PREVENTION OF GROUND-WATER QUALITY DEGRADATION DURING RECLAMATION OF A URANIFEROUS LIGNITE MINE, NORTH DAKOTA[1]

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Abstract.--About 590,000 pounds of uranium oxide were recovered from 85,000 tons of lignite in at least 16 North Dakota pits between 1955 and 1967. Because uranium salts in the overburden generally were not recovered, spoil piles at abandoned mine sites contain elevated uranium contents. Reclamation of these mines is required to eliminate public hazards due to elevated radiation and toxic-element levels.

A pilot reclamation project was implemented at one abandoned mine pit in northwestern Stark County. Basically, the reclamation involved the replacement of spoil material into the pits from which it was removed. Based on analyses of drill-hole cutting samples obtained from 2-foot depth increments on a 50-foot grid over the 7.25-acre spoil pile, spoil material with radium-226 concentrations exceeding 5 picocuries per gram above background or with uranium concentrations exceeding 5 times background was identified and mapped in three dimensions. This "most-contaminated" spoil material was selectively replaced in the mine pits above the water table to prevent dissolution of uranium salts and under a minimum of 5 feet of cover to minimize postreclamation surface-radiation levels. Similarly, areas of spoils with specific conductance greater than 5,000 microsiemens per centimeter were replaced at least 6 feet below the postreclamation ground surface to promote revegetation and above the water table to prevent enrichment of dissolved-solids concentrations in the aquifer. Finally, replaced zones of high radioactivity and soluble salts were capped with clay from the base of an adjacent pit; and the surface topography was mounded to minimize infiltration that might introduce radioactive and other soluble salts into the aquifer.

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INTRODUCTION

Between 1955 and 1967, lignite was mined at several sites in southwestern North Dakota for the uranium it contained. The uraniferous lignite, which contained from 0.001 to more than 2.1 percent uranium oxide, was strip mined and burned either in the mine pits or at nearby rotary kilns to concentrate the uranium in its ash. The ash then was shipped to processing plants in South Dakota, Colorado, and New Mexico for further enrichment. Uranium products derived from the ash were sold to the U.S. Atomic Energy Commission. Total production of uranium from the North Dakota lignites is believed to have been 592,288 pounds of U_3O_8 from 85,138 tons of lignite (U.S. Atomic Energy Commission, 1972). The North Dakota Geological Survey (Noble, 1973) estimates a comparable quantity of uranium ore remains in economically recoverable lignite in North Dakota.

Uraniferous lignite beds occur in the upper part of the Paleocene Fort Union Formation in parts of eastern Montana, northwestern South Dakota, and western North Dakota (Wyant and Beroni, 1950; Denson and Gill, 1956, 1965); however, the uranium ore has been mined only in selected areas (fig. 1). The abandoned uraniferous lignite mine sites in North Dakota are located in Billings, Stark, and Slope Counties within a north-south-trending corridor centered on the town of Belfield (fig. 2). The mine areas range in size from 10-acre single pit and spoil pile sites to 100-acre complexes comprising multiple pits and piles.

The companies that conducted the mining operations made no attempt to reclaim the mine sites during or after mining. Within mine areas, piles of ash and unprocessed ore remained as radiation hazards; and pits and spoil piles posed physical hazards. Subsequently, most of the mine pits filled with ground water. Hydrogeochemical and meteorological processes combined to spread environmental contaminants from the mine sites to surrounding areas where the potential for human exposure to these contaminants is increased. Ground water became contaminated by soluble radioactive materials and salts, affecting the quality of domestic and livestock wells for about 4 miles surrounding mine sites (Houghton and others, 1984a,b,c). Precipitation runoff drained mine lands, carrying contaminants to surrounding surface-water bodies. Wind also spread particulate contaminants from piles of ore and ash remaining in mine pits and from associated spoil piles to surrounding croplands and rangelands. Mine spoils traditionally have been tempting sources of sand for building construction. Because structures built on uraniferous mine spoils or built using spoils sand could accumulate unhealthy levels of radon gas produced by radioactive decay of residual uranium, this practice has been strongly discouraged.

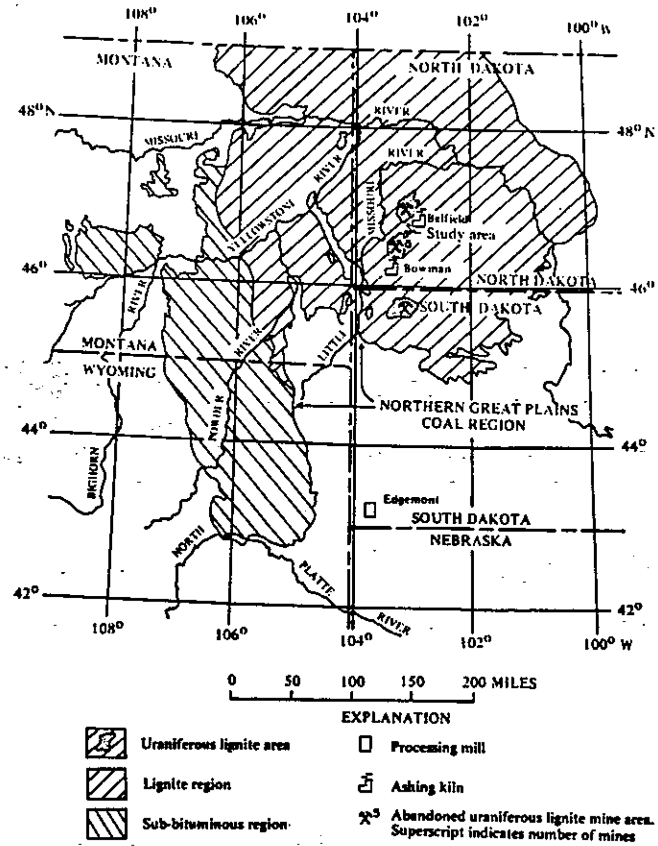

Figure 1.—Location of abandoned uraniferous lignite mines and associated uraniferous lignite deposits in Montana, North Dakota, and South Dakota.

In 1981, a reclamation project was implemented by the North Dakota Public Service Commission at an abandoned uraniferous lignite mine located in southern Billings County. This 10-acre site, referred to as the Howie site (fig. 2), contained two dry pits and three spoil piles prior to reclamation. The reclamation project replaced the spoil material back into the pits following a selective-handling plan based upon a prereclamation surface gamma-radiation survey. Although the reclamation project successfully eliminated the physical hazards and improved the aesthetic quality of the site, the radiological results of the reclamation process were disappointing. Though surface gamma-radiation levels at the site generally were reduced in the postreclamation environment, levels high enough to restrict postreclamation land use remained in parts of the project area. In retrospect, the U.S. Environmental Protection Agency suggested that the effectiveness of future uraniferous lignite mine reclamation efforts could be improved only if more detailed environmental data were available for more comprehensive site-characterization purposes.

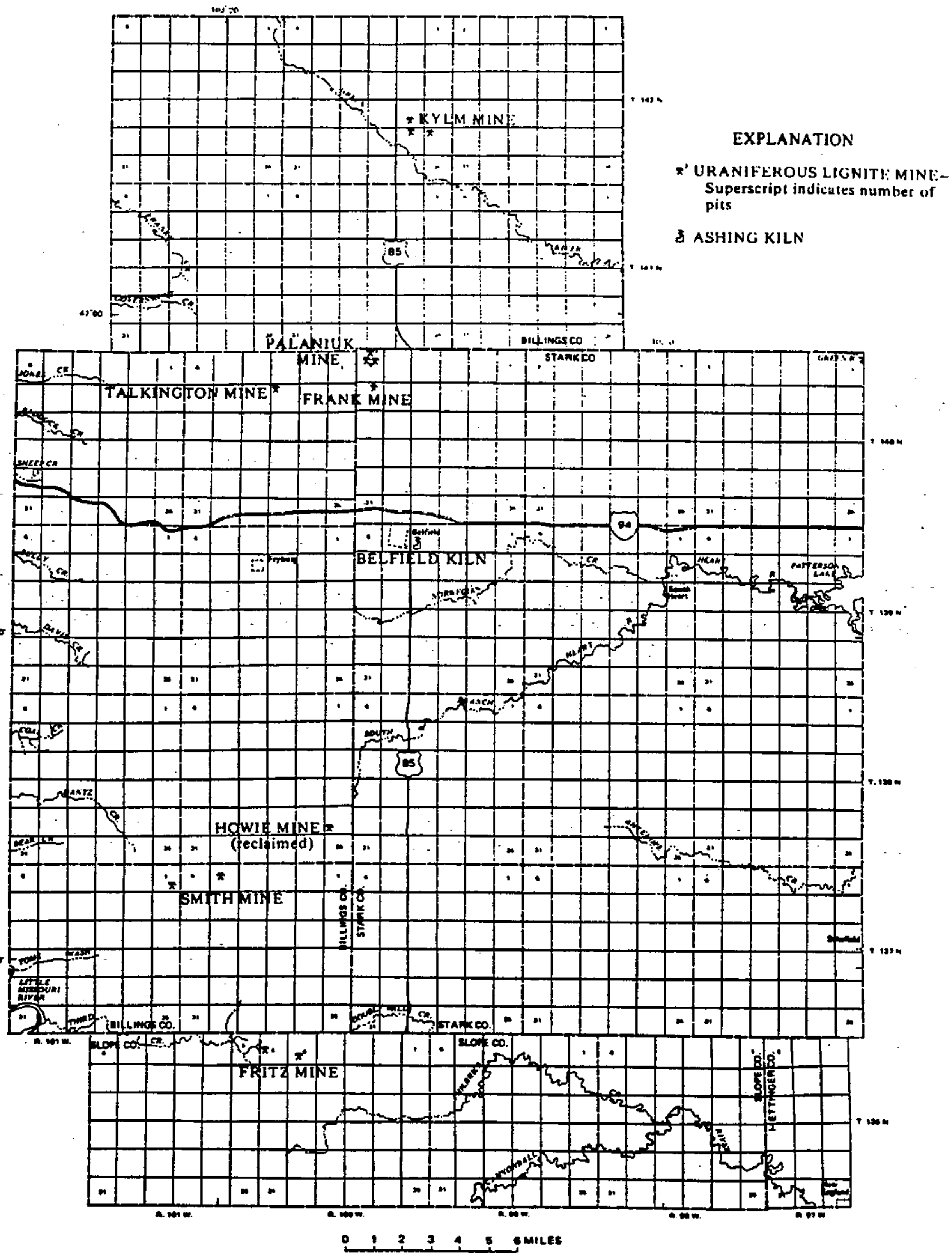

Figure 2.—Location of abandoned uraniferous lignite mines in western North Dakota.

As a prelude to additional reclamation projects, a regional assessment of all the known uraniferous lignite mine sites in North Dakota was conducted in 1982. Aerial photographs were used to develop detailed topographic maps of each site. In the fall of 1982, a joint-funding agreement was developed between the Public Service Commission and the U.S. Geological Survey to initiate hydrogeochemical assessments of each site. Assessments included chemical analysis of surface water and bottom materials, ground water, residual ash and ore, and samples of drill cuttings and cores obtained from spoils and undisturbed settings. Preliminary summaries of these assessments were reported by Houghton and others (1984a,b,c; 1987a). Under contract from the U.S. Environmental Protection Agency, EG&G Energy Measurements, Inc., also completed an aerial radiological survey of the mine sites in July 1983 (Clark, 1984). Surface gamma-ray exposure levels above soils adjacent to mine sites and uranium and radium-226 contents in these soils were determined by Lyon and others (1986).

In October 1983, representatives of the Abandoned Mine Lands (AML) Division of the North Dakota Public Service Commission, the North Dakota State Department of Health, the U.S. Geological Survey, and the U.S. Environmental Protection Agency met in Bismarck to discuss the preliminary findings of these investigations and determine an appropriate course of action to reclaim the remaining abandoned uraniferous lignite mines. To evaluate the effectiveness of the reclamation procedures suggested by participants, it was decided to implement these procedures first in a small-scale reclamation pilot project. A small, single pit-and-spoil-pile site (fig. 3) in the Palaniuk mine complex in extreme northwestern Stark County was selected to evaluate reclamation procedures because the site contained all the hydrogeochemical and radiological conditions that occurred at any of the other mines (residual ash and ore, flooded pit, contaminated spoils and adjacent soil, moderately high surface-radiation levels, and consolidated rocks scattered on the spoil pile). This report describes the design, implementation, and results of this reclamation project, referred to as the Palaniuk Pilot Project.

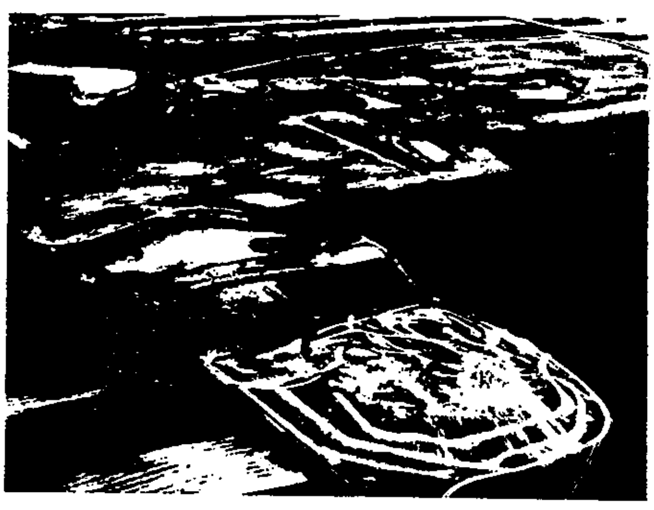

Figure 3.--Pits and spoil pile at the Palaniuk Pilot Project prior to reclamation with associated abandoned uraniferous lignite mine pits in background.

SETTING

The Palaniuk Pilot Project is situated on the gently rolling uplands of northwestern Stark County in the unglaciated Missouri Plateau section of the Great Plains physiographic province of Fenneman (1946). The project area consisted of a 5.08-acre mine pit and a 7.25-acre associated spoil pile occupying a low, north-south-trending ridge in the center of sec. 6, T. 140 N., R. 99 W. (fig. 3). Total relief in the section is about 60 feet, rising from coulees bordering the section on the east and west to a knob in the southeastern corner of the section. Maximum relief on the spoil pile was about 30 feet (fig. 4).

The pit was separated into two sections by a causeway that was constructed about halfway through the mine's operation to reduce the pit area that had to be maintained free of ground water by pumping. A maximum depth of 36 feet below land surface occurred in the west part of the pit. Situated approximately 5 miles north of Belfield, N. Dak., the flooded pit had been a popular swimming hole for area children and once had been stocked with trout. Two residences are within a half mile of the site.

Geology

The Palaniuk Pilot Project is situated on the southwest flank of the Williston structural basin. The north-south-trending synclinal basin axis is located about 20 miles east of the study area. A combined thickness of more than 14,000 feet of sediments, ranging in age from Cambrian through Quaternary, occurs in the basin. Regional dip is to the northeast toward the center of the basin at about 20 feet per mile. Sediments of the Paleocene Fort Union Formation are exposed on the surface over most of the area (Trapp and Croft, 1975; Carlson, 1983).

The uraniferous lignite beds in North Dakota occur only in the Sentinel Butte and Tongue River Members of the Paleocene Fort Union Formation. The uranium content of these lignite beds is believed to have originated in volcanic ash ejected from the Absaroka volcanic field of western Wyoming and deposited in the Miocene

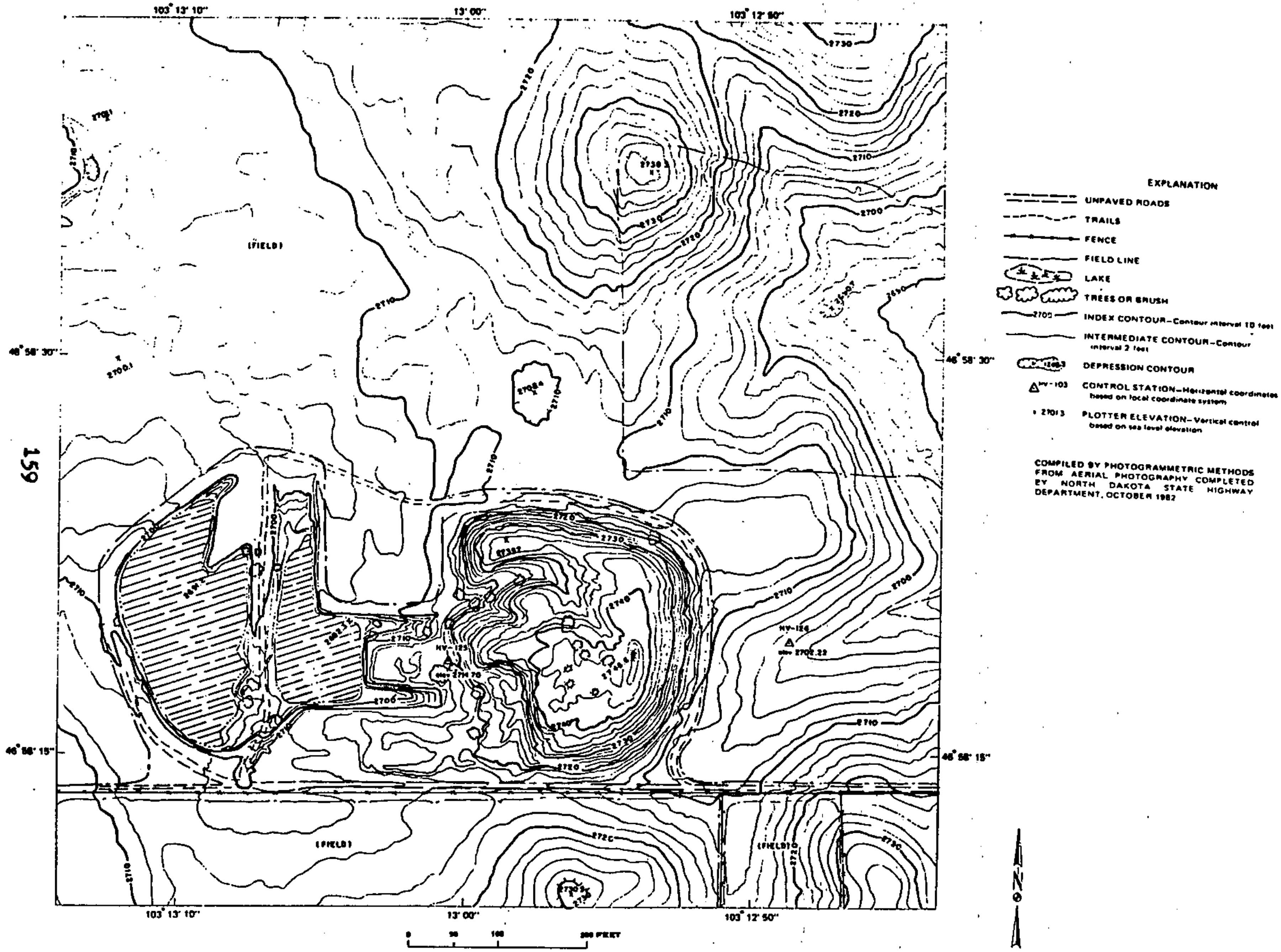

Figure 4.—Prereclamation topography at the Palaniuk Pilot Project.

Arikaree Formation within the Williston basin (Denson and Gill, 1956, 1965; Bergstrom, 1956; Denson and others, 1959). Absaroka volcanic ash was enriched greatly in uranium and heavy metals (Denson and Gill, 1965). Infiltrating precipitation leached uranium from the ash as the water moved toward the water table (Denson and Gill, 1956; Haines, 1958). Reprecipitation of the uranium occurred at the first organic-rich zone encountered by reduction to the uranyl ion and formation of uranyl humate complexes (Breger and Deul, 1955). Because of the localized effects of Oligocene erosion, the uraniferous lignite beds generally occupy discontinuous stratigraphic positions in the Fort Union Formation.

In the vicinity of the Palaniuk Pilot Project, the uraniferous lignite bed occurs in the upper part of the Sentinel Butte Member. It underlies approximately 6 square miles of the north-south-trending ridge at an average elevation of 2,690 feet above mean sea level. At the Pilot Project, the lignite bed is overlain by approximately 16 feet of silty sandstone and sandstone (fig. 5). A fine- to very fine grained channel sandstone with a silt-and-clay content ranging from 6 to 8 weight percent immediately overlies the lignite bed. The lignite bed varies from 1-4 feet thick, thinning toward the eastern and western margins of the ridge. At depths less than 15 feet, the lignite has been oxidized to leonardite. At its margins, the bed grades into a carbonaceous shale. The lignite is underlain by clay and silty claystone totaling more than 40 feet thick.

Soils developed on the Sentinel Butte Member in the Palaniuk Pilot Project area generally are thin well-drained moderately sandy members of the Vebar soils series (Larson and others, 1968). Organic contents are low, but salt contents can be relatively high, especially on margins of topographic depressions. Soil thicknesses vary from 0 to about 2 feet in thickness.

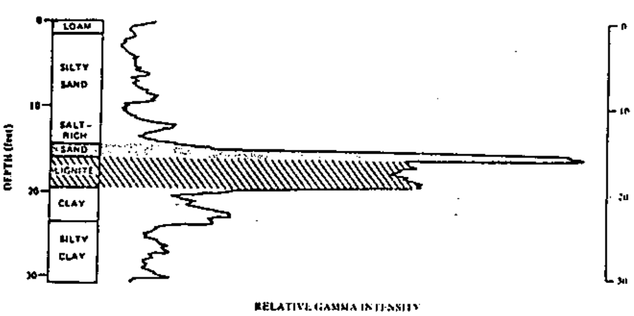

Figure 5.--Lithologic section and gamma log at the Palaniuk Pilot Project.

Hydrology

Precipitation falling on the project area drains predominantly east or west from the ridge crest to coulees that channel water south to the Heart River. However, some local precipitation runoff drains into mine pits. Flows in the coulees peak at 20 cubic feet per second during spring snowmelt and approach zero by midsummer.

Mean annual precipitation at Belfield is 15.50 inches, and mean annual snowfall is about 31 inches (U.S. Environmental Data Service, 1973). Most precipitation falls between April and June in thunderstorms. Because average annual lake evaporation (37 inches) significantly exceeds precipitation (Kohler and others, 1959), most precipitation is lost to evapotranspiration. Runoff and infiltration events are restricted to snowmelt periods and exceptional thunderstorm events.

The only shallow ground water in the area occurs in the uraniferous lignite bed and immediately overlying sandstone. The lignite-sandstone aquifer is recharged by local precipitation and discharges by evapotranspiration, seepage to coulees along its margins, and leakage through the basal claystone to the regional Sentinel Butte sandstone aquifer. The saturated thickness of the aquifer averages 6 feet. Flow in the aquifer generally is from south to north-northwest, but local flow systems develop around dominating recharge-discharge sites like the mine pits.

Most recharge is depression-focused and occurs during spring snowmelt. Snowmelt runoff accumulates in depressions until the underlying soil thaws and permits the water to infiltrate. Double-ring infiltrometer experiments in the project area suggest that infiltration rates of approximately 12 feet per second occur in the undisturbed areas, and rates of more than 24 feet per second occur through mine spoils.

Most discharge occurs by evapotranspiration. Seepage measurements along the coulees suggest ground-water seepage in the range of 1-2 cubic feet per second supports base flow. In the project area, the thickness of the basal claystone effectively minimizes leakage to underlying aquifers. Approximately 150 feet of dry sandstone separates the claystone from the regional Sentinel Butte aquifer of Trapp and Croft (1975). Mine pits interact with the ground-water system in dual fashion. During the snowmelt period, the pits receive runoff and recharge the lignite aquifer. During the remainder of the year, ground water seeping from the aquifer into the pits is lost by evapotranspiration.

An aquifer test conducted about one-quarter mile north of the project site indicated a hydraulic conductivity of 8-96 feet per day

(Houghton and others, 1987a), compared to a hydraulic conductivity of 94-1,200 feet per day reported for lignite aquifers in the Sentinel Butte Member of Billings, Golden Valley, and Slope Counties (Anna, 1981). Because of the effects of fractures on flow in the lignite aquifer, the results of aquifer tests can be deceptive. A large-scale slug test was simulated during reclamation of the pilot project when water in the project pit was pumped into an adjacent mine pit. Return of water levels in the mine pit to prepumping levels suggests an average hydraulic conductivity in the aquifer adjacent to the pit of 26 feet per day. Hydraulic conductivity of the sandstone part of the aquifer is estimated at 3-6 feet per day based on particle-size data using the method of Johnson (1963), compared with the hydraulic conductivity of 0.4 foot per day for area sandstones reported by Anna (1981). Yields reported for domestic wells in the area range from 5-50 gallons per minute. Chloride- and radiation-tracer experiments suggest effective solute transport rates of 1.2-3.5 feet per day (Houghton and others, 1987a).

Hydrochemistry

Numerous investigators have demonstrated that the quality of shallow ground water in the northern Great Plains is governed predominantly by the dissolution and precipitation of gypsum and carbonate minerals, ion exchange, and reduction-oxidation reactions (Moran and others, 1978; Houghton, 1982; Groenewold and others, 1983; Houghton and others, 1987b). Houghton and others (1984c) indicated that dissolution reactions at the uraniferous lignite mines involved a much larger range of efflorescent salts, with uranium concentrations controlled by the dissolution of uranyl sulfate septahydrate.

The quality of surface water in the region varies widely. During spring snowmelt, dissolved-solids concentrations in the coulees range from 120-640 mg/L; and the water is suitable for any use. During early summer, the quality of water in the coulees resembles that of ground water in the lignite aquifer. However, by early fall, evapotranspiration has increased the concentration of dissolved solids to 5,000-7,000 mg/L.

Houghton and others (1984c) demonstrated that trace-element concentrations in the coulees during base flow are enriched within 4 miles of mine sites. Uranium concentrations in base flow within mine areas commonly exceed 200 µg/L, approximately 10 times regional background concentrations. Stream sediments also were found to be enriched in uranium in the vicinity of mines.

Water in the lignite aquifer is dominantly of sodium sulfate-bicarbonate type, with dissolved-solids concentrations ranging from 260 to 2,250 mg/L at the Palaniuk Pilot Project site. The ground water generally is slightly undersaturated with respect to calcite and gypsum but saturated with respect to jarosite and uranyl sulfate septahydrate. Uranium concentrations in the lignite-sandstone aquifer range from less than 0.02 to 756 µg/L and correlate most closely with concentrations of hydroxybenzene. Although the United States has not yet adopted drinking-water standards for uranium, numerous investigators have recommended a maximum concentration of 15 µg/L. The potential health risks of drinking water containing more uranium than that concentration have been discussed in detail by Cothern and others (1983). Houghton and others (1984c) demonstrated that concentrations of uranium in ground water near mine sites averaged more than 10 times greater than concentrations in ground water more than 4 miles from the mine sites. Although radium-226 concentrations in the aquifer commonly exceed the 5 pCi/L drinking-water standard of the U.S. Environmental Protection Agency (1986), especially near mine sites, three domestic supply wells are screened in the lignite aquifer within 1 mile of the project site. Two livestock wells also occur in the area. Until 1985, an irrigation permit existed for water in the mine pits; however, the water was never used for this purpose, and the sodic hazard of the water is extreme.

The quality of water in mine pits closely resembles that in the aquifer. However, evapotranspiration produces dissolved-solids concentrations up to double those in the aquifer by late fall. No water-quality differences were observed between the quality of pit water on opposite sides of the Palaniuk Pilot Project causeway. Uranium concentrations in the pit water have been as great as 270 µg/L, and radium-226 concentrations have been as great as 5.2 pCi/L. The uranium of native mussels and of the livers of turtles living in the pit ranged from 92 to 403 µg/g, indicating a 4- to 7-fold increase relative to pit water. The environmental significance of these enrichments is unknown.

Geochemistry

The distribution, speciation, and mobility of uranium and associated trace elements at the uranium sites were discussed in detail by Houghton and others (1984c). Uranium contents in the lignite are proportional to humic content. At the Palaniuk Pilot Project, uranium contents in the lignite bed range from 0.01 to 0.9 percent U_3O_8. The uranium content in the lignite bed decreases abruptly from top to bottom (fig. 5). Additionally, where the lignite has been oxidized, some of the uranium has been remobilized from the lignite and occurs as uranyl sulfate septahydrate in association with sodium jarosite in the sandstone immediately overlying the lignite. Radium occurs dominantly in secondary barite.

The association of uranium with sulfate salts in the overburden was not recognized during mining, so the spoil piles continue to contain an appreciable content of uranium. Because salts were originally situated immediately overlying the lignite, the stripping process generally emplaced them near the surface of the spoil pile. Although highly soluble, these salts continue to be reconcentrated at the spoil surface by evaporation and capillary action. Accordingly, those salts buried at depth in the spoil also have tended to migrate toward the spoil surface or, during exceptional infiltration events, to migrate downward and be concentrated in organic-rich soils underlying the spoil pile.

One result of the strip-mining process at the uraniferous lignite mines in North Dakota was the excavation of highly radioactive spoil material immediately overlying the lignite seam and the distribution of this contaminated spoil over the upper surface of the spoil pile as well as around the pit and pile on haul roads and ramps. Subsequent erosional processes have worked to spread this contaminated spoil to areas immediately adjacent to the spoil piles and pits. As a result, a peripheral band of contaminated soil about 50 feet wide is present around the disturbed mine areas (Lyon and others, 1986). The radiological contamination generally is restricted to the upper 6 inches of the soil zone except in areas that have been tilled where the contamination is more evenly distributed throughout the tilled soil zone.

Content of uranium in ash resulting from combustion of the uraniferous lignite in pit bottoms generally was 10 times greater than the content of the original lignite (Houghton and others, 1984c). Ash recovered from the bottom of the western pit of the Palaniuk Pilot Project had a uranium content of 1-4 percent. The lesser degree of uranium enrichment in this ash compared to the average at other sites may reflect removal of soluble uranium fractions since the ash was submerged beneath pit waters for more than 20 years.

Uranium and radium-226 contents in surface soils within 50 feet of the mine spoils were enriched relative to soils beyond this distance by approximately 3 to 4 times. This enrichment was attributed by Lyon and others (1986) to deposition of windblown spoils on the soil surface. In the vicinity of the spoil pile at the Palaniuk Pilot Project, this enrichment was slightly less than the regional mean, probably because the Palaniuk Pilot Project site is the only mine site at which land within 50 feet of the spoil pile is plowed and cropped. To estimate the availability of uranium and radium-226 to vegetation grown on the spoils or on adjacent enriched soils, samples of spoils from the project area and from adjacent soil were leached following the procedure of Soltanpour and Workman (1980). Uranium and radium were found to behave similarly in these extractions, suggesting an average partition coefficient of 82 between plants and soil. Analysis of western wheatgrass growing on the spoil pile indicated a partition coefficient of 77, reasonably close to the predicted value. Based on this partitioning, uranium contents would not be expected to achieve hazardous levels in vegetation or the muscles of grazing animals.

Radon, specifically radon-222, is one of the daughter products of the radioactive decay of uranium. Radon emanates from the uraniferous lignite bed throughout the project area. Background surface-radon concentrations were determined to average 1.2 pCi/L using alpha-track detectors. Surface concentrations over the unreclaimed spoils averaged 16.8 pCi/L; however, radon concentrations in spoils ranged from 3,100 to 6,800 pCi/L. If trapped within a structure built over land with such emanations, radon concentrations could pose a significant health hazard as detailed by Cothern and Lappenbusch (1984) and Thomas and others (1985).

RECLAMATION ACTIVITIES

Because reclamation activities at the Palaniuk Pilot Project involved exposure to radioactive materials, radiological protection measures were instituted for all personnel working at the project site. All personnel were given complete health physicals at the beginning and end of each reclamation season. Personnel were required to wear personnel monitoring devices and half-face air-purifying respirators at all times. Additionally, a water truck was continually operated to suppress airborne dust. All personnel also wore thermoluminescent dosimeters to measure their radiation exposure.

Showers were constructed on site, and all personnel were required to shower before leaving the site each day. Disposable coveralls were distributed to all construction workers. Once used, the coveralls were disposed of in a 55-gallon drum and buried at the site with contaminated soils.

During the 1985 reclamation season, all personnel monitoring devices recorded radiation exposures less than the minimum detectable level (10 millirems). However, during the 1986 reclamation season, two monitors recorded exposures above the minimum detectable level. These monitors recorded levels of 12 and 28 millirems during the quarter. By comparison, the maximum permissible dose per quarter is 1,250 millirems. Accordingly, health measures undertaken during the reclamation project appear to have been successful in limiting undue exposure to radiation.

Reclamation Objectives

The primary objectives of any mine-reclamation project are to eliminate the physical hazards to humans at a mine site and return the land surface as nearly as possible to its premining condition. Because of the occurrence of elevated radiation levels and the presence of ground water in pits at the site of the Palaniuk Pilot Project, additional objectives included reduction of surface-radiation levels, minimizing postreclamation contamination of soil with radioactive materials, and protection of ground water from reclamation-induced degradation. Because the U.S. Environmental Protection Agency has not yet established standards for uranium-mine cleanup, it also was hoped that this project could contribute toward the development of these reclamation guidelines. To this end, the Palaniuk Pilot Project was planned, conducted, thoroughly documented, and evaluated such that the procedures used and data obtained would be useful toward the development of widely applicable guidelines for reclamation of uranium mines.

Reclamation Plan

The basic plan for reclamation of the Palaniuk Pilot Project consisted of replacement of spoil material into the pits from which it was removed. To control postreclamation radiation levels, the spoils would have to be replaced selectively in the pit to provide maximum burial for the most highly radioactive material. Reclamation also would have to include contaminated soil material surrounding the mine.

Because the mine pits at the Palaniuk Pilot Project were flooded, replacement of spoils containing soluble radioactive materials and associated salts had the potential for causing serious reclamation-induced ground-water contamination. Emplacement of materials containing appreciable salts near the post-reclamation land surface also could preclude adequate revegetation.

In an effort to prevent such contamination, a reclamation plan was developed jointly by representatives of the North Dakota Public Service Commission, North Dakota State Department of Health, U.S. Environmental Protection Agency, and U.S. Geological Survey. Detailed geochemical and radiometric characterization of the spoil pile and adjacent soil was to be used to segregate spoil volumes requiring different degrees of special handling.

Geochemical and Radiometric Characterizations

In May 1985, a 100-foot square grid was estabished at the Palaniuk Pilot Project for purposes of geographic control. Perpendicular base lines were surveyed north and west of the mine area with stations placed 100 feet apart and marked with survey hubs. Grid stations were surveyed with a transit and flagged. When the 100-foot grid was completed, a 50-foot square grid was placed on the spoil pile using measuring tapes between 100-foot grid stations. This horizontal control grid was used throughout the project to locate stations for radiation surveys, soil sampling, drilling, and excavation and placement of spoil material.

To supplement the aerial radiological survey of the project site (Clark, 1984), the North Dakota State Department of Health and the U.S. Environmental Protection Agency conducted ground-level radiometric surveys of soil surrounding the mine site. Surveys included:

1. Scintillometer measurements at 3 feet above ground level, at ground level (open shield), and at ground level (closed shield);
2. Pressurized ion chamber measurements at 3 feet above the ground;
3. Analysis of soil samples for uranium and radium-226 contents at points of scintillometer measurements; and
4. Measurements of radon-222 emanation using charcoal canisters.

Lyon and others (1986) reported the mean radiation levels at ground level of 17 μR/hr corresponded to radium-226 contents of 4.7 pCi/g in surface soils. Because surface soils distant from the mine site average 3.2 pCi/g and range to approximately 10 pCi/g, surface soils adjacent to project spoils were only slightly contaminated by windblown spoil material. However, because the soils adjacent to the spoil pile at the Palaniuk Pilot Project were tilled as cropland, contamination extended more than 10 inches deep.

The U.S. Geological Survey supervised geochemical characterization of the spoil pile. The pile was drilled on 50-foot centers using air-rotary methods. Gamma-ray geophysical logging of drill holes provided preliminary radiological characterization of the spoil pile. Drill cuttings were collected in 2-foot increments from the surface to the base of the spoil pile. Cutting samples were analyzed by neutron-activation analysis for total uranium and radium-226 content. Because uranium and radium were the principal radiation sources at the Palaniuk Pilot Project, these analyses provided detailed confirmation of the radiation potential of the spoil material. Additionally, saturated-paste extracts of each sample were analyzed for paste pH and specific conductance using the method of Sandoval and Power (1977) and for soluble uranium and radium-226 as described by Thatcher and Janzer (1977). These extracts defined the potential of the radiochemicals for remobilization by percolating ground water.

For the purposes of characterizing the spoil pile, it was decided to separate the spoil material into three categories based on its handling requirements. These categories were delineated as follows:

A) Material Subject to Special Handling: to be replaced in the pit above the water table to prevent dissolution of soluble radioactive material and salts, replaced at least 5 feet below reclaimed land surface so that surface radiation would be minimized and salt content would not inhibit revegetation, and capped with at least 3 feet of clay to inhibit ground-water percolation through the material;

B) Material Subject to Selected Handling: to be replaced above the water table to prevent dissolution of soluble radioactive material and salts and at least 3 feet below land surface to minimize surface-radiation levels; and

C) Material Subject to no Special Handling: to be placed in any location in pit to be reclaimed.

Category "A" material was defined as spoil material containing uranium contents in excess of 25 µg/g, radium-226 contents greater than 20 pCi/g, or specific conductance greater than 5,000 µS/cm at 25°C. The uranium and radium-226 contents selected to characterize Category "A" material represent contents exceeding maximum background contents by approximately 10 µg/g and 10 pCi/g, respectively.

Category "B" material was defined as spoil material containing uranium contents greater than 10 µg/g, radium-226 contents greater than 10 pCi/g, or specific conductance greater than 2,250 µS/cm at 25°C. The uranium and radium-226 contents selected to characterize Category "B" material represent contents exceeding mean background contents by approximately 5 µg/g and 5 pCi/g, respectively. Although no standards currently exist for cleanup of uranium mines, standards for remedial action at inactive uranium processing sites currently require postreclamation radium-226 contents not exceed 5 pCi/g above background content (U.S. Environmental Protection Agency, 1983). The 2,250 µS/cm specific conductance corresponds to the maximum specific conductance that had been observed in the ground water underlying the project area.

To assist project engineers in identifying horizons of each category during field construction activities, panel diagrams were prepared for each of the constituents used to characterize the spoil material, such as the panel diagram for uranium content presented in figure 6. Subsequently, a composite panel diagram identifying the distribution of material in each category was prepared (fig. 7) along with a plan for emplacement of the material in the mine pit (fig. 8). These panel diagrams were maintained in the field office of the construction supervisor throughout reclamation activities.

Reclamation Construction

In addition to identifying and selectively handling spoil material in each category as it was replaced in the mine pit, construction teams had to address a variety of other concerns, including: topsoil salvage; removal of pit water; handling of ash and ore remaining on the pit bottom; disposal of rocks from the spoil pile; identifying and handling unexpected pockets of category "A" material; locating, excavating, and emplacing clay as a cap for category "A" spoil; and recontouring and revegetating the postreclamation project surface.

Topsoil Salvage

To permit revegetation of the project site, sufficient topsoil had to be available for surface spreading. Results of radiation surveys and soil analysis were used to determine which topsoil was sufficiently uncontaminated (containing less than 10 pCi/g radium-226) that it could be returned to land surface. Uncontaminated topsoil was salvaged within and immediately adjacent to the area to be reclaimed. Within approximately 50 feet immediately adjacent to the spoil pile, the topsoil was determined to be contaminated and unsalvageable. Beyond this contaminated zone the topsoil was salvageable and therefore was stripped with scrapers and stockpiled for future use. In this manner, approximately 7,500 cubic yards of topsoil were determined to be available for respreading after reclamation.

During excavation of the spoil pile, the premine soil horizon was uncovered. Radiometric readings indicated elevated levels of radiation in the upper surface of this horizon. Excavation of the contaminated material progressed at 2-inch intervals until the radiometric reading reached background levels. Contaminated soil was treated as category "B" material.

Pit Water

Both pits of the Palaniuk Pilot Project contained significant amounts of water. This water was primarily ground water that had filled the pits to the level representing the

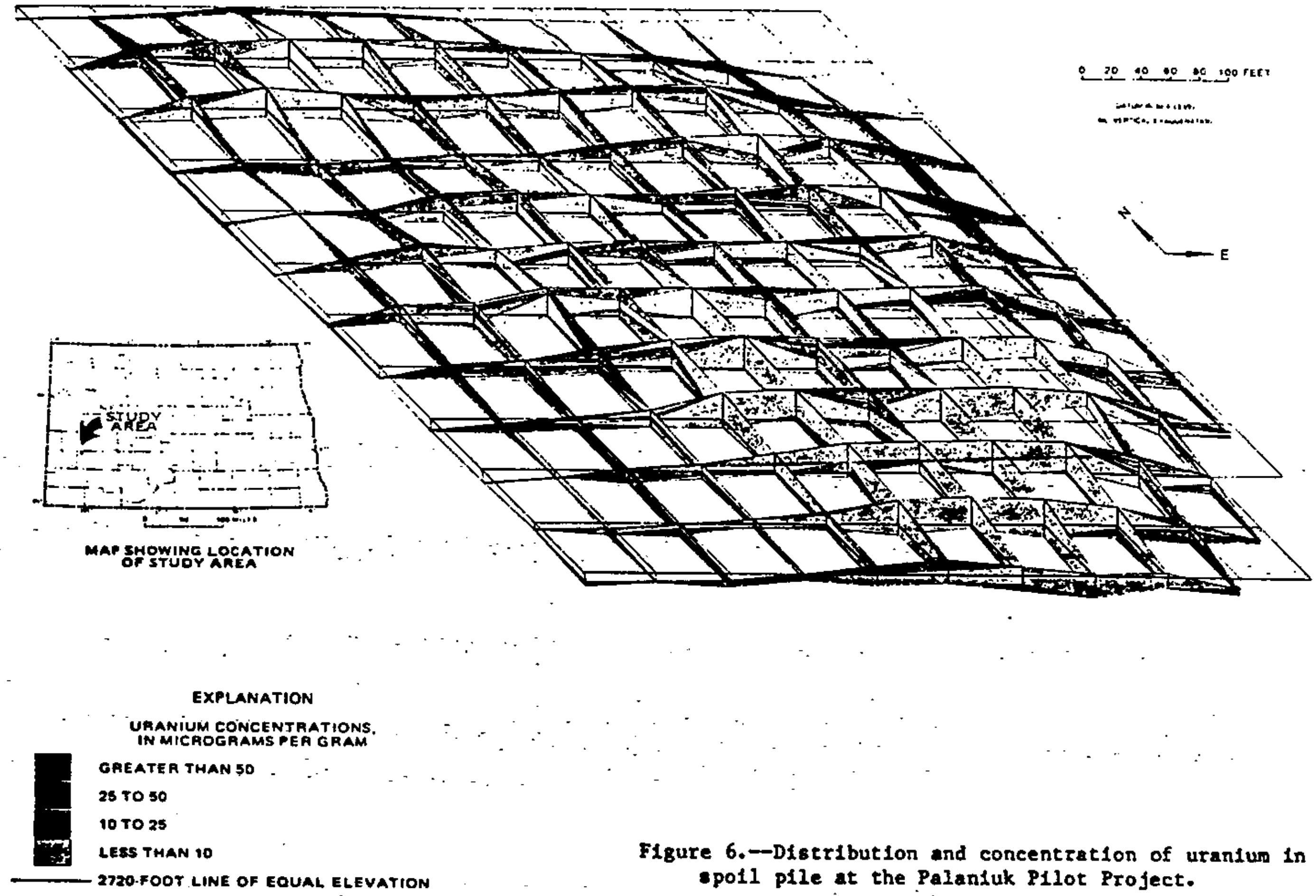

Figure 6.--Distribution and concentration of uranium in spoil pile at the Palaniuk Pilot Project.

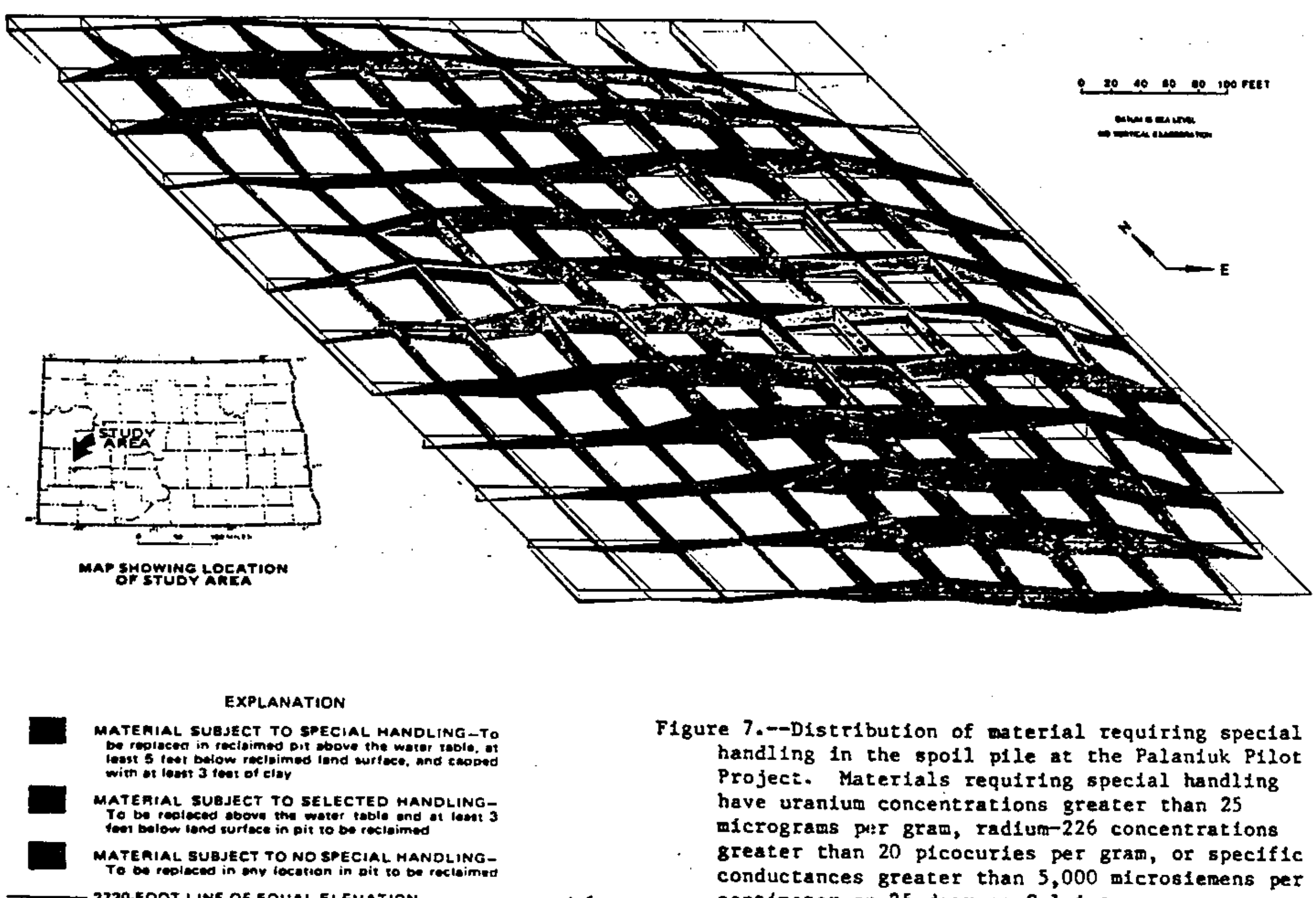

Figure 7.--Distribution of material requiring special handling in the spoil pile at the Palaniuk Pilot Project. Materials requiring special handling have uranium concentrations greater than 25 micrograms per gram, radium-226 concentrations greater than 20 picocuries per gram, or specific conductances greater than 5,000 microsiemens per centimeter at 25 degrees Celsius.

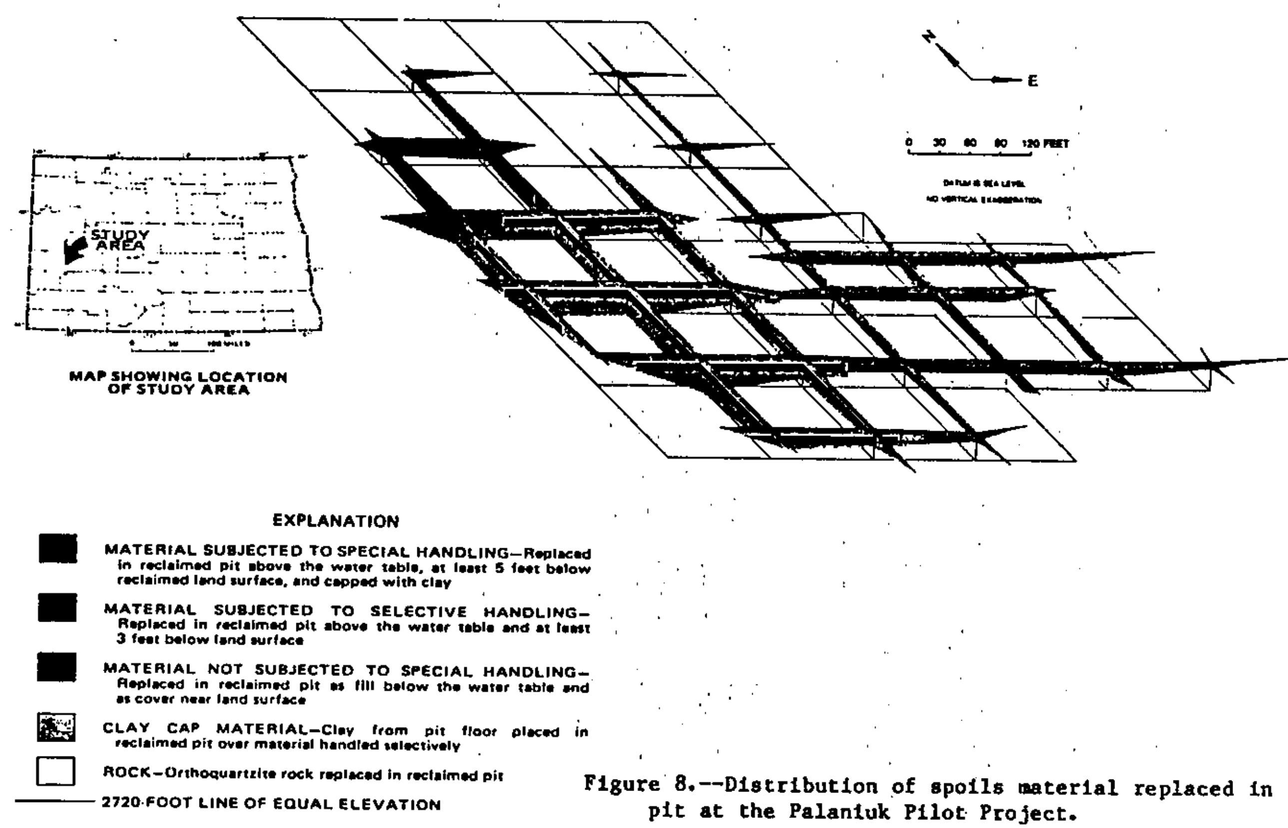

Figure 8.--Distribution of spoils material replaced in the pit at the Palaniuk Pilot Project.

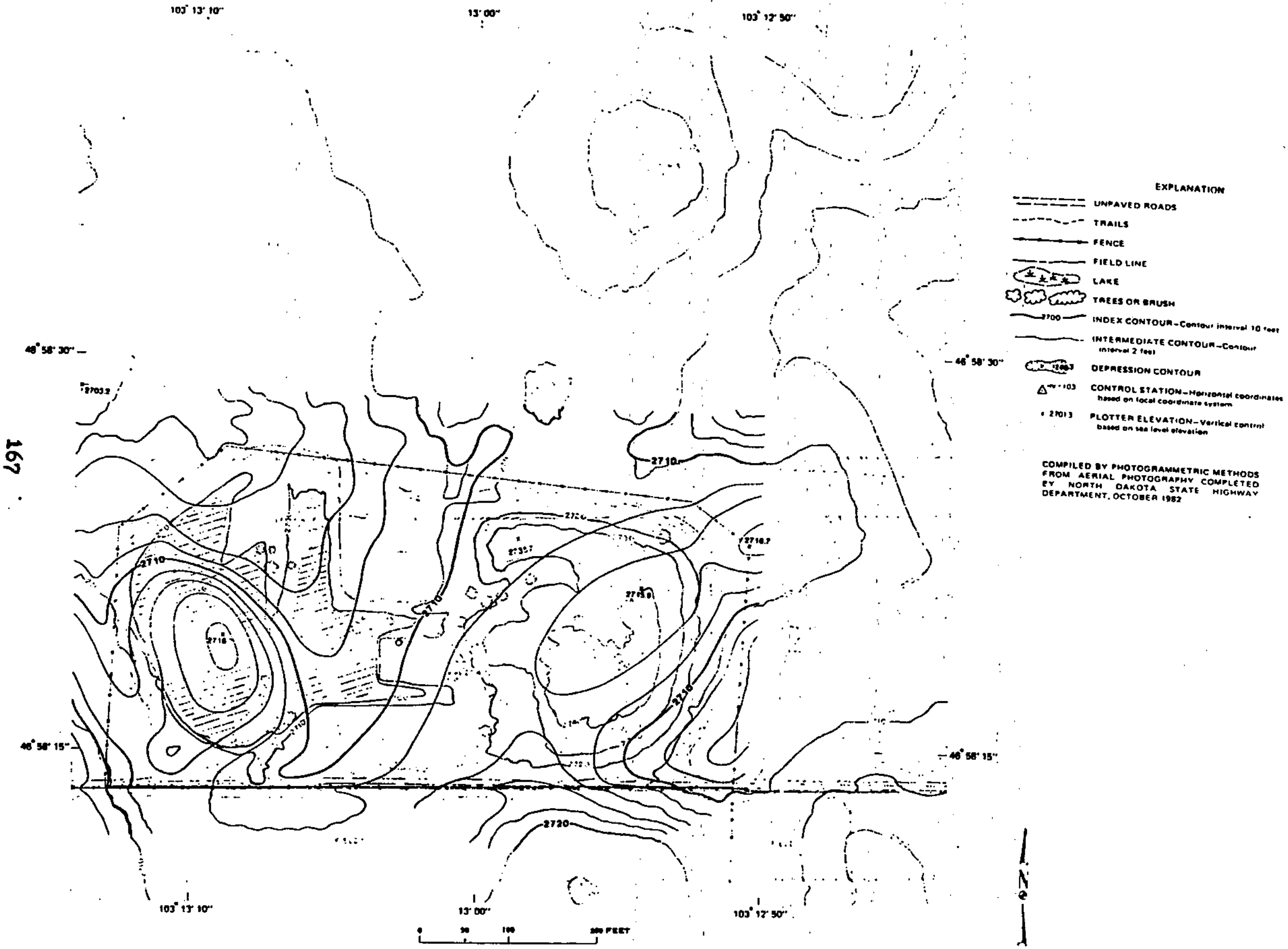

Figure 9.—Postreclamation topography at the Palaniuk Pilot Project.

potentiometric surface of the lignite-sandstone aquifer. To attain the project objective of preventing ground-water contamination caused by placing contaminated spoil material beneath the postreclamation water table, it was necessary to construct a pad with uncontaminated material to an elevation 3 feet higher than the highest recorded potentiometric surface (approximately 2,695 feet above mean sea level).

Construction of the pad required draining a large portion of the water from the pits. Two 500-gallon-per-minute pumps and approximately 2,500 feet of 6-inch irrigation pipe were installed to transfer the pit water to another water-filled pit to the west of the Pilot Project. This nearby mine pit allowed for convenient disposal of the pit water without treatment. Careful monitoring of the pipeline for leaks prevented contamination of the intervening agricultural lands.

Residual Ash and Ore

Near the end of the dewatering process, a dark reddish-purple material was found to partly cover the bottom of the west pit. The material was arranged in mounds approximately 3 feet high, resembling windrows used for pit-bottom concentration of uranium in lignite ash. Analysis of the material indicated it qualified as category "B" material; however, because the material apparently consisted of ore and ash, it was decided that this material should be excavated as completely as possible and disposed of as category "A" material.

A platform was constructed near the southern edge of the west pit using category "C" material to an elevation of approximately 2,698 feet above sea level. A 1.5-cubic-yard dragline then was used to excavate the residual ash and ore from the pit bottom and place it on the platform. When the dragline could no longer easily reach remaining parts of the pit bottom, it would retreat and allow scrapers and bulldozers to advance the platform onto the recently cleaned section of the pit floor. This process was repeated until the pit bottom was completely clean of the residual ash and ore.

Construction of the Platform in the West Pit

Platform construction was initiated using category "C" material from the southernmost part of the spoil pile. This material was hauled along a clean haul road to the south end of the west pit. Platform construction began in the southernmost tip of the pit and progressed northward along the highwall. Before placing contaminated material on the pad, surface elevations were checked to ensure proper position above the ground-water table. To verify the quality of pad construction material, scintillometer surveys were performed at the excavation site and on the pad surface throughout the construction process.

Approximately 50 percent of the category "C" material in the southernmost part of the pile was retained for final cover above the clay cap. To expose sufficient category "C" material to complete construction of the platform from elsewhere in the spoil pile, some category "B" material had to be excavated. To avoid cross contamination, material of different categories were never hauled simultaneously. After handling category "B" material and prior to hauling category "C" material, scrapers and other equipment were cleaned and checked with scintillometers to avoid transporting contamination to an uncontaminated area of the project. To avoid double handling of the category "B" material, a section of platform always was completed to provide a disposal site before any category "B" material was handled. Throughout this sequence of hauling category "B" material, category "C" material, and category "B" material again, the integrity of the uncontaminated haul road always was maintained.

Category "A" Material in Spoil Pile

The majority of the most highly radioactive and saline spoil material (category "A") was located at the north, east, and west margins of the pile (fig. 7). Small, isolated lenses of category "A" material occurred elsewhere in the pit. Generally, these lenses were thin (less than 6 feet thick) and at or very near the surface. These materials were individually excavated and hauled to the category "A" disposal area. Continuous radiation monitoring using scintillometers assured that all category "A" material was identified and properly disposed. Areas were not considered clean until scintillometer readings indicated background levels (30 μR/hr). Removal of material classified as category "A" on the basis of specific conductance as opposed to its content of radioactive elements was not confirmed independently in the field.

When excavation approached an indicated interface between materials of different category designation, scintillometer surveys were used to adjust the boundaries material associated with each category following each scraper pass. Commonly, only 2 inches of material were excavated per pass to avoid overexcavation. Although this type of equipment operation is not highly productive, it proved very effective in isolating material attributed to each category and in establishing final grade beneath the spoil pile.

Rocks

Hundreds of large orthoquartzite rocks were left at the ground surface by mining operations at the project site. Most rocks were located between the two ramps leading from the east pit, in the area directly south of the east pit, and covering the southwestern part of the spoil pile. Radiation levels and chemical analyses indicated the rocks could be treated as category "C" material. Accordingly, most of the rocks were disposed of in the bottom of the east pit.

Rocks south of the east pit and between the ramps leading from the east pit were bulldozed into the east pit. During the bulldozing operation, care was taken to roll rather than push the rocks. This manner of moving the rocks avoided dragging any potentially contaminated soil material into the east pit.

Rocks located on the spoil pile were picked up by front-end loaders and transported either to the east pit or, if it was situated in category "A" spoils, to the platform constructed in the west pit for category "A" material. Prior to transporting a rock off the spoil pile, it was determined whether it was within a zone containing "Special Handling" material. To avoid carrying contaminated spoil along with the rocks during excavation and disposal, a rock bucket was used on the front-end loader. The loader made every attempt to loosen any unconsolidated material from the rocks prior to transportation and disposal.

East Pit

Platform construction in the east pit followed excavation of the majority of the category "A" material. Accordingly, the pit was filled using scrapers and bulldozers hauling category "C" material. Platform construction progressed from south to north. However, a veneer of category "A" material was discovered on the northernmost ramp of the east pit. This material was excavated using scrapers until the scintillometer readings indicated background radiation levels and disposed of in the west pit.

After the platform in the east pit was completed, it was believed that all category "A" material had been disposed of. However, scintillometer surveys of the remaining spoil-pile material indicated small zones of category "A" material remained. Excavation of these small zones was accomplished one load at a time. Following each scraper load, the area was checked with a scintillometer to delineate remaining contaminated material. Although not totally unexpected, the presence of these small zones of contamination and the increased quantity of contaminated material required slight expansion of the disposal area for category "A" material in the west pit.

Clay Cap

The clay cap was designed to minimize contact between downward percolating ground water and category "A" material. Such contact could result in dissolution of radioactive constituents and associated salts and contamination of the underlying ground water.

Clay for the cap was obtained from another uraniferous lignite mine pit located approximately one-half mile south of the Palaniuk Pilot Project site. After remaining lignite, ash, and other debris had been scraped off the dry pit bottom, the underlying clay was ripped with bulldozers and excavated with scrapers. The scrapers hauled the clay to the project site along a specially constructed, uncontaminated haul road. Initially, the clay was bulldozed over the contaminated material to prevent contamination of the scraper tires and off-site transport of contaminated material. After approximately 1 foot of clay had been placed over the entire mound, the scrapers could safely deposit their loads directly on the clay cap. The clay cap was constructed to a thickness of at least 3 feet over the body of category "A" material and feathered out around the edges.

Final Cover

Clean material for final cover was excavated from the remaining southeastern part of the spoil pile and spread over the backfilled pit areas to a depth of at least 3 feet. This cover was established to provide a final radiation barrier and to prevent degradation of the clay cap due to frost, deep-rooting plants, and burrowing animals. Rocks encountered were handpicked, checked with a scintillometer, and disposed of in a nearby mine pit.

After all excavation and material transport was completed, surface elevations were established to provide positive drainage for the entire area. A well-defined hill was established over the site of the clay cap to encourage further surface runoff instead of infiltration. The surface then was bladed smooth and rocks again were picked and disposed of off site. Final postreclamation topography is shown in figure 9.

Following final grading, a final scintillometer survey was conducted to assure that reclamation efforts had reduced surface radiation to background levels. Then, stockpiled topsoil was respread over the western half of the project area to a thickness of approximately 4-6 inches. The eastern half of the project area where the spoil pile had been was not respread with topsoil because the majority of this area retained some of the original topsoil horizon. After topsoil respreading, the surface was bladed and surveyed again to assure drainage. Rocks encountered were again handpicked and disposed of off site.

Seeding and Revegetation

Following completion of topsoil respreading, a seedbed was prepared on the project area. The area formerly buried by the spoil pile was plowed with a chisel plow to loosen the hardened surface caused by heavy-equipment compaction. The entire area then was disced, and all surface rocks were removed and disposed of off site.

In June 1986, a cover crop of oats was seeded on the project area at the rate of 20 pounds per acre. Simultaneously, a commercial fertilizer (28%N, 29%P, 0%K) was applied at the rate of 20 pounds per acre. In September 1986, the project area again was disced to incorporate the cover crop as mulch, reseeded with a tame grass mixture (50% western wheatgrass, 25% thickspike wheatgrass, 25% pubescent wheatgrass) at the rate of 12 pounds per acre, and again fertilized (28%N, 29%P, 0%K) at 20 pounds per acre.

Postreclamation Management

Following seeding of the cover crop, a fence was erected around the perimeter of the project area to: (1) Delineate the reclamation project area for future reference, (2) prevent livestock from grazing on the reclaimed area, and (3) discourage harvesting of grass in the reclaimed area. Restricting agricultural access to the reclamation area is a necessary step toward successful establishment of a healthy postreclamation vegetative cover.

Long-term land-use management is ultimately the responsibility of the landowner. Because the reclamation area is privately owned, land-use policy cannot be dictated by the State and Federal agencies involved in the reclamation effort. However, appropriate land uses and management techniques are suggested to the landowner. Because limited topsoil was available at the Palaniuk Pilot Project area, the postreclamation land surface cannot be tilled without mixing the soil with underlying spoil material. The effect of this mixing could be detrimental to soil productivity and surface-radiation levels. Similarly, planting deep-rooting plants such as alfalfa could provide for reconcentration of soluble radioactive species at the surface by evapotranspiration and compromise the integrity of the clay cap over the most highly radioactive material. The suggested long-term land use for the reclamation area is as rangeland or hayland. However, even these uses of the area should be delayed for at least 2-3 years to allow sufficient time for revegetation to become established.

Postreclamation Monitoring

In June 1986, a postreclamation radiological survey of the Palaniuk Pilot Project site was conducted by the North Dakota State Department of Health. Measurements were made on a 100-foot grid corresponding to sites of the prereclamation survey. Gamma exposure rates measured using a pressurized ion chamber at 22 sites ranged from 13 to 18 µR/hr. The approximate upper boundary of normal background in the area is believed to be 25 µR/hr.

Comparison of the postreclamation radium-226 content of project soils from 22 grid stations with the content of prereclamation soils is shown in table 1. Mean radium-226 contents corresponded well with background contents. Maximum postreclamation contents were only slightly greater than background maxima. Targeting postreclamation radium-226 contents for less than 5 pCi/g above background in accordance with standards for reclamation of inactive uranium processing sites (U.S. Environmental Protection Agency, 1983), only soil samples at one site exceeded the target content slightly.

Alpha-track detectors placed at the project site to measure ambient radon concentrations November 1986 indicated concentrations ranging from 0.5 to 2.1 pCi/L with an average of 1.0 pCi/L. Background radon concentrations in the vicinity of the Palaniuk Pilot Project average 1.2 pCi/L. Radon concentrations over the unreclaimed spoils had averaged 16.8 pCi/L.

Thus, it appears that the overall radiation levels at the Palaniuk Pilot Project site, including the surface gamma exposure rates and the surface radium contents, have been reduced significantly; thereby reducing the radiation risk to the environment and to public health and safety.

All monitoring wells, pressure-vacuum lysimeters, and radon detectors destroyed during reclamation construction were replaced at their original locations during the summer of 1986. Because ground-water quality data are available for only one season since reclamation and because 1986 was an unusually wet year, the effect of reclamation on ground-water quality can only be estimated. Groenewold and others (1983) and Houghton and others (1987b) have previously demonstrated that disturbance of spoils during reclamation usually results in a degradation of ground-water quality comparable to that which resulted during original mining.

Table 1.—Radium-226 content of prereclamation and postreclamation soils

Depth (inches)	Number of samples	Picocuries per gram Radium-226 content Maximum	Minimum	Mean	Standard deviation
Background sites					
0-12	54	6.2	2.7	4.3	1.4
12-24	54	5.4	3.2	4.3	1.6
Spoil pile					
0	6	24.2	7.5	12.4	6.2
Postreclamation sites					
1- 6	22	10.6	2.3	5.1	1.8
6-12	22	9.7	2.2	4.2	1.8

However, dissolved-solids concentrations in postreclamation ground water averaged 27 percent less than dissolved-solids concentrations in prereclamation ground water. In general, calcium concentrations showed an increase relative to sodium, indicative of juvenile water. Observed concentrations of postreclamation uranium, radium-226, and sulfate also decreased by 20 to 32 percent. A decrease in mean pH from 8.1 to less than 7.0 suggests that dilution may be responsible for most of the apparent decrease in dissolved-solids concentrations.

CONCLUSIONS

Geochemical characterization of spoil material is essential to the development of environmentally sound reclamation plans for abandoned mines. At the Palaniuk Pilot Project, reclamation plans were developed to control the principal geochemical processes that might lead to mobility of uranium and associated constituents. These plans involved reducing surface radiation by burial of the most radioactive material at depth. These procedures proved effective in reducing surface radiation and radon-gas emanations to near background levels. Selected placement of saline spoil material above the water table and below a mounded clay cap to reduce infiltration of precipitation appears to have resulted in a general decrease in dissolved-solids concentrations in local ground water. Because concentrations of uranium in ground water also were controlled by dissolution of a uranium-sulfate salt, uranium concentrations in ground water also improved. The postreclamation land surface is appropriate for use for grazing or haying.

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