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ENVIRONMENTAL ANALYSIS OF A FORMERLY UTILIZED MED/AEC SITE

SITE A AND PLOT M, PALOS FOREST PRESERVE, PALOS PARK, ILLINOIS

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ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

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ENVIRONMENTAL ANALYSIS OF A FORMERLY UTILIZED MED/AEC SITE

SITE A AND PLOT M, PALOS FOREST PRESERVE, PALOS PARK, ILLINOIS

prepared by
Division of Environmental Impact Studies

September 1979

prepared for
Office of Remedial Action Programs
Assistant Secretary for Energy Technology
U.S. Department of Energy
Washington, D.C. 20545

FOREWORD

More than a hundred sites were used by the Manhattan Engineer District (MED), by the U.S. Atomic Energy Commission (AEC) for research facilities, and by the AEC's uranium suppliers and processors during the early years of development of the nuclear program in the United States. Although operations have long ceased at many of these sites, in many instances radioactive substances remain which can be a potential source of exposure to the public. Traces of radioactivity may remain on building and equipment surfaces and in the soil or subsoil. The U.S. Department of Energy is currently active in a program to ensure that the necessary precautions are taken in the management of these properties to provide for adequate protection of public health while allowing further use of land and other resources.

This environmental analysis report (EAR) addresses one of these MED/AEC sites known as Site A/Plot M, located in Palos Park, Illinois. The EAR describes the existing site environment and evaluates the environmental impacts of a number of options for remedial action, including the option of allowing buried waste material to remain undisturbed. Conformity or conflict with federal, state, or local statutes, regulations, and standards was determined, especially in regard to compliance with decontamination criteria and guidelines. Finally, the necessary program of measurements, documentation, and control to demonstrate compliance with these criteria and guidelines was identified.

A companion document, "Engineering Evaluation of a Formerly Utilized MED/AEC Site, Site A and Plot M, Palos Forest Preserve, Palos Park, Illinois" (ANL/ES-80), has also been prepared. The engineering evaluation report (EER) describes in technical detail the options for remedial action that could be taken with respect to the contamination at Site A/Plot M, and presents estimates of the costs associated with these options.

This EAR contributes to a better understanding of the mitigation or resolution of environmental problems posed by the subject MED/AEC site and serves as a basis for determining whether or not remedial actions are warranted. The knowledge derived from the evaluation of a number of remedial options should be helpful in the final disposition of other MED/AEC sites located elsewhere.

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Activity	The number of nuclear transformations occurring in a given quantity of material per unit time.
Alpha particle (α)	A positively charged particle emitted from certain radioactive materials. It consists of two protons and two neutrons, hence is identical with the nucleus of the helium atom. It is the least penetrating of the common radiations (α,β,γ); thus it is not dangerous unless alpha-emitting substances have entered the body.
Aquitard	A low permeability layer that retards but does not prevent the flow of water to or from an adjacent aquifer.
Aquifer	A water-bearing formation that contains sufficient saturated permeable material to conduct groundwater and to yield significant quantities of groundwater to wells.
Background radiation	Naturally occurring low-level radiation to which all life is exposed. Background radiation levels vary from place to place on the earth.
Bedrock	A general term for rock that underlies soil or unconsolidated surficial material.
Beta particle (β)	A particle emitted from some atoms undergoing radioactive decay. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron. Beta radiation can cause skin burns, and beta emitters are harmful if they enter the body.
Curie (Ci)	Originally, the activity associated with 1 gram of radium-226. Now defined as being equivalent to 3.7×10^{10} nuclear transformations per second.
Dolomite	A magnesium-rich variety of limestone usually containing 90% dolomite, $CaMg(CO_3)_2$, and 10% calcite, $CaCO_3$.

GLOSSARY

Endangered species	A species whose survival is in jeopardy. Its peril may result from destruction of habitat, change in habitat, overexploitation by man, predation, adverse interspecific competition, or disease; or because the species is at the edge of its geographical range. An endangered species must receive protection, or extinction probably will follow.
External gamma radiation	Gamma radiation emitted from a source(s) external to the body, as opposed to internal gamma radiation emitted from ingested or inhaled sources.
Exposure	Related to electrical charge produced in air by ionizing radiation per unit mass of air.
Gamma ray (γ)	High-energy electromagnetic radiation emitted from the nucleus of a radioactive atom, with specific energies for the atoms of different elements, and having high penetrating power.
Glacial drift	A general term applied to all rock material (clay, sand, gravel, boulders) transported and deposited by a glacier either directly or indirectly.
Glacial lobe	A large, rounded, tongue-like projection of ice from the margin of the main mass of an ice sheet.
Glacial moraine	A general term applied to distinct accumulations of glacial drift and glacial till occurring in a variety of topographic landforms.
Glacial till	Unconsolidated, unsorted, and unstratified sand, gravel, clay, and boulders deposited by a glacier without subsequent reworking by water; it is, therefore, very heterogeneous.
Groundwater	Subsurface water in the zone of full saturation which supplies wells and springs.
Half-life	The time required for a radioactive substance to lose half of its activity by decay (through nuclear transformation) to another "daughter" substance.
HEPA filter	High-efficiency particulate air filter, sometimes known as an absolute filter with an efficiency of 99.95% in removal of particles down to 0.3 μm.

GLOSSARY

Impact	The effect brought about by a proposed action to alter an existing condition; an impact may be adverse or beneficial.
Intermittent stream	A stream that flows only at certain times of the year, as when it receives water from springs or a surface source.
Isotope	One of two or more species of atoms with the same atomic number (the same chemical element) but with different atomic weights. Isotopes usually have very nearly the same chemical properties, but somewhat different physical properties.
Knob and kettle topography	An undulating glaciated landscape in which knolls, mounds, or ridges of glacial drift are interspersed with irregular depressions.
Low specific activity	For the purposes of transporting radioactive material, low specific activity can refer to materials of low radioactivity concentrations such as residues or solutions from chemical processing; wastes such as building rubble, metal, wood, fabric scrap, glassware, paper, and cardboard; and solid or liquid plant waste, sludge, and ash.
Maximum permissible concentration (MPC)	The highest concentration of a particular radionuclide in air or water that is permissible for occupational or general exposure without taking steps to reduce exposure.
Modified Mercalli Scale	One of the earthquake intensity scales, having twelve divisions ranging from I (not felt by people) to XII (damage nearly total); based on subjective observations of damage following an earthquake.
Nanocurie (nCi)	10^{-9} curie.
Nuclide	A species of atom characterized by the constitution of its nucleus and hence the number of protons, neutrons, and energy content; if the species is radioactive, it may be called a radionuclide.
Perched water table	An abnormal elevation of the water table separated from an underlying main body of groundwater by an unsaturated zone or aquitard.

GLOSSARY

Picocurie (pCi)	10^{-12} curie.
Pleistocene epoch	An epoch of the Quaternary period of geologic time generally considered to immediately precede the Holocene (recent and existing) epoch and known worldwide as a time of great glacial activity.
Radioactivity	The spontaneous decay or disintegration of an unstable atomic nucleus, usually accompanied by the emission of ionizing radiation.
Rare species	A species not currently threatened with extinction, but occurring in such small numbers that it may become endangered if its environment deteriorates further or other limiting factors are altered. Continued observation of its status is essential.
Recharge	The process by which water is absorbed and added to the zone of saturation of an aquifer, either directly or indirectly.
Roentgen (R)	A unit of exposure to ionizing radiation. It is that amount of gamma or X rays required to produce ions carrying 1 electrostatic unit of electrical charge, either positive or negative in 1 cm^3 of dry air under standard conditions (numerically equal to 2.58×10^{-4} coulombs/kg).
Roentgen equivalent man (rem)	The unit of dose of any ionizing radiation which produces the same biological effect as a unit of absorbed dose of ordinary X rays, numerically equal to the absorbed dose in rads multiplied by the appropriate quality factor for the type of radiation. The rem is the basic recorded unit of accumulated dose to personnel.
Seep	An area, generally small, where water percolates slowly to the land surface. Usually has flows too small to be considered a spring.
Seismicity	The phenomenon of earth movements; the relative amount and intensity of earthquake activity reported to occur in one region relative to other regions.
Soil moisture	Water that occupies the voids of the soil located above the water table.

GLOSSARY

Stratigraphy	The arrangement of rock strata (layers), as to geographic position and chronological order of sequence.
Transferable alpha	Particulate alpha-emitting isotopes found on surfaces, usually in the form of dust, that can be removed from the surface by dry or wet wiping using the smear technique.
Tritium (H-3)	The hydrogen isotope with one proton and two neutrons in the nucleus. Tritium decays with a half-life of 12.3 years and has a specific activity of 9640 Ci/g.

1. SUMMARY AND CONCLUSIONS

This environmental analysis report (EAR) was prepared for the U.S. Department of Energy, Office of Remedial Action Programs, by the Division of Environmental Impact Studies, Argonne National Laboratory.

1. The subject of this EAR is a formerly utilized MED/AEC site known as Site A/Plot M, located in the Palos Forest Preserve, Palos Park, Illinois. Site A refers to the 7.9-ha (19-acre) experimental area where the CP-2 and CP-3 reactors and associated buildings and laboratories were built and operated by the University of Chicago Metallurgical Laboratory and Argonne National Laboratory from 1943 to about 1956. Plot M refers to a 0.4-ha (1-acre) radioactive waste burial site 610 m (2000 ft) north of Site A.

2. The only important means of exposure to the public from buried radionuclides is the increase in tritium in picnic wells. The maximum dose to people from this pathway is estimated to be 0.7 mrem/year as compared to the EPA drinking-water standard of 4 mrem/year.

3. The options for remedial action that are evaluated are:

   a. Option I: No remedial action taken (status quo); radiological monitoring of the sites would continue.

   b. Option II: Excavation and removal of buried materials at Site A and Plot M.

   c. Option III: Waterproofing the concrete cover and installing drain tiles around Plot M to prevent surface waters from penetrating the cover and leaching the buried materials into the groundwater.

   d. Option IV: Installation of a fully enclosed well bore through contaminated perched water to provide water with much lower tritium content than water from existing wells.

   e. Option V: Installation of a cover with drain tile over the buried material at Site A to prevent surface waters from reaching the buried material.

   f. Option VI: Installation of a barrier wall around the buried wastes to minimize contact with groundwater.

   g. Option VII: Closing the picnic wells to prevent the public from drinking the tritiated water.

   h. Option VIII: Providing the public with a substitute source of water having a much lower tritium content.

4. The environmental impacts that could result from implementation of the remedial action options may be summarized as follows:

   a. Option I would have negligible radiological impact on the public. The tritium concentrations that currently exist in the drinking-water wells at the Palos Forest Preserve are low enough so that a child who regularly consumes a liter of this well water per day would receive a dose of 0.5 mrem/year. Option II would not improve the quality of the well water, may aggravate the tritium seepage, and may lead to a worsening of water quality. Options III, V, and VI all serve to control seepage from Site A and Plot M and implementation of a combination of or all of these three alternatives would reduce the probability of seepage of any remaining tritium or other nuclides out of Site A and Plot M. Option VII would close the picnic wells and would eliminate the exposure of the public to tritium. Options IV and VIII would provide the public with drinking water that has much less tritium in it than the existing water supply.

   b. Options I, IV, VII, and VIII require little or no surface construction activity at the sites, which could result in surface-water-quality impacts. Also, the receiving waters (canal waters) for surface runoff from Site A/Plot M are of such poor quality that little, if any, measurable impact on existing water quality and use would occur. Options II, III, V, and VI require substantially more surface activities than Options I, IV, VII, and VIII. However, when considered against the existing poor quality of area surface waters, the small amount of additional degradation resulting from surface activities would be minor and temporary. If proper mitigative measures are employed, the surface water quality could be maintained essentially as it exists presently.

      If, as is inferred, the bulk of the tritium is already in the saturated zone (water table), groundwater quality would incur little or no additional degradation as a result of surface activities related to any of the eight options. However, only with Options I, II, III, V, and VI is there potential for continued tritium contamination of nearby picnic wells. Options IV, VII, and VIII, on the other hand, would not reduce or eliminate continued tritium contamination but (except for Option VII) could assure a good quality, uncontaminated drinking-water supply for forest preserve visitors.

   c. Options III, V, and VI would involve unavoidable disruption and injury to the terrestrial biota. Vegetation and relatively immobile organisms at the work sites would be destroyed and nearby biota would be disturbed. In addition, the construction of new access roads would increase the area of destruction and disturbance.

      Option II would have similar effects on the terrestrial biota, but the period of disturbance would be longer, the area involved greater, and the site from which the new fill would be provided would also be disrupted. The remaining options would have little or no impact on the terrestrial biota in the area.

The above adverse impacts can be mitigated by regrading and reseeding the disturbed and eroded areas and by keeping the affected areas off limits to vehicular traffic. If proper reclamation procedures are followed, none of these options would permanently impact the terrestrial biota of the area enough to prevent full recovery.

d. Option II could potentially cause adverse impacts on the aquatic biota near the excavation site due to possible offsite transport of toxic materials. Also, construction activities related to road repairs, removal of overburden, backfilling, and grading when the excavation is completed could potentially increase sediment loading in nearby streams, especially during periods of increased precipitation. The above impacts could be mitigated by building diversions which direct all site drainage to a lined sediment basin prior to discharge into a nearby stream. Also, the disturbed areas should be stabilized as quickly as possible by filling, regrading, and revegetating to reduce wind and water erosion.

e. Closing the picnic wells (Option VII) without providing a substitute source of water (Option VIII) could have an adverse impact on the recreational value and use of the Red Gate Woods area which attracts many visitors annually. Without potable water available, appreciation of the area could decrease since users would perceive it as less pleasant and convenient. Other options requiring surface activities would probably necessitate limiting public access to the disturbed sites. However, this step is temporary and intended to ensure public health and safety.

2. HISTORICAL BACKGROUND

After the successful operation of the first nuclear reactor (CP-1) by Dr. Enrico Fermi and his collaborators at the University of Chicago on December 2, 1942, it was necessary to move the project since adequate space was not available. The congested city was not a proper location for nuclear research at that stage of its development, and isolation was necessary to preserve secrecy. The U.S. Army Corps of Engineers leased 415 ha (1025 acres) of land from the Cook County Forest Preserve District for continuing research. The site, located in the Palos Forest Preserve about 32 km (20 miles) southwest of the center of Chicago, included a golf course, girl scout camp, and picnic facilities. Only about 8 ha (19.8 acres) of the total area were used for laboratory purposes. Site A refers to the 7.9-ha (19.5-acre) area which contained the CP-2 and CP-3 reactors and associated buildings and laboratories; Plot M refers to the 0.4-ha (1-acre) radioactive waste burial site about 610 m north of Site A.

The CP-1 reactor was disassembled at the University of Chicago during March of 1943, moved to Site A, rebuilt and renamed CP-2, and placed into operation. The reactor utilized uranium metal fuel and a graphite moderator. On May 15, 1944, a second reactor, CP-3, which was heavy-water cooled and moderated began operation at this site. In 1953, CP-3 was updated, by replacing the natural uranium fuel with enriched uranium, and designated as CP-3'. Both reactors continued operation until 1954. Programs carried out at this site during and after World War II were: fission product separations, reactor physics studies, tritium recovery from irradiated lithium, and studies of the metabolism of radionuclides in laboratory animals. In 1947, the present site of Argonne National Laboratory (ANL) was obtained, and by 1949 the first permanent buildings at this location were completed. As the facilities at ANL were completed, the programs were transferred from Site A to ANL.

The original lease agreement of 1942 was made in furtherance of the Manhattan Engineer District (MED) program, and it was not contemplated that the land used would be permanently lost as forest preserve. Consequently, even though the reactor buildings were permanent structures and difficult to remove, after acquisition of the DuPage County site for ANL, it was considered necessary that the forest preserve areas be restored to their original use. A new lease was signed in 1947 releasing most of the original land to the Cook County Forest Preserve District. The remainder of the land was to be released by June 30, 1956. A condition of the new lease was the necessity, upon leaving, for the Federal Government to "remove, destroy, or render harmless any or all installations, structures, appurtenances, materials, or conditions of the ground or terrain which shall be dangerous, perilous, or hazardous in nature or which, if permitted to remain, would interfere with the full use and enjoyment of the said premises by the public as a part of the Forest Preserve District."[1]

In the spring of 1955, work to comply with these requirements was begun. As programs were moved to ANL, the empty buildings were surveyed, decontaminated if necessary, and razed. The buildings housing CP-2 and CP-3' were the

only areas requiring extensive decontamination. The reactors were dismantled, the heavy water was removed, and the fuel was shipped to Oak Ridge National Laboratory for reprocessing. The tank which had contained the heavy water in the CP-3' reactor was filled with concrete. The space between the tank and the biological shield was also filled with concrete into which was dumped hardware, piping, and miscellaneous radioactive items. An excavation 12-m (40-ft) deep was dug next to the CP-3' containment shell, and with the use of explosives, the reactor shell was tumbled into the pit. The shell was covered with CP-2 and CP-3' building rubble and then with dirt. After demolition was completed at Site A, the area was graded and an inscribed granite marker placed near the location of the buried reactor.

Plot M was used for the burial of low-level radioactive waste both from the University of Chicago Metallurgical Laboratory and Site A operations. The first recorded use of this site as a radioactive waste burial ground was in early 1943. During the first several years of operation, radioactive materials--both solid and liquid--in glass or metal containers were placed at the bottom of the 1.8-m (6-ft) deep trenches. Sufficient soil was used to cover the material to reduce the radiation to acceptable levels. (No information is available on what was considered acceptable in 1943.) Additional radioactive material was placed on top of the original material and also covered; this procedure was continued until the trench was full. Sometime prior to July 6, 1948 (possibly early in 1948), material was placed into steel bins which were placed in the trenches and covered with soil. The burial area eventually covered an area 46 by 43 m. No precise inventory of the buried material was kept, and the early records gave little indication of the identity and quantity of specific nuclides involved.

Beginning on May 24, 1949, the bins were removed to search for some missing uranium-235, which was subsequently found. The bins were not reburied, but shipped to the present ANL site. After this work was completed on June 10, 1949, burial at Plot M was discontinued and the area was covered with additional soil and seeded with a grass cover.

Plot M remained in this condition until the spring of 1956, when an inverted concrete box was constructed to cover the entire burial plot. The concrete sidewalls were extended 2.4 m into the ground and a 0.3-m (1-ft) thick concrete slab was placed over the entire area. The concrete was covered with about 0.5 m of soil, grass was seeded, and an inscribed granite marker was placed in the center of Plot M. The purpose of the concrete barrier was to protect the contents and impede the flow of water through the buried radioactive materials. The decision to decommission the plot in this way was made after considering alternative methods, including removal of the contents of the burial plot.

By summer of 1956, all demolition and restoration work was complete at both Site A and Plot M. A radiation survey of the site indicated no detectable surface contamination. All personnel were removed and the sites were turned over to the Cook County Forest Preserve District. Since that time, no limitations of usage have been applied or needed other than restrictions on digging in the Site A/Plot M areas; the only activity has been continued radiological monitoring.

A chronology of Site A and Plot M is given in Table 2.1.

Table 2.1. Chronology for Site A and Plot M

July 1942	415 ha of forest preserve were leased from Cook County Forest Preserve District by Manhattan District, U.S. Corps of Engineers.
Dec. 1942	Nuclear chain reaction (CP-1 reactor) was successfully demonstrated at West Stands, University of Chicago.
Mar. 1943	CP-1 nuclear reactor was moved from West Stands to Site A.
1943	Low-level radioactive waste burial in trenches began at Plot M.
May 1944	Heavy-water cooled and moderated nuclear reactor (CP-3) began operation at Site A.
1947	Original lease for 415 ha was terminated and replaced by new lease running to 1956, covering only Site A and Plot M. About 407 ha were returned to the Forest Preserve District in fully usable condition.
1947	DuPage County site for Argonne National Laboratory was acquired. Operations were transferred from Site A as buildings were completed at DuPage site.
1948	Burial of radioactive wastes at Plot M in open trenches was discontinued and replaced by burial in steel bins.
1948	Environmental monitoring program around Site A and Plot M commenced. Original program was very limited but was gradually extended.
May 1949	Steel bins were removed and burial of wastes at Plot M discontinued.
1951	Discussions commenced on methods for releasing Site A and Plot M to Forest Preserve District.
1955	Decontamination and demolition or removal of Site A facilities began.
1956	Demolition, decontamination, and burial of Site A facilities were completed. Plot M was covered with concrete cap and dirt.
1956	Both sites were returned to Forest Preserve District at presumably background radioactivity level.
1973	Small amounts of tritium were found in Red Gate Woods well.

REFERENCE (Sec. 2)

1. "Formerly Utilized MED/AEC Sites Remedial Action Program; Radiological Survey of Site A, Palos Park Forest Preserve, Chicago, Ill.," Final Report, DOE/EV-0005/7, Prepared for U.S. Department of Energy, Division of Environmental Control Technology, Washington, D.C., 87 pp., April 1978.

3. WASTE-DISPOSAL GUIDELINES AND ASSOCIATED CRITERIA

The materials buried at Site A/Plot M are comprised of laboratory wastes, contaminated structures, and, possibly, small amounts of fission products (see Sec. 4.9 for a detailed characterization). The Site A location contains only the CP-2 and CP-3' building rubble, some contaminated structures, and what remained of these reactors after their fuel, graphite, and heavy water had been removed to Oak Ridge National Laboratory. Waste-disposal and radiation protection guidelines, which may be applied to the question of how much, if any, remedial action is required, are discussed below.

3.1 CRITERIA FOR RADIOACTIVE WASTES

In November 1978, the U.S. Environmental Protection Agency released for comment a set of six proposed criteria for the "storage and disposal of all forms of radioactive wastes."[1] The third criterion is of particular interest and relevance to the Site A/Plot M situation. This criterion proposes that "radiation protection requirements for radioactive wastes should be based primarily on an assessment of risk to individuals and populations . . . ." Thus, the decision on whether or not further remedial actions are needed may be based on a consideration of the risks that the materials at Site A/Plot M represent to present and future generations.

3.2 REGULATIONS FOR DRINKING WATER

The material buried at Site A/Plot M would cause radiation dosage less than 1% of the natural background level (to whole body, lung, bone, or gastro-intestinal tract) to be incurred by individuals who frequent the nearby park and daily drink liter quantities of water out of the park wells (see Sec. 5.7.2.1). The maximum contaminant levels given in the National Interim Primary Drinking Water Regulations (40 CFR 141) may be used to aid in the assessment of the level of risk to which such individuals would be exposed.

3.3 STANDARDS FOR PROTECTION AGAINST RADIATION

The radiation dose limits for individuals in unrestricted areas and the maximum permissible concentrations of various radionuclides are given in the Standards for Protection Against Radiation (10 CFR 20) for activities licensed by the U.S. Nuclear Regulatory Commission. Also given are the requirements concerning survey procedures, waste disposal, survey records, monitoring records, disposal records, and personnel exposure reports. The requirements of 10 CFR 20 could serve as guidelines to be met in the event that the buried material is excavated and removed to another location, even though this activity was not subject to licensing.

3.4 STANDARDS FOR SOIL CONTAMINATION

Currently, no generally applicable standards have been adopted that cover soil contamination and acceptable decontamination levels for the radionuclides of concern at Site A/Plot M where basically clean overburden is found over waste that is located in a rather limited volume. The main problem lies in ensuring that at the end of remedial operations, any recontaminated soil at Site A/Plot M would be removed and the remaining soil would be clean enough for the area to be released for unlimited access. To facilitate the final radiation survey, external gamma radiation (EGR) levels may be used as a parameter by which the soil is judged to be acceptably free of contamination. The following EGR levels above background are suggested: target - <5 μR/hour; maximum - 20 μR/hour. The background levels in the vicinity of the site are approximately 10 μR/hour.

In addition, surface soil over the filled-in areas and areas where overburden was stored during remedial operations should be analyzed for Sr-90, Pu-239, and H-3. Soil should not be used as cover material if concentrations of Sr-90 and Pu-239 exceed the background levels for the vicinity. The radiological survey[2] of soil around Site A/Plot M indicated that the Sr-90 concentration in soil uncontaminated by the buried materials is less than 0.1 pCi/g. For Pu-239, less than 0.1 pCi/g was the observed level. The background level of H-3, as determined from Argonne environmental monitoring results, is about 0.25 nCi/L of soil moisture at locations remote from Site A/Plot M. The EPA drinking-water regulations (40 CFR 141) list 20 nCi/L as the limit for tritium in drinking water. The value 2 nCi/L may be used as the upper limit for tritium concentration in soil moisture for the cover soil at Site A/Plot M, this value being one-tenth of the drinking-water limit as well as being near enough to background to be readily achievable.

REFERENCES (Sec. 3)

1. "Criteria for Radioactive Wastes, Recommendations for Federal Radiation Guidance," U.S. Environmental Protection Agency, Fed. Regist. 43(221): 53262-53268.

2. "Formerly Utilized MED/AEC Sites Remedial Action Program; Radiological Survey of Site A, Palos Park Forest Preserve, Chicago Illinois," Final Report, DOE/EV-0005/7, Prepared for U.S. Department of Energy, Division of Environmental Control Technology, Washington, D.C., 87 pp., April 1978.

4. CHARACTERIZATION OF THE EXISTING SITE ENVIRONMENTS

4.1 LOCATION AND PHYSIOGRAPHY

4.1.1 Location

Site A and Plot M are located in the Palos Hills Forest Preserve (Red Gate Woods) south of the boundary between DuPage and Cook counties along the Des Plaines River Valley (Fig. 4.1), about 16 km (10 miles) southwest of Chicago, Illinois and 30 km (18 miles) west of Lake Michigan. Plot M is situated approximately 490 m (1600 ft) north of Site A in T37N, R12E, at approximately lat. 41°42' N. and long. 87°54' W.

4.1.2 Physiography

The sites are located on an isolated, wedge-shaped portion of glacial deposits typical of those occurring in northeastern Illinois and southern Wisconsin (Fig. 4.2). The glacial deposits in this region exhibit rough knob and kettle topography. Erosional features include drainageways produced by glacial meltwaters, bluffs along shores, numerous small valleys, and ponds and marshes.

The isolated portion of glacial deposits is bordered on the north and west by the Illinois and Michigan Canal, the Chicago Sanitary and Ship Canal, and the Des Plaines River; on the south by the Calumet Sag Channel; and on the east by the low relief Chicago lake plain. Maximum topographic relief at the site is about 52 m (170 ft). Elevations vary from about 230 m (750 ft) just west of Site A to 213 m (700 ft) at Plot M to about 180 m (580 ft) at the two canals. Site A straddles the surface drainage divide which directs surface runoff and local groundwater flow both to the north and south. Plot M is situated farther down the north slope of the moraine where surface and subsurface drainage is generally northerly (Fig. 4.3).

4.2 CLIMATE

4.2.1 General Influences

The climate of the Palos Hills area is characterized as continental, ranging from relatively cold in the winter to relatively warm in the summer. The weather is slightly modified by Lake Michigan which is as close as 30 km (18 miles) to the site. Due to the absence of natural obstructions, such as mountain ranges, the area is subject to frequently changing weather.

Weather data is available from the Argonne National Laboratory meteorological tower,[1] located 8.9 km (5.5 miles) west of Site A, and Chicago's Midway Airport,[2] located 16 km (9.3 miles) northeast. The 15-year (1950-1964) average daily air temperature as recorded at Argonne is 8.9°C (48.0°F); the long-term (1941-1970) normal value at Midway Airport is 10.3°C (50.5°F).

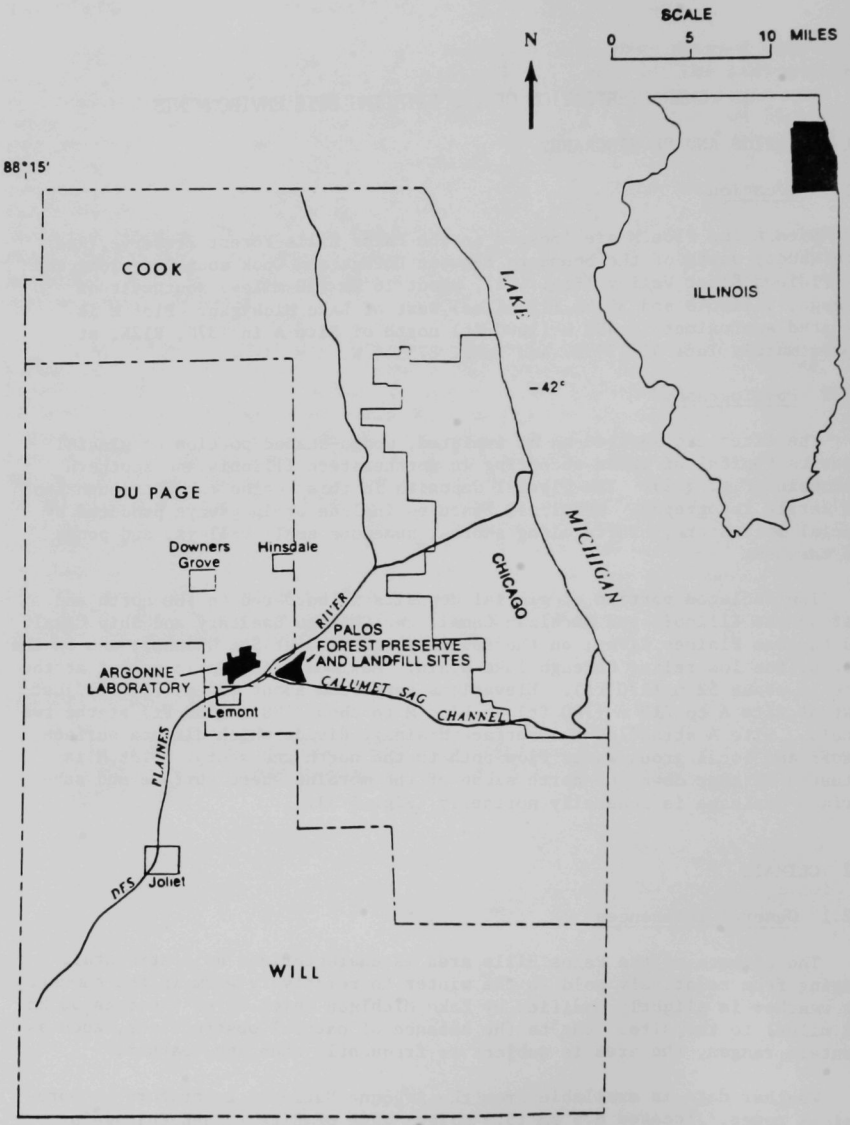


Fig. 4.1. Location of the Palos Forest Preserve on a Chicago Area Map. Conversion factor: 1 mile = 1.609 km. Adapted from Reference 24.

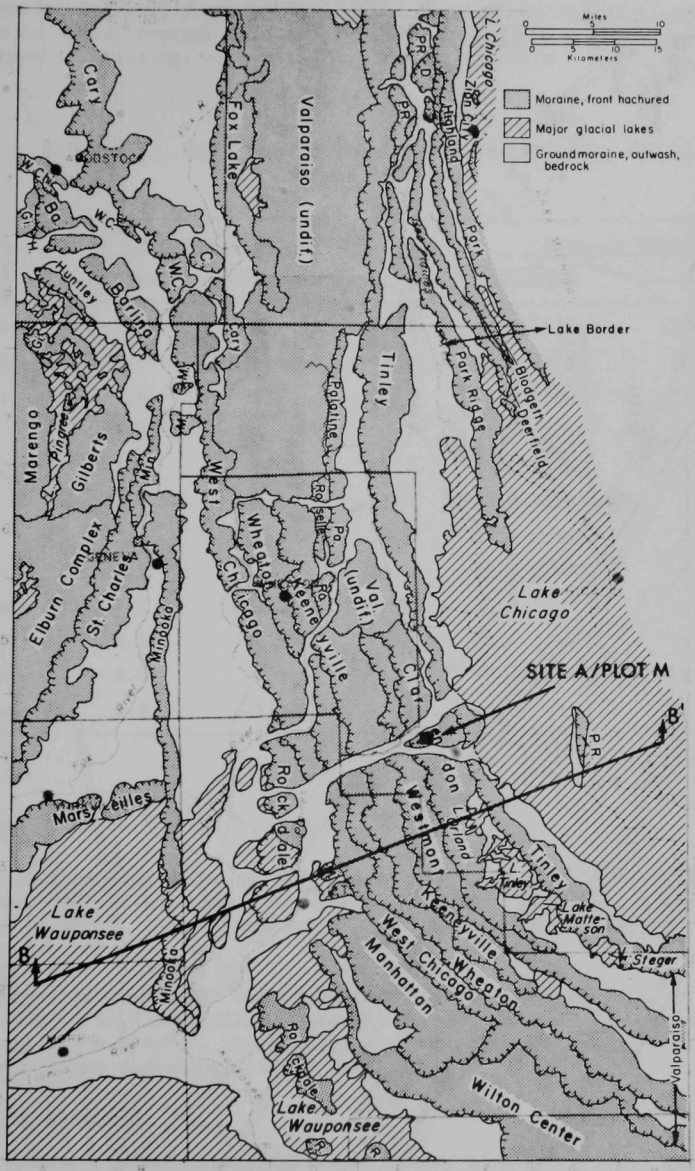


Fig. 4.2. Major Glacial Features of the Chicago Area. Source: Reference 20 (location of sites and line B-B' added).

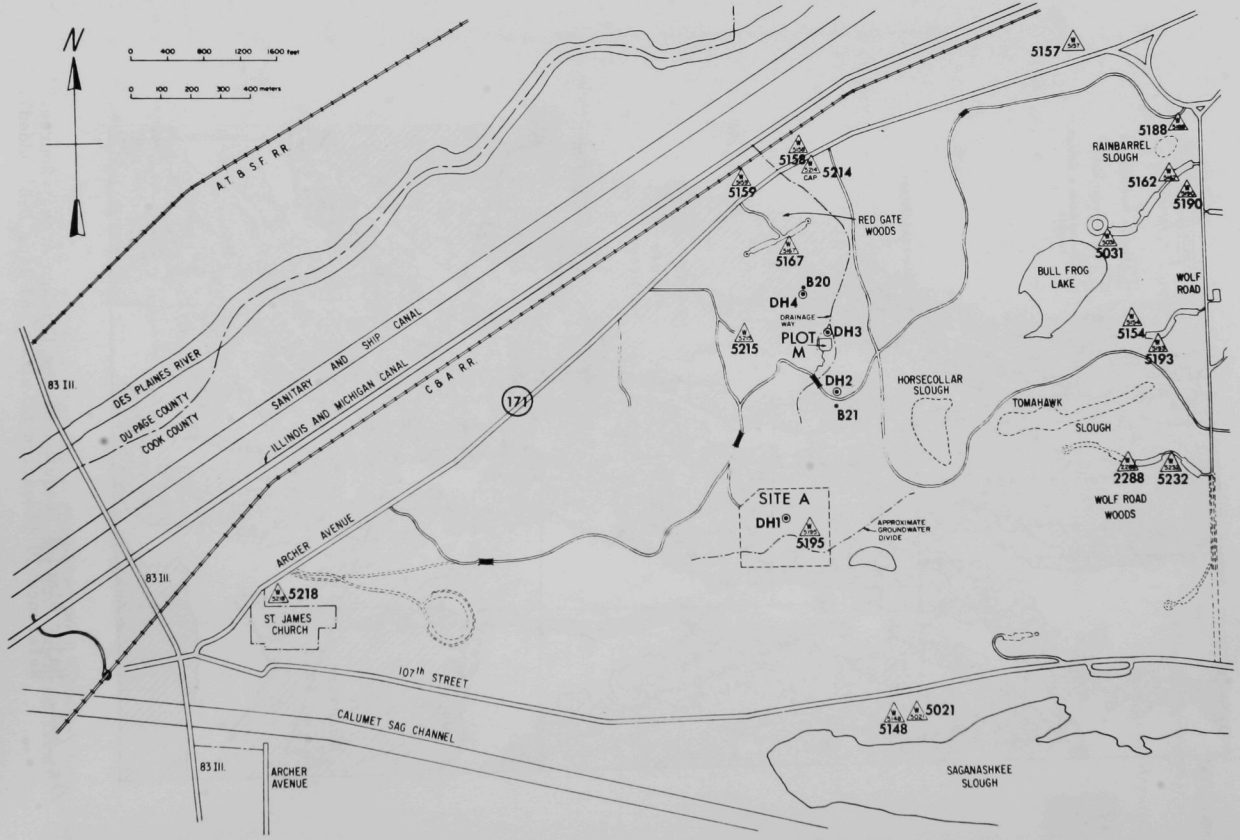


Fig. 4.3. Location of Site A and Plot M in the Palos Forest Preserve. Legend: △ - forest preserve wells; ⊙DH - holes drilled into dolomite bedrock; ●B - borings into the soil overburden. Adapted from Reference 17.

Daily variations range from 7.6C° (13.7F°) in December to 11.4C° (20.6F°) in May with an annual average of 9.8C° (17.6F°).[2] Table 4.1 shows monthly mean and extreme temperatures as recorded at Midway Airport.

Table 4.1. Monthly Mean and Extreme Temperatures (°C) at Midway Airport

	Normal (1941-1970)			Extreme (Year)	
Month	Maximum	Minimum	Mean	Maximum	Minimum
January	-0.3	-8.3	-4.3	19.4 (1950)	-28.3 (1977)
February	1.4	-6.6	-2.6	23.9 (1976)	-26.1 (1951)
March	7.0	-1.7	2.7	27.8 (1945)	-21.7 (1943)
April	15.2	4.7	9.9	31.1 (1977)	-8.9 (1975)
May	21.3	9.8	15.6	35.0 (1977)	-1.7 (1966)
June	27.0	15.7	21.4	40.0 (1953)	1.7 (1945)
July	29.1	18.3	23.7	39.4 (1956)	7.8 (1972)
August	28.5	17.8	23.2	38.3 (1947)	6.1 (1965)
September	24.3	13.3	18.8	38.3 (1947)	1.1 (1974)
October	18.4	7.6	13.0	34.4 (1963)	-6.7 (1948)
November	8.9	0.3	4.7	27.2 (1950)	-18.9 (1950)
December	1.8	-5.8	-1.9	21.7 (1970)	-25.6 (1960)

4.2.2 Winds

The average wind speed as recorded at Midway is 17.3 km/h (10.8 miles/h). Calms occur 3.7% of the time. The predominant wind direction is out of the southwest quadrant. Wind speed and direction data from the airport are illustrated in Table 4.2.

The average wind speed recorded at Argonne at a height of 45.7 m (150 ft) above ground is 19.8 km/h (12.3 miles/h); calms occur 2.0% of the time at this height. At 5.8 m (19 ft), the average wind speed is 12.2 km/h (7.6 miles/h), with calm periods occurring 3.1% of the time.

4.2.3 Precipitation

The average annual precipitation at Midway is 87.5 cm (34.4 inches); the 15-year (1950-1964) average at Argonne is 80.0 cm (31.5 inches). Most of the precipitation occurs from April to September, usually in the form of thunderstorms. Snow and sleet average 81.8 cm (32.2 inches) per year. The monthly

Table 4.2. Joint Frequency of Average Wind Speed and Direction for Midway Airport, January 1965-December 1974

Direction	Speed (knots) 0-3	4-6	7-10	>11	Total
N	0.3	1.1	2.2	2.5	6.1
NNE	0.1	0.5	1.1	1.7	3.4
NE	0.2	0.8	2.0	2.2	5.2
ENE	0.3	1.0	2.1	1.5	4.9
E	0.4	1.5	2.6	1.4	5.9
ESE	0.2	0.8	0.9	0.4	2.3
SE	0.3	1.2	1.7	1.0	4.2
SSE	0.2	0.8	1.5	1.1	3.6
S	0.9	3.5	6.0	6.4	16.8
SSW	0.5	2.0	3.3	3.0	8.8
SW	0.5	1.8	2.8	2.6	7.7
WSW	0.5	1.6	2.5	2.5	7.1
W	0.7	2.0	3.1	3.3	9.1
WNW	0.4	1.2	1.9	2.0	5.5
NW	0.4	1.3	2.1	2.1	5.9
NNW	0.2	0.7	1.3	1.3	3.5
Total	6.1	21.8	37.1	35.0	

Conversion factor: 1 knot = 1.85 km/h (1.15 miles/h).

median, maximum, and minimum precipitation for Midway Airport are given in Table 4.3. Potential evaporation has an annual average of 99 cm (39 inches).[3]

4.2.4 Storms

Snowfalls in excess of 10 cm (6 inches) occur on an average of only once or twice each year. However, in January 1979, storms brought 102.6 cm (40.4 inches) of snow in that month alone. The winters of 1977-1978 and 1978-1979 have been the snowiest on record; over 200 cm (79 inches) of snowfall occurred in both seasons. Severe ice storms occur only once every four or five years.

Thunderstorm days average about 40 annually and occasionally bring hail, damaging wind, and tornadoes. From 1915-1968, there have been more deaths from tornadoes in Illinois than in any other state.[4] From 1957-1969, tornado incidences in the state have numbered 371.[5] More than 65% of Illinois tornadoes

Table 4.3. Mean and Extreme Precipitation at Midway Airport, 1941-1970

Month	Precipitation (cm) Mean	Maximum	Minimum	Snow (cm) Mean[a]
January	4.7	10.3	0.7	25.1
February	4.0	8.5	0.6	21.1
March	6.9	13.6	0.8	19.1
April	9.5	21.2	1.1	3.5
May	8.7	19.3	2.0	trace
June	10.0	22.5	2.0	0
July	10.3	22.8	3.4	0
August	8.0	24.6	2.0	0
September	7.6	35.9	1.2	0
October	6.7	30.6	0.5	0.7
November	5.6	12.8	1.4	7.4
December	5.3	16.9	0.8	27.4
Annual	87.4			104.3

[a]Records from 1938-1978.

occur from March to June. The probability of a tornado striking Site A/Plot M is 8.54×10^{-4} per year, or about once every 1200 years.[6] However, this does not preclude the possibility of more frequent tornado incidence. In a period of 26 months, two tornadoes were observed at Argonne National Laboratory just 6.4 km (4 miles) west of Site A.

Floods occur nearly every year and can affect any part of the state. Thunderstorms account for many flash floods throughout the warm season. In July 1957, 15.8 cm (6.2 inches) of rain fell at Midway Airport in 24 hours.

4.3 AIR QUALITY

Site A is located in Air Quality Control Region 67, and air monitoring is extensive throughout this area. The proposed action involves the use of motor vehicles powered by diesel fuel, so the combustion products from those vehicles must be considered. In order to assess the environmental impacts, the baseline conditions must be determined. Therefore, air pollution concentrations from monitoring sites surrounding the site were used to estimate the area's present air quality. Monitoring data for 1977 and part of 1978 were obtained from USEPA Region V in Chicago. National ambient air quality standards for total suspended particulates (TSP), sulfur dioxide (SO_2), and nitrogen dioxide

(NO_2) are as follows:

TSP	Annual geometric mean	75 $\mu g/m^3$
	24-hour maximum concentration (standard not to be exceeded more than once a year)	260 $\mu g/m^3$
SO_2	Annual arithmetic mean	80 $\mu g/m^3$
	24-hour maximum concentration (standard not to be exceeded more than once a year)	365 $\mu g/m^3$
NO_2	Annual arithmetic mean	100 $\mu g/m^3$

The TSP values from receptors located around the Palos Hills area are listed in Table 4.4. In addition, SO_2 and NO_2 have been monitored at two locations. In 1977, SO_2 and NO_2 levels averaged 19 and 73 $\mu g/m^3$, respectively, at Blue Island, and 10 and 77 $\mu g/m^3$, respectively, at Harvey; the highest and second highest 24-hour SO_2 concentrations were 414 and 223 $\mu g/m^3$ at Blue Island, and 100 and 89 $\mu g/m^3$ at Harvey (telephone conversation with K. Kamilick, Surveillance and Analysis Division, USEPA Region V, Chicago, Ill.). Because there are no federal regulations other than the annual standard at this time, NO_2 is not measured on a 24-hour basis.

Table 4.4 Ambient Levels ($\mu g/m^3$) of Total Suspended Air Particulates in the Palos Hills Area, 1977

Receptor Location	Geometric Mean	24-Hour Level	
		Highest	2nd Highest
Midlothian, 16.6 km SE	49	158	158
Orland Park, 9.3 km SSE	52	177	142
Blue Island, 18.7 km ESE	78	282	216
Harvey, 22.8 km SE	67	229	221
Romeoville, 14.5 km WSW	59	160	155
Lockport, 18.7 km SW	64	164	157
Argonne National Laboratory, 8.3 km W	52	102	98

The dispersive ability of the atmosphere depends on the depth of the mixing layer.[7] Deeper mixing layers allow more dilution of the pollutants. Poor mixing conditions occur when wind speeds are less than 4 m/s and mixing

depths are less than 1000 m for greater than 48-hour periods. The average annual mixing depth in the Palos Hills area is 500 m in the morning and 1200 m in the afternoon. The average annual wind speed averaged through the morning mixing layer is 6 m/s and averaged through the afternoon mixing layer is 7.5 m/s. Over a period of five years there are, on the average, nine episodes of poor atmospheric dispersion, each lasting at least two days. No episode is likely to last for five consecutive days.[7]

4.4 SOCIAL AND ECONOMIC PROFILE

4.4.1 Demography and Settlement Pattern

4.4.1.1 Demography

As part of the Palos Forest Preserve (Red Gate Woods) in southwestern Cook County (see Sec. 4.1), Site A and Plot M fall within the Chicago Standard Metropolitan Statistical Area (SMSA). This SMSA region is comprised of six Illinois and two Indiana counties. Cook County, which includes the city of Chicago, had a 1975 estimated population of 5,369,328, representing a decrease of 124,438 or 2.3% since the 1970 census. This decrease may be attributed to Chicago, where population decreased by approximately 8% between 1970 and 1975. In contrast, the county outside of Chicago increased in population 7.9% during the same time period.[8-10] Population density for the county was 2173 person/km^2 (5728 person/mi^2).[8-10] Cook County's yearly transient population, primarily tourist and conventioneers, averages about 6 million people.[11] Average visitor population to the county's forest preserves was over 29 million in 1976.[12]

Palos Township, located in Cook County approximately 16 km (10 miles) southwest of the city limits of Chicago, had an estimated 1976 population of 43,646, an increase of 33.6% since the 1970 census.[9] Of the township's 5796 ha (14,315 acres), about 3% is residential, whereas 72% is devoted to forest preserves.[10] In 1976, approximately 20,000 persons visited Red Gate Woods, which was about 0.6% of the total visitor population to the county's forest preserves.[13]

Hickory Hills, Palos Park, Palos Hills, and Willow Springs are the local communities that border the Palos Forest Preserve. The combined total population of these communities increased approximately 21.3% from 1970 to 1975. The largest increase in population was Palos Hills, gaining about 105.2%, whereas Palos Park increased by only 1.8% (see Table 4.5).[8]

4.4.1.2 Settlement Pattern

The settlement pattern of Cook County is characterized by major railroad lines, expressways, and waterways that lead north, west, and south from the city of Chicago to the outlying suburbs. The suburbs, generally located along or near these major arteries, are delineated by urban-residential and, in some cases, industrial development.[10,14]

The municipalities of Hickory Hills, Palos Park, Palos Hills, and Willow Springs, which border the Palos Forest Preserve, are exclusively urban-residential with limited retail establishments and no industrial development planned for the near future.[15]

Table 4.5. Population Data, 1970-1976

County/Township/City	1970	1975	1976	1970-1975 Difference	1970-1975 %	1970-1976 Difference	1970-1976 %
Cook County	5,493,766	5,369,328	--	124,438	-2.3	--	--
Palos Township	32,669	42,460	43,646	+9,791	+30.0	+10,997	+33.6
Hickory Hills	13,263	14,190	--	+927	+7.0	--	--
Palos Park	3,297	3,356	--	+59	+1.8	--	--
Palos Hills	6,629	13,602	--	+6,973	+105.2	--	--
Willow Springs	3,318	3,540	--	+222	+6.7	--	--

Sources: References 8 and 9.

4.4.2 Social Organization and Services

4.4.2.1 Social Organization

The sociocultural organization of Cook County tends to reflect the modern urban-industrial society. The communities near Chicago tend to be heterogeneous, with people from mixed cultural backgrounds living in a densely populated area. Typically, the population in a metropolitan area is more individually oriented and relationships more transitory in contrast to that in a rural area. In this type of environmental setting, the area is economically tied to nonagricultural pursuits, with the incorporated as well as the unincorporated areas being strongly influenced by the general characteristics of the central city.[15,16]

4.4.2.2 Social Services - Recreation

The Palos Forest Preserve offers the outdoor recreational enthusiast such activities as hiking, horseback riding, cross country skiing, and picnicking. More specifically, Red Gate Woods, which is the closest access point to Site A/Plot M, is used primarily for picnics and parking for hikers.[12,13] Potable drinking water for users of the park is provided by wells in the vicinity of Red Gate Woods. These wells provide water only for the forest preserve and are independent of the surrounding municipalities' water supply.[13,17]

4.5 LAND RESOURCES

4.5.1 Land Ownership

Site A (approximately 7.7 ha [19 acres]) and Plot M (approximately 0.4 ha [1 acre]) are owned by the Cook County Forest Preserve District.[17]

4.5.2 Land Use

Currently, Site A and Plot M are surrounded by the Palos Forest Preserve, with the nearest developed recreational area being Red Gate Woods.

Specifically, Site A and Plot M are not in a developed section of the woods, and, consequently, are not readily accessible to the public by vehicular transportation. The area, however, has many trails (used for hiking, cross-country skiing, and horseback riding) which give the public access to Site A/Plot M. Existing and future land-use plans indicate that no changes are anticipated in land use for the immediate future.[17,18]

4.5.3 Neighboring Areas

4.5.3.1 Urban Areas

There are four urban areas that border the Palos Forest Preserve: Hickory Hills (pop. 14,190), Palos Park (pop. 3356), Palos Hills (pop. 13,602), and Willow Springs (pop. 3540).[8] All four municipalities are approximately 6.4 km (4 miles) from Site A/Plot M. The site itself is located in Palos Township, which is an urban-residential area with approximately 43,600 residents. Palos Township and the four bordering communities are part of the more than 520 units (i.e., municipalities, school districts, townships, and special districts) that form Cook County. Although the residences and population surrounding the Palos Forest Preserve are increasing, land-use plans indicate that 72% of the land will continue to be devoted to parks, forest preserves, and recreational open space.

4.5.3.2 Rural and Agricultural Areas

As previously discussed in Section 4.5.3.1, Site A and Plot M are located in an urban setting, and thus there are no rural areas surrounding them. The nearest agricultural and rural area is to the south of the site in Will County.[10]

4.6 HISTORICAL AND ARCHEOLOGICAL RESOURCES

Cultural resources are well-known for the area surrounding Site A/Plot M. In Cook County, where the site is located, more than 100 historic properties have been listed in the National Register. More specifically, within an approximate 24-km (15-mile) radius of the site, there is one historic property listed in the National Register (the Lemont Central Grade School, 410 McCarthy Road, Lemont, Ill. [3-7-75]), and 40 landmarks of special historic importance identified by the Illinois Historic Structures Survey, Illinois Historical Landmarks Survey, and several other historical societies and historians.[19] Nine of these landmarks are located in the Palos Forest Preserve area and include several cemeteries, private buildings, and fort sites constructed between 1700 and 1900 (see Fig. 4.4 and Appendix A).

4.7 WATER RESOURCES

4.7.1 Surface Water

4.7.1.1 Hydrological Properties

Surface hydrological features in the vicinity of Site A/Plot M include the "Illinois Waterway," an abandoned canal (Illinois and Michigan Canal), lakes, ponds (sloughs), intermittent streams, and marshy areas.

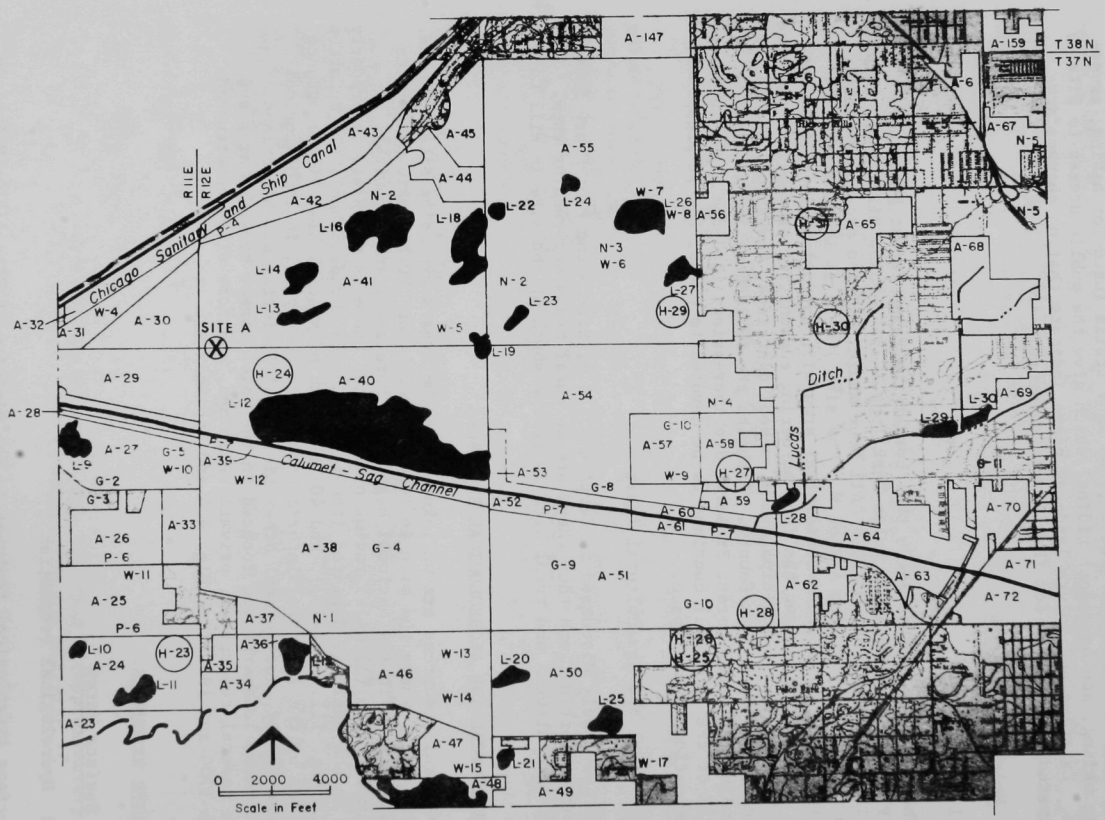


Fig. 4.4. Landmarks of Special Historic Importance Located in the Palos Forest Preserve Area. (See Appendix A for descriptions.) Conversion factor: 1 ft = 0.305 m. Adapted from Reference 19.

The major surface hydrological system in the area is the "Illinois Waterway" (Fig. 4.3), which is comprised of portions of the Des Plaines River main channel, the Chicago Sanitary and Ship Canal (north of Site A/Plot M), and the Calumet-Sag Channel (south of Site A/Plot M). The waterway extends some 523 km (327 miles) from Lake Michigan to Grafton, Illinois, on the Mississippi River. In the site vicinity, the waterway cuts through a low divide via an excavated channel in the bedrock floor of the Des Plaines Valley. A branch called the Calumet-Sag Channel extends from the Lake Calumet industrial district on Chicago's south side to the main channel near Sag Bridge about 2 km (1-1/2 miles) west of Site A/Plot M. The minimum depth of the channel is 2.7 m (9 ft).[20] West of Site A/Plot M (below Lockport, Illinois), the waterway consolidates into the Des Plaines River main channel and follows that channel until it joins the Kankakee River to form the Illinois River. The major uses of the waterway are navigation, waste dilution for sewage treatment effluent and storm runoff from Chicago, and channeling regulated diversions of lake water and runoff from the Lake Michigan watershed. Flow in the waterway is controlled by locks and dams and is partially regulated by a decree of the U.S. Supreme Court.[17] From the standpoint of public water supplies, water in the waterway is of poor quality for many miles above and below Site A/Plot M, to the point of being considered a health hazard.[21]

The principal surface drainage near Plot M is an intermittent stream that drains to the north past the east side of the plot. A small tributary drains the west side of the plot and joins the main stream north and downgradient of Plot M (Fig. 4.5). The stream continues north until it joins the Illinois and Michigan Canal about 730 m (800 yd) north of Plot M. It is only after heavy precipitation, which is common in the spring, that the flow reaches the canal. During periods of lighter rain, the water infiltrates into a gravelly area in the streambed near Red Gate Woods that is unsaturated during much of the year.

4.7.1.2 Water Quality

Water samples from the stream at various points around and downstream of Plot M were collected and analyzed for tritiated water in March and April of 1976, and again in the spring of 1977. Water samples collected from the stream in the spring of 1954, and retained, were also analyzed and corrected for decay back to 1954. The sampling locations are shown in Figure 4.5, and the analytical results are given in Reference 17 (Table 24). All the samples were taken from the stream except the one at map location #6 in Figure 4.5; this was a low-volume seep at the northeast base of the Plot M hill whose water flowed into the intermittent streambed.

The apparent trend of the tritiated water concentration is to increase as the water moves from upstream to below the Plot M area and then to decrease downstream of Plot M as a result of dilution by downstream contributions of surface water runoff. Comparison of 1954 samples with samples collected in 1976 and 1977 shows the same general trend, although the concentrations differ in magnitude.[17]

Other samples included water from the Chicago Sanitary and Ship Canal, the Des Plaines River in the vicinity of the Palos Forest Preserve, and the Illinois and Michigan Canal downstream from the point where drainage from the

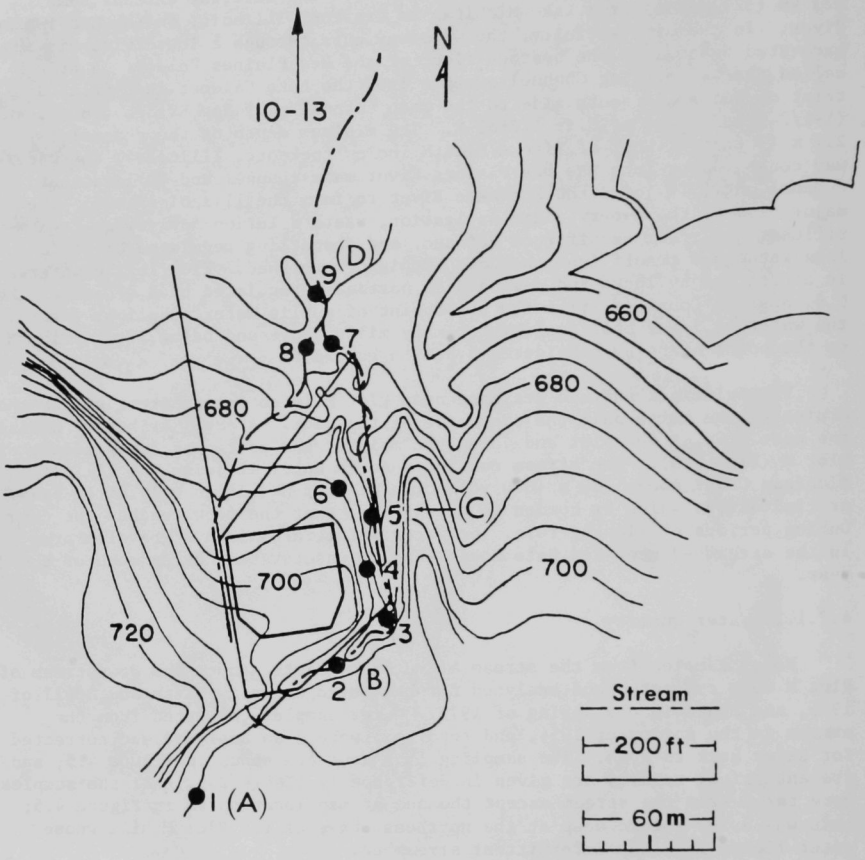


Fig. 4.5. Surface Water Sampling Locations Near Plot M. Adapted from Reference 17.

Plot M site enters the canal. These samples were analyzed for tritium, and the concentrations were less than the detection limit of 0.2 nCi/L. Water was also collected from two small ponds in the Red Gate Woods south of the Red Gate Woods well. No tritiated water was detected in either of the ponds.[17]

As part of the 1977 Environmental Monitoring Program at Argonne National Laboratory,[22] samples from the Des Plaines River were analyzed to determine the concentrations of various radiological parameters. All the measured values were only fractions of the concentration guides for allowable releases.[17] The alpha concentration in 35 samples from the Des Plaines River averaged 1.9×10^{-9} μCi/mL; the beta concentration was measured at 20×10^{-9} μCi/mL. Strontium-90 averaged less than 0.6×10^{-9} μCi/mL, plutonium-239 averaged less than 0.00066×10^{-9} μCi/mL, and natural uranium averaged 2.3×10^{-9} μCi/mL.[17]

Radiochemical analyses for gross alpha and beta, strontium-90, uranium, plutonium-239, and other transuranic nuclides (TU) were also performed on some surface water samples collected at Plot M.[17] The results are tabulated in Reference 17 (Tables 2 and 25). Considering the Sr-90 concentration at upstream Location A (Fig. 4.5) as fallout background for precipitation, the elevated concentrations in the seep water--sample location #6 (Fig. 4.5)--can be attributed to contributions from Plot M. Plutonium was also measurable in the seep water at very low concentrations and, like the Sr-90, may have been leached from the plot. The volume of water from the seep is very small and becomes highly diluted in the stream so that at Location D (Fig. 4.5), all radionuclide concentrations were at background levels. The uranium concentrations were in their normal range at all locations.[17]

4.7.2 Groundwater

Groundwater resources in northeastern Illinois include four aquifer systems:

1. Glacial drift,
2. Shallow dolomite,
3. Cambrian-Ordovician (deep sandstone), and
4. Mount Simon (sandstone of Cambrian age).

The Mount Simon aquifer is the deepest and highest yielding aquifer. However, water quality is such (saline, high chloride concentrations) as to render it unfit for ordinary use.[23] In the Chicago region, it is estimated that only 59 wells finished in the Mount Simon aquifer were in use as of 1974.[23]

The Cambrian-Ordovician aquifer is encountered at an average depth of about 150 m (500 ft), averages 305 m (1000 ft) in thickness, and is composed of sandstones and dolomites. This aquifer is effectively separated from the underlying Mount Simon aquifer by the relatively impermeable Eau Clair Formation. Wells in the Cambrian-Ordovician aquifer have yields in excess of 44 L/s (700 gal/min).[23]

The shallow dolomite aquifer consists of Silurian dolomite wherein good quality groundwater occurs in joints, fissures, solution cavities, and other openings. Wells in the dolomite range in depth from 5 to 137 m (15 to 450 ft). Yields of wells are variable but are known to exceed 30 L/s (500 gal/min).[23]

Glacial drift aquifers occur where somewhat continuous water-yielding sand and gravel zones of considerable thickness are present. In the area of Site A/Plot M, wells in glacial drift yield up to 6 L/s (100 gal/min)[17] or more, but are generally less reliable than dolomite wells.

Most groundwater supplies in the Site A/Plot M area (Palos Forest Preserve) are derived from the shallow dolomite aquifer. Recharge of the dolomite aquifer occurs via slow percolation of precipitation through the overlying glacial drift.

4.7.2.1 Geohydrology of Site A/Plot M

The sites are underlain by sandy, silty, clay till that averages about 40 m (130 ft) in thickness above the dolomite bedrock. To the north, south, and west, the thickness of the till decreases to zero where bedrock is exposed in the valley floors, isolating the glacial deposits on which Site A/Plot M is located.

Water levels were measured periodically[17] in soil borings and bedrock wells to determine the elevation of the water table and the piezometric level, respectively, and the extent of seasonal variations. Spring and fall are usually periods of high groundwater (water table) levels, and summer and winter are periods through which water levels decline. Water table levels vary from about 4.5 m (15 ft) to 7.6 m (25 ft) below the surface, and groundwater movement is generally toward the north.[17]

Tritium analyses of soil boring samples (Reference 17, Table 36) indicate that the northeastern direction is a preferential pathway for tritium migration. The existence of a steep drainageway in the eastern periphery of Plot M influences the vertical movement of groundwater, namely at the center of Plot M, before the groundwater changes its course toward the north and northeast.

The highest tritium concentrations--as high as 10^5 nCi/L (see Table B.1 [App. B])--were detected in the immediate vicinity of Plot M. On the other hand, the lowest concentration, corresponding to 10^3 nCi/L, was found downgradient of Plot M. The concentration profiles at wells SB-22 and SB-23 (Fig. 4.6) within Plot M suggest that a large concentration of tritium was released from the upper 3 or 6 m (10 or 20 ft) of soil where the radioactive materials were buried. In the absence of more data, influence of the impermeable concrete layer covering the site of Plot M on the movement of tritium cannot be known with certainty. Nevertheless, there is enough evidence to suggest that much of the tritium must have migrated into the saturated zone of the aquifer in the days preceding the covering of Plot M with concrete.

A geohydrologic study[24] of Site A/Plot M indicated that hydraulic conductivities in the saturated till ranged from 1.2×10^{-8} to 3.2×10^{-6} cm/s (3.61×10^{-5} to 9.09×10^{-3} ft/day). The resulting groundwater velocity (vertical) through the till was estimated to be 0.08 m/day (0.27 ft/day). However, another study on similar till at Argonne National Laboratory, about 5.6 km (3.5 miles) from Site A/Plot M, indicated that groundwater velocity through the till could be as low as 2.5×10^{-3} m/day (0.01 ft/day).[25] Preliminary calculations based on 0.08 m/day indicated that the time for water (containing tritium) to move through the till to the dolomite would be

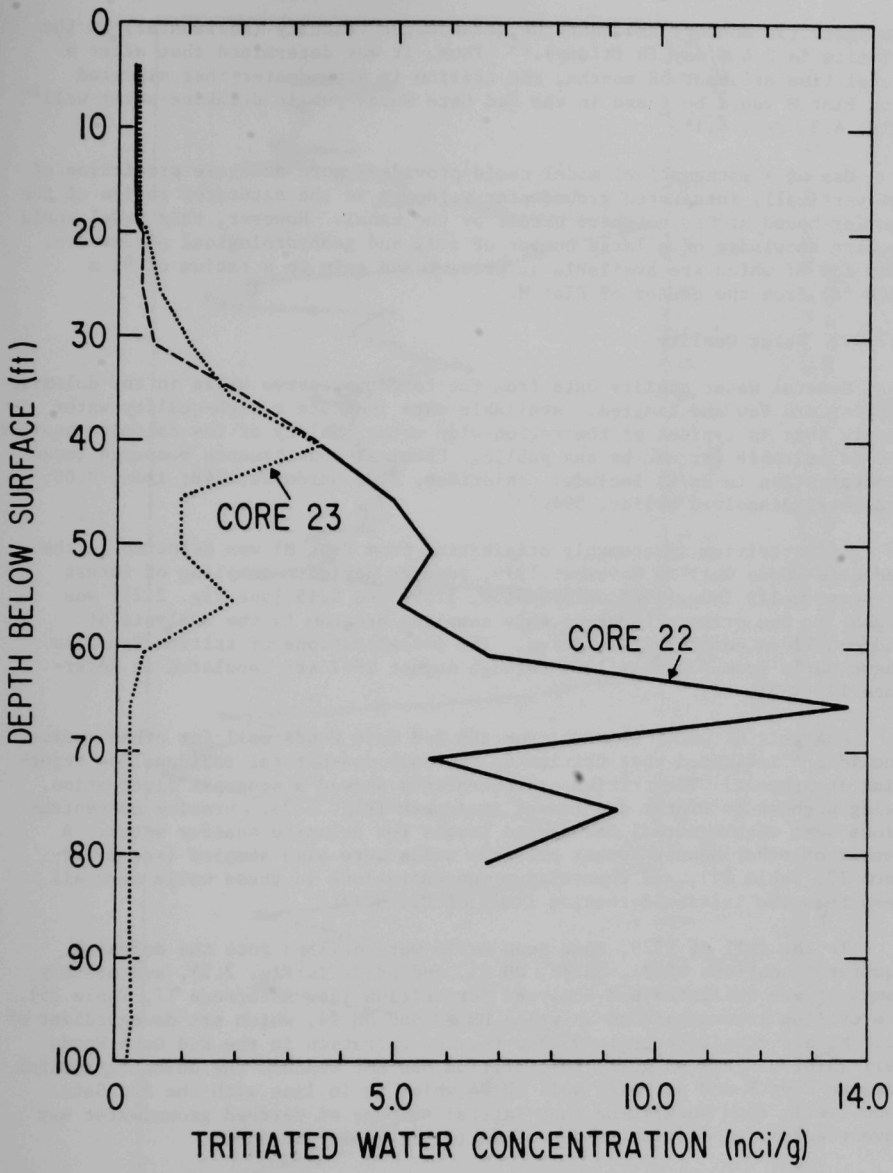


Fig. 4.6. Tritiated Water Concentrations as a Function of Depth Beneath Plot M. Conversion factor: 1 ft = 0.305 m. Source: Reference 17.

4.6 years (55 months) and that the groundwater velocity (horizontal) in the dolomite is 2.4 m/day (8 ft/day).[24] Thus, it was determined that after a travel time of about 58 months, the tritium in groundwater that migrated from Plot M would be found in the Red Gate Woods public drinking-water well[24] (Fig. 4.3, Sec. 4.1).

Use of a mathematical model could provide a more accurate prediction of the vertically integrated groundwater velocity in the saturated region of the aquifer bound at its northern border by the canal. However, this model would require knowledge of a large number of soil and geohydrological parameters, very few of which are available at present and only to a radius of 91 m (300 ft) from the center of Plot M.

4.7.2.2 Water Quality

General water quality data from the forest preserve wells in the dolomite aquifer are few and limited. Available data indicate a high-quality water supply that is typical of the region-wide water quality of the dolomite aquifer and is suitable for use by the public. Chemical constituents measured (mean concentration in mg/L) include: chlorides, 2.0; hardness, 548; iron, 0.80; and total dissolved solids, 594.[23]

After tritium (presumably originating from Plot M) was detected in the Red Gate Woods well in November 1973, regular periodic sampling of forest preserve wells (Nos. 5167, 5157, 5158, 5159, and 5215 [see Fig. 2.2]) was begun.[17] The primary focus of this sampling program is the analysis of radionuclides, especially tritium. The concentrations of tritium found in these wells from November 1973 through August 1977 are tabulated in Reference 17 (Table 32).

Analysis of water samples from the Red Gate Woods well for other radionuclides[17] indicated that tritium is the only non-natural radionuclide occurring at present. The tritium concentrations showed a seasonal fluctuation, being highest in winter and lowest in summer (Fig. 4.7). Uranium concentrations were within normal background levels for dolomite aquifer water. A number of other nearby forest preserve wells were also sampled (see Reference 17, Table 34), and the tritium concentrations in these wells were all less than the tritium detection limit of 0.2 nCi/L.

In the fall of 1976, four deep wells were drilled into the dolomite aquifer (locations DH #1, DH #2, DH #3, and DH #4 in Fig. 2.2), and monthly samples were collected and analyzed for tritium (see Reference 17, Table 35). The tritium concentrations in wells DH #3 and DH #4, which are downgradient of Plot M, are considerably less than the concentration in the Red Gate Woods well (5167). This suggests that tritium has not reached the dolomite aquifer between Plot M and at least well DH #4 which is in line with the Red Gate Woods well, thus suggesting that lateral seepage of perched groundwater may have transported tritium to the wells (5167, 5158, and 5159).

In addition to the deep wells into the dolomite aquifer, a series of ten bore holes (cased for water sampling) were sunk around Plot M. The water that collected in these bore holes was periodically sampled and analyzed for tritium. The relative concentrations of tritium in water from these bore holes (see

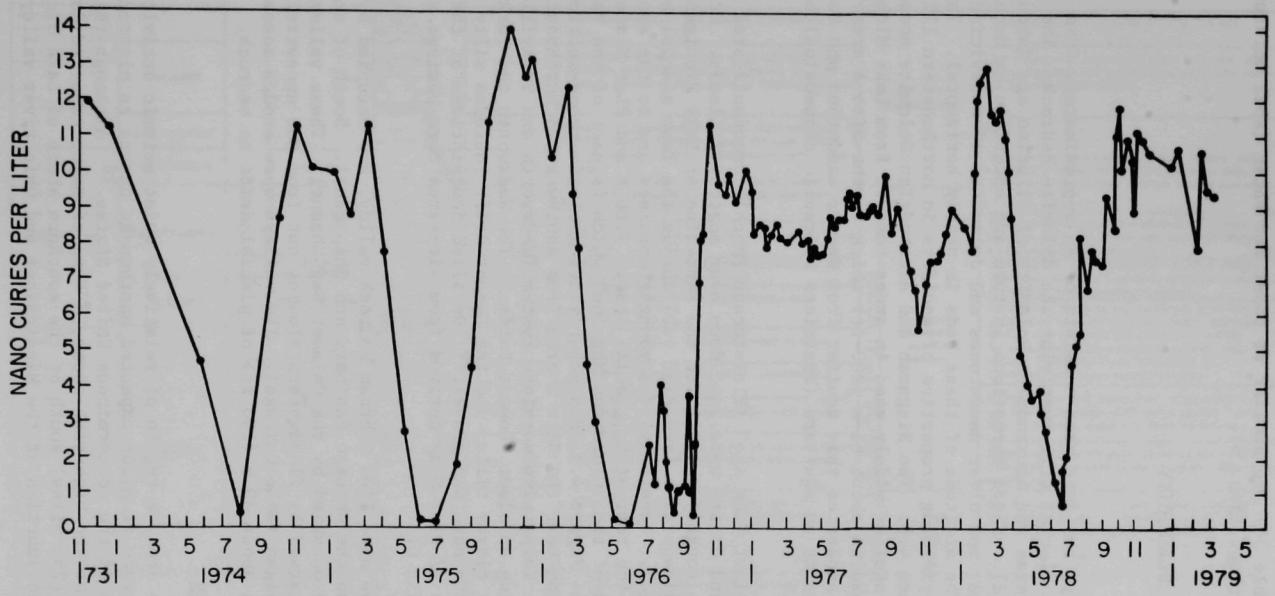


Fig. 4.7. Tritium Content of Water from Red Gate Woods Well (5167). Source: Reference 17 (1978-1979 data obtained from J. Sedlet, Argonne National Laboratory).

Reference 17, Table 36) are similar to those for water (soil moisture) obtained from the soil borings (App. B).

4.8 GEOLOGY AND SEISMICITY

4.8.1 Geology

Geologically, the site area consists of an approximately 40-m (130-ft) thick deposit of glacial till overlying the dolomite bedrock. The bedrock at the site is Niagaran and Alexandrian Dolomite of Silurian age (about 400 million years old). These formations in turn are underlain by Maquoketa Shale of Ordovician age, and older sandstones and dolomites of Ordovician and Cambrian age. The attitude of these beds is nearly horizontal. The stratigraphy and water-yielding properties of aquifers in northeastern Illinois are depicted in Figure 4.8. The Niagaran and Alexandrian Dolomite comprise the shallow bedrock aquifer widely used in areas removed from Lake Michigan (e.g., DuPage County) and is about 61-m (200-ft) thick in the Site A area. The Maquoketa Shale separates this aquifer from deeper sandstone and dolomite aquifers and acts as an aquitard (restricts hydraulic connection) between the two aquifers.

During the last "Ice Age" (Pleistocene Epoch), unconsolidated glacial deposits (till and drift) were laid down over most of Illinois. Crescent-shaped moraines, roughly parallel to the shoreline of Lake Michigan, were formed in the Chicago area (see Fig. 4.2) during the last glacial stage (the Wisconsinan stage). Generally, the younger moraines are to the east, tracing the position of the retreating glacial lobe. Site A and Plot M are on an isolated portion of the "Clarendon Moraine" which is part of the Valparaiso morainic system. Figure 4.9 is a generalized geologic cross-section through the Chicago region near the Site A area from southwest to northeast; the figure shows the Valparaiso morainic system (Wadsworth and Yorkville Till Members) overlying an older "Lemont Drift." The Wadsworth and Yorkville Till Members are gray clayey tills, and the Lemont Drift includes silty till that grades upward into sand and gravel.[20] Detailed descriptions of the glacial deposits at Site A/ Plot M as derived from site-area core borings are presented in Appendix C.

North of the site lies a broad bedrock valley, now occupied by the Des Plaines River and the Chicago Sanitary and Ship Canal. South of the site lies a similar valley occupied by the Calumet Sag Channel. These valleys were, for the most part, carved by floodwaters flowing out from the ancestral predecessor to Lake Michigan (Lake Chicago). The valleys were eroded across the moraines through about 30 m (100 ft) of glacial drift to bedrock.

4.8.2 Seismicity

The Chicago area, a region of relatively quiet seismic activity, is wholly within a zone of minor expected earthquake damage as plotted on a seismic risk map of the conterminous United States.[26] Although the Chicago area is outside of the high-risk areas, a zone of major expected damage (which is about 400 km [250 miles] south of the southern shore of Lake Michigan) is designated at the junction of the Mississippi and Ohio river valleys. Also,

SYSTEM	SERIES	MEGA-GROUP	GROUP OR FORMATION	GRAPHIC LOG	THICKNESS (FEET)	DESCRIPTION	AQUIFER SYSTEMS	
QUATERNARY	PLEISTOCENE				0 - 400 +	Unconsolidated ice- and water-laid deposits, pebbly clay (till), silt, sand and gravel, generally discontinuous and interbedded; alluvial silts and sands commonly present along streams.	Glacial drift aquifer system	Sand and gravel beds serve as aquifers. Some wells yield more than 1000 gpm. Large supplies of water available from thick, relatively continuous sand and gravel deposits.
PENNSYLVANIAN					0 - 175	Shale; sandstones, fine grained; limestones; coal; clay.	Shallow bedrock aquifer system	Fractured beds yield small supplies locally.
MISSISSIPPIAN* DEVONIAN					0 - 400 +	Dolomite, very pure to very silty, cherty; shale partings; thin shales and argillaceous beds frequently present in lower parts of Silurian dolomite.		Not consistent; some wells yield more than 1000 gpm. Crevices and solution channels more abundant near bedrock surface.
SILURIAN	NIAGARAN				0 - 165	Upper and middle units—shale, light gray to green, plastic to brittle, some dolomite, silty; dolomite, mostly silty, argillaceous; minor limestone. Lower unit—shale, dark gray, black, brown, plastic to brittle; some dolomite in upper part; silty, argillaceous.		Yields water from fractured beds. Shales, particularly in lower unit, act as confining beds at the base of the shallow bedrock aquifer system.
	ALEXANDRIAN				0 - 250 +			
ORDOVICIAN	CINCINNATIAN		Maquoketa				Deep bedrock aquifer systems	
	CHAMPLAINIAN	OTTAWA	Galena Platteville		150 - 350+	Dolomite, cherty; sandy at base; limestone; shale partings.	Cambrian-Ordovician aquifer system	Where below shales, development and yields of crevices are small; where not capped by shales, dolomites are fairly permeable.
			Glenwood St. Peter		75 - 650	Sandstone, fine to coarse grained; shale at top; locally cherty red shale at base.		Glenwood-St. Peter Sandstone. Small to moderate quantities of water. T probably about 15% of that of Cambrian-Ordovician aquifer system.
	CANADIAN	KNOX	Prairie du Chien		0 - 340	Dolomite, sandy, cherty, interbedded with sandstone.		Crevices in dolomite and sandstone generally yield small amounts of water. Potosi dolomite locally well creviced and partly responsible for exceptionally high yields of several deep wells. T probably about 35% of that of Cambrian-Ordovician aquifer system.
			Eminence Potosi		0 - 225	Dolomite, white, fine grained, sandy at base; drusy quartz.		
CAMBRIAN	CROIXAN		Franconia		45 - 175	Sandstone, dolomite, and shale, glauconitic, green to red, micaceous.		
			Ironton Galesville		103 - 275	Sandstone, fine to medium grained, well sorted, upper part dolomitic.		Ironton-Galesville Sandstone. Most productive part of Cambrian-Ordovician aquifer system. T probably about 50% of entire system.
			Eau Claire		235 - 450	Shale and siltstone, dolomitic, glauconitic; sandstone, dolomitic, glauconitic; dolomite, sandy.		Shales generally not water yielding; act as confining bed at the base of the Cambrian-Ordovician aquifer system.
		POTSDAM	Mt. Simon		2000 ±	Sandstone, coarse grained, white, red in lower half; lenses of shale and siltstone, red, micaceous.	Mt. Simon aquifer system	Mt. Simon Sandstone. Data sparse; probably less permeable than Ironton-Galesville; quality of water deteriorates with depth.
PRECAMBRIAN						Not penetrated by wells in Chicago area. Nearby wells encounter red or gray granite or similar rocks.		

Modified from Suter et al., 1959, p. 24; Zeizel et al., 1962, p. 14; Walton and Csallany, 1962, p. 9.

* Mississippian rocks present in Des Plaines Disturbance.
Devonian rocks present as crevice fillings in Silurian rocks.

Fig. 4.8. Stratigraphy and Aquifer Systems of Northeastern Illinois, with Hydrologic Properties of Main Water-Yielding Units of the Bedrock. Source: Reference 23.

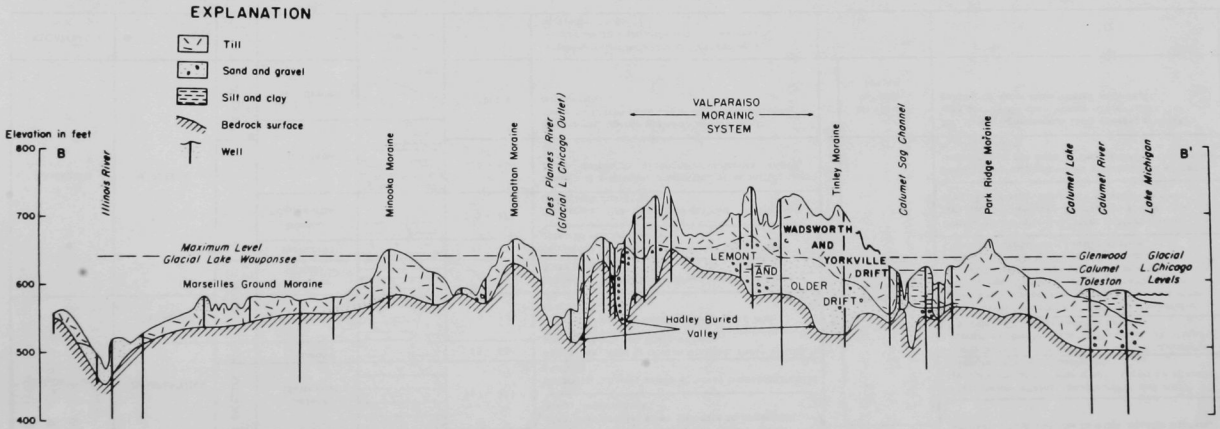


Fig. 4.9. Cross-section Showing Glacial Deposits in the Chicago Area. The line of the cross-section corresponds with line B-B' as shown on Figure 4.2. Modified from: M. Suter et al., "Preliminary Report on Ground-Water Resources of the Chicago Region, Illinois," Ill. State Water Surv. Coop. Ground-Water Rep. 1, 1959 (Fig. 6).

120 to 160 km (75 to 100 miles) southeast of the junction of the Ohio-Indiana-Michigan borders is a zone of moderate expected damage in western Ohio.

A tabulation of seismic activity which has been recorded in a 160-km (100-mile) radius of Site A/Plot M is presented in Table 4.6. Nine earthquakes were recorded for this area through 1977; only two were within an 80-km (50-mile) radius of the sites.

Table 4.6. Earthquakes Recorded Within 160 km (100 miles) of Site A/Plot M

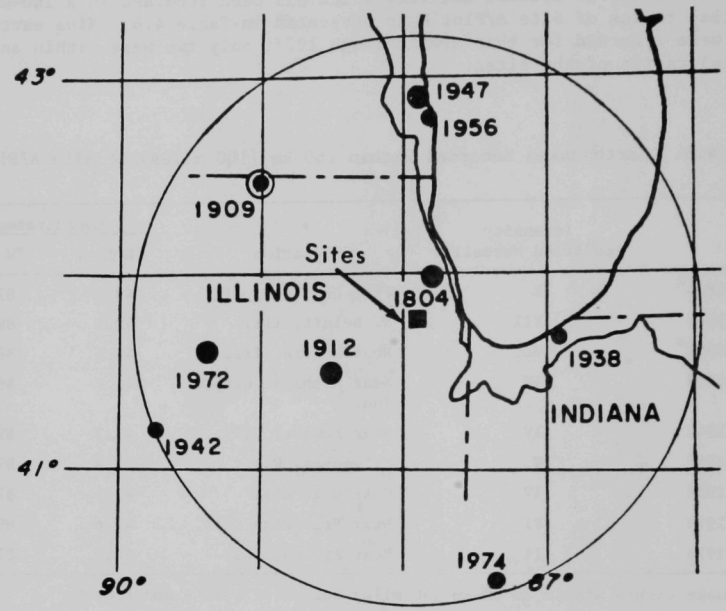
Date	Intensity (modified Mercalli)	Location	Coordinates °N Lat.	Coordinates °W Long.
24 Aug 1804[a]	V	Fort Dearborn, Ill.	42.0	87.8
26 May 1909	VII	S. Beloit, Ill.	42.5	89.0
2 Jan 1912[a]	VI	Near Morris, Ill.	41.5	88.5
12 Feb 1938	IV	Near Michigan City, Ind.	41.7	86.9
1 Mar 1942	IV	Near Kewanee, Ill.	41.2	89.7
6 May 1947	V	Milwaukee, Wis.	47.9	87.9
18 Jul 1956	IV	Oostburg, Wis.	43.6	87.8
15 Sep 1972	VI	Near Princeton, Ill.	41.6	89.4
25 Nov 1974	II	Near Attica, Ind.	40.3	87.4

[a]Earthquake events within an 80-km (50-mile) radius of Site A and Plot M.

Source: "Hypocenter Data File, 1900-1977," National Geophysical and Solar-Terrestrial Data Centers, NOAA/EDS, 1978.

The location of earthquakes within about a 160-km (100-mile) radius of the sites is shown in Figure 4.10. The most significant earthquakes felt at the sites were those at Fort Dearborn in 1804 and near the Wisconsin border in 1909. The former is not well documented; it was assigned a maximum intensity between VI and VII (modified Mercalli scale) and was reported to be felt as far east as Fort Wayne, Indiana.[27] The latter event was felt from Missouri to Michigan and from Minnesota to Indiana. An intensity of VII was noted over a considerable area, and the site area may have experienced intensities as high as VI.

The Chicago area has felt tremors as a result of large earthquakes occurring outside of the region. A series of major earthquakes which took place in southeastern Missouri (New Madrid) in 1811 and 1812 are considered among the greatest in recorded history. These shocks of intensity XII resulted in an estimated intensity of III or more in the southern Lake Michigan region.



LEGEND

- INTENSITY II-IV
- INTENSITY V-VI
- INTENSITY VII-VIII

SCALE IN KILOMETERS

0 25 50 75 100

SCALE IN MILES

0 10 20 30 40 50

Fig. 4.10. Earthquakes Within a 160-km Radius of the Sites. Adapted from Reference 27.

4.9 CHARACTERISTICS OF BURIED WASTE MATERIALS

4.9.1 Physical: Quantity and Size Distribution

4.9.1.1 Reactors CP-2 and CP-3 - Site A

A detailed description of the dismantling and disposal of the CP-2 and CP-3' reactors, with photographs, is given by Tyrell et al.[28] The CP-2 reactor was essentially the historic CP-1 in which the first self-sustaining chain reaction was demonstrated in Chicago on December 2, 1942. The uranium and graphite were removed when the reactor was decommissioned in 1955, so the only remaining material from this reactor is concrete rubble from the demolition of the shield. This, together with other building rubble, was used as backfill when the CP-3 reactor was buried. No details on the design of CP-2 are available, but some information may be derived from a historical account[29] which includes an artist's conception of the CP-1 experiment. The original uranium/graphite lattice was a flattened sphere about 5.5 m (18 ft) in diameter, and this was rebuilt in the form of a cube, with added shielding, when the reactor was moved to Site A early in 1943. With this shielding, it was possible to operate at a thermal power of 2 kW without excessive radiation exposure of personnel. The maximum neutron flux was probably on the order of 10^{10} neutron/cm^2/s ($n \cdot cm^{-2} \cdot s^{-1}$).

The design of the CP-3 (CP-3') reactor has been published.[30] The cylindrical aluminum reactor vessel which contained the heavy water was 1.83 m (6 ft) in diameter with a side wall about 0.5 cm (3/16 inch) thick, and 2.3 m (7.5 ft) high. If it is assumed that the top and bottom plates were 2 cm thick, the mass of this vessel would be about 350 kg (770 lb). The octagonal concrete shield was 7.9 m (26 ft) across opposite flat sides, and 4.3 m (14 ft) high. The thermal power was limited to 300 kW by the cooling system, and the maximum neutron flux was 4×10^{12} $n \cdot cm^{-2} \cdot s^{-1}$, with enriched uranium fuel.

When the CP-3' reactor was decommissioned, the heavy water was removed and the uranium-aluminum fuel was shipped to the National Reactor Testing Station (NRTS) in Idaho.[28] The space above the empty reactor vessel and all the cavities in the shield were filled with concrete, into which were dumped various pieces of radioactive or suspect hardware. The shield was toppled by means of explosives into an excavation about 15 m (50 ft) deep, where it landed upside down. There is, therefore, at least 10 m (30 ft) of rubble and dirt between the shield and the present ground surface. The mass of the shield as buried was estimated[28] to be 725 metric tons (800 tons).

4.9.1.2 Laboratory Waste - Plot M

Plot M was used for the disposal of radioactive or potentially contaminated materials from radiochemical and radiobiological laboratory operations in Chicago and at Site A between 1943 and 1949. The material, which after 1948 was contained in steel bins, was dumped into 2-m (6-ft) deep trenches and covered with soil. Further layers of waste and soil were added, and the trenches were finally filled with soil. An inverted concrete box, with walls extending to a depth of 2.4 m (8 ft) and covering the entire plot, was installed in 1956 to improve containment and reduce leaching by infiltrating surface water.

No detailed information is available concerning the nature and quantity of the materials buried at Plot M, principally because the work at Chicago and Site A was classified at that time, and has never been reported in unclassified form in sufficient detail. The estimates given here can only be characterized as educated guesswork; they are based on the recollections of people who worked in the project at that time and others familiar with the radiochemical techniques then used (including the author of this section, whose radiochemical experience dates from 1946, at ANL and elsewhere).

The total area of the plot was 43 × 46 m (140 × 150 ft). In order to make a very rough estimate of the volume of waste, it may reasonably be assumed that only about a quarter of this area was used for trenches, in order to allow space for access between trenches. The bins were retrieved in 1949 for inspection, transferred to the present ANL site, and finally shipped to Oak Ridge National Laboratory for disposal. The waste material accumulated between 1943 and 1949, without bins, is probably the only material remaining. Again using a very rough estimate, if it is assumed that this material occupies an average depth of 60 cm (2 ft) in the trenches between layers of soil, the total volume of uncontained waste is about 300 m^3 (10,000 ft^3), sufficient to fill about 1400 standard 55-gal drums, such as those still used for low-level solid waste disposal. This would represent an average accumulation rate of less than one drum per day over a 5- to 6-year period. This rate of accumulation is not unreasonable for the type and scale of operations carried out at Site A.

From the author's recollection and from interviews, the radiochemical laboratory trash was probably similar to that discarded from similar laboratories today; it consisted of small glass and metal items, possibly containing radioactive materials in solid or liquid form, in addition to such items as contaminated rubber gloves, shoe covers, paper towels and tissues, and glass or metal plates (planchets) on which radioactive materials had been deposited for counting. Then, as now, discarded items were probably placed in small containers such as cardboard ice-cream cartons and sealed with adhesive tape. Liquids were reduced to the smallest practicable volume or absorbed in porous solid materials. Highly contaminated items were placed in secondary containers (e.g., screw-top glass bottles). Polyethylene and polyvinyl chloride, the thermoplastic materials which greatly facilitate such disposal operations at the present time, did not come into general use until about 1950. In addition to these radiochemical wastes, animal carcasses from radiobiological experiments were also buried at Plot M. No information is available on the number and character of these animal carcasses.

4.9.2 Chemical

4.9.2.1 Site A

The buildings which housed the reactors and laboratories were cleaned and surveyed before demolition. Although it is not specifically stated, it may be presumed that any stocks of chemicals were removed and that Site A contains only the buried reactor shields.

4.9.2.2 Plot M

Many chemicals were used in the radiochemical and radiobiological work carried out at Site A. Most of these were common laboratory chemicals which would be found in any laboratory where radiochemical work on heavy elements and fission products is carried out. Certainly the most frequently used chemicals were the mineral acids (nitric, hydrochloric, and sulfuric); ammonium, sodium, and potassium hydroxides; oxidizing agents such as potassium permanganate and dichromate; reducing agents such as potassium iodide, hydroxylamine, and hydrazine; hydrofluoric acid; perchloric acid; and organic solvents such as acetone, ethanol, methanol, carbon tetrachloride, diethyl ether, and chloroform. In addition, some specialized organic chemicals such as methyl isobutyl ketone (hexone), thenoyl trifluoroacetone (TTA), and tributyl phosphate (TBP) were used in heavy-element and fission-product separations. It is difficult to recollect any possible uses for highly toxic chemicals--such as beryllium, barium, lead, and arsenic compounds, or cyanides--although it cannot be stated with certainty that none of these materials were used. The quantities of chemicals used were probably small, and because of the danger of contamination, unused chemicals were probably disposed of as potentially contaminated. Radioactive materials are more toxic than any of the chemicals used; therefore, the precautions observed in disposal would be more than adequate. Probably the most prevalent chemical constituent of the radiochemical wastes is ammonium nitrate from the neutralization of nitric acid solutions with ammonium hydroxide. This is a relatively harmless compound which has, in fact, been used as a fertilizer.

From personal observation, there is no visible evidence of any adverse effect of the buried chemicals on vegetation or wildlife; visually, except for the granite marker, there is nothing to distinguish Plot M from the surrounding terrain at the present time, about 30 years after burial operations ceased.

4.9.3 Radionuclides of Concern

4.9.3.1 Activation Products - Site A

Since all uranium fuel and heavy water were removed from the CP-3' reactor, the principal radioactive materials of concern are activation products of structural materials. All materials exposed to neutrons during reactor operation are still inside the concrete shield, which was adequate to protect personnel during reactor operation, when vastly greater radiation levels existed in the reactor vessel. A survey of the reactor shield after removal of fuel[28] showed some external contamination, which was reduced by decontamination procedures to no more than 200 mr/h at any accessible point (mr refers to milliroentgens which were the radiation units in use at the time; mr can now be replaced by millirem for X rays and low-energy gamma radiation). This reading would have included any contribution from activation products in the reactor vessel. After 30 years, the external radiation level is probably less than this value by several orders of magnitude, and unless the shield is broken up, the activation products are probably unimportant.

If the shield is ever opened or broken up, the reactor vessel may present a radiation hazard and a remote handling problem. A similar aluminum vessel from the NRX reactor (a natural uranium-heavy water research reactor) at Chalk

River, Ontario, presented a very difficult problem following a partial meltdown of uranium fuel in 1952. In order to remove the reactor vessel from the shield and transport it to a burial site, it was necessary to improvise shielding for personnel (crane and tractor operators) who were many feet from the reactor vessel during the operation. In this case, the reactor had been operating at a power of several megawatts until a few weeks before the accident, and it is not certain that all of the partially melted uranium metal fuel had been removed. The CP-3 reactor vessel must have a very much lower level of activity because of the lower reactor power, the period which has elapsed since operation, and the complete removal of uranium fuel.

The aluminum used for the CP-3 reactor vessel was of the highest obtainable purity consistent with workability and mechanical strength. Any long-lived activation products remaining in this vessel are most probably the products of impurities or alloying ingredients such as iron, nickel, and zinc (2.7-year Fe-55, 8×10^4-year Ni-59, and 244-day Zn-65). Cobalt, yielding 5.3-year Co-60, would be a less probable but very undesirable impurity because of the long half-life and penetrating radiation emitted. Modern methods of gamma-ray spectroscopy, which were not available in 1955, would make possible an analysis of the activation products.

Absorption of neutrons by the heavy water in CP-3 must have produced small quantities of tritium which may account for a small part of the tritiated water detected during the subsequent radiological survey. However, much greater quantities of tritium were produced deliberately by neutron irradiation of lithium, and residues from this work, buried at Plot M, are no doubt the major source of the tritium observed in the environment.

4.9.3.2 Radiochemical Wastes - Plot M

The radionuclides of concern at Plot M are heavy elements (uranium, thorium, plutonium, transplutonium elements, and their decay products), tritium, and fission products. The four heavy element decay series, the long-lived fission products, and some nuclides of particular concern (strontium-90, cesium-137, tritium, plutonium-239, and the transplutonium elements) are discussed generally in this section. Additional detailed information is given in Appendix D.

Uranium Series

The complete decay series descending from uranium-238 is shown in Appendix D, Table D.1. In natural uranium minerals, all decay products have reached equilibrium; each decay of a U-238 atom to Pb-206 (stable) results eventually in the emission of 8 alpha particles and 4 to 5 beta particles which may be accompanied by gamma radiation.

It is unlikely that any natural uranium minerals were among the wastes buried at Plot M. The uranium irradiated to produce fission products or plutonium was most probably chemically purified (chemical reagent or reactor grade). Purification removes all decay products, leaving only the uranium isotopes U-238, U-235, and U-234 in their natural abundances (99.3%, 0.72% and 0.0054%, respectively). The short-lived products--Th-234, Pa-234m, and Pa-234 (UX1, UX2, and UZ)--grow back to equilibrium within a few months, and for many

years represent the major beta-gamma activities. It would require thousands of years for detectable quantities of radium-226 and its decay products, including radon, to appear. In the interim, Pa-234 is the major source of penetrating radiation. Its activity at equilibrium is equal to the rate of decay of U-238--12,400 disintegrations per second per gram of uranium or 335 μCi per kg.

Uranium in its normal (uranyl) chemical state is not strongly adsorbed by soils and migrates quite rapidly with water flow. However, thorium in its normal tetravalent state (Th^{4+}) is strongly adsorbed by soils, particularly clays (zeolites). Thorium-234 (UX1) would therefore be retained by soils and would decay in situ, yielding Pa-234m (UX2) and Pa-234 (UZ) in equilibrium, while the parent uranium would remain in solution. Because of their short half-lives, neither of these decay products would persist for more than a few months after leaching of uranium from the waste ceased.

Since the quantity of uranium buried at Plot M is likely to be on the order of grams rather than kilograms, the radioactivity due to decay products must be very small. Residual fission products (strontium and cesium), remaining in residues from radiochemical separations are likely to contribute much greater radioactivity than uranium decay products. Although traces of uranium of natural isotopic composition have been detected in surface soils, no decay products have been detected in subsurface soils or in surface water or groundwater.

Thorium Series

Thorium (100% Th-232) was irradiated in reactors to produce U-233 which, like U-235 and Pu-239, is fissionable by slow neutrons and is a promising fuel for future breeder reactors. Thus, some residues containing thorium could be buried at Plot M. The thorium (4n) series is shown in Appendix D, Table D.2. This series is simpler than the uranium series, and it is evident from the half-lives involved that decay products grow back faster into chemically purified thorium than into uranium (the longest half-life is 6.7-year Ra-228 which occurs early in the series). In natural thorium minerals, 6 alpha particles and 4 beta particles are emitted for every atom of Th-232 decaying. Since thorium is strongly adsorbed by soils, any thorium which may have leached from the waste materials is probably fixed in soil directly below Plot M. The specific (alpha) activity of Th-232 is 4073 disintegrations per second per gram or 110 μCi per kg. In the 30 years which have elapsed, equilibrium would be established, and each decay product in the main chain would exhibit this activity if no chemical fractionation has occurred due to differential adsorption in soils.

Radium and actinium are less strongly adsorbed, and may have been segregated from thorium if leaching has taken place.

Neptunium Series

The neptunium (4n+1) series is shown in Appendix D, Table D.3. It has been named the neptunium series because 2.1×10^6-year Np-237 is the longest-lived progenitor. No member of this series has been detected in nature, except the end product, stable Bi-209. Because of its long half-life, large

quantities of Np-237 are required to generate decay products in significant activities. Gram quantities of Np-237 can be recovered in the reprocessing of uranium reactor fuel, but this is not normally done. Unless specially recovered, the neptunium is mostly discarded with the high-level fission-product wastes. Gram quantities of Np-237 were not available until the 1960s and could not have been used in investigations at Site A.

Uranium-233, produced by neutron irradiation of thorium, is the only possible source of this decay series at Plot M. The quantities of this nuclide available were on the order of milligrams. Because of its scarcity and also because it is a "Special Nuclear Material" (SNM) like plutonium and U-235, it is unlikely that more than microgram quantities of U-233 were discarded. The activities of decay products resulting from such quantities of U-233 would be negligible, although it is possible that trace amounts of decay products were present in discarded residues from radiochemical studies. Even so, the decay product activities present at Plot M must be limited by the quantity of U-233 available, and are probably below the microcurie level. The only decay product of possible concern is 7340-year alpha-emitting Th-229 which would be strongly adsorbed in soils.

Actinium Series

The actinium (4n+3) series is shown in Table D.4, Appendix D. Its naturally occurring ancestor is 7×10^8-year U-235, the fissile isotope of uranium which constitutes about 0.72% of natural uranium but can be enriched by physical processes such as gaseous diffusion. The fuel in the CP-3' reactor was an aluminum alloy containing 2% uranium which had been enriched to greater than 90% U-235. Since all fuel was removed from the reactor, it can be ruled out as a source of decay products at Site A or Plot M. Apart from the reactor fuel, small (gram) quantities of enriched uranium were handled at Site A, but because this is classified as SNM, AEC regulations required strict inventory control. The drums of waste buried at Plot M were retrieved in 1949 to search for a few grams of enriched uranium which was unaccounted for. The material was found, but because of the concern generated by this incident, it is unlikely that similar quantities were discarded inadvertently. Because of the long half-life of U-235, its small natural abundance, and the long-lived decay product, protactinium-231, it is not possible on a laboratory scale to isolate more than tracer (microcurie) amounts of the later decay products, among which is the first isotope of element 87 (francium) to be discovered (1939).

Man-made plutonium-239 is also a progenitor of the actinium series; like U-235 it is fissionable and is classified as SNM. Plutonium-239 also has a very high radiotoxicity. Traces of Pu-239 and Pu-238, above the levels expected from weapons testing fallout, have been detected in soils at Plot M. Since any work with plutonium was certainly classified at the time, no records of quantities used are available, although the facilities were not suitable for work with more than milligram amounts. Any Pu-239 used at Site A was probably obtained from other AEC installations, since no reactor fuel was reprocessed at ANL.

It is very unlikely that more than microgram quantities of Pu-239 were discarded. A microgram of Pu-239 represents about 0.06 μCi, and any decay

products from this source must be quite negligible because of the long half-life (7×10^8 years) of the immediate decay product, U-235.

For the reasons discussed above, the radioactivity at Plot M due to the actinium series is probably undetectable.

Mixed Fission Products

The studies conducted at Site A were primarily radiochemical and radiobiological. A major part of the radiochemical work was aimed at understanding the mechanism of the fission process, which was then a fairly recent discovery (1938). This involved the production, separation, and identification of fission products; studies of their decay processes; and measurement of relative fission yields. The radiobiological work was concerned with the effects of radiation on living organisms, including the metabolism of fission products and other radioactive materials in laboratory animals. Fission products were produced by irradiating small (gram-scale) uranium samples in a reactor. It may be assumed that all fission products produced in this way were eventually disposed of at Plot M--either as residues from separations, containing mixed fission products and uranium, or as separated products discarded after use in experiments (e.g., radioactive animal carcasses). Since no detailed records are available, the fission products buried at Plot M must be regarded as "mixed". The uranium fuel from the reactors at Site A must have contained many kilocuries of fission products when it was removed prior to decommissioning, but as far as is known, none of this material was buried at Plot M. Order-of-magnitude estimates of the activity levels involved may be made by considering the facilities available.

The neutron flux available in CP-2 was probably on the order of 10^{10} $n \cdot cm^{-2} \cdot s^{-1}$, and could have produced only millicurie quantities of long-lived fission products such as 30-year Cs-137 in small-scale irradiations. In CP-3 (designated CP-3' after enrichment of fuel), a neutron flux in excess of 10^{12} $n \cdot cm^{-2} \cdot s^{-1}$ was available, sufficient to make curie quantities of such long-lived products in irradiations of a few days or weeks. The radiochemical laboratories were not designed for the remote handling of high levels of radioactivity, and microcurie or millicurie quantities would have been adequate for the studies conducted. For those reasons, it is unlikely that any individual items discarded without shielded containers contained more than a few millicuries of activity, measured within days or weeks of production.

Freshly produced fission products contain hundreds of radionuclides with diverse half-lives and chemical properties. The short-lived products have high specific activities and contribute a large fraction of the initial activity, even though their mass yields may be relatively small. Mixed fission products therefore decay rapidly at first, but the decay rate decreases with time as the longer-lived products predominate. At this point, the total activity has been reduced by several orders of magnitude. The complete fission-product distribution can be calculated if the fission cross-sections, fission yields, and nuclear properties (half-lives and cross-sections) of all the products are known. Such calculations are tedious and, therefore, are conveniently done by using an advanced computer code such as the ORIGEN code[31] developed at Oak Ridge National Laboratory, primarily for application to high-level fission-product wastes produced in commercial nuclear power reactors.

Specimen output from this code for the specific case of a pressurized-water reactor fueled with 3.3% enriched uranium is presented in Reference 31, but these data are not strictly applicable to natural uranium irradiated in low-flux reactors. For instance, some long-lived products (e.g., Cs-134) are produced by secondary neutron capture and are much more important in high neutron flux irradiations (e.g., in a power-producing reactor with a neutron flux of about 6×10^{13} $n \cdot cm^{-2} \cdot s^{-1}$) than in the early research reactors. Differences in the neutron energy spectra also cause relative fission yields to vary from one type of reactor to another.

For the present case, a simplistic approach was adopted, which considers only those fission products which may be present in detectable amounts after 30 years decay. These products are those with half-lives longer than about one year, which occur in the decay chains with masses 90, 99, 106, 125, 135, 137, 144, 147, and 155. These chains are shown in simplified form in Table 4.7. After a few years, nearly all the atoms with these masses will exist as certain long-lived products. In some cases, there is a short-lived daughter in equilibrium with the long-lived product, and this contributes equal activity. All the fission products considered here decay by beta emission which may be accompanied by penetrating gamma rays. The short-lived metastable Ba-137, in equilibrium with Cs-137, emits X rays and energetic (0.6 MeV) electrons, and is radiologically equivalent to a beta-gamma emitter.

The initial activity of a given product is directly proportional to the fission yield of the mass chain and inversely proportional to the half-life. On this basis it is clear that the high-yield products, 29-year Sr-90 and 30-year Cs-137 (and their short-lived daughters), are the important long-lived nuclides, although initially Ce-144 and Ru-106 will contribute greater activity. From the above considerations, a composite decay curve such as that shown in Figure 4.11 can be constructed. In Figure 4.11, the activities of the long-lived products are normalized to unit total activity at time zero. Since only long-lived products are included, this curve is valid only for decay periods longer than a few years (in ten half-lives, the activity of a given product is reduced by a factor of 1024). The dozens of shorter-lived products would contribute much greater activity at short decay times. Nevertheless, Figure 4.11 demonstrates that after 20 years the residual fission-product activity is due almost entirely to Sr-90 and Cs-137, and is decaying with a half-life of about 30 years, determined by these nuclides. Because of the similarity in half-lives and fission yields, the individual decay lines for these two nuclides are almost coincident, but both were included in the sum.

Since any mixed fission-product activity at Plot M is now decaying with a half-life of about 30 years, no significant reduction in activity can be expected for several decades in the future.

4.10 SOILS

The natural soils occurring at or adjacent to Site A and Plot M are clayey and derived from till of the Clarendon moraine, a subunit of the Valparaiso morainic system.[20] The till extends downward 40 m (130 ft) to dolomitic bedrock of Silurian age[24] (see Sec. 4.8). The soils at Site A and

Table 4.7. Fission Decay Chains Yielding Long-Lived Products[a]

Mass Number (A)	Fission Yield[b] (Y_A %)	Terminal Nuclides in Decay Chain[c]
90	5.93	Br-90 (1.8s) → Kr-90 (33s) → Rb-90 (3m) → Sr-90 (29y) → Y-90 (64.3h) → Zr-90 (Stable)
99	6.1	Y-99 (1.5s) → Zr-99 (2.3s) → Nb-99 (2.4m) → Mo-99 (67h) → Tc-99 (1.21×10^5y) → Ru-99 (Stable)
106	0.40	Tc-106 (36s) → Ru-106 (368d) → Rh-106 (30s) → Pd-106 (Stable)
125	0.029	Sn-125 (9.6m) → Sb-125 (2.73y) → Te-125 (Stable)
135	6.5	Te-135 (19.2s) → I-135 (6.6h) → Xe-135 (9.09h) → Cs-135 (2.3×10^6y) → Ba-135 (Stable)
137	6.23	I-137 (24.5s) → Xe-127 (3.85m) → Cs-137 (30.17y) → Ba-137m (2.55m) → Ba-137 (Stable)
144	5.48	La-144 (40s) → Ce-144 (284.4d → Pr-144 (17.3m) → Nd-144 (V. Long)
147	2.23	Pr-147 (13.6m) → Nd-147 (11d) → Pm-147 (2.62y) → Sm-147 (V. Long)
155	0.032	Sm-155 (22.2m) → Eu-155 (4.76y) → Gd-155 (Stable)

[a]The radionuclides of concern are underlined. In some cases, a short-lived decay product contributes equal activity at equilibrium.

[b]Percent of fission events (in U-235 with slow neutrons) yielding products of given mass. Since two fragments are produced, the yields for all possible masses sum to 200% rather than 100%.

[c]The first nuclide shown may not be the primary fission fragment, but if any precursors are known, they are shorter lived. The end product in each case is naturally occurring (either stable or radioactive with a very long half-life). Arrows indicate the major decay processes which are by negative beta emission except Ba 137 m → Ba 137 which is an isomeric transition.

Plot M are continually disturbed and compacted by vehicular traffic, and in some spots significant erosion and gullying are taking place (observation made during site visit, October 1978).

There is no other available description of the site, and a more detailed description would require a field survey and soil analysis using standard techniques.

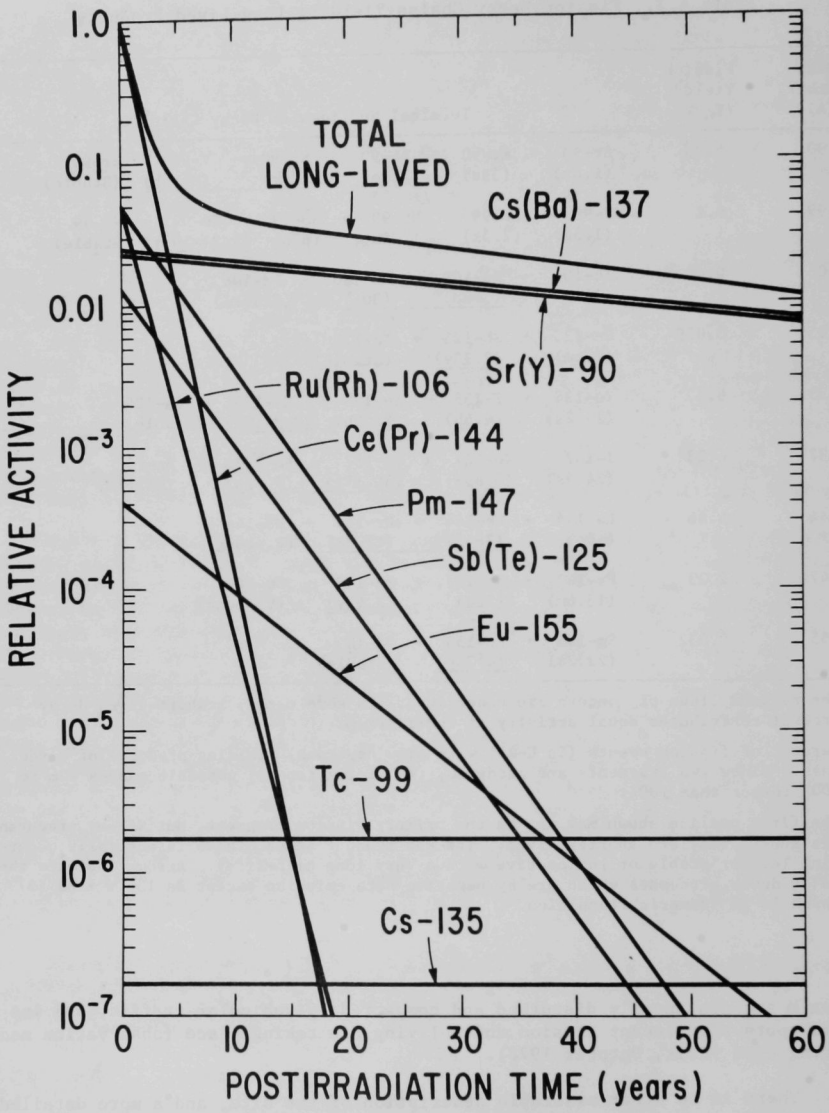


Fig. 4.11. Relative Activities of Long-Lived Fission Products vs. Postirradiation Time.

4.11 BIOTA

4.11.1 Terrestrial

Site A/Plot M and the surrounding area, now part of the Palos Forest Preserve, were formerly farmlands. Trees and shrubs cover the area, which is dissected by intermittent streams, and a beaver pond and some marshy areas adjoin Site A.

The species of flora and fauna that inhabit the Palos Forest Preserve are the same as those which occur at Argonne National Laboratory and nearby Waterfall Glen Forest Preserve, which have the same geological history and soil.[20] A listing of the flora and fauna is given in ecological surveys of those sites.[32,33]

The forested area is primarily red oak (*Quercus rubra*)-white oak (*Quercus alba*). Associates of the dominant oaks such as shagbark hickory (*Carya ovata*), black cherry (*Prunus serotina*), and hawthorn (*Crataegus* sp.) are common.

The amphibians and reptiles typical of the site are the tiger salamander (*Ambystoma tigrinum*), tree frog (*Pseudacris triseriata*), bullfrog (*Rana catesbiana*), fox snake (*Elaphe vulpina*), and garter snake (*Thamnophis sirtalis*).

Birds typical of the site are the ring-necked pheasant (*Phasianus colchicus*), yellow-shafted flicker (*Colaptes auratus luteus*), crow (*Corvus brachyrhynchus*), brown thrasher (*Toxostoma rufum*), and red-winged blackbird (*Agelaius phoenicus*).

Typical mammals are the opossum (*Didelphis virginiana*), brown bat (*Myotis* sp.), raccoon (*Procyon lotor hirtus*), fox squirrel (*Sciurus niger rufiventer*), deer mouse (*Peromyscus* sp.), and white-tailed deer (*Dama virginiana borealis*).

4.11.1.1 Site A

Plant associations of the disturbed portions of the site, about 46 m (150 ft) square, are typical of early successional stages for the area. Hawthorns, sumacs (*Rhus* sp.), and 9- to 12-m (30- to 40-ft) high cottonwoods (*Populus deltoides*) growing along ridge lines of the disturbed areas are the most common tree and shrub species.

Only the concrete foundations and floors of the former buildings remain in situ. Erosion around the foundations and piles of debris and burrowing animals have created a system of burrows and tunnels under the foundations. During the site visit in October 1978, there was some evidence that snakes might be using these subterranean tunnels as a hibernaculum. A fox snake (*Elaphe vulpina*) and a garter snake (*Thamnophis sirtalis*) were observed sunning themselves within 4.6 m (5 yards) of each other near burrows under a concrete pad.

In a slough adjacent to the site, the remains of muskrat houses, raccoon scats, and tree stumps with obvious beaver marks were observed. It is reasonable to assume that fox, deer, and rodents common to this section of Illinois[32,33] are present on and around the site.

4.11.1.2 Plot M

The disturbed portion of Plot M is roughly a square grassy field, about 46 m (150 ft) square, fringed by shrubs and understory trees (sumac and hawthorn), with undisturbed red oak-white oak forest surrounding it. It overlies a pit that was filled with radioactive waste, capped with concrete, and covered with 0.6 m (2 ft) of soil from the excavation plus 15.2 cm (6 inches) of "topsoil." The plot was then seeded with blue grass and perennial rye grass. There are occasional small (0.9- to 1.5-m [3- to 5-ft] high), shrubby hawthorns encroaching upon the area, but the grass cover is excellent where it has not been disturbed. However, the central area, over the concrete cap, is rutted and eroding. The ruts result from motorcycle traffic in the plot. The erosion will undoubtedly increase, particularly on the slopes. There is also evidence of picnic fires in the area as well as garbage (beer cans, etc.).

The wildlife in the plot is undoubtedly the same as that to be found at Site A (discussed above) as well as at Argonne National Laboratory[32] and Waterfall Glen Forest Preserve.[33]

A list of endangered and threatened plant and animal species that might occur in and around Site A and Plot M is given in Tables 4.8 and 4.9.

Table 4.8. Endangered and Threatened Flora[a]

Scientific Name	Common Name	Family	Habitat	Status[b]
Asclepias medii	Mead's milkweed	Asclepiadaceae	Dry prairie	P
Lespedeza leptostachya	Prairie bush clover	Fabaceae	Prairie	P
Petalostemum foliosum	Leafy prairie clover	Fabaceae	Prairie	P
Panax quinquefolius	Ginseng	Araliaceae	Rich woods	T
Boltonia asteroides var. *decurrens*	False aster	Asteraceae	Marsh	T
Astragalus tennesseensis	Milk vetch	Fabaceae	Dry prairie. Believed to be extinct east of Iowa	T
Cypripedium candidum	White lady's slipper	Orchidaceae	Wet prairie, calcareous	T
Hydrastis canadensis	Golden seal	Ranunculaceae	Deep rich woods	T

[a]The species listed are those which can occur in this geographic region and for which suitable habitat can be found in the Palos Forest Preserve.

[b]Status determined from the Federal Register (June 6, 1976) list of threatened and endangered species. P = proposed; T = threatened.

Sources: References 33-37.

4.11.2 Aquatic

The area surrounding the Site A/Plot M complex contains numerous aquatic habitats, predominantly sloughs and marshes; seasonally, there are a few intermittent streams running down some of the draws either north toward the Illinois and Michigan Canal, or south toward the Calumet Sag Channel. To the

Table 4.9. Endangered Fauna[a]

Scientific Name	Common Name	Habitat
Myotis sodalis	Indiana bat	Summer nurseries in Oak-Hickory woods; overwinters in limestone caves
Falco peregrinus anatum	American peregrine falcon	Occasional transient or overwintering individual
Falco peregrinus tundrius	Arctic peregrine falcon	Occasional transient or overwintering individual

[a]The species listed are those which may occur in this geographic region and for which suitable habitat can be found in the Palos Forest Preserve. Status was determined from the Federal Register (June 6, 1976) list of threatened and endangered species.

Sources: References 38-40.

east of the old Argonne site (see Fig. 4.3), there are several large (>10 ha) bodies of standing water including Maple and Bull Frog lakes and Tomahawk and Longjohn sloughs. These larger lakes are located in depressions probably created during the last glacial period. The depressions are now largely filled in with sediments and must be dredged by the local park district to maintain stocked fish populations.

The two aquatic habitats most closely associated with Site A/Plot M are (1) an unnamed shallow slough adjacent to the southeast corner of Site A, where standing water occurs in most years, and (2) an ephemeral stream in Palos Park that flows northerly past the east boundary of Plot M, through the Red Gate Woods, and empties into the Illinois and Michigan Canal. These habitats are described below.

Based on calculations from a topographic map, it is estimated that the slough has a maximum size of about 2.25 ha. Field observations suggest a minimum water depth of <2 m. This eutrophic water body fluctuates considerably in size and depth from one season to another but appears to contain some open water area in most years. Depending upon the surface recharge and height of the groundwater table, the ratio of open water to mudflat/marsh may vary from 1.0 to <0.25. Despite the low water level in the fall of 1978, indications of a muskrat population were observed in the limited open-water area. The slough is also frequented by waterfowl and larger vertebrates such as deer and raccoon.

Although the slough is considerably smaller than the lakes to the east, it represents an advanced successional stage; the other lakes would normally undergo similar development if left undisturbed by man. Thus, the planktonic and benthic communities in this slough can be expected to differ somewhat from the lake communities.

In the littoral zone, there are several different types of aquatic vegetation and marsh plants including the ubiquitous cattails (*Typha* sp.) and bulrushes (*Scirpus* sp.). Duckweed (*Lemna* sp.) was observed in open water, and the presence of visible zooplankton indicates the presence of a phytoplankton community. Overall, the slough is probably not a year-round aquatic habitat for some organisms because when the water level is low, the pond can freeze

into the bottom during the winter. However, there are indications that at some point in time this pond supported beaver, which suggests that the entire water column has not always been frozen during the winter.

In the vicinity of Plot M, there is an ephemeral stream which normally flows only during the spring months and after major summer rain storms. Depending upon the amount of runoff, the streamflow may not extend all the way to the canal.[17] Rather, water in the stream channel may infiltrate the bed and surface flow may cease somewhere in the vicinity of Archer Avenue. For the remainder of the year, the stream channel is dry. This 1.05-km stream has an average gradient of ∿33m/km, and because of its steepness, the stream bed contains predominantly riffle habitat with relatively little pool area. However, a sizable pool in the upper reaches of the stream does retain water after the stream has ceased to flow. Generally, the stream bottom is rocky, composed mainly of small boulders, sand, and gravel. The stream banks are quite steep, and the surrounding terrain is wooded.

Since the stream flows for such short periods, it is inhabited by organisms adapted to an ephemeral habitat. Hynes[41] recognizes six groups of aquatic organisms which can populate such habitats: (1) running-water species living in permanent pools, (2) organisms which burrow into the stream bottom, (3) species with an egg stage enabling survival during periods of drought, (4) reinvading species, such as insects, which are capable of rapid and wide dispersal, (5) biota that occupy the pools only during the dry season, and (6) species which have specifically adapted to life in ephemeral streams. In this stream, it is likely that there exist representative organisms of all the types listed by Hynes except type (1). Included in the stream biota could be such specialized (type 6) organisms as *Ironoquia* (= *Caborius*), a form of caddisfly found in a similar intermittent stream in Indiana.[42] In the pool, mosquitoes (H. Svoboda, Argonne National Laboratory, personal communication, 1979), chironomids, and beetles are likely to be found along with snails, mites, and oligochaetes.

Some phytoplankton are probably present during periods of flow; however, the organic matter for the ecosystem most likely comes predominantly from leaf decomposition. Because the water velocity in such a steep channel must be high during peak runoff, the stream bottom is probably well scoured each spring, as evidenced by the paucity of leaf packs in the stream. Nevertheless, during the period of flow this stream likely supports an aquatic biota composed of phytoplankton, zooplankton, and benthic invertebrates including insects and crustaceans; all are commonly occurring inhabitants of ephemeral streams.[42]

During a site visit in October 1978, visual evidence indicated that crayfish inhabit the stream. It appeared that the crayfish had burrowed a minimum of 40 cm into the dry stream bed to avoid desiccation.

4.12 RADIATION ENVIRONMENT

4.12.1 Radiological Survey of Site A and Plot M

4.12.1.1 Subsurface Soil

Plot M

A study of the subsurface soil has resulted in conclusive evidence that elevated levels of tritium exist in the soil around Plot M and that the tritium originated from Plot M. Plot M was used as a burial site until 1949, and the concrete cap was not put on the area until 1956 when control reverted to the Cook County Forest Preserve District; thus, precipitation infiltrated the buried materials for several years. The study (fully described in a 1978 DOE report[17]) was designed to yield information regarding the vertical and horizontal distribution of various radionuclides in the subsurface soil.

Between the springs of 1976 and 1977, a total of 18 core borings were dug, including eight borings around Plot M. Two were made at angles of 45°, from the edge of Plot M to points 12 m (40 ft) vertically beneath the plot. The precision of the sampling and measurement techniques was confirmed with two corings made close to two others; the data from the second sampling essentially duplicated the results of the first sampling.

The data from the first 10 core samples show that elevated concentrations of tritiated water exist throughout the Plot M area, with the highest level reported in the core nearest the plot to the north. The samples from the two angled borings show that the tritium concentrations in soil were relatively low until the region beneath the plot was reached; then, the levels increased to about an order of magnitude above those from the vertical borings around the plot. This, and the fact that concentrations were higher in the soil downgradient from the plot, confirm that the tritium found in the wells north of the site originated from the buried material at Plot M.

In subsurface soil, the uranium concentrations were normal, and the cesium-137 and strontium-90 concentrations were all less than the detection limit; no plutonium was detected. A boring was made midway between Plot M and the Red Gate Woods well, and another was made south of Plot M, across the intermittent stream between Plot M and Site A. The samples from these two borings indicated that Sr-90, plutonium, and gamma-ray emitters were below detection limits, and that uranium concentrations were normal. The tritium concentrations were relatively low between Site A and Plot M but were higher between Plot M and the Red Gate Woods well.

Two control cores were also made: the first in Argonne Park, about 6.4 km (4 miles) west of Site A/Plot M; and the second near Route 83, about 4 km (2.5 miles) southeast of Site A/Plot M. The tritium concentrations and distributions from these two borings can reasonably be attributed to fallout from atmospheric nuclear tests. A comparison of the tritium distribution from the test borings with that from the controls indicated that the source of tritium in at least some of the test borings was at Plot M or Site A.

In the spring of 1977, two cores were dug through and beneath Plot M to measure the radioactivity distribution with depth directly under the buried

material. Analyses of samples from these cores indicated that tritium had migrated deep into the underlying subsoil, the highest tritium concentration being 20 m (65 ft) below the surface, as shown in Figure 4.6 (see also App. B). Estimates of the migration rate of the tritiated water indicate that the peak tritium concentration would reach the dolomite aquifer in about 30 years. By that time, radioactive decay would have reduced the peak concentration to 19% of its present value, or to about 2.6 nCi/g. It is estimated that there is in the order of 3000 Ci of tritium, as water, in the Plot M area.[17]

Some of the samples obtained from the top 3 m (10 ft) of soil in the area contained elevated concentrations of uranium, plutonium, and Sr-90. The highest plutonium level found below the trench area was about twice the fall-out level of surface soil. Since some of the waste material was in liquid form, and possibly acidic, when first disposed of, these solutions could have moved downward some distance before becoming bound to the soil. Thus, the existence of radioisotopes below the plot may have resulted from an initial movement of the acidic solution and not from a long-term leaching effect.

Site A

At Site A, four vertical holes were drilled to depths of 18 m (60 ft) in the vicinity of the CP-3' reactor shield. Sixteen samples were obtained from each boring and analyzed for tritiated water and gamma-emitting nuclides. Selected samples were also analyzed for nonvolatile alpha and beta activity, Sr-90, uranium, and plutonium.[17]

Concentrations of activity within ranges that are normal for the Chicago area were found for nonvolatile alpha and beta emitters and for uranium. No Sr-90 or plutonium nuclides were found, and the concentration of all gamma-ray emitting fission or activation products was less than the detection limit except for some samples which contained Cs-137 in the range produced by atmospheric fallout.

Tritiated-water concentrations were above normal when compared with the samples from the control borings and may be attributed to heavy water used in the CP-3' reactors. Each core showed an increase in tritiated-water concentration, with depth, to a maximum at about 4.5 m (15 ft) below the ground surface, followed by a decrease in concentration to a minimum at about 12 to 15 m (40 to 50 ft), and then an increase at the greatest depths.

4.12.1.2 Surface Soil

A study of the surface soil has been conducted over the entire Site A area.[17] Samples were taken at 7.6-m (25-ft) intervals in the center of the site near the reactor, at 15-m (50-ft) intervals outside of this area, and at 30.5-m (100-ft) intervals at the site perimeter, for a total of 104 samples. The samples were analyzed for nonvolatile alpha and beta activity and by gamma-ray spectrometry. Concentrations of alpha and beta activity were in the normal range for surface soil in the Chicago area, and most of the samples contained normal amounts of gamma-ray emitters. Some samples contained Cs-137, Sb-125, and Co-60 concentrations that were slightly above background, indicating that small amounts of radionuclides from Site A operations remain at random locations.

4.12.1.3 Surface Water

The surface drainage around Plot M is described in Section 4.7.1. The drainage is principally by an intermittent stream that travels south to north along the east side of the plot. Water samples were taken at various times in 1954, 1976, and 1977, and the samples were analyzed for tritiated water (see Reference 17, Table 24). The results indicate that the concentration of tritium presently in surface water is lower by at least an order of magnitude when compared with the concentrations in 1954. Among the latest samples (taken on 5 May 1977), the highest concentration analyzed was 17 nCi/L at a downstream location; the concentration of a sample taken in 1954 from the same location was 2010 nCi/L.

4.12.1.4 Well Water

After the detection of tritiated water in the Red Gate Woods picnic well in November 1973, regular periodic sampling was started in this and the four additional wells closest to the woods. The results of the program are given in Reference 17 (Table 32). The Red Gate Woods picnic well has the highest tritium content among all the wells. The highest concentrations are in the winter when the picnic area is used the least. During each summer (except 1977), the tritium concentration was at or near the detection limit of 0.2 nCi/L. The highest concentration in any single sample was 14 nCi/L, and the annual average was about 7 nCi/L. The cyclic changes in concentration may stem from repeated charging of the groundwater in the spring, providing a means by which tritiated-water movement can occur. This movement is also discussed in Reference 17.

4.12.1.5 Gamma-Ray Measurements

Gamma-ray measurements were made in the initial eight vertical bore holes around Plot M. A 5-cm (2-inch) diameter sodium iodide (NaI [Tl]) detector was lowered into the cased bore holes, and the data were collected by multichannel analyzer and stored on magnetic tape. The measurements showed only the presence of natural gamma-ray emitting nuclides at normal concentrations. A gamma survey of the surface of Plot M detected no radioactivity that could be attributed to buried waste materials.

An aerial survey of the Site A/Plot M area[43] was made in May 1976, using NaI detectors carried in a helicopter. Gross gamma-ray distributions were plotted on an aerial photograph of the site, and isopleths of the various radiation levels were constructed. The distribution and levels appeared normal by comparison to radiation data from neighboring areas.

Thermoluminescent dosimeters (TLD) were used in the Plot M area to measure external radiation. Dose measurements made in 1976 and in 1977 yielded dose rates ranging from 93 to 123 mrem/year.

4.12.2 Surrounding Environment

As part of a continuing environmental monitoring program performed by the Argonne National Laboratory, external penetrating radiation dose measurements are taken in communities around the laboratory site.[22] These measurements are

made using thermoluminescent dosimeters that are exposed for periods of approximately two months throughout the year. The results indicate that the external radiation dose rate in the communities around Site A/Plot M was about 90 mrem/year for the year 1976. The five-year average from 1972 to 1976 was 98 mrem/year.

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5. ENVIRONMENTAL IMPACTS OF POSSIBLE OPTIONS FOR REMEDIAL ACTION

5.1 AIR QUALITY

The present air quality of the Site A/Plot M area has been described in Section 4.3. There are no impacts upon air quality expected from Option I in which no remedial action is to be taken. However, several options include certain actions that will have impacts on air quality;* these actions are discussed separately. The impact from each is assumed not to change from one option to the next.

Vehicular traffic over improved dirt roads is expected to degrade the air quality very little. The emission factor for unpaved roads published by the EPA[1] indicates that an estimated 22.2 g of fugitive dust can be expected per vehicle mile traveled. Under worst-case conditions (e.g., 1000 vehicles visiting the site on a blustery day with a persistent wind direction), the increased level of particulates 1 km downwind will be less than 5 $\mu g/m^3$ averaged over a 24-hour period and the increased levels of SO_2 and NO_x are not expected to exceed 1 $\mu g/m^3$ for either pollutant.

The diesel generators used for electrical power will also have a minor effect on air quality. Assuming the same worst-case conditions, the estimated 24-hour increase of SO_2, NO_x, and particulates from the diesel engines at 1 km downwind are 0.24 $\mu g/m^3$, 3.54 $\mu g/m^3$, and 0.25 $\mu g/m^3$, respectively.[2]

Excavation at Site A and Plot M will also have a negligible effect on air quality because the operation will be carried out inside a specially constructed containment building (a more detailed description is presented in the companion EER, "Engineering Evaluation of a Formerly Utilized MED/AEC Site, Site A and Plot M, Palos Forest Preserve, Palos Park, Illinois"). Since any excavated material will be placed in bins for shipment, no degradation of air quality is expected from this aspect of the removal process.

5.2 LAND RESOURCES

5.2.1 Impacts on Land Use

5.2.1.1 Option I

If Option I is implemented, no foreseeable changes in land use are expected to occur in the Red Gate Woods, the nearest access point to Site A/Plot M. Although the local news media has publicized the potential problems connected with Site A/Plot M and their relationship to the potable water wells

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*The dispersion equations used for the calculations in this section are from the "Workbook of Atmospheric Dispersion Estimates," U.S. Environmental Protection Agency, Research Triangle Park, N.C., Revised, 1970.

in the vicinity of Red Gate Woods, use of the area by the public has not declined. In fact, the number of visitors to the Red Gate Woods, a picnic and parking area for hikers, has been increasing over recent years. In 1978, approximately 25,000 persons visited the area, an increase of about 6000 persons (32%) over the previous year.[3] Winter visitation to the Red Gate Woods depends upon weather conditions suitable for cross-country skiing, and when skiing is favorable can exceed 10,000 persons during the season (conversation with R. Buck, Chief Landscape Architect, Cook County Forest Preserve District, January 31, 1979).

5.2.1.2 Options II, III, IV, V, and VI

No permanent impacts are expected if any of Options II through VI are implemented. Although the area would be under excavation or construction, strict safety and security precautions would be incorporated to protect the public from any potential hazards.

5.2.1.3 Option VII

The impacts on land use from implementing Option VII (closing the picnic wells) may be adverse. Currently, the Red Gate Woods is a popular picnic area, attracting many visitors (especially permit users) because of its adequate facilities which include drinking water, sanitary facilities, and a recently constructed shelter. Without water, appreciation of the area would decrease since users would perceive it as less pleasant and less enjoyable. Coupled with user dissatisfaction would be the concern of the Cook County Forest Preserve District over decreased visitor use of the new shelter. If the wells are closed, the benefits of the shelter would be decreased, thereby reducing the value of the forest preserve district's investment (conversation with R. Buck, January 31, 1979).

5.2.1.4 Option VIII

The Red Gate Woods is a popular picnic area because of its natural setting and satisfactory facilities. Since the number of visitors to the woods appears to be contingent upon the existence of adequate facilities, if an alternative source of water (Option VIII) is provided to the public, no impacts are expected to occur.

5.2.2 Mitigative Measures

There appears to be no foreseeable impacts to land use if Option I (no action) is implemented. Also, no impacts are expected to be created by implementation of Options II through VI, and thus there are no required mitigative measures. Closing the picnic wells (Option VII) would necessitate provision of an alternate water supply. This mitigative measure would itself be provided by Option VIII.

5.3 HISTORICAL AND ARCHEOLOGICAL RESOURCES

Implementation of any of Options II-VIII as proposed for Site A/Plot M will require a two-phase cultural resource management program for the protection

of historical and archeological resources. The specific details of this program--particularly requirements for mitigation, monitoring, or protection--will depend upon which option is selected. Phase 1 should include a definition of a study area where it is feasible, a literature review, and a preliminary surface/environmental observation. Phase 2 should contain a field reconnaissance study to locate and evaluate surface and subsurface resources, and should be based on a well-designed research program.

5.4 WATER RESOURCES

5.4.1 Surface Water Impacts

In this section, the remedial action options are analyzed in terms of the potential for their implementation resulting in environmental impacts on surface water resources.

5.4.1.1 Option I

If Alternative I is selected, low volume seepage of local groundwater and surface runoff from the area of Site A/Plot M into drainageways will continue. However, flow in the drainageways carrying surface runoff to the canals is intermittent (spring and fall, usually) and the existing quality of canal waters is poor (Sec. 4.7.1). Therefore, even though surface-water analyses (Sec. 4.7.1) have shown that tritium concentrations exceed the EPA drinking-water standard (20 nCi/L), little if any impact on water quality and use will occur.

5.4.1.2 Option II

Implementation of Option II would have little effect on surface water quality and use in the area. Again, considering existing surface water quality, runoff from excavation activities will contribute very little (and only temporary) degradation of water quality, particularly if excavation sites are covered by structures. Also, due to the removal of contaminant sources, local percolating groundwater that may later seep into surface drainageways from the sites will no longer be able to contribute contaminants.

5.4.1.3 Options III and V

Implementation of Options III and V would result in impacts similar to those in Option II except that leaching by local groundwater and subsequent seepage into surface drainageways would only be reduced but not eliminated. Thus, these options would have little and probably only temporary impact on surface water quality and its use; however, more protection would be provided against leaching and continued seepage than by Option I, the no-action option, due to the engineered barriers.

5.4.1.4 Option IV

Option IV, if implemented, would have the same impacts as the no-action option (Option I) since the only action is that of providing a substitute noncontaminated source of well water for picnic areas. The only additional impacts, related to drilling activities, would be temporary.

5.4.1.5 Option VI

Implementation of Option VI would result in impacts similar to those ensuing from Options II, III, and V. These impacts, primarily the result of excavation activities, would be minor and temporary.

5.4.1.6 Option VII

Option VII, if carried out, would have the same impact on surface water as Options I and IV--that is, no effect on surface water beyond that presently occurring.

5.4.1.7 Option VIII

Implementation of Option VIII should have little, if any, additional surface water impact than that existing at present. Drilling activities in search of a new water supply would result only in temporary impacts that would not differ greatly from those accompanying Option IV.

5.4.2 Groundwater Impacts

The hydrological conditions at Plot M are described in Section 4.7. It is believed that tritium was leached out of the buried wastes from the time that it was first placed in the trenches. A large concentration of tritium (10^5 nCi/L) exists in the water table beneath Plot M and is believed to be the source of the tritium that is observed in the public drinking-water well at Red Gate Woods.

Additional impacts on groundwater (beyond the radiological impacts discussed in Sec. 5.7) through implementation of all but Options I and VII would be minor and would result from surface activities, such as well drilling, pile driving, and excavating. These surface disturbances would provide the potential for temporary increases in percolation and infiltration of surface water (precipitation) to the saturated zone (water table). This could result in subsequent leaching of contaminants through the unsaturated zone to the water table. However, soil-boring analyses (Sec. 4.7 and App. B) indicate that tritium is already in the saturated zone (water table) and apparently has reached the dolomite aquifer. If this is indeed the case, any activities at the surface will have very little, if any, additional impact on groundwater quality. If, however, radioactive contamination still exists in or near the trenches above the water table, its removal would be most beneficial in that additional groundwater contamination would not occur.

Implementation of Options I and VII provide the least potential for affecting tritium concentrations in groundwater in the Site A/Plot M area. As indicated in Section 4.7.2.1, groundwater (and tritium) travel times from Plot M to the forest preserve well at Red Gate Woods were estimated to range from about 5 to 8 years. Under Option I, movement of tritiated water toward the public well would continue unabated at or about the above rate. As presently perceived, the zone of highest tritium concentration is still in the area of Plot M and at about 18 m (60 ft) in depth. It is possible that higher concentrations of tritium than those now observed at the Red Gate Woods well would occur in the future if no action is taken. Option VII, on the other

hand, although permitting continued movement of tritium, would eliminate potential adverse impact to well water users because the picnic wells would be sealed. In either case, the only potential point of concern is drinking-water supplies in the forest preserve picnic areas. Water quality in the canals (Sec. 4.7) is such that if additional degradation is caused by the tritium transported in the groundwater seeping to the surface at the canals, there would be little if any impact on water use.

5.4.3 Mitigative Measures

In this section, each option is analyzed in terms of recommended mitigative measures which, if employed, would reduce the potential for adverse effects on water resources due to construction-excavation activities at Site A/Plot M.

5.4.3.1 Options I, IV, VII, and VIII

Options I, IV, VII, and VIII would involve little or no surface activity at Site A/Plot M or anywhere in the forest preserve and therefore require no mitigative measures.

5.4.3.2 Option II

Additional measures are suggested that would further control runoff from the sites being excavated due to implementation of Option II. These include:

1. Timing - If excavations are carried out during a period of low precipitation, the potential for runoff and siltation in drainageways would be reduced.

2. Diversion Ditches - If excavation and storage areas are isolated from the surrounding areas by runoff diversion ditches that direct runoff away from the loose excavated material, erosion and siltation effects in drainageways would be reduced.

3. Settling Pond - If a settling pond (the pond must be lined) is used in conjunction with site-area diversion ditches for runoff control, the runoff water could be stored, silt and possible contaminants could settle out, and water could be monitored for release when water quality criteria are met.

4. Recapping - If recapping (as described in Options III and V) is installed at the sites--due to the possibility that a large portion of the tritium at the site is in the water table--vertical groundwater recharge from the sites would be reduced, and this would act to slow the tritium transport in the water table.

5.4.3.3 Options III, V, and VI

Options III, V and VI, if implemented, would involve excavation activities similar to but of less magnitude than those in Option II. Thus, the same mitigative measures recommended for Option II are recommended for these options, where applicable.

5.5 SOILS

5.5.1 Physical Impacts

At Site A, there are areas adjacent to the concrete pads where the soils are compacted and eroding as the result of vehicular traffic, and the soil in these areas is unsuitable as a growth medium. In the areas where vehicle use has not been extensive, vegetational succession appears normal.

At Plot M, soil compaction, erosion, and gullying due to vehicular activity are more extensive than at Site A. The shallow layer of soil (0.6 m or 2 ft) is, at best, not conducive to revegetation back to its original state as forest. The vehicular activity further prevents any soil and vegetation development over the concrete cap.

With all of the options presented, the ongoing and potential impacts described above will continue.

5.5.2 Nonradiological Chemical Impacts

There appears to have been no nonradiological chemical impacts at Site A as judged by the normal successional stages of vegetational development.

At Plot M, there is no evidence for or against such impacts. The trench under the concrete cap probably contains a variety of organic and inorganic chemicals which, if leached out into surrounding territory, would be expected to have highly significant impacts on the terrestrial and aquatic biota as well as on the structure of the soil. Option II would result in removal of all chemicals and the source of any future contamination. Options III through VIII would decrease the chance that chemicals would migrate away from the sites. Option I would retain the status quo.

It would be necessary to carry out a thorough soil analysis at both sites to determine if any changes related to nonradiological chemical impacts are occurring before a decision is made concerning the most appropriate option to use.

5.5.3 Mitigative Measures

To prevent erosion and gullying, it will be necessary to add a new layer of uncompacted soil, top it off with a nutritive "topsoil," and revegetate the area with grasses. Equally essential is that the area be made inaccessible to vehicular traffic both by fiat and by fencing. These measures will permit the development of the soil to a structure, texture, and use compatible with the surrounding forest preserve.

These mitigative procedures are necessary at present for all options except Option II. When all concrete and buried materials are removed from the site, reclamation should be followed by fencing. In about 10 years, it will no longer be necessary to protect the site with fencing, due to natural succession.

5.6 BIOTA

5.6.1 Impacts on Terrestrial Biota

The eight options can be separated into three groups according to similarities of their impact on terrestrial biota.

The first group includes Options I, IV, VII, and VIII. Implementation of these four options would have little or no impact on the terrestial biota in the area.

The second group includes Options III, V, and VI. If implemented, any of these options would deleteriously impact the terrestrial biota. Vegetation and relatively immobile organisms at the work sites would be destroyed and nearby biota would be disturbed. In addition, the construction of new access roads that would be built to implement these options would increase the area of destruction and disturbance.

The third group includes only Option II. The effects of this option on terrestrial biota would be the same as those of the second group plus additional effects--i.e., the period of disturbance would be longer, the area involved would be greater, and the site from which the new fill would be provided would also be disrupted.

5.6.2 Impacts on Aquatic Biota

5.6.2.1 Option I

Implementation of Option I (no action) would have no direct impact on the aquatic biota or its habitat for either the running or standing waters in the area of Site A/Plot M.

5.6.2.2 Option II

Site A - Construction Phase

Implementing this option could potentially cause adverse impacts on aquatic ecosystems near the excavation site due to possible offsite transport of buried materials. Because surface waters and groundwaters from Site A do not drain toward the slough located southeast of the site, and since the slough is at least 100 m from the excavation site, impacts to this aquatic habitat and its biota are likely to be minimal.

Site A - Operation Phase

Although particulate radioactive atmospheric emissions are not expected to escape from the containment building to a substantial extent, it is possible that some of these materials could be deposited in nearby aquatic ecosystems. However, the potential quantities involved would be very small. Also, wetting the soil to reduce fugitive dust during excavation activities could result in the leaching of some radioactive materials into the substrate; however, the rate of leaching and the quantity of material leached would both be so low that the environmental consequences would be negligible. The most direct way that excavation activities at Site A could affect the aquatic biota

in the slough would result from road repairs and increased vehicular traffic on the perimeter road, resulting in a slight increase in the rate of sediment accumulation in the already nearly filled-in slough.

Plot M - Construction Phase

The results of implementing Option II could adversely affect the aquatic ecosystem in the stream located to the east of Plot M. Many of the construction activities such as repairing the roadway, erecting the fence, removing the overburden, and backfilling and grading when the excavation is completed could potentially contribute sediments to the stream, especially if these activities were carried out in the spring.

Plot M - Operating Phase

As mentioned for Site A, radioactive materials escaping from the containment building, either atmospherically or through other pathways, could potentially affect the stream ecosystem. However, the probability of either or both events occurring is low, and the associated impacts are both expected to be slight.

5.6.2.3 Options III through VIII

For Options III through VIII, the potential aquatic impacts are summarized in Table 5.1. For those options where sediment transport is considered a potential problem, the concern is focused on additions of inorganic particles to the stream and the consequent effects on aquatic biota. Because fugitive dust from activities at the site could be blown into nearby aquatic habitats or deposited onto the watershed and subsequently washed into these areas during periods of precipitation, this source of particulate materials could also affect aquatic biota. However, the amount of particulates contributed through atmospheric fallout is expected to be negligible. Additionally, the contribution of minor quantities of asbestos fibers from the asbestos-board waterproofing method of Option III is expected to have a minimal to negligible impact on the stream ecosystem adjacent to Plot M.

Table 5.1. Summary of Potential Aquatic Impacts from Implementation of Options III through VIII

	Option					
Impacts	III	IV	V	VI	VII[a]	VIII
Sediments	X			X		
Fugitive dust	X		X	X		
Particulate radionuclides	X		X			
Asbestos fibers	X		X			
Cement-mixer slag	X			X		
Drilling muds		X				X
Excessive drawdown						X

[a]No direct impact.

If cement-mixer slag is poured on the ground near the stream, an adverse aquatic impact could result. The magnitude of the impact would be a function of the slagging location and the amount of material deposited.

For both Options IV and VIII, a well or wells are proposed to be drilled in the forest preserve picnic area, which could result in the release of drilling wastes (solid and liquid); this, in turn, could affect the nearby intermittent stream, if the drill site is close to the stream channel and if drilling were carried out during the period of stream flow. The aquatic impacts of the drilling activities are expected to be minimal because it is unlikely that drilling would be performed during wet periods when the stream is flowing through the forest preserve. Moreover, the amount of drilling fluids produced is expected to be small, especially for shallow drilling operations. An additional aquatic impact which could result from installing the well(s) is related to drawdown of the water table as a result of the operation of the installed well. However, the amount of water consumed from a public drinking well is relatively small, and thus no adverse impact is expected.

5.6.3 Mitigative Measures

5.6.3.1 Terrestrial

The staff recommends that the eroded areas of Site A and Plot M be regraded and reseeded. It is also essential that all vehicular use of these two areas be prohibited, to prevent a recurrence of the erosion and gullying that has resulted from such activity in past years.

If proper reclamation procedures are followed, the terrestrial biota of the area will fully recover.

5.6.3.2 Aquatic

Option I

Implementation of Option I (no action) would require no mitigative measures.

Option II

To minimize the impacts associated with Option II, steps should be taken to reduce the quantity of sediments entering the stream near Plot M. One way of accomplishing this is to build diversions which direct all site drainage through a sediment basin prior to discharging it into the stream. In addition, the overburden which is removed and saved should be protected from erosion; if the excavation process is expected to proceed for an extended period, the stockpile should be vegetated to reduce wind and water erosion. At Plot M, the site should be returned, as closely as possible, to the approximate original contour. This, too, should help reduce erosion problems, especially after vegetation has been established on the regraded slope.

Options III through VIII

In addition to the applicable mitigative actions prescribed above, steps should be taken to avoid the deposition of concrete slag and drilling wastes

on the site. Proper site management and equipment-operator awareness are important to adequately control the potential impact from the disposal of solid and liquid wastes.

5.7 RADIOLOGICAL IMPACTS

5.7.1 Radiological Impacts from Options for Remedial Action

The options for remedial action were analyzed primarily in terms of their potential for environmental impacts resulting from modification of groundwater movement, air release of contaminants, and changes in the concentration of tritium found in the existing public drinking-water wells at the Palos Forest Preserve.

5.7.1.1 Groundwater Contaminants

The hydrological conditions at Plot M are described in Section 4.7. It is believed that tritium was leached out of the buried wastes from the time that it was first placed in Plot M in 1947 to the time that a concrete cover was placed over Plot M in 1956. It is also believed that after 1956, leaching of tritium out of the wastes was drastically reduced but that a considerable quantity had already seeped into the underlying soil. It is not known how much tritium remains in the Plot M wastes, but a large (approximately 3000 Ci) reservoir exists in the ground beneath the wastes and is possibly the source of the tritium that is now being found in the public drinking-water wells at Palos Forest Preserve. In this section, the options are considered in terms of their impacts on the public drinking-water supply and their effectiveness in limiting any further transfer of tritium from the buried wastes to the underlying soil and the groundwater.

Option I

If Option I is chosen, it can be expected that the tritium levels in the water of the public drinking wells will continue to exhibit an annual cycle of a winter maximum and a summer minimum. The highest level observed in any of the wells to date has been 14 nCi/L, which is still below the EPA drinking water limit of 20 nCi/L.

Option II

The excavation and removal of buried waste at Plot M/Site A would have the beneficial impact of reducing, if not eliminating, the possibility of groundwater contamination by radioactive constituents (other than tritium) present in the wastes--the more extensive the removal of buried waste, the more protection achieved against possible groundwater contamination.

Prior to implementation of Option II, the concrete cover at Plot M serves to decrease, to some extent, the seepage rate of water from the surface to the tritium reservoir. After removal of the concrete cover and the buried wastes, the seepage rate from the surface to the reservoir may increase, so that the rate of movement of the tritium through the soil may be increased. Since removal of the wastes will not affect the tritium concentration in the

underlying soil but may increase the seepage rate, Option II may increase the extent of drinking-water contamination. However, Option II specified a vegetative cover on the surface that would reduce seepage to some degree. Thus, the exact extent of any drinking-water contamination is uncertain. If the radiological survey subsequent to the implementation of Option II detects a rise in tritium concentration in drinking water, waterproof barriers similar to those described in Options III and V should be installed over the surface of the excavated sites.

Options III, V, and VI

Implementation of Options III, V, or VI, individually or in combination, is not expected to result in a decrease in the concentration of tritium in drinking water. However, the wastes and the reactor shield would be better isolated, resulting in greater assurance that any tritium remaining in the wastes and reactor shield would not be washed out. The isolation would be increased by implementing possible combinations of these options.

Options IV and VIII

Implementation of Options IV and VIII would result in a decrease in the tritium concentration in the public drinking-water supply. However, the rate of seepage of the tritium in the ground would not be affected.

Option VII

If the picnic wells are closed (Option VII), public drinking water would no longer be available at Palos Forest Preserve and the tritium seepage rate would be unaffected.

5.7.1.2 Airborne Contaminants

It is expected that only Option II would result in airborne contaminants that could be released to the environment. To estimate the radiological impact from this option, consideration was given to the following factors: (1) the type and quantity of the radioisotopes present, (2) the physical nature and particle sizes of the radioactive dusts that might be generated, and (3) the effectiveness of the procedures proposed in Option II in containing the radioactive material.

Plot M

At Plot M, particulate releases are expected only from breaking the concrete cover, and not from the buried wastes. The buried material is comprised of laboratory wastes in various forms such as solutions, solids, laboratory equipment, animal carcasses, and irradiated slugs of lithium-aluminum alloy. The "inventory by recollection" did not suggest that material in the form of a fine powder may be buried at Plot M. In any case, an uncontained buried powder would have become associated with the clayey soil typical of the area. Thus, it is not expected that any wastes exist at Plot M as a readily suspendible powder.

Although soil samples have been collected in the area around and below Plot M and tested for tritium, no similar analyses have been conducted of the

overburden at Plot M. However, it is reasonable to assume that water would move downward in the overburden and that the tritium concentration in the overburden would therefore not exceed that at the interface of the buried wastes and the overburden. It has been reported[4] that the tritium concentration in soil moisture at this interface is about 120 nCi/L; this would represent an upper limit to the tritium concentration in the overburden.

It is expected that excavation activities in the containment buildings would begin in the spring and continue through the summer. Calculations of the evaporation rate of water into the building over Plot M were made assuming typical summertime relative humidity and soil temperature and an enclosed area equivalent to that of the building (15 × 12 m). The ventilation rate was the specified 10 air changes per hour (11,000 m^3/hour). Based on these assumptions, the concentration of tritium released from the containment building exhaust would be 1.4×10^{-10} μCi/mL, which is below MPC (2×10^{-7} μCi/mL) by a factor of 1400. Tritium release at these concentrations is not expected to have a measurable environmental impact.

Site A

The CP-3' reactor shield--filled with concrete, piping, and other miscellaneous contaminated items--is buried at Site A. On top of the CP-3' reactor shield, there is decontaminated rubble from the buildings that once stood at Site A. Twelve meters (40 ft) of overburden cover the rubble and reactor shield. Excavation of the buried structure would require removing the overburden and cutting up the concrete-filled reactor shield.

No tests have been made to determine the amount of tritium that exists in the overburden at Site A. In the absence of contrary data, it is assumed that the concentrations of tritium in the overburden are the same as that at Plot M, i.e., 120 nCi/L. Following an analysis similar to that used for Plot M, it is estimated that the tritium concentration in the exhaust of the building ventilation system would not exceed 3.5×10^{-10} μCi/mL.

Small particles from the reactor shield will be produced during the process of cutting it up. Selective wetting is planned for controlling the amount of dust released into the air in the building. Since the dust will come from decontaminated building rubble and the CP-3' reactor shield and its concrete-embedded contents of piping and activated structures, some of the dust can be expected to be radioactive. However, particulate emissions can be controlled by the HEPA filters used in the building ventilation system.

Summary

As described above, filtration of the effluent from the containment buildings through the use of HEPA filters would adequately control airborne contaminants. Particulate release (primarily from breaking and cutting concrete) would be controlled within the buildings by wetting (to minimize dusting); gaseous or vapor releases are expected to be so low that control would be unnecessary. Therefore, the radiological impacts of Option II are expected to be negligible so long as the emission-control measures are fully implemented.

5.7.1.3 Surface Soil Contamination

Only Option II would have any possibility for surface soil contamination, since the other alternatives do not call for excavation or transportation of soil. With continuous health-physics supervision and monitoring during excavation operations, contamination of the soil surrounding the excavation areas can largely be avoided. Any contaminated soil could be removed.

A comprehensive standard covering soil contamination has not yet been established, although proposals have been made regarding plutonium concentration in soil.[5] Since no contamination standards exist and large areas of ground will have to be surveyed, it is suggested that external gamma radiation (EGR) levels be used as a basis for determining soil contamination. For the purpose of maintaining Site A/Plot M as unrestricted areas, it is suggested that the following EGR levels above background be applied: target - <5 μR/hour; maximum - 20 μR/hour. These EGR levels are given in the NRC document, "Interim Land Cleanup Criteria for Decommissioning Uranium Mill Sites."[6] For a comparison, the Grand Junction Remedial Action Criteria do not require remedial action in cases where the EGR is less than 50 μR/hour.) The limits suggested for concentrations of Sr-90, Pu-289, and H-3 (in soil moisture) in the cover material at Site A/Plot M are: Sr-90 - 0.1 pCi/g; Pu-239 - 0.1 pCi/g; H-3 (in soil moisture) - 2 nCi/L.

5.7.1.4 Direct Gamma Radiation

Option II is the only option from which direct gamma radiation could reasonably be expected to produce any radiological impact. The buried wastes at Plot M are primarily low specific activity (LSA) wastes that originated from radiochemical and radiobiological laboratory operations at both the University of Chicago and Site A between 1943 and 1949. A description of what could possibly be buried at Plot M is given in Section 4.9.1.2. Although above-background levels of gamma radiation can be expected to exist in the immediate area around Plot M when the wastes are uncovered, the levels are estimated to be so low that external radiation at the Red Gate Woods picnic area would not be measurably increased. At Site A, the uncovered reactor shield rests at the bottom of a 12-m (40-ft) deep hole. Small, shippable pieces will be removed one at a time from the hole and placed in special bins. The radiation levels from each shipment must meet LSA transportation criteria.

5.7.2 Evaluation of Radiological Impacts on the Public

5.7.2.1 Option I

Option I, the no-action option, will have a negligible impact on the public. The levels of tritium in the water of the drinking wells can be expected to remain below the EPA drinking-water limit of 20 nCi/L; the average concentration has been 7 nCi/L. If a child consumed one liter of water each day at this concentration, the resulting dose would be 0.5 mrem/year (less for an older individual). If allowance were given for the fact that this water is not used by anyone on a daily basis and that any use would probably occur in summer (when the tritium concentrations are lowest) rather than winter, the actual dose expected would be very much lower than 0.5 mrem/year. In effect, the radiation dose to the general public from Option I would be less than 1% of the total natural background dose.

5.7.2.2 Option II

Option II involves uncovering and removing the buried reactor shield and laboratory wastes. The emissions of radioisotopes from Site A/Plot M during the excavation and removal of the wastes would be under close control. The combination of selective wetting of certain dust-producing operations, work being performed within a containment building, and the HEPA filtration of the exhaust is expected to effectively control dust release. Tritium release in the form of vapor is expected to be negligible, and the dose to the general public from inhalation of tritium would be only a very small fraction of the dose to the whole body from natural background radiation. Thus, provided appropriate health-physics precautions are taken and the containment building ventilation/filtration scheme remains operational, the radiological impact of Option II would be negligible.

The removal of the buried reactor shield and laboratory wastes would have negligible effect on the seepage rate of the tritium that is already in the soil, provided that impermeable barriers are built over Site A and Plot M. Without the barriers, it is possible that the tritium seepage rate would increase, resulting in higher concentrations of tritium in the Palos Forest Preserve drinking-water wells. Thus, Option II could actually result in a deterioration of the water quality at the forest preserve wells.

5.7.2.3 Options III, V, and VI

The basic objectives of Options III, V, and VI are to improve the existing protective barrier system around Plot M and to build a protective cover over Site A. No aboveground radiological impacts would result from these actions, but the chances of transfer of tritium or other materials from Site A/Plot M into the surrounding soil and groundwater would be reduced. The barriers to be built cannot control the tritium that is already in the soil; therefore, the quality of the drinking-water wells at Palos Forest Preserve would not change in the immediate future. The longer-term effects of these possible actions on well water quality are very uncertain.

5.7.2.4 Options IV, VII, and VIII

Implementation of Options IV, VII, and VIII would have negligible aboveground impacts; the seepage rate of tritium in the ground would also be unaffected. The quality of the drinking water available in the forest preserve would depend on the quality of water from the new supply sources.

5.7.2.5 Summary

The tritium concentration levels in the well water can be expected to continue in their present cyclical trend and remain below drinking-water limits. No immediate remedial action is therefore necessary unless the concentrations show a sustained increase beyond the drinking-water limits, at which time a decision can be made to implement one or a combination of the above options. Option I does not pose an unreasonable risk to public health because changes in tritium concentration can be expected to occur only gradually. Moreover, if necessary, action could easily be taken to prevent further use of the wells before anyone has imbibed more than a fraction of the normal annual water intake volume of an individual.

Options III, V, and VI would serve to better contain any materials remaining at Site A/Plot M. Options VII would eliminate the existing wells as water supply sources for the public, and Options IV and VIII would provide the public with drinking water that has less tritium in it than the existing water supply. Option II, involving excavation and removal, would not improve the water supply, and it might aggravate the tritium seepage situation, leading to a worsening of the water quality; also, it would be very costly.

The waste material will be placed in bins and transported in an enclosed truck. No environmental impact is expected from transportation if no accidents occur. The consequences of an accident are discussed in Section 5.10.

5.7.3 Occupational Dose

Only the operations associated with Option II can be expected to result in occupational doses to workers. Health-physics personnel would be present to perform radiation monitoring, air sampling, and other analyses necessary to ensure that exposures are as low as practicable and within occupational limits. All workers within the containment buildings would be supplied with clean air for breathing and would wear protective clothing. By using appropriate respiratory protective devices, radiation doses through the inhalation pathway can be virtually eliminated.

At Plot M, the nature of the waste is such that a high gamma radiation field would not be expected. Most of the manipulation of waste would be done by machine, with a backhoe used to dig up the waste and load it into special bins for shipping.

At Site A, the reactor shield, reactor components, and other buried wastes may contain both fission and activation products. Twenty-four years have elapsed since the reactor was dismantled so that the short-lived products will have decayed away, leaving only longer-lived products such as cesium-137 and strontium-90 at the site. It is uncertain how much Cs-137 and Sr-90 may be present at Site A, and health-physics precautions will be necessary in order to ensure that radiation doses incurred by individual workers will remain within occupational limits.

5.7.4 Mitigative Measures

The nature and quantities of the buried materials at Site A/Plot M are only approximately known. Although most of the materials are believed to be wastes from radiochemical and radiobiological laboratories and from the decontaminated CP-3' reactor hardware and building structures, it is possible that small amounts of highly radioactive substances and objects may also be buried with the wastes (see Sec. 4.9). The following mitigative measures should therefore be taken to minimize the risks to which workers are exposed and to ensure safe and efficient implementation of remedial Option II.

5.7.4.1 Health-Physics Monitoring

During excavation, reactor shield cutting, and removal of the wastes, external radiation and air sample monitoring should be performed. Workers' exposure should be controlled, based on the results of this monitoring program. The air sample results will provide information on the radiological

nature and potential hazard of the dust in the building and guide the choice of respiratory protection devices.

5.7.4.2 Personnel Monitoring

A personnel monitoring program should be set up for the equipment operators and other workers involved with the operations. This should include personnel dosimeters and, if there is significant airborne activity, a bioassay program as well.

5.7.4.3 Inspection of Wastes

An inspection (including visual and radiological) of the wastes on the ground should be performed by health-physics personnel prior to the wastes being handled by heavy equipment. This will decrease the possibility of fragile containers, such as cartons and bottles, being broken open. At the same time, an inventory of the wastes should be done and records kept of the material being packed for shipment.

5.7.4.4 Monitoring of Building Exhaust

In the unlikely event that the health-physics monitoring program indicates that concentrations of radionuclides within the containment buildings exceed a tenth of maximum permissible concentration, then the exhaust flow of the building ventilation system should be monitored for particulate radioactivity as well as tritium activity levels. A flow rate sensor and alarm should be built into the system to warn of a failure. Also, a pressure sensor and alarm should be included upstream of the exhaust filters to warn of filter failure or omission due to an error during routine filter replacement.

For Options III, V, and VI, it is recommended that health-physics monitoring be performed during the digging and construction operations. Monitoring should include constant air monitoring, measurements with portable tritium detection equipment, and radioactivity surveys of the machinery used in the operations.

Options IV, VII, and VIII do not require health-physics monitoring, although water samples from the new supply sources should be analyzed for tritium and other contaminants that may be present.

5.8 SOCIOECONOMIC IMPACTS

5.8.1 Options I through VI

No foreseeable or measurable impacts are expected to occur to the population using Red Gate Woods if Options I through VI are implemented.

5.8.2 Option VII

Implementation of Option VII (closing the picnic wells) may have adverse impacts to the Red Gate Woods picnic area. The area attracts many annual visitors because of its adequate facilities (i.e., potable water, sanitary

facilities, and shelter). Without water, however, many of the visitors may perceive the area as less pleasant and enjoyable and thus seek a more suitable picnic area. The Cook County Forest Preserve District has been improving the Red Gate Woods facility (i.e., shelter, picnic tables, barbecue grills, etc.) over the past few years because of its growing popularity. By closing the wells, benefits from the expenditures made for overall improvements to the facility may be lost by decreased utilization of the area (conversation with R. Buck, Chief Landscape Architect, Cook County Forest Preserve District).

5.8.3 Option VIII

Implementation of Option VIII would require surface activities that may limit public access to the disturbed area. This may create temporary adverse impacts; however, it is intended to ensure public health and safety.

5.9 CONFORMITY OR CONFLICT WITH FEDERAL, STATE, OR LOCAL STATUTES, REGULATIONS, STANDARDS, LIMITATIONS, OR POLICIES

5.9.1 Air Quality

5.9.1.1 Option I

No violations of air quality regulations would occur under Option I.

5.9.1.2 Option II

In Option II, all excavation will be done under cover, and ventilation air will be filtered before release (see the EER for detailed description). Excavated material will be shipped in externally cleaned, sealed bins to prevent any radioactive dust dispersion. Consequently, the operations connected with Option II should have no deleterious effects on air quality; therefore, no conflict with air quality regulations should arise.

5.9.1.3 Options III through VIII

Options III through VIII involve no operations that would affect air quality and no violations of the regulations will occur.

5.9.2 Water Quality

5.9.2.1 Option I

In a surface-water seep just below Plot M, maximum values of 3.1 pCi/L for Sr-90 and 0.0087 pCi/L for Pu-239 have been measured. Maximum values for H-3 in 1976 and 1977 were 128 and 44 nCi/L respectively.[7]

For Sr-90, the Illinois Environmental Protection Agency standard (surface water) is 2 pCi/L; thus, the seep at 3.1 pCi/L apparently does exceed this standard. The background level (atom bomb test fallout) in an intermittent stream uphill of the seep has been measured at about 1.2 pCi/L; therefore the addition is less than 2 pCi/L. The seep volume is very low and the activity

level in the intermittent stream where the seep empties had returned to background about 70 m downstream; thus, the interpretation of a violation of the standard is uncertain. For comparison, other standards that have been set for Sr-90 in water are 300 pCi/L by the Illinois Department of Public Health[8] for immersion in water and 8 pCi/L by the U.S. Environmental Protection Agency (USEPA) for drinking water.[9] It is unlikely that the seep would be used for either purpose. The most restrictive standard for Pu-239 is that of the Illinois Public Health Department (also DOE): 5000 pCi/L for immersion; the seep is far below this value. For H-3, the Illinois Department of Public Health standard (external exposure) is 3000 nCi/L compared to the observed recent values of 128 and 44 nCi/L in the intermittent stream. The USEPA standard for H-3 in drinking water is 20 nCi/L; again, it is unlikely that the stream would be used for this purpose.

The maximum H-3 measured in any of the potable water wells has been 14 nCi/L compared to the USEPA standard of 20 nCi/L. In addition, the highest values have occurred in winter when there is very little or practically no use of the forest preserve wells, whereas the standards are determined on the basis of continuous use of the given water. Consequently, any dosage would be far below standards.

Summarizing Option I in relation to applicable water quality or pollution standards, the Sr-90 standard for surface water has been slightly exceeded in the past. The standards for H-3 in potable water have not been exceeded although levels slightly elevated above background have been measured. Although Option I does not conflict with Illinois standards, the state does require that every reasonable effort be made to reduce radiation exposures to "as low as reasonably practicable." In the evaluation of practicability, available technology, economics, benefits, and safety must be taken into account. It is possible that Option I may not comply with the "as low as practicable" policy.

5.9.2.2 Option II

The degree of increased compliance with water quality rules under Option II would be uncertain (especially in regard to tritium exposure), but some improvement toward "as low as practicable" could occur, particularly in future years. However, compliance in terms of reduction in tritium concentration would be doubtful. The construction activities might have minor effects on water quality, but these are viewed as transitory.

5.9.2.3 Option III

The desired effects would be similar to those of Option II. The degree of increased compliance is uncertain.

5.9.2.4 Option IV

Although the drinking water wells in the forest preserve presently meet the USEPA drinking-water standard for H-3, the development of wells uncontaminated with H-3 may be necessary to meet the Illinois "as low as practicable" condition. Compliance with surface-water standards would not be affected by this option.

5.9.2.5 Option V

This action at Site A is similar to Option III at Plot M. The purpose, expected results, and compliance with water-quality standards would be the same as for Option III.

5.9.2.6 Option VI

The movement of near-surface contaminants would probably be decreased or eliminated by this option, and consequently nearby surface discharges would be brought closer to the "as low as practicable" condition. At Plot M, it is doubtful that the deeper-lying H-3 entering the drinking water would be affected by this option, and no change in compliance with drinking-water standards would occur.

5.9.2.7 Options VII and VIII

In Option VII, the picnic wells would be closed without providing a substitute water supply. The action would remove a source of water where the radioactivity level might not be "as low as practicable." In Option VIII, a substitute source of water would be provided for the picnic area. Presumably, this water supply would meet all Illinois Department of Health standards.

5.9.3 Disposal of Wastes and Toxic Materials

5.9.3.1 Option I

No new materials have been buried at Plot M since 1949; demolition and restoration of Site A was completed in 1956. Consequently, the current regulations of the Illinois Pollution Control Board for solid-waste burial are not applicable. At the time of burial, definitive rules for radioactive material burial had not been formulated, and the methods of waste disposal used generally reflect the lack of such a policy.

5.9.3.2 Option II

In Option II, the wastes at Plot M and Site A are to be removed and shipped to a licensed disposal area where they will be reburied in compliance with NRC regulations. At present, no disposal sites for radioactive materials are licensed in Illinois, and disposal within the state is uncertain. Only temporary storage would be allowed at the Argonne site.

Shipment of the wastes will be in Department of Transportation (DOT) approved containers (steel bins for the presumably low specific-activity wastes) and in compliance with DOT regulations. No other actions where solid-waste-disposal regulations apply have been identified.

5.9.3.3 Other Options

None of the remaining options will produce solid hazardous wastes, and those already present will remain undisturbed.

5.9.4 Land Use

5.9.4.1 Option I

Prior to war and postwar use of Site A and Plot M for laboratory purposes, the area was used as a recreational forest preserve. Upon release of the land in 1956 by the AEC, the area was returned to its original use without impedance or restrictions except with regard to digging in the Site A/Plot M areas. Under Option I, this unrestricted use would continue without change. Monitoring of the area is to continue to ensure that no restrictions on land use are necessary.

5.9.4.2 Option II

In Option II, the wastes are to be removed, requiring temporary land-use restrictions during the operation period. After the waste removal is completed and the areas restored, unrestricted use will again be instituted.

5.9.4.3 Other Options

At most, the other options will require temporary land-use restrictions during any construction periods.

5.10 ENVIRONMENTAL IMPACTS OF ACCIDENTS

5.10.1 Onsite Accidents

The probability of a tornado occurring in the vicinity of Site A is about 1.02×10^{-3} per year (recurrence interval 980 years). Two tornadoes touched down near the Argonne National Laboratory site in recent years, one in 1976 and another in 1978. In the event that a tornado were to strike during excavation operations, the containment buildings would be completely destroyed and any low-density loose material would become airborne. The worst possible time for a tornado to strike would be at the time when the buried materials or reactor shield are first uncovered. At Plot M, it is planned for operations to proceed on only a portion of the waste at any time; thus, not all of the waste would be exposed and available for dispersal by a tornado at any given time. The containment building measures 12 × 15 m (40 × 50 ft), with part ($\sim$ 20%) of its area taken up by the scalping hopper. Of the remaining area, if half were left for the backhoe to maneuver, the exposed area would be about 74 m^2 (800 ft^2), somewhat less than 9 × 9 m (30 × 30 ft) or less than 5% of the total Plot M area.

Since the type and quantity of waste at Plot M is not well-known, it is not possible to make reasonable estimations of the effects of a tornado strike. However, it is believed that the wastes do not exist as fine powders or concentrated gases that could be inhaled. Only 5% or less of the total area would be exposed at any given time, so that, at worst, only part of the total wastes would be dispersed. Given the low specific activity of the wastes and the dilution that a tornado could provide, a tornado strike at Site A/Plot M can be analyzed using methodology used for tornado accidents at uranium mills where, despite the greater quantities of radioactive materials involved,

tornado accidents have negligible radiological impacts.[10] Thus, it is unlikely that a tornado at Site A/Plot M would disperse radioactive materials to an extent that would be injurious to the total population.

5.10.2 Transportation Accidents

The reactor-shield pieces and waste materials would be shipped in Department of Transportation (DOT) approved low specific activity (LSA) containers, which are required to meet the 9-m (30-ft) drop test criterion. At the moment of impact from a 9-m (30-ft) drop, the container would be moving at a speed of about 48 km/hour (30 miles/hour). It is reasonable to assume, therefore, that the containers would not spill their contents in the event that the truck carrying the containers were to come to an abrupt halt from 48 km/hour (30 miles/hour). In reality, for most accidents, the colliding truck would not stop abruptly, so the containers could survive accidents at speeds somewhat higher than 48 km/hour without losing their integrity.

In the case of Site A reactor-shield pieces, if containers were involved in an accident and spilled their contents, the greatest hazard would be from external gamma radiation. Since the shipments must meet DOT transportation criteria with respect to LSA materials transported in a closed vehicle consigned as exclusive use, the radiation levels from a container involved in an accident could be as high as 1000 mrem/hour at 0.9 m (3 ft) from the container. However, it is not expected that the reactor shield pieces would exhibit such high radiation levels.

As the waste at Plot M is being uncovered, appropriate precautions would be taken to ensure that radioactive material would be transported safely. Thus, liquids would be processed into paste or solid form, and readily dispersible solids, if any, would be provided with additional containment. In the event of a spill, the packaged material would not readily spread and would not be expected to emit high levels of radiation. The packaged Plot M waste is low-density in nature and is not expected to be spilled from containers in the event of a truck accident.

The Site A/Plot M materials may be shipped to Barnwell, South Carolina (a distance of 1400 km); Hanford, Washington (3000 km); or Beatty, Nevada (2850 km). The probability of a truck accident is in the range of 1 to 1.6×10^{-6}/km.[11,12] It is estimated that 250 truckloads would be required to ship the waste. Thus, the expected number of accidents for shipment to Barnwell is less than one, and for shipment to Hanford is about equal to one. For Beatty, Nevada the expected number of accidents would be one.

5.10.3 Mitigative Measures

5.10.3.1 Tornado Emergency

Emergency plans should be made in anticipation of a tornado strike at either Site A or Plot M. A strike could easily destroy the containment buildings and disperse any loose items within. Under conditions of a tornado watch, any uncovered waste at Plot M should be covered with overburden stored nearby for this purpose. A tornado strike would be less of a problem at Site A because the reactor shield lies at the bottom of a 12-m (40-ft) hole.

However, even though the shield itself would not be moved by the tornado, smaller pieces cut from it might, so some precautions should be taken to anchor smaller pieces and loaded shipping containers to the ground.

5.10.3.2 Transportation Accident

The waste will be packaged according to existing requirements and shipped in "sole-use" vehicles. An accident enroute can be dealt with according to established procedures for similar waste. The Site A/Plot M material is not of an unusually hazardous nature, and no special treatment will be necessary.

REFERENCES (Sec. 5)

1. "Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions," EPA-450/3-77-010, PB-272-288, U.S. Environmental Protection Agency, Research Triangle Park, N.C.

2. "Compilation of Air Pollutant Emissions Factors," AP-42, U.S. Environmental Protection Agency, Research Triangle Park, N.C., August 1977.

3. Letter dated November 14, 1978, from R. Buck, Chief Landscape Architect, Cook County Forest Preserve District, to T. Predl, Argonne National Laboratory.

4. "Formerly Utilized MED/AEC Sites Remedial Action Program; Radiological Survey of Site A, Palos Park Forest Preserve, Chicago, Illinois," Final Report, DOE/EV-0005/7, Prepared for U.S. Department of Energy, Division of Environmental Control Technology, Washington, D.C., 87 pp., April 1978.

5. J. W. Healy, "An Examination of the Pathways from Soil to Man for Plutonium," LA-6741-MS, Los Alamos Scientific Laboratory of the University of California, Los Alamos, New Mexico, April 1977.

6. U.S. Nuclear Regulatory Commission, "Staff Technical Position, Fuel Processing and Fabrication Branch, Interim Land Cleanup Criteria for Decommissioning Uranium Mill Sites," May 1978.

7. "Radiological Survey of Site A, Palos Park Forest Preserve, Chicago, Illinois," Final Report, U.S. Department of Energy, April 1978.

8. "Rules and Regulations for Protection Against Radiation," Illinois Department of Health, September 1976.

9. U.S. Environmental Protection Agency National Interim Primary Drinking Water Standards, CFR 40, Part 141, Subpart A, Section 141.16, 1977.

10. "Final Environmental Statement Related to the Operation of Sweetwater Uranium Project, Minerals Exploration Company," Chap. 5, December 1978.

11. "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Plants," U.S. Atomic Energy Commission, Directorate of Regulatory Standards, WASH-1238, December 1972.

12. "An Assessment of the Risk of Transporting Plutonium Oxide and Liquid Plutonium Nitrate by Truck," Battelle Northwest Laboratories, BNWL-1846, August 1975.

6. NECESSARY PROGRAM OF MEASUREMENTS, DOCUMENTATION, AND CONTROL (TO DEMONSTRATE COMPLIANCE WITH CLEANUP CRITERIA AND GUIDELINES)

A program for monitoring the hydrological and radiological parameters at Site A/Plot M is currently in effect, and the data gained from this program can be used to demonstrate compliance with appropriate criteria and guidelines. The elements of the program that can provide data to demonstrate compliance are given herein. These program elements should remain in effect until such time as those knowledgeable in such matters decide (after analyzing the monitoring data) that there is no further need (or hazard), particularly after one or more of the remedial actions have been performed.

6.1 SURFACE WATER MONITORING

There are 13 stream and surface water sampling locations in the Palos Forest Preserve, most of which are along the drainageways adjacent to Plot M. It is recommended that these locations be maintained and sampled as described in Table 6.1.

6.2 GROUNDWATER MONITORING

Monitoring of groundwater in the Palos Forest Preserve includes sampling of 15 existing public and private wells, five forest preserve wells, fifteen cased bore holes equipped with well points, and four deep wells cased into the dolomite aquifer. The recommended groundwater monitoring program is described in Table 6.1.

6.3 SURFACE SOIL SURVEY

Surface soil and vegetation should be surveyed at the end of any remedial actions at Site A/Plot M. The survey should include external gamma radiation (EGR) readings as well as analyses of soil and vegetation samples. Surface soil and vegetation samples should be collected from the Site A/Plot M area and analyzed for total alpha and beta activity, and gamma-ray emitters. On the basis of these results, selected samples should be analyzed for plutonium, uranium, strontium-90, and tritiated water. For purposes of releasing Site A/Plot M for unrestricted use, the criteria proposed in Sections 3 and 5.7.1.3 for EGR, H-3, Sr-90, and Pu-239 should be used.

Table 6.1. Monitoring Program for Site A/Plot M

Sample	Sample Collection				Sample Measurement	
	No.	Location	Type	Frequency[a]	Frequency	Parameter
Surface streams	12	Upstream and downstream of Plot M in adjacent drainageway	Grab	Weekly during spring and fall (when water is flowing)	Weekly	Tritium; pH; uranium, plutonium and Sr-90; total alpha and beta activity; gamma ray emitters
Surface streams	1	Illinois and Michigan Canal at confluence of drainageway from Plot M	Grab	Quarterly (biweekly during spring and fall)	Quarterly (biweekly)	Tritium; pH; uranium, plutonium, and Sr-90; total alpha and beta activity; gamma ray emitters
Groundwater	15	Public and private wells	Grab[b]	Quarterly	Quarterly	Tritium; water elevation (public wells only); total alpha and beta activity
Groundwater	5	Forest preserve wells	Grab[b]	Quarterly (biweekly during spring and fall)	Quarterly[c] (biweekly)	Tritium; pH; water elevation; uranium, plutonium, and Sr-90; total alpha and beta activity; gamma ray emitters
Groundwater	15	Cased boreholes with well points	Grab[b]	Quarterly (weekly during spring and fall)	Quarterly (weekly)	Tritium; water elevation; total alpha and beta activity
Groundwater	4	Deep wells cased in the dolomite	Grab[b]	Quarterly (biweekly during spring and fall)	Quarterly[c] (biweekly)	Tritium; water elevation; total alpha and beta activity

[a]Spring = March 30-June 15; fall = September 1-November 1.

[b]Wells and boreholes should be pumped prior to sampling to ensure new water (not standing in the casing).

[c]One quarterly sample per year would also be analyzed for nitrate, iron, sulfate, total dissolved solids, hardness, and aluminum, cadmium, chromium, magnesium, manganese, nickel, and zinc.

7. INSTITUTIONAL ARRANGEMENTS FOR LONG-TERM CONTROL OF RADIOACTIVE MATERIALS

Under the terms (Section 2) of the 1956 agreement between the Cook County Forest Preserve District and the U.S. Atomic Energy Commission (AEC), the district has unrestricted ownership and use of Site A and Plot M. The agreement did not explicitly transfer ownership of the wastes and building rubble at Plot M and Site A so that these materials might be considered as the permanent property or responsibility of the AEC (DOE).

The agreement involved the understanding that residual wastes and structures as buried would pose no hazards to humans, plants, or animals and would in no way interfere with the full use of the forest preserve. If hazards appeared or restrictions on use were necessary, it could be considered that the AEC (DOE) had not fulfilled its obligations under the agreement. In various public announcements, the DOE has since stated that it will continue to meet its responsibilities for monitoring and for any controls of the wastes that are found to be necessary and that DOE has the authority to undertake. The continuing monitoring program and this environmental analysis document are evidence of this responsibility.

In addition to the Cook County Forest Preserve District and the U.S. Department of Energy with primary responsibilities, other agencies have authority or interest in various aspects of the wastes. The Illinois EPA has authority to enforce the water quality standards set up by the Illinois Pollution Control Board. The Illinois Department of Health can enforce rules relating to radiation exposure from water or other sources of radiation. The Cook County Department of Environmental Control is primarily involved in air quality enforcement and noise limitations, and the Cook County Health Department has a general interest in health matters. There has been a general cooperation and exchange of information among all of these agencies.

APPENDIX A. LANDMARKS OF SPECIAL HISTORIC IMPORTANCE LOCATED IN THE PALOS FOREST PRESERVE AREA

Table A.1. List of Landmarks of Special Historic Importance Located in the Palos Forest Preserve Area

No.	Description
H-22	St. James Church, located in SW 1/4 of Section 13, T37N, R11E, at Route 83 and Route 171. This stone church was built in 1833. Church services are still held in it. Accurate size and measurements were not available.
H-23	Old cemetery, located in NW 1/4 Section 30, T37N, R12E, on Will Cook Road between Ford and McCarthy Roads, was started in the middle to late 1800s. The headstones that marked a few of the older graves have been stolen. The cemetery is not being maintained and is overgrown with grass and weeds.
H-24	Indian Sites, located in the Cook County Forest Preserves in Section 7 and N 1/2 of Sections 17 and 18, T37N, R12E, date to before 10,000 B.C., when the earliest Indian artifacts of this area have been found. It is speculated that the Indians used to camp on the higher ground and hunt in the lower wetlands. Exact size and measurements of these Indian villages are not available, as accurate historical information is sparse.
H-26	Jacob Rodataz Mansion, located in NE 1/4 of Section 27, T37N, R12E, on the southeast corner of 90th Avenue and 121 Street in Palos Park, was built in 1898. A brick fence surrounds the 26-room brick mansion, which is privately owned and well maintained. Newer houses stand next to this estate today. Accurate size data were not available.
H-27	Busch and Lucas Farmhouse, located in Section 15, T38N, R12E, near 109th Street and Kean Avenue in Palos Hills, was built in the 1840s by the first settler in this area. The farmhouse was destroyed by fire in the 1960s; only its stone foundation remains. Accurate size and measurements were not available.
H-28	Lund House, located in Section 27, T37N, R12E, near the corner of 91st Avenue and 121st Street, was built in the 1870s. This wood frame house was built by Mr. Lund, a famous architect of the period. Accurate size and measurements were not available.
H-29	Sacred Heart Cemetery, located in Section 10, T37N, R12E, at Kean Avenue and 102nd Street, was started in the 1840s. This is one of the earliest cemeteries in the area. Many of the older grave markers have been stolen. The cemetery is a triangular plot of land of approximately 12 acres in area.
H-30	Fort sites, built by the French in the 1700s, are to have been located in NW 1/4 Section 14, T37N, R12E, at 103rd Street and 86th Avenue where Palos Hills City Hall now sits and in Section 15, T37N, R12E, near 107th Street and Kean Avenue. All that remains of these and possible other fort sites are a few artifacts and a written record that they existed. The original size and measurements are not known.
H-31	Cemetery, located in NW 1/4 Section 11, T37N, R12E, at 96th Street and 86th Avenue, was started before the Civil War. Members of the Winkler family, early settlers of the area, are buried here. The cemetery is being cared for by Mr. Ott.

Source: Bauer Engineering, Inc., "Environmental Resource Inventory: Calumet-Sag Channel Watershed - Cook, Du Page, and Will Counties, Illinois," Prepared for the Soil Conservation Service, Lisle, Ill., Vol. II, October 1975.

APPENDIX B. RADIOCHEMICAL ANALYSES OF SOIL MOISTURE IN CORE SAMPLES FROM BORINGS THROUGH PLOT M

Table B.1. Analysis of Core No. 22 Collected April 18, 1977, Through the Concrete Cap, 50 ft W and 25 ft S of NE Corner

Sample Number	Depth (ft)	Water Content (%)	H-3 nCi/L	H-3 pCi/g	Sr-90 pCi/g	U-234 pCi/g	U-235 pCi/g	U-238 pCi/g	Pu-238 fCi/g	Pu-239 fCi/g	γ^a pCi/g
77S1	3.5-5	17.9	27.2	4.87	< 0.1	0.51	0.02	0.68	< 0.1	1.1	< 0.1
77S2	6-7.5	19.8	30.4	6.01	< 0.1	0.64	0.02	0.90	< 0.1	2.1	< 0.1
77S3	7.5-9	15.7	52.4	8.22	< 0.1	0.56	0.02	0.77	< 0.1	1.0	< 0.1
77S4	10-11.5	13.4	64.0	8.57	< 0.1	0.72	0.03	0.94	< 0.1	< 0.1	< 0.1
77S5	11.5-13	13.4	63.9	8.56	< 0.1	0.80	0.03	1.03	< 0.1	0.7	< 0.1
77S6	13-14.5	12.1	179	21.7	< 0.1	0.59	0.03	0.77	< 0.1	< 0.1	< 0.1
77S7	14.5-16	12.3	218	26.8	-	-	-	-	-	-	< 0.1
77S8	16-17.5	12.4	299	37.1	-	-	-	-	-	-	< 0.1
77S9	17.5-19	12.3	539	66.3	-	-	-	-	-	-	< 0.1
77S10	19-20.5	11.7	1.72×10^3	202	< 0.1	0.54	0.02	0.68	< 0.1	1.7	< 0.1
77S11	25-26.5	11.6	4.06×10^3	471	-	-	-	-	-	-	< 0.1
77S12	30-31.5	10.7	9.54×10^3	1.02×10^3	-	-	-	-	-	-	< 0.1
77S13	35-36.5	12.5	1.45×10^4	1.81×10^3	-	-	-	-	-	-	< 0.1
77S14	40-41.5	11.2	3.23×10^4	3.62×10^3	-	-	-	-	-	-	< 0.1
77S15	45-46.5	11.0	4.52×10^4	4.97×10^3	< 0.1	0.60	0.09	0.83	< 0.1	< 0.1	< 0.1
77S16	50-51.5	11.9	4.76×10^4	5.67×10^3	-	-	-	-	-	-	< 0.1
77S17	55-56.5	12.6	4.00×10^4	5.04×10^3	-	-	-	-	-	-	< 0.1
77S18	60-61.5	12.2	5.56×10^4	6.79×10^3	-	-	-	-	-	-	< 0.1
77S19	65-66.5	12.8	1.07×10^5	1.36×10^4	< 0.1	0.49	0.02	0.61	< 0.1	< 0.1	< 0.1
77S20	70-71.5	11.0	5.18×10^4	5.70×10^3	-	-	-	-	-	-	< 0.1
77S21	75-76.5	15.2	6.09×10^4	9.26×10^3	-	-	-	-	-	-	< 0.1
77S22	80-81.5	10.7	6.35×10^4	6.80×10^3	-	-	-	-	-	-	< 0.1

[a]Each gamma-ray emitting fission or activation product.

Conversion factor: 1 ft = 0.305 m.

Source: "Formerly Utilized MED/AEC Sites Remedial Action Program; Radiological Survey of Site A, Palos Park Forest Preserve, Chicago, Ill.," Final Report, DOE/EV-0005/7, Prepared for U.S. Department of Energy, Division of Environmental Control Technology, Washington, D.C., 87 pp., April 1978.

Table B.2. Analysis of Core No. 23 Collected April 27, 1977, Through the Concrete Cap, 65 ft W and 75 ft S of NE Corner

Sample Number	Depth (ft)	Water Content (%)	H-3 nCi/L	H-3 pCi/g	Sr-90 pCi/g	U-234 pCi/g	U-235 pCi/g	U-238 fCi/g	Pu-238 fCi/g	Pu-239 fCi/g	γ^a pCi/g
77S23	3.5-5	19.3	118	22.8	0.46	1.61	0.04	1.86	< 0.1	145	< 0.1
77S24	5-6.5	17.4	111	19.3	1.47	1.61	0.06	1.80	0.25	80	0.46 (Cs-137)
77S25	6.5-8	18.0	156	28.1	2.43	8.33	0.39	7.95	2.22	1.08×10^3	1.0 (Cs-137) 1.7 (Eu-152)
77S26	8-9.5	14.7	246	36.1	2.90	0.70	0.03	0.88	0.39	119	< 0.1
77S27	9.5-11	15.0	275	41.2	0.45	0.72	0.04	0.90	< 0.1	30.5	< 0.1
77S28	11-12.5	12.2	293	35.8	0.20	0.73	0.04	0.88	< 0.1	8.6	< 0.1
77S29	12.5-14	12.8	308	39.4	0.38	0.82	0.04	1.01	< 0.1	71.1	< 0.1
77S30	14-15.5	6.0	339	20.3	0.13	0.80	0.03	0.92	< 0.1	6.4	< 0.1
77S31	15.5-17	12.1	435	52.6	-	-	-	-	-	-	< 0.1
77S32	17-18.5	11.7	695	81.3	-	-	-	-	-	-	< 0.1
77S33	18.5-20	12.0	1.14×10^3	137	-	-	-	-	-	-	< 0.1
77S34	25-26.5	12.6	1.53×10^3	193	-	-	-	-	-	-	< 0.1
77S35	30-31.5	10.3	3.95×10^3	407	-	-	-	-	-	-	< 0.1
77S36	35-36.5	8.6	2.34×10^4	2.01×10^3	-	-	-	-	-	-	< 0.1
77S37	40-41.5	10.7	3.37×10^4	3.60×10^3	< 0.1	0.39	0.02	0.41	< 0.1	< 0.1	< 0.1
77S38	45-46.5	11.7	7.95×10^3	930	-	-	-	-	-	-	< 0.1
77S39	50-51.5	6.2	1.54×10^4	952	-	-	-	-	-	-	< 0.1
77S40	55-56.5	12.6	1.51×10^4	1.90×10^3	-	-	-	-	-	-	< 0.1
77S41	60-61.5	11.2	2.05×10^3	230	-	-	-	-	-	-	< 0.1
77S42	65-66.5	10.6	28.3	3.0	< 0.1	0.68	0.04	0.82	< 0.1	< 0.1	< 0.1
77S43	70-71.5	13.0	112	14.6	-	-	-	-	-	-	< 0.1
77S44	75-76.5	11.0	148	16.2	-	-	-	-	-	-	< 0.1
77S45	80-81.5	7.5	63.3	4.8	-	-	-	-	-	-	< 0.1
77S46	85-86.5	11.8	76.6	9.0	-	-	-	-	-	-	< 0.1
77S47	90-91.5	12.9	93.1	12.0	-	-	-	-	-	-	< 0.1
77S48	95-96.5	13.7	249	34.1	-	-	-	-	-	-	< 0.1
77S49	100-101.5	18.0	46.6	8.4	< 0.1	0.60	0.03	0.72	< 0.1	< 0.1	< 0.1

[a]Each gamma-ray emitting fission or activation product.

Conversion factor: 1 ft = 0.305 m.

Source: Same as for Table B.1.

APPENDIX C. DESCRIPTION OF THE GLACIAL DEPOSITS AT PALOS PARK SITE A AND PLOT M

Table C.1. Lithologic Data for Soil Borings and Bedrock Wells

Description	Interval (ft)
Soil Boring SB 1, Elevation 702.2	
Topsoil, silty clay, black; contains organic material	0-0.5
Clay, slightly silty; with small stones	0.5-15.5
Sand, clayey, oxidized brown; with stones to 1 inch	15.5-16.5
Clay, silty to clayey silt, oxidized brown; with small stones	16.5-27.5
Clay, gray, moist, firm; with layers of sandstone and dolomite pebbles	27.5-40
Clay, gray, firm, saturated; with small stones and sandy partings	40-41.5
Soil Boring SB 2, Elevation 692.7	
Clay, silty, oxidized brown; with pebbles	0-26
Clay, silty to clayey silt, gray; with dolomite pebbles	26-35.5
Sand, with gravel and silty clay	35.5-36
Clay, silty, gray; with dolomite pebbles	36-40.5
Soil Boring SB 3, Elevation 693.4	
Soil, clay and silt, dark brown	0-0.5
Clay and silt, brown; with small pebbles	0.5-25
Clay and silt, gray, moist; with dolomite pebbles	25-42
Soil Boring SB 4, Elevation 682.0	
Clay and silt, brown; with numerous pebbles	0-10
Sand, fine, clayey, very wet; with small pebbles	10-11
Clay, silty, brown; with small pebbles	11-17
Sand, fine to coarse, silty, brown	17-20
Clay, silty, gray; with small dolomite pebbles; moist toward bottom	20-42
Soil Boring SB 5, Elevation 671.7	
Soil, clayey silt, dark brown to yellowish brown	0-2
Clay, silty, brown; with small pebbles	2-11.5
Clay, silty, gray; with dolomite pebbles; silty sand layer at 25.7 ft	11.5-42
Soil Boring SB 6, Elevation 704.7	
Soil, silty clay, brown; contains organic matter	0-2
Clay, silty, brown; sandy parting at 6.2 ft	2-7
Clay, silty, brown; with pebbles	7-20
Clay, slightly silty, gray; with dolomite pebbles; sandy parting at 35.3 ft	20-41.5

Table C.1. (Continued)

Description	Interval (ft)
Soil Boring SB 7, Elevation 709.8	
Clay, silty, brown; with small stones	0-7.5
Clay, silty, mottled gray; with small stones	7-9.5
Clay, silty, brown; with small stones	9-12
Sand, silty, brown	12-15
Clay, silty, brown; with small stones	15-22
Clay, silty, gray; with dolomite pebbles	22-41.5
Soil Boring SB 8, Elevation 731.0	
Clay, silty, brown, with few small pebbles; gray mottling at 4 to 5 ft; fine sand at 10 ft; 45° fracture at 16 ft; near fractures at 20 to 22 ft; 30° fracture at 26 ft, containing small crystals	0-31
Clay, silty, gray; brown at 35 to 35.5 ft; very moist from 40 to 42 ft	31-42
Bedrock Well BW 1, Elevation 743.0	
Clay, brown	0-25
Clay, brown; with dolomite pebbles	25-45
Clay, gray, calcareous	45-75
Clay, gray; with dolomite pebbles	75-170
Dolomitic bedrock, white	170-205
Dolomitic bedrock, red, gray, and white	205-215
Bedrock Well BW 2, Elevation 721.1	
Clay, brown	0-40
Clay, gray; with gravel and dolomite pebbles	40-152
Dolomitic bedrock, white, fractured	152-154
Dolomitic bedrock, white	154-201
Bedrock Well BW 3, Elevation 679.4	
Clay, brown	0-25
Clay, gray; with dolomite pebbles	25-122
Dolomitic bedrock, white; with blue clay seam at 146 ft	122-173
Bedrock Well BW 4, Elevation 674.7	
Clay, brown	0-25
Clay, gray; with dolomite pebbles	25-109
Dolomitic bedrock, white; with clay layer at 124 to 124.5 ft	109-274
Shale	274-280

Conversion factors: 1 ft = 0.3048 m; 1 inch = 2.54 cm.

APPENDIX D. DECAY SERIES FOR URANIUM (4n+2), THORIUM (4n), NEPTUNIUM (4n+1), AND ACTINIUM (4n+3)

Table D.1. Uranium (4n+2) Decay Series

Main Series	Branching Products	Classical Name	Half-Life	Comments
U-238		Uranium I	4.47×10^9 years	
↓ α				
Th-234		Uranium X_1	24.1 days	
↓ β				
Pa-234m		Uranium X_2	1.175 min	a,b
↓ β	IT → Pa-234	Uranium Z	6.7 hours	
U-234	β	Uranium II	2.44×10^5 years	
↓ α				
Th-230		Ionium	2.47×10^4 years	
↓ α				
Ra-226		Radium	1600 years	
↓ α				
Rn-222		Ra emanation (Radon)	3.82 days	
↓ α				
Po-218	β → At-218	Radium A	3.05 min	
↓ α		-	∿2 sec	c
Pb-214	α	Radium B	26.8 min	
↓ β				
Bi-214		Radium C	19.7 min	b
↓ β	α			
Po-214		Radium C'	1.64×10^{-4} sec	
↓ α	Tl-210	Radium C"	1.30 min	
Pb-210	β	Radium D	20.4 years	b
↓ β				
Bi-210	α	Radium E	5.0 days	
↓ β	Tl-206	-		
Po-210		Radium F (Polonium)	138.4 days	
↓ α	β			
Pb-206		Radium G	Stable lead	

[a]The two forms of Pa-234 are an example of nuclear isomerism which occurs in many nuclides with odd atomic number and even mass number. The isomeric transition (IT) involves no change in mass or charge; it is accompanied by x-rays and conversion electrons, but no energetic gamma radiation (see footnote b).

[b]Energetic beta decay accompanied by penetrating gamma radiation. Bi-214 and Pb-210 (radium C and D) are the principal sources of penetrating radiation emitted by radium and radon. They are removed from uranium during chemical purification, but grow back into separated radium. The gamma radiation associated with Pa-234m (UX2) accompanies the beta decay, not the isomeric transition.

[c]See footnote d, Table D.4.

Table D.2. Thorium (4n) Decay Series

Main Series	Branching Products	Classical Name	Half-Life	Comments
Th-232		Thorium	1.40×10^{10} years	
↓ α				
Ra-228		Mesothorium I	6.7 years	
↓ β				
Ac-228		Mesothorium II	6.13 hours	b
↓ β				
Th-228		Radiothorium	1.910 years	
↓ α				
Ra-224		Thorium X	3.64 days	
↓ α				
Rn-220		Th emanation (Thoron)	55.3 sec	a
↓ α				
Po-216		Thorium A	0.16 sec	
↓ α				
Pb-212		Thorium B	10.64 hours	
↓ β				
Bi-212	α → Tl-208	Thorium C	60.5 min	b
↓ β		Thorium C"	3.10 min	b
Po-212		Thorium C'	0.3 μsec	
↓ α	β →			
Pb-208		Thorium D	Stable lead	

[a]The name "thoron" is now used only to distinguish Rn-220 from Rn-219 (actinon) and the original "radon" (Rn-222). All are isotopes of element 86, the noble gas now referred to generally as radon.

[b]Beta decay accompanied by penetrating gamma radiation.

Table D.3. Neptunium (4n+1) Decay Series

Main Series	Branching Products	Half-Life	Comments
Pu-241		14.7 years	a
↓ β			
Am-241		432 years	a
↓ α			
Np-237		2.14×10^6 years	
↓ α			
Pa-233		27.0 days	b
↓ β			
U-233		1.62×10^5 years	
↓ α			
Th-229		7340 years	
↓ α			
Ra-225		14.8 days	
↓ β			
Ac-225		10.0 days	
↓ α			
Fr-221		48 min	
↓ α			
At-217		0.0323 sec	
↓ α			
Bi-213	α → Tl-209	47 min	b
↓ β		2.2 min	b
Po-213		4.2×10^{-3} sec	
↓ α	β ↙		
Pb-209		3.3 hours	
↓ β			
Bi-209		Stable bismuth	

[a] Pu-241 and Am-241 are present in reactor-produced plutonium and are members of the 4n+1 series, but the longer-lived Np-237 is regarded as the parent of the series.

[b] Beta decay accompanied by gamma radiation.

Table D.4. Actinium (4n+3) Decay Series

Main Series	Branching Products	Classical Name	Half-Life	Comments
Pu-239			2.411×10^4 years	a
↓ α				
U-235		Actinouranium	7.04×10^8 years	
↓ α				
Th-231		Uranium Y	25.52 hours	
↓ β				
Pa-231		Protoactinium	3.28×10^4 years	b
↓ α				
Ac-227	α → Fr-223	Actinium	21.77 years	
↓ β		Actinium K	22 min	c
Th-227		Radioactinium	18.72 days	
↓ α	β → Fr-223			
Ra-223		Actinium X	11.43 days	
↓ α				
Rn-219		Ac emanation (Actinon)	3.96 sec	
↓ α				
Po-215		Actinium A	1.78×10^{-3} sec	
↓ α	β → At-215	-	1×10^{-4} sec	d
Pb-211		Actinium B	36.1 min	e
↓ β	α → At-215			
Bi-211		Actinium C	2.14 min	
↓ α	β → Po-211	Actinium C'	0.53 sec	
Tl-207		Actinium C"	4.77 min	e
↓ β	α → Po-211			
Pb-207		Actinium D	Stable lead	

[a]Pu-239 is a progenitor of the actinium series, but since any primordial plutonium in nature has long since decayed, plutonium is, for practical purposes, a man-made element. The longer-lived Np-237 is regarded as the ancestor of the series.

[b]The name was originally spelled protoactinium (precursor of actinium), but the o has now been dropped, and protactinium is the accepted spelling. Other isotopes of protactinium occur in the uranium series (UX2 and UZ) and in the neptunium series.

[c]The chemical characterization (in 1939) of "actinium K" as an alkali metal (element 87) constituted the discovery of the element francium (Fr). See also footnote d.

[d]Astatine (element 85) was first produced in 1937 by alpha particle bombardment of bismuth. It is the heaviest known member of the halogen group. The discoveries of astatine and francium filled two vacant positions (numbers 85 and 87) in the heavy element section of the periodic table. Both of these elements are also members of the neptunium (4n+1) series (Table D.3).

[e]Energetic beta decay with penetrating gamma radiation.

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