee West Chicago

NAREL Sample ID	Client Sample ID	TOT/DISS	Th227 Activity	PQ	Uncertainty	MDC	Th228 Activity	PQ	Uncertainty	MDC	Th230 Activity	PQ	Uncertainty	MDC	Th232 Activity	PQ	Uncertainty	MDC
98.00081P	GW-RKP-1	TOT	3.96E-03	=	8.90E-03	1.80E-02	-7.17E-03	=	3.30E-02	6.10E-02	8.55E-03	=	8.00E-03	9.80E-03	9.07E-03	=	7.90E-03	8.30E-03
98.00082Q	GW-RKP-1	DISS	2.85E-03	=	8.70E-03	1.90E-02	1.92E-02	=	3.50E-02	5.80E-02	8.19E-03	=	7.70E-03	9.40E-03	3.07E-03	=	4.30E-03	4.60E-03
98.00083R	GW-RKP-2	TOT	-1.36E-02	=	8.60E-03	4.00E-02	5.90E-02	=	5.00E-02	7.90E-02	4.17E-02	UB	2.00E-02	1.50E-02	2.19E-02	=	1.50E-02	1.50E-02
98.00084T	GW-RKP-2	DISS	6.77E-03	=	1.20E-02	2.10E-02	1.01E-03	=	4.30E-02	7.80E-02	2.92E-03	=	8.30E-03	1.70E-02	4.37E-03	=	6.20E-03	6.60E-03
98.00085U	GW-RKP-3	TOT	1.44E-02	=	3.80E-02	7.60E-02	5.36E-02	=	9.50E-02	1.60E-01	8.67E-02	=	4.10E-02	2.40E-02	2.63E-02	=	2.30E-02	2.40E-02
98.00086V	GW-RKP-3	DISS	5.37E-03	=	2.50E-02	6.00E-02	-5.47E-02	=	7.80E-02	1.50E-01	2.46E-02	UB	2.20E-02	2.30E-02	1.01E-02	=	1.90E-02	3.40E-02
98.00087W	GW-RKP-4	TOT	7.40E-02	=	8.10E-02	1.20E-01	3.25E-03	=	1.60E-01	2.90E-01	4.56E-02	=	4.30E-02	5.20E-02	0.00E+00		2.00E-02	5.80E-02
98.00088X	GW-RKP-4	DISS	8.34E-02	=	6.50E-02	6.90E-02	1.11E-02	=	1.30E-01	2.30E-01	9.01E-02	=	4.80E-02	3.20E-02	2.25E-02	=	2.50E-02	3.20E-02
98.00089Y	GW-MW-2	TOT	0.00E+00		1.50E-02	4.00E-02	3.07E-02	=	5.50E-02	9.30E-02	-8.50E-04	=	8.50E-03	2.20E-02	7.64E-03	=	1.10E-02	1.70E-02
98.00090Q	GW-MW-2	DISS	1.35E-02	=	2.10E-02	3.50E-02	7.88E-02	=	7.20E-02	1.20E-01	2.81E-02	UB	1.90E-02	9.40E-03	-2.08E-03	=	2.90E-03	1.90E-02
98.00090Q	GW-MW-2 DUP	DISS	2.51E-02	=	2.40E-02	2.80E-02	1.83E-03	=	6.10E-02	1.10E-01	2.42E-02	UB	1.80E-02	1.80E-02	1.94E-03	=	6.10E-03	1.50E-02
98.00091R	GW-MW-1	TOT	8.08E-02	=	9.00E-02	1.40E-01	1.12E-01	=	2.00E-01	3.40E-01	1.77E-01	=	8.30E-02	6.90E-02	7.53E-02	=	5.30E-02	4.50E-02
98.00092T	GW-MW-1	DISS	1.72E-02	=	3.80E-02	7.60E-02	-5.24E-02	=	9.20E-02	1.80E-01	2.41E-02	=	2.50E-02	3.40E-02	5.55E-03	=	1.10E-02	1.70E-02
98.00093U	GW-MW-6	TOT	1.76E-02	=	2.70E-02	4.60E-02	5.84E-02	=	8.50E-02	1.40E-01	5.23E-03	=	1.50E-02	3.10E-02	7.84E-03	=	1.40E-02	2.70E-02
98.00094V	GW-MW-6	DISS	-8.10E-03	=	1.10E-02	3.90E-02	3.39E-02	=	4.70E-02	7.90E-02	2.11E-03	=	9.44E-03	2.00E-02	2.81E-03	=	1.10E-02	2.20E-02
98.00610T	GW-MW5	TOT	5.12E-02	=	1.40E-01	3.00E-01	5.19E-02	=	4.10E-01	7.20E-01	9.34E-02	=	9.10E-02	1.00E-01	2.66E-02	=	6.00E-02	1.20E-01
98.00611U	GW-MW5	DISS	1.85E-01	=	2.40E-01	3.90E-01	1.20E-01	=	4.20E-01	7.30E-01	5.14E-02	=	1.00E-01	1.90E-01	0.00E+00		6.30E-02	1.60E-01
98.00612V	FB121797	TOT	7.92E-02	=	7.00E-02	9.50E-02	1.57E-01	=	1.40E-01	2.10E-01	8.06E-02	UB	4.40E-02	3.10E-02	9.82E-03	=	2.20E-02	4.40E-02
98.00613W	GW-RKP-5	TOT	1.40E-02	=	4.30E-02	9.50E-02	9.95E-03	=	1.40E-01	2.40E-01	1.72E-01	=	7.20E-02	3.80E-02	3.63E-02	=	3.70E-02	4.90E-02
98.00614X	GW-RKP-5	DISS	1.03E-02	=	4.80E-02	1.10E-01	1.66E-01	=	2.00E-01	3.20E-01	8.83E-02	=	5.70E-02	5.50E-02	1.87E-02	=	5.00E-02	9.70E-02
98.00615Y	FB012798	TOT	1.96E-02	=	2.70E-02	4.40E-02	-2.05E-02	=	7.30E-02	1.30E-01	1.93E-02	=	1.90E-02	2.50E-02	1.25E-02	=	1.80E-02	3.00E-02

Notes
TOT - Total
DISS - Dissolved
pCi/L - picoCurie per Liter
MDC - Minimum Detectable Concentration
PQ - Project Qualifier
U - Indicates that the samplewas analyzed,but the analyte was not detected above the stated concentration The result is considered "undetected."
Qualified for reasons not stated above refe to the text of the validation worksheet.
= - Indictes no qualification flag was assigned (placeholder).

Table 4 Ra226
Kerr McGee West Chicago

NAREL Sample ID	Client Sample ID	Units	TOT/DISS	Radium Activity	Proj Qual	Uncertainty	MDC
98.00081P	GW-RKP-1	PCI/L	TOT	1.60E-01	UB	1.40E-02	9.60E-03
98.00082Q	GW-RKP-1	PCI/L	DISS	3.02E-01	UB	1.90E-02	9.70E-03
98.00083R	GW-RKP-2	PCI/L	TOT	4.08E-01	UB	2.30E-02	1.50E-02
98.00084T	GW-RKP-2	PCI/L	DISS	4.21E-01	=	2.30E-02	1.10E-02
98.00085U	GW-RKP-3	PCI/L	TOT	1.95E-01	UB	1.50E-02	1.20E-02
98.00086V	GW-RKP-3	PCI/L	DISS	2.58E-01	UB	1.80E-02	1.10E-02
98.00087W	GW-RKP-4	PCI/L	TOT	4.44E-01	UB	2.40E-02	1.10E-02
98.00088X	GW-RKP-4	PCI/L	DISS	4.30E-01	UB	2.30E-02	8.60E-03
98.00089Y	GW-MW-2	PCI/L	TOT	1.78E-01	UB	1.40E-02	1.00E-02
98.00090Q	GW-MW-2	PCI/L	DISS	2.22E-01	UB	1.60E-02	1.00E-02
98.00090Q	GW-MW-2 DUP	PCI/L	DISS	1.97E-01	UB	1.50E-02	1.00E-02
98.00091R	GW-MW-1	PCI/L	TOT	6.93E-01	=	3.00E-02	1.00E-02
98.00092T	GW-MW-1	PCI/L	DISS	3.60E-01	=	2.80E-02	1.90E-02
98.00093U*	GW-MW-6	PCI/L	TOT	3.08E-01	=	1.90E-02	8.70E-03
98.00094V	GW-MW-6	PCI/L	DISS	1.47E-01	UB	1.40E-02	1.30E-02
98.00610T	GW-MW5	PCI/L	TOT	1.46E-01	UB	1.30E-02	1.20E-02
98.00611U	GW-MW5	PCI/L	DISS	1.28E-01	UB	1.30E-02	1.10E-02
98.00612V	FB121797	PCI/L	TOT	9.84E-02	UB	1.10E-02	1.00E-02
98.00614X*	GW-RKP-5	PCI/L	DISS	2.97E-01	=	1.90E-02	9.50E-03
98.00613W	GW-RKP-5	PCI/L	TOT	4.01E-01	UB	2.30E-02	1.40E-02
98.00615Y*	FB012798	PCI/L	TOT	7.67E-02	UB	1.00E-02	9.20E-03

Notes
TOT - Total
DISS - Dissolved
pCi/L - picoCurie per Liter
MDC - Minimum Detectable Concentration
PQ - Project Qualifier
J - The result is considered "estimated."
U - Indicates that the samplewas analyzed,but the
analyte was not detected above the stated
concentration.The result is considered "undetected."
B - Qualified because of blank contamination problems
Qualified for reasons not stated above refe to the
text of the validation worksheet.
= - Indictes no qualification flag was assigned (placeholder).
* - Reanalysis results reported on June 17, 1998

Table 5 Ra228
Kerr McGee West Chicago

NAREL Sample ID	Client Sample ID	Units	TOT/DISS	Radium Activity	Proj Qual	Uncertainty	MDC
98.00081P	GW-RKP-1	PCI/L	TOT	2.20E-01	UJBQS	3.00E-01	5.10E-01
98.00082Q	GW-RKP-1	PCI/L	DISS	4.03E-01	UJBQS	3.30E-01	5.30E-01
98.00083R	GW-RKP-2	PCI/L	TOT	4.45E-01	UJBQS	3.50E-01	5.50E-01
98.00084T	GW-RKP-2	PCI/L	DISS	5.86E-01	UJBQS	3.40E-01	5.10E-01
98.00085U	GW-RKP-3	PCI/L	TOT	7.56E+00	JSQ	7.90E-01	5.20E-01
98.00086V	GW-RKP-3	PCI/L	DISS	2.28E-01	UJBQS	3.20E-01	5.30E-01
98.00087W	GW-RKP-4	PCI/L	TOT	6.96E-01	UJBQS	3.60E-01	5.30E-01
98.00088X	GW-RKP-4	PCI/L	DISS	2.83E-01	UJBQS	3.30E-01	5.40E-01
98.00089Y	GW-MW-2	PCI/L	TOT	3.37E-01	UJBQS	3.20E-01	5.20E-01
98.00090Q	GW-MW-2	PCI/L	DISS	8.15E-01	UJBQS	4.10E-01	5.90E-01
98.00090Q	GW-MW-2 DUP	PCI/L	DISS	6.10E-01	UJBQS	4.10E-01	6.30E-01
98.00091R	GW-MW-1	PCI/L	TOT	7.87E-01	UJBQS	3.50E-01	4.90E-01
98.00092T	GW-MW-1	PCI/L	DISS	1.26E+00	UJBQS	8.10E-01	1.20E+00
98.00093U	GW-MW-6	PCI/L	TOT	1.89E-01	UJBQS	3.10E-01	5.20E-01
98.00094V	GW-MW-6	PCI/L	DISS	1.48E-01	UJBQS	3.00E-01	5.10E-01
98.00610T	GW-MW5	PCI/L	TOT	1.07E+00	UJBS	3.80E-01	5.00E-01
98.00611U	GW-MW5	PCI/L	DISS	4.53E-01	UJBS	3.20E-01	5.00E-01
98.00612V	FB121797	PCI/L	TOT	5.25E-01	UJBQS	3.60E-01	5.50E-01
98.00614X	GW-RKP-5	PCI/L	DISS	6.84E-01	UJBQS	3.90E-01	5.80E-01
98.00613W	GW-RKP-5	PCI/L	TOT	1.96E-01	UJBQS	3.70E-01	6.20E-01
98.00615Y	FB012798	PCI/L	TOT	2.35E-01	UJBQS	3.40E-01	5.80E-01

Notes
TOT - Total
DISS - Dissolved
pCi/L - picoCurie per Liter
MDC - Minimum Detectable Concentration
PQ - Project Qualifier
J - The result is considered "estimated."
U - Indicates that the sample was analyzed,but the
analyte was not detected above the stated
concentration.The result is considered "undetected."
S - Qualified because recovery control limits were exceeded for MS/MSDs.
B - Qualified because of blank contamination problems
Q- Qualified for reasons not stated above refer to the
validation worksheets (in these cases, the 180 day holding time was exceeded).
= - Indictes no qualification flag was assigned (placeholder).

Table 6 GrossAlpha&Beta
Kerr McGee West Chicago

Gross Alpha and Beta Not Validated

NAREL Sample ID	Client Sample ID	TOT/DISS	Alpha Activity	Uncertainty	MDC	Beta Activity	Uncertainty	MDC	Units
98.00081P	GW-RKP-1	TOT	-2.66E-01	1.10E+00	2.80E+00	7.35E-01	2.00E+00	3.50E+00	PCI/L
98.00082Q	GW-RKP-1	DISS	-1.81E-01	1.30E+00	3.10E+00	9.01E-01	2.20E+00	3.70E+00	PCI/L
98.00083R	GW-RKP-2	TOT	6.80E-01	2.40E+00	5.00E+00	2.41E+00	2.40E+00	3.80E+00	PCI/L
98.00084T	GW-RKP-2	DISS	-4.96E-01	2.10E+00	5.20E+00	3.94E+00	2.30E+00	3.60E+00	PCI/L
98.00085U	GW-RKP-3	TOT	2.43+00	2.50E+00	3.80E+00	3.92E+00	2.40E+00	3.60E+00	PCI/L
98.00086V	GW-RKP-3	DISS	1.37E+00	2.10E+00	3.70E+00	2.67E+00	2.30E+00	3.60E+00	PCI/L
98.00087W	GW-RKP-4	TOT	1.01E+01	5.70E+00	6.20E+00	7.16E+00	2.80E+00	3.90E+00	PCI/L
98.00088X	GW-RKP-4	DISS	1.24E+01	5.70E+00	5.40E+00	5.22E+00	3.20E+00	5.00E+00	PCI/L
98.00089Y	GW-MW-2	TOT	6.00E-02	1.90E-01	3.70E-01	2.62E-01	2.80E-01	4.50E-01	PCI/L
98.00090Q	GW-MW-2	DISS	1.45E+00	1.70E+00	2.80E+00	1.36E+00	2.80E+00	4.70E+00	PCI/L
98.00090Q	GW-MW-2 DUP	DISS	3.25E+00	3.20E+00	5.00E+00	3.02E+00	2.80E+00	4.60E+00	PCI/L
9800091R	GW-MW-1	TOT	1.30E+01	5.30E+00	5.30E+00	1.14E+01	3.40E+00	4.70E+00	PCI/L
98.00092T	GW-MW-1	DISS	4.31E+00	3.00E+00	4.10E+00	3.28E+00	2.90E+00	4.60E+00	PCI/L
98.00093U	GW-MW-6	TOT	2.34E+00	2.30E+00	3.60E+00	9.54E-01	2.60E+00	4.50E+00	PCI/L
98.00094V	GW-MW-6	DISS	5.92E-01	1.20E+00	2.30E+00	3.62E+00	2.70E+00	4.20E+00	PCI/L
98.00610T	GW-MW5	TOT	4.25E+01	1.50E+01	1.20E+01	2.05E+01	6.20E+00	8.10E+00	PCI/L
98.00611U	GW-MW5	DISS	3.60E+01	1.50E+01	1.40E+01	2.00E+01	6.30E+00	8.30E+00	PCI/L
98.00612V	FB121797	TOT	-1.12E-01	1.00E+00	2.40E+00	-1.01E+00	1.80E+00	3.50E+00	PCI/L
98.00613W	GW-RKP-5	TOT	5.02E+00	5.80E+00	9.40E+00	6.23E+00	4.50E+00	7.00E+00	PCI/L
98.00614X	GW-RKP-5	DISS	1.28E+01	6.00E+00	5.90E+00	4.22E+00	2.50E+00	3.70E+00	PCI/L
98.00615Y	FB121798	TOT	-2.43E-01	7.40E-01	2.00E+00	-2.79E-01	1.80E+00	3.30E+00	PCI/L

Notes

TOT	Total
DISS	Dissolved
pCi/L	picoCurie per Liter
MDC	Minimum Detectable Concentration

Table 7 VOC
Kerr McGee West Chicago

Parameter	SampleID	98ZR0601		98ZR0602		98ZR0603		98ZR0604		98ZR0605		98ZR0606		98ZR0607		98ZR0608		98ZR0609		98ZR0610		98ZR0611	
	StationID	GW-RKP-1		GW-RKP-2		GW-RKP-3		GW-RKP-4		GW-RKP-5		GW-MW-5		GW-MW-2		GW-MW-2-DUF		GW-MW-1		GW-MW-6		FB121797	
	DateCollected	12/16/97		12/16/97		12/16/97		12/16/97		12/16/97		12/17/97		12/17/97		12/17/97		12/17/97		12/17/97		12/17/97	
	SampleType	N		N		N		N		N		N		N		N		N		N		EB	
	Units																						
Chloromethane	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Bromomethane	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Vinyl Chloride	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Chloroethane	ug/L	10	UJ	10	UJ	10	UJ	10	UJ	10	UJ	10	UJ	10	UJ	10	UJ	10	UJ	10	UJ	10	U
Methylene Chloride	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	6	J
Acetone	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	30	=
Carbon Disulfide	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
1,1-Dichloroethene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
1,1-Dichloroethane	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
1,2-Dichloroethene (total)	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Chloroform	ug/L	10	U	24	=	9	J	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
1,2-Dichloroethane	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
2-Butanone	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	66	B
1,1,1-Trichloroethane	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Carbon Tetrachloride	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Bromodichloromethane	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
1,2-Dichloropropane	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
cis-1,3-Dichloropropene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Trichloroethene	ug/L	10	U	10	U	10	U	10	U	2	J	10	U	10	U	10	U	10	U	10	U	10	U
Dibromochloromethane	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
1,1,2-Trichloroethane	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Benzene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
trans-1,3-Dichloropropene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Bromoform	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
4-Methyl-2-Pentanone	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
2-Hexanone	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Tetrachloroethene	ug/L	10	U	10	U	10	U	10	U	1	J	10	U	10	U	10	U	10	U	10	U	10	U
1,1,2,2-Tetrachloroethane	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Toluene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Chlorobenzene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Ethylbenzene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Styrene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	T0	U
Xylenes (total)	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
CARBON DIOXIDE (TIC)	ug/L	580	U			500	U	560	U	500	U	530	U	380	U	380	U					190	JB
CARBON DIOXIDE (TIC)	ug/L													28	U							6	NJ

Table 8 SVOC
Kerr McGee West Chicago

Parameter	SampleID	98ZR0601		98ZR0602		98ZR0603		98ZR0604		98ZR0605		98ZR0606		98ZR0607		98ZR0608		98ZR0609		98ZR0610		98ZR0611	
	StationID	GW-RKP-1		GW-RKP-2		GW-RKP-3		GW-RKP-4		GW-RKP-5		GW-MW-5		GW-MW-2		GW-MW-2-DUP		GW-MW-1		GW-MW-6		FB121797	
	DateCollected	12/16/97		12/16/97		12/16/97		12/16/97		12/16/97		12/17/97		12/17/97		12/17/97		12/17/97		12/17/97		12/17/97	
	SampleType	N		N		N		N		N		N		N		N		N		N		EB	
	Units																						
Phenol	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Bis (2-chloroethyl) ether	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
2-Chlorophenol	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
1,3-Dichlorobenzene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
1,4-Dichlorobenzene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
1,2-Dichlorobenzene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
2-Methylphenol	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Bis (2-Chloroisopropyl) ether	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
N-Nitroso-di-n-propylamine	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
4-Methylphenol	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Hexachloroethane	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Nitrobenzene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Isophorone	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
2-Nitrophenol	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
2,4-Dimethylphenol	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Bis (2-chloroethoxy) methane	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
2,4-Dichlorophenol	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
1,2,4-Trichlorobenzene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Naphthalene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
4-Chloroaniline	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Hexachlorobutadiene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
4-Chloro-3-Methylphenol	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
2-Methylnaphthalene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Hexachlorocyclopentadiene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
2,4,6-Trichlorophenol	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
2,4,5-Trichlorophenol	ug/L	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U
2-Chloronaphthalene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
2-Nitroaniline	ug/L	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U
Acenaphthylene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
2,6-Dinitrotoluene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
3-Nitroaniline	ug/L	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U
Acenaphthene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
2,4-Dinitrophenol	ug/L	25	UJ	25	UJ	25	UJ	25	UJ	25	UJ	25	UJ	25	UJ	25	UJ	25	UJ	25	UJ	25	U
Dibenzofuran	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
4-Nitrophenol	ug/L	25	UJ	25	UJ	25	UJ	25	UJ	25	UJ	25	UJ	25	UJ	25	UJ	25	UJ	25	UJ	25	U
Fluorene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Dimethylphthalate	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Diethylphthalate	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
4-Chlorophenyl-phenylether	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
4-Nitroaniline	ug/L	25	UJ	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	UJ	25	U
4,6-Dinitro-2-methylphenol	ug/L	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U
N-Nitrosodiphenylamine (1)	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
4-Bromophenyl-phenylether	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Hexachlorobenze	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Pentachlorophenol	ug/L	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U	25	U
Phenathrene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Anthracene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Di-n-Butylphthalate	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	0.3	J
Fluoranthene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Pyrene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Butylbenzylphthalate	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Benzo (a) Anthracene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
3,3'-Dichlorobenzidine	ug/L	10	UJ	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	UJ	10	U
Chrysene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
bis(2-ethylhexyl) Phthalate	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Di-n-octylphthalate	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Benzo (b) fluoranthene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Benzo (k) fluoranthene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Benzo (a) pyrene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Indeno (1,2,3-cd) pyrene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Dibenzo (a,h) anthracene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Benzo (g,h,i) perylene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
Carbazole	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
2,4-Dinitrotoluene	ug/L	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U	10	U
CYCLOHEXENE (TIC)	ug/L	320	R																				
UNKNOWN (TIC)	ug/L							3	U			2	U									3	J
UNKNOWN KETONE (TIC)	ug/L			13	U	19	U	24	U	16	U	12	U	15	U	27	U	6	U	11	J	7	JB
UNKOWN ALCOHOL (TIC)	ug/L													3	J	4	J						

Table 9 Metals
Kerr McGee West Chicago

SampleID		98ZR0601			98ZR0602			98ZR0603			98ZR0604			98ZR0605			98ZR0606			98ZR0607			98R0608			98ZR0609			98ZR0610			98ZR0611	
StationID		GW-RKP-1			GW-RKP-2			GW-RKP-3			GW-RKP-4			GW-RKP-5			GW-MW-5			GW-MW-2			GW-MW-2-DUF			GW-MW-1			GW-MW-6			FB121797	
DateCollected		12/16/97			12/16/97			12/16/97			12/16/97			12/16/97			12/17/97			12/17/97			12/17/97			12/17/97			12/17/97			12/17/97	
SampleType		N			N			N			N			N			N			N			N			N			N			EB	
Parameter	Units																																
Aluminum, total	ug/L	36.8	U		443	=		446	=		212	=		243	=		569	=		39.2	J		53.1	J		1520	=		36.8	U		36.8	U
Antimony, total	ug/L	25.3	U		25.3	U		25.3	U		25.3	U		25.3	U		25.3	U		25.3	U		30.1	J		25.3	U		25.3	U		25.3	U
Arsenic, total	ug/L	2.2	U		2.2	U		2.2	U		2.2	U		2.3	J		2.2	U		2.2	U		2.2	U		2.5	J		2.2	U		2.2	U
Barium, total	ug/L	35.8	J		92.1	J		86.1	J		101	J		64.1	J		36.1	J		43.3	J		44.8	J		107	J		40.4	J		5.8	B
Beryllium, total	ug/L	0.3	U		0.3	U		0.3	U		0.03	U		0.3	U		0.3	U		0.3	U		0.3	U		0.3	U		0.3	U		0.3	U
Cadmium, total	ug/L	3	U		3	U		3	U		3	U		3	U		3	U		3	U		4	J		3	U		3	U		3	U
Calcium, total	ug/L	72400	=		106000	=		109000	=		165000	=		293000	=		395000	=		72500	=		74300	=		109000	=		75400	=		190	B
Chromium, total	ug/L	9.3	U		9.3	U		9.3	U		9.3	U		9.3	U		9.3	U		9.3	U		9.3	U		16.6	=		9.3	U		9.3	U
Cobalt, total	ug/L	6.8	U		6.8	U		6.8	U		6.8	U		6.8	U		6.8	U		6.8	U		6.8	U		6.8	U		6.8	U		6.8	U
Copper, total	ug/L	9.5	U		9.5	U		11.7	J		9.5	U		9.5	U		9.5	U		9.5	U		9.5	U		12.1	J		9.5	U		9.5	U
Iron, total	ug/L	24.5	J		1030	=		1930	=		1020	=		747	=		985	=		53.6	J		75.9	J		3280	=		43	J		5.5	U
Lead, total	ug/L	0.64	U		0.64	U		0.76	U		0.064	U		0.64	U		1.5	U		0.64	U		0.64	U		2.9	U		0.64	U		0.64	U
Magnesium, total	ug/L	38800	=		57500	=		63700	=		83200	=		61300	=		103000	=		40500	=		40800	=		65600	=		41600	=		44.1	U
Manganese, total	ug/L	19.1	J		200	J		192	J		581	=		668	U		1560	J		3.6	J		4	J		89.5	J		1.9	U		1.9	U
Mercury, total	ug/L	0.007	U		0.007	U		0.007	U		0.007	U		0.007	U		0.007	U		0.007	U		0.007	=		0.007	U		0.007	U		0.007	U
Nickel, total	ug/L	9.5	U		9.5	U		9.5	U		9.5	U		9.5	U		9.5	U		9.5	U		9.5	U		15	J		9.5	U		9.5	U
Potassium, total	ug/L	303	J		4410	J		4330	J		2990	J		5120	=		13300	=		627	J		809	J		3080	J		890	J		264	U
Selenium, total	ug/L	1.4	U		2.2	U		1.6	U		3.1	U		5.7	=		7.6	=		2.1	U		2	U		3.3	U		2.8	U		0.33	U
Silver, total	ug/L	5	U		5	U		5	U		5	U		5	U		5	U		5	U		5	U		5	U		5	U		5	U
Sodium, total	ug/L	4870	J		124000	=		43000	=		77900	=		78800	=		63000	=		5270	=		5440	=		24500	=		3570	J		195	B
Thallium, total	ug/L	1.4	UJ		7	UJ		7	UJ		1.4	UJ		7	UJ		7	UJ		1.4	UJ		1.4	UJ		1.4	U		1.4	UJ		1.4	U
Vanadium, total	ug/L	5.2	U		5.2	U		5.2	U		5.2	U		5.2	U		5.2	U		5.2	U		5.2	U		5.2	U		5.2	U		5.2	U
Zinc, total	ug/L	3.9	U		7.3	U		14.2	U		5.5	U		10.8	U		10.8	U		3.9	U		5.6	U		24.3	U		3.9	U		3.9	U
Aluminum, dissolved	ug/L	36.8	U		36.8	U		36.8	U		36.8	U		36.8	U		46.8	J		44.3	J		36.8	U		36.8	U		36.8	U		N/A	
Antimony, dissolved	ug/L	25.3	U		25.3	U		25.3	U		25.3	U		25.3	U		25.3	U		25.3	U		25.3	U		25.3	U		25.3	U		N/A	
Arsenic, dissolved	ug/L	2.2	U		2.2	U		2.2	U		3.4	J		3.3	J		3.6	J		2.2	U		2.2	U		2.2	U		2.2	U		N/A	
Barium, dissolved	ug/L	35.1	J		84.9	J		80.1	J		99.9	J		61.1	J		36.1	J		42.4	J		42.1	J		102	J		42	J		N/A	
Beryllium, dissolved	ug/L	0.3	U		0.3	U		0.3	U		0.3	U		0.3	U		0.3	U		0.3	U		0.3	U		0.3	U		0.3	U		N/A	
Cadmium, dissolved	ug/L	3	U		3	U		3	U		3	U		3	U		3	U		3.5	J		3	U		3	U		3	U		N/A	
Calcium, dissolved	ug/L	72200	=		98700	=		104000	=		162000	=		273000	=		407000	=		73200	=		75100	=		91600	=		75500	=		N/A	
Chromium, dissolved	ug/L	9.3	U		9.3	U		9.3	U		9.3	U		9.3	U		9.3	U		9.3	U		9.3	U		9.3	U		9.3	U		N/A	
Cobalt, dissolved	ug/L	6.8	U		6.8	U		6.8	U		6.8	U		6.8	U		6.8	U		6.8	U		6.8	U		6.8	U		6.8	U		N/A	
Copper, dissolved	ug/L	9.5	U		9.5	U		9.5	U		9.5	U		9.5	U		9.5	U		9.5	U		17.2	U		9.5	U		9.5	U		N/A	
Iron, dissolved	ug/L	5.5	U		26.6	U		13.3	U		614	=		5.5	U		6.1	U		5.5	U		23.1	U		7.2	U		5.5	U		N/A	
Lead, dissolved	ug/L	0.64	U		0.64	U		0.64	U		0.64	U		0.64	U		1	U		0.71	U		0.64	U		0.64	U		0.64	U		N/A	
Magnesium, dissolved	ug/L	39000	=		54600	=		61800	=		80600	=		51900	=		105000	=		39400	=		39600	=		55200	=		41600	=		N/A	
Manganese, dissolved	ug/L	16.2	=		171	=		168	=		547	=		561	=		1620	=		1.9	U		1.9	U		25.9	=		1.9	U		N/A	
Mercury, dissolved	ug/L	0.034	U		0.038	U		0.038	U		0.036	U		0.056	U		0.036	U		0.04	U		0.035	U		0.038	U		0.034	U		N/A	
Nickel, dissolved	ug/L	9.5	U		9.5	U		9.5	U		9.5	U		9.5	U		9.5	U		9.5	U		9.5	U		9.5	U		9.5	U		N/A	
Potassium, dissolved	ug/L	587	J		3920	J		3990	J		2690	J		4610	J		13800	=		870	J		859	J		2370	J		951	J		N/A	
Selenium, dissolved	ug/L	1.8	U		0.7	U		1.8	U		2.1	U		5.4	=		7.9	=		2.6	U		2	U		0.48	U		2	U		N/A	
Silver, dissolved	ug/L	5	U		5	U		5	U		5	U		5	U		5	U		5	U		5	U		5	U		5	U		N/A	
Sodium, dissolved	ug/L	4870	J		118000	=		41400	=		75300	=		74100	=		65100	=		5200	=		5410	=		23300	=		3650	J		N/A	
Thallium, dissolved	ug/L	1.4	UJ		7	UJ		7	UJ		1.4	UJ		1.4	UJ		7	UJ		1.4	UJ		2.4	J		1.4	UJ		1.4	UJ		N/A	
Vanadium, dissolved	ug/L	5.2	U		5.2	U		5.2	U		5.2	U		5.2	U		5.2	U		5.2	U		5.2	U		5.2	U		5.2	U		N/A	
Zinc, dissolved	ug/L	9.4	U		3.9	U		5.6	U		3.9	U		18.9	U		7.7	U		3.9	U		4.5	U		4.5	U		3.9	U		N/A	