draft

NUREG-0399

environmental statement

related to operation of

WYOMING MINERAL CORPORATION

IRIGARAY SOLUTION MINING PROJECT

APRIL 1978

Docket No. 40-8502

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U. S. Nuclear Regulatory Commission • Office of Nuclear Material Safety and Safeguards

NUREG-0399

DRAFT ENVIRONMENTAL STATEMENT

related to the

WYOMING MINERAL CORPORATION

IRIGARAY SOLUTION MINING PROJECT

(Johnson County, Wyoming)

prepared by the

U.S. Nuclear Regulatory Commission

Washington, D.C. 20555

April 1978

SUMMARY AND CONCLUSIONS

This draft environmental impact statement was prepared by the staff of the U.S. Nuclear Regulatory Commission and issued by the Commission's Office of Nuclear Material Safety and Safeguards.

1. This action is administrative.

2. The proposed action is the issuance of a source material license to Wyoming Mineral Corporation for implementation of the Irigaray project, Docket No. 40-8502, in accordance with the Corporation's statement in its application and accompanying Environmental Report.

   The Irigaray project consists of solution mining (in situ leaching) operations involving uranium ore deposits in Johnson County, Wyoming. Solution mining activities will include a processing facility with an annual production of 500,000 lb of U_3O_8 from up to 50 acres of well fields through the initial license authorization. The Irigaray project has an estimated lifetime of 10 to 20 years with known ore deposits and the current level of solution mining technology. The Nuclear Regulatory Commission staff proposes to limit initially the scope of the project as indicated in items 7 and 8.

3. Summary of environmental impacts and adverse effects:

   a. The site is mostly used as grazing land for cattle and sheep. Pronghorn antelope, which graze primarily on big sagebrush, are common on the site. Initiation of the Irigaray project would result in the temporary removal from grazing and the disturbance of approximately 60 acres during operation as proposed by the staff. All disturbed surface areas will be reclaimed and returned to their original use.

   b. With the staff's proposed production and restoration limitations approximately 1.2×10^6 m^3 (1000 acre-ft) of water will be withdrawn from the ore zone aquifer. This water will be conveyed to the onsite waste ponds for evaporation. The long-term effects on groundwater use are expected to be minimal. An estimated 4.2×10^5 m^3 (340 acre-ft) of groundwater is expected to temporarily contain increased concentrations of radioactive and toxic elements during the operation of each 4-ha (10-acre) well field. Restoration should return this water to a condition that is consistent with its premining use (or potential use). Surface water will not be affected by normal operations.

   c. There will be no discharge of liquid effluents from the Irigaray project. Atmospheric effluents will be within acceptable limits, and the effects will be insignificant. The dose rates of radionuclides in the air at the nearest ranches from the plant site are given in the following table.

Dose rates of radionuclides in the air at the nearest ranches from the plant site

Operation	Dose rate (millirems/year)				
	Total body	Bone	Lung	Kidney	Bronchial epithelium
Irigaray Ranch					
Well field	0.00013	0.00071	0.000080	0.0015	0.30
Recovery plant	0.0022	0.028	0.26	0.0071	
Total	0.0023	0.029	0.26	0.0088	0.031
Reculusa Ranch					
Well field	0.00048	0.0027	0.00028	0.0056	0.089
Recovery plant	0.0086	0.11	1.1	0.028	
Total	0.0091	0.11	1.1	0.033	0.089

d. The Irigaray project proposes the production and utilization of 500,000 lb per year of uranium resources. Small amounts of common construction materials, chemicals, reagents, and fuels will be irretrievably committed.

e. The Irigaray project will not produce any significant socioeconomic impact on the local area because of the small number of employees that will be employed at the project.

4. The principal alternatives considered were the following:

a. Alternative mining methods.

Open-pit, underground, and solution mining (in situ leaching) methods were considered as well as a comparison of impacts associated with each. Solution mining (in situ leaching) is the preferred method for mining the Irigaray ore deposits although open-pit mining has not been precluded. Impacts associated with in situ leaching are generally less severe than impacts associated with open-pit and underground uranium mining.

b. Alternative leach solutions.

Alkaline and acidic leach solutions were examined. An alkaline leach solution is more favorable for the Irigaray ore deposits because of the mineral composition of the host sandstone.

c. Alternative mill process for an alternative open-pit or underground mine.

The conventional uranium milling processes are described and were compared with a solution mining operation. Solution mining does not require extraction of the ore, and no tailings are produced. The quantity of solid wastes from a solution mining operation is expected to be about 1% of the quantity generated by a conventional mill of comparable production.

d. Alternative methods for waste management.

Waste management alternatives that were considered included various onsite disposal methods as well as transport of solid wastes to an active mill tailings pond. Onsite disposal would result in the proliferation of small solid waste impoundments. The transfer of solid wastes to an active tailings pond is the recommended alternative.

e. Alternative energy sources.

Fossil and nuclear fuels were compared, and solar, geothermal, and synthetic fuels were considered.

f. Alternative of no licensing action.

The denial of a source material license is an alternative available to the NRC. If denied, the ore deposit could not be mined using the solution mining (in situ leaching) method.

5. The following Federal, State, and local agencies are being asked to comment on this draft environmental statement:

Department of Commerce
Department of the Interior
Department of Health, Education, and Welfare
Federal Energy Regulatory Commission
Department of Transportation
Environmental Protection Agency
Department of Agriculture
Advisory Council on Historic Preservation
Department of Housing and Urban Development
Department of Energy

Department of Environmental Quality, State of Wyoming
Board of Commissioners, Johnson County, Wyoming

6. This draft environmental impact statement will be made available to the public, to the Environmental Protection Agency, and to other specified agencies in April 1978.

7. From the analysis and evaluation made in this statement, the staff proposes that the source material license issued for the Irigaray project be limited to a maximum well field area of 20 ha (50 acres) and contain the following conditions:

   a. The use of an ammonium bicarbonate lixiviant will be limited to a maximum well field area of 20 ha (50 acres). This area will include the existing well field for the 100-gpm, pilot-scale test (Sect. 5.1.5).

   b. Restoration of the first production unit [up to 4-ha (10-acre) well field] must be initiated upon completion of mining of this unit (Sect. 5.1.5).

   c. This production unit should be sufficiently isolated from any further operating well field within the 20-ha (50-acre) area to ensure that restoration operations will not be compromised by ongoing mining activities (Sect. 5.1.5).

   d. Restoration of at least the first production unit must be completed prior to mining any area beyond the maximum 20 ha (50 acres) with an ammonium bicarbonate lixiviant (Sect. 5.1.5). (The applicant must provide a detailed mining plan that reflects these requirements prior to issuance of the source material license.)

   e. The applicant will be required to develop and conduct an experimental study on ammonia transport and conversion on the restored section of the 517 test site (Sect. 6.3.2.2).

   f. The applicant will dispose of all radioactive and toxic wastes by transporting them to an active tailings pond (Sects. 4.6.4 and 12.3.2).

      In addition, (1) a maximum accumulation of two years of calcite waste will be permitted prior to removal from the site; (2) other radioactive or toxic wastes from production and restoration activities will be removed and transferred to the tailings pond as the ponds fill or at the time of site reclamation; and (3) contract arrangements for the disposal of such solid wastes must be obtained and maintained by the applicant.

   g. The applicant shall maintain a liquid seal on all waste storage ponds except when removing the solids content for disposal (Sect. 4.6.5).

   h. The applicant shall implement the environmental monitoring programs as discussed in Sect. 8. These include (1) preoperational monitoring of surface water and groundwater (Sect. 8.1.5), (2) operational monitoring of waste ponds (Sect. 8.2.1) and well fields (Sect. 8.2.3), (3) radiological monitoring (Sect. 8.2.2), and (4) postoperational well field monitoring (Sects. 8.2.3.7 and 8.2.3.8).

   i. The applicant shall provide plans and procedures for implementing the necessary mitigating actions for any transportation accidents (Emergency action plan, Sect. 7.3.1)

   j. The applicant will provide plans for minimizing environmental impact on riparian habitats or stream beds (i.e., Willow Creek) prior to the development of activities in such areas (Sects. 6.6.1 and 6.6.3).

   k. The applicant shall establish a program which shall include written procedures and instructions to control all activities discussed in items a-j and shall provide for periodic reports to verify the fullfilment of these conditions.

   l. Before engaging in any activity not evaluated by the NRC staff, the applicant will prepare and record an environmental evaluation of such activity. When the evaluation indicates that such activity may result in a significant adverse environmental impact that was not evaluated, or that is significantly greater than that evaluated in this environmental statement, the applicant shall provide a written evaluation of such activities and obtain prior approval of NRC for the activities.

m. If unexpected harmful effects or evidence of irreversible damage not otherwise identified in this statement are detected during construction or operations, the applicant shall provide to NRC an acceptable analysis of the problem and a plan of action to eliminate or significantly reduce the harmful effects or damage.

8. The position of the NRC is as follows:

Solution mining (in situ leaching) of uranium is a developing technology. Uncertainties regarding environmental impacts, particularly with respect to groundwater contamination and the effectiveness of aquifer restoration techniques, have been recognized. Because of this, the Nuclear Regulatory Commission staff proposes to limit the scope of the Irigaray project through the above license conditions until additional data and experience are gained.

The proposed position of the Nuclear Regulatory Commission is that after weighing the environmental, economic, technical, and other benefits of the Irigaray project against environmental and other costs and considering available alternatives, the action called for under the National Environmental Policy Act of 1969 (NEPA) and 10 CFR 51 is the issuance of a source material license to the applicant, subject to conditions 7a-m above.

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FOREWORD

This draft environmental impact statement is issued by the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Material Safety and Safeguards, in accordance with the Commission's regulation, 10 CFR Part 51, which implements the requirements of the National Environmental Policy Act of 1969 (NEPA).

The NEPA states, among other things, that it is the continuing responsibility of the Federal government to use all practicable means, consistent with other essential considerations of national policy, to improve and coordinate Federal plans, functions, programs, and resources to the end that the nation may:

- Fulfill the responsibilities of each generation as trustee of the environment for succeeding generations.
- Assure for all Americans safe, healthful, productive, and aesthetically and culturally pleasing surroundings.
- Attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences.
- Preserve important historical, cultural, and natural aspects of our national heritage, and maintain, wherever possible, an environment which supports diversity and variety of individual choice.
- Achieve a balance between population and resource use which will permit high standards of living and a wide sharing of life's amenities.
- Enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources.

Further, with respect to major Federal actions significantly affecting the quality of the human environment, Sect. 102(2)(C) of the NEPA calls for preparation of a detailed statement on:

(i) the environmental impact of the proposed action,

(ii) any adverse environmental effects which cannot be avoided should the proposal be implemented,

(iii) alternatives to the proposed action,

(iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and

(v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

Pursuant to 10 CFR Part 51, the NRC Division of Fuel Cycle and Material Safety has determined that a detailed statement on the foregoing considerations with respect to Wyoming Mineral Corporation's application for a source material license for a uranium solution mining (in situ leaching) operation is required.

This statement is based on information contained in correspondence, applications, and reports received from the Wyoming Mineral Corporation. The following documents were mainly used in preparing the statement: application for source material license dated January 28, 1976; applicant's Environmental Survey dated January 28, 1976; correspondence from applicant dated May 6, 1976, June 15, 1976, November 16, 1976 (Amplifications on Environmental Survey); applicant's responses to NRC representatives (staff) questions of March 1, 1977; applicant's revised Environmental Report dated July 29, 1977, and clarifications received October 17, 1977; agency comments on applicant's revised Environmental Report, November 1977; the applicant's restoration demonstration reports of March 1978 and consultants' reviews in various disciplines in environmental concerns. Copies of the applicant's Environmental Report and correspondence are available for inspection in the NRC Public Document Room, 1717 H Street, N.W., Washington, D.C. 20006.

In conducting the required NEPA review, NRC representatives (staff) met with the applicant to discuss items of information in the environmental reports, to seek new information from the applicant that might be needed for an adequate assessment, and generally to ensure a thorough understanding of the proposed project.

In addition, the staff sought information from other sources to assist in the evaluation and to conduct field inspections of the project site and surrounding area. Members of the staff also met with State and local officials who are charged with protecting State and local interests. On the basis of all the foregoing and other such activities or inquiries as were deemed useful and appropriate, the staff made an independent assessment of the consideration specified in Sect. 102(2)(C) of the NEPA.

This evaluation led to the issuance of this Draft Environmental Statement by the Office of Nuclear Material Safety and Safeguards. The statement has been distributed to Federal, State, and local governmental agencies and other interested parties for comment. A summary notice has been published in the *Federal Register* with respect to the availability of the applicant's Environmental Report and the Draft Environmental Statement. Comments should be addressed to the Director, Division of Fuel Cycle and Material Safety, U.S. Nuclear Regulatory Commission, Washington, D.C. 20555.

After comments on the Draft Statement have been received and considered, the staff will prepare a Final Environmental Statement that includes discussion of questions and comments submitted by reviewing agencies or individuals. Further environmental considerations are made on the basis of these comments and combined with the previous evaluation; the total environmental costs are then evaluated and weighed against the environmental, economic, technical, and other benefits to be derived from the proposed project. The consideration of available alternatives and environmental costs and benefits provides a basis for denial or approval of the proposed action, with appropriate conditions to protect environmental values.

Single copies of this statement, NUREG-0399, may be obtained by writing:

Division of Technical Information and Document Control
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

1. INTRODUCTION

1.1 THE APPLICANT'S PROPOSAL

An application for a source material license was filed by the Wyoming Mineral Corporation (hereafter referred to as the applicant or WMC) on January 28, 1976, to conduct production-scale solution mining of uranium (in situ leaching) at the Irigaray site in Johnson County, Wyoming. This consists of leaching uranium from subsurface ore-bearing sandstone by adding chemical reagents to existing groundwater to reverse the natural uranium precipitation process that deposited the uranium in the host sandstone. The resulting uranium-bearing liquor is recovered (pumped) from the mineralized (sandstone) zone to a surface processing plant where the uranium is extracted by conventional uranium recovery techniques. The solution from the uranium recovery operation, after further reagent addition, is recycled to the mineralized zone to dissolve additional uranium. After the ore zone is depleted of recoverable uranium, the reagents and other mobilized ionic species remaining in the zone are removed from the groundwater to restore it. Restoration is defined as the returning of affected groundwater to a condition consistent with its premining use (or potential use).

The applicant's proposal for solution mining is summarized below and described in more detail in Sect. 4. Because uranium solution mining is a developing technology with related uncertainties in the environmental impacts, particularly with respect to groundwater contamination and effectiveness of aquifer restoration techniques, the Nuclear Regulatory Commission staff proposes to limit the scope of the project through license conditions until additional data and experience are gained. These limitations are discussed in Sect. 5.

1.2 BACKGROUND INFORMATION

The WMC's proposed Irigaray project is located in northeast Wyoming within the Powder River Basin. As shown in Fig. 1.1, the Irigaray property is in southeast Johnson County, approximately 10 miles northeast of Sussex and 43 miles southeast of Buffalo. Access to the property is via gravel roads from the north and south.

The Irigaray property includes approximately 21,100 acres of leases and claims in T46N, R76W; T45N, T46N, and T47N, R77W; and T44N, T45N, and T46N, R78W (Fig. 1.2). Within the boundary of the Irigaray property, production-scale solution mining activities will initially be conducted in Section 9, T45N, R77W. The initial production plant and associated facilities will occupy a 5-acre site, and the initial well field, located some 1,500 ft to the east, will include an area of up to 50 acres.

Subsequent well fields will be developed to follow the mineralized trend. Future mining may occur in Sections 19, 30, 29, and 32 of T46N, R77W and Sections 5, 4, 16, 21, and 28 of T45N, R77W (Fig. 1.2). Additional production plants may be constructed at different locations near the well fields depending on processing capacity requirements. It is anticipated that solution mining activities will affect approximately 1,000 acres of the 21,100 acres that comprise the Irigaray property over the lifetime of the project. These potential activities, however, are not covered under the initial license and will require additional licensing action.

1.2.1 Present activities

Under NRC license, two pilot-scale solution mining tests are presently in operation on the Irigaray property (Fig. 1.2). The 517 test area consists of a trailer-mounted plant and three five-spot well patterns occupying a 1-acre site in Section 5 of T45N, R77W. Research and development activities were initiated at this site in November 1975; aquifer restoration tests have been conducted and are discussed in Sect. 5.

A second test site was developed in 1977. It consists of a 1.5-acre portion of the planned production operation in Section 9 of T45N, R77W. Plant equipment is temporarily housed in the building shell which will eventually contain the 500,000-lb/year processing equipment. The well field, with ten seven-spot well patterns, is located near the center of the initial proposed production well field. Pilot test operations at the site began during the summer of 1977.

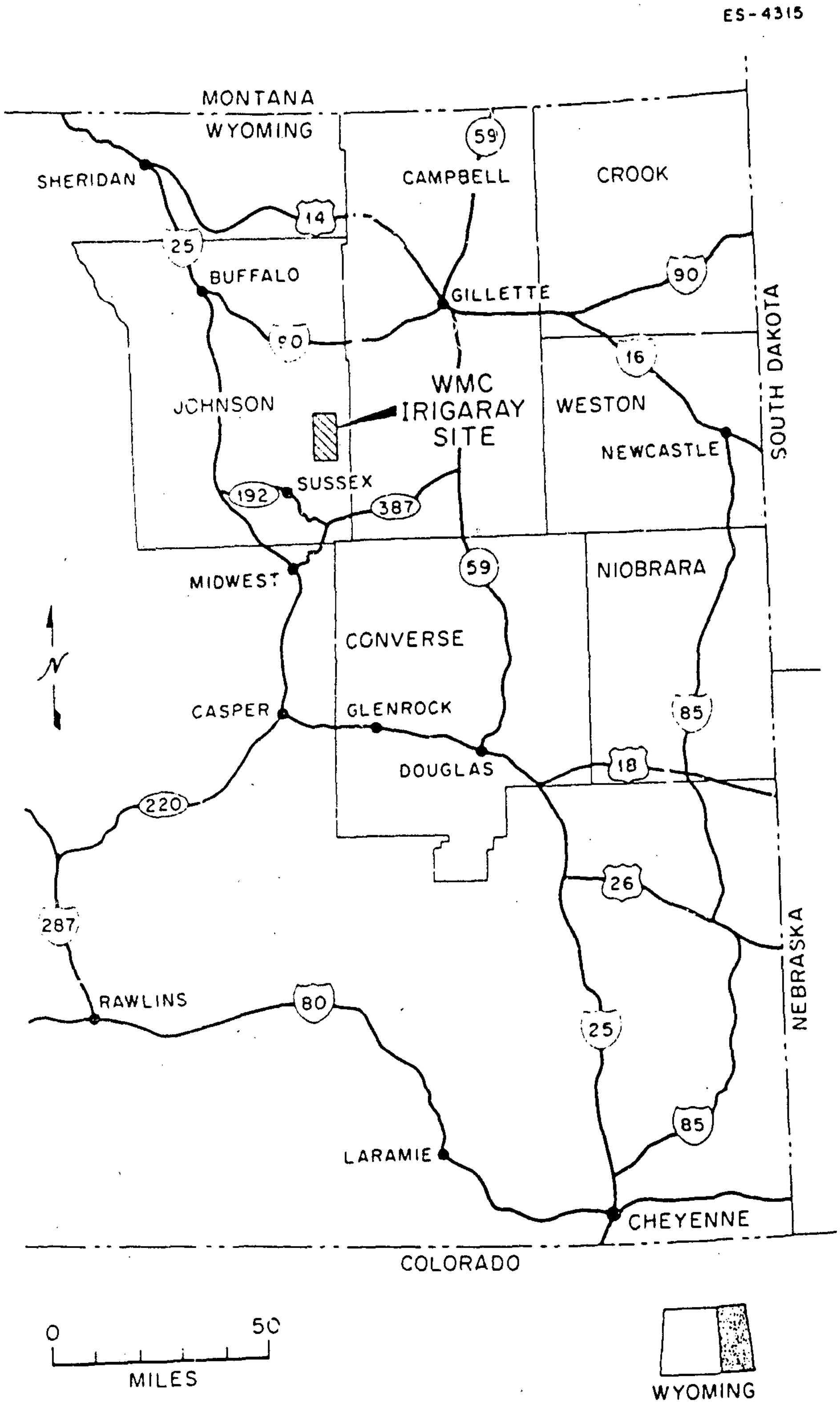

Fig. 1.1. Regional location of the Wyoming Mineral Corporation Irigaray Project.

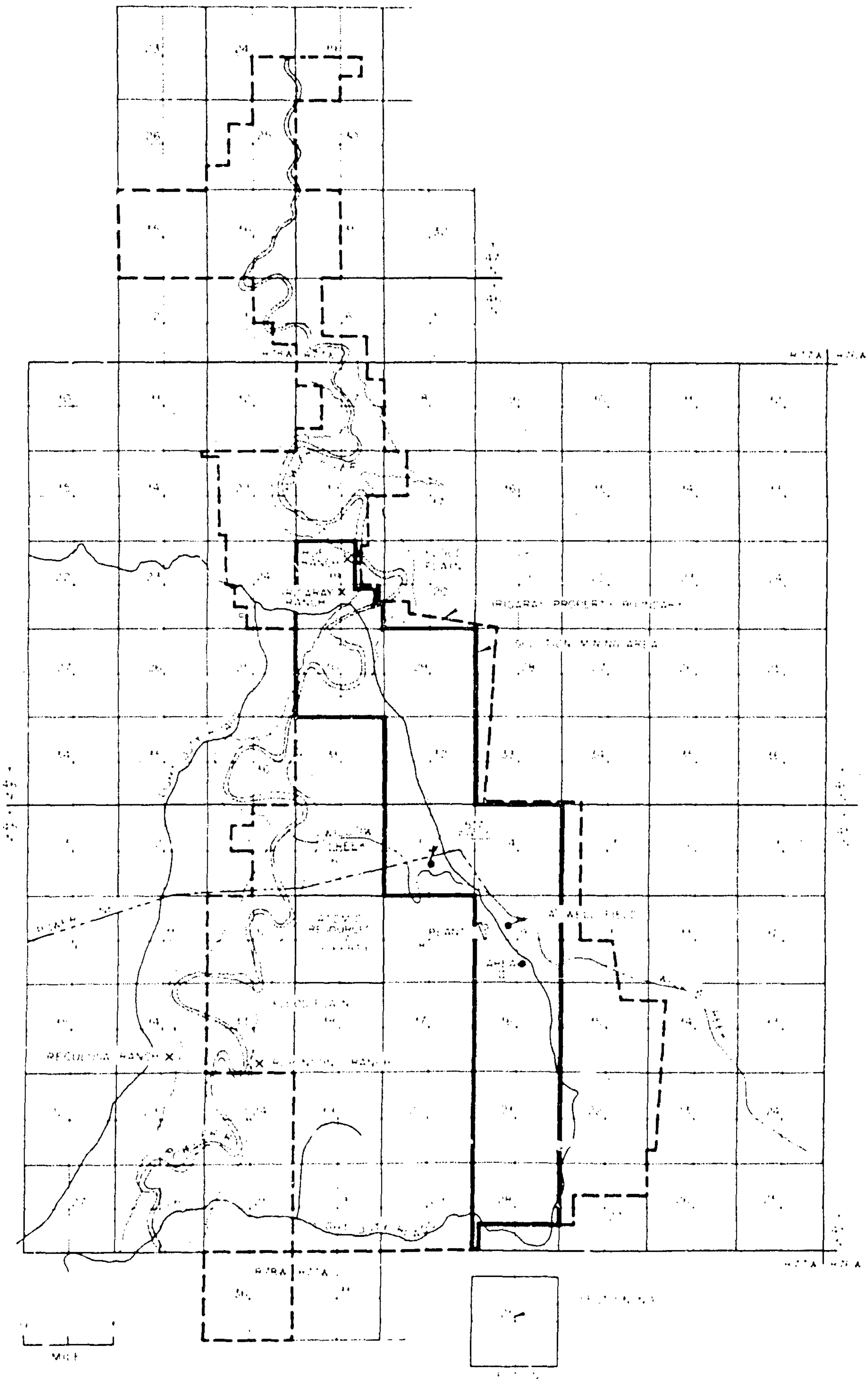

Fig. 1.2. Irigaray property and its immediate vicinity.

1.3 FEDERAL AND STATE AUTHORITIES AND RESPONSIBILITIES

Under 10 CFR Part 40, an NRC license is required in order to "receive title to, receive, possess, use, transfer, deliver . . . any source material . . ." (i.e., uranium and/or thorium in any form, or ores containing 0.05% or more by weight of those substances). Title 10, Code of Federal Regulations, Part 51, provides for the preparation of a detailed environmental statement pursuant to the National Environmental Policy Act of 1969 (NEPA) prior to the issuance of an NRC license for an action that may significantly affect the quality of the human environment.

The State of Wyoming Department of Environmental Quality administers the State's Environmental Quality Act of 1973 and implementing rules and regulations. Article 4 of the act established a permit and licensing scheme which is designed to ensure adequate reclamation of mined lands. The licensing procedure is based on the operator's submission of a detailed reclamation plan to the State. A performance bond is required for reclamation. A performance bond will also be required for aquifer restoration.

1.4 STATUS OF REVIEWS AND ACTIONS BY STATE AGENCIES

The approvals and permits required from Wyoming State agencies are listed in Table 1.1. The applicant will obtain all necessary permits required for the proposed project.

Table 1.1. Regulatory approvals and permits required prior to initiation of solution mining project

Permit or license	Granting authority
License to mine	DEQ – LQD[a]
Permit to mine	DEQ – LQD
Air permit to construct	DEQ – AQD[b]
Air permit to install recovery plant processing equipment	DEQ – AQD
Sanitary sewage disposal	DEQ – WQD[c]
Potable water supply	DEQ – WQD
Water wells	SE[d]
Construction of an impoundment	SE
Industrial siting permit	WISC[e]
Air permit to operate	DEQ – AQD
Industrial waste disposal site	DEQ – SWMD[f]

[a]Wyoming Department of Environmental Quality – Land Quality Division.
[b]Wyoming Department of Environmental Quality – Air Quality Division.
[c]Wyoming Department of Environmental Quality – Water Quality Division.
[d]Wyoming State Engineer.
[e]Wyoming Office of Industrial Siting Administration.
[f]Wyoming Department of Environmental Quality – Solid Waste Management Division.

1.5 NRC LICENSING ACTION

NRC licensing of production-scale solution mining (in situ leaching) operations currently follows the same procedures used in licensing a uranium mill. In accord with 10 CFR Part 40, a source material license is required in order to process or refine ores. An applicant for such a license is required to provide detailed information as discussed in NRC Regulatory Guide 3.5. The application must be accompanied by an Environmental Report in order for the NRC to assess the potential environmental effects of the proposed activity pursuant to 10 CFR Part 51. The information required in an Environmental Report is discussed in NRC Regulatory Guide 3.8.

In keeping with these requirements, the applicant submitted an application for source material license accompanied by an Environmental Survey (hereafter referred to as the ES) on January 28, 1976.[1] Subsequent submittals by the applicant have included (1) Amplification of the Environmental Survey (hereafter referred to as the Amplification),[2] (2) correspondence from the applicant, dated May 6 and June 15, 1976, (3) applicant's response to staff questions,[3] (4) Environmental Report (hereafter referred to as the ER),[4] (5) Clarification and Information on the revised ER,[5] (6) clarification and response to staff questions,[6] (7) Irigaray Restoration Demonstration Program, Final Report,[7] and (8) Irigaray Restoration Data Package.[8] These documents form the basis for the staff evaluation of the applicant's proposed project pursuant to 10 CFR Part 51.

The NRC will publish a generic statement on uranium milling operations (excluding solution mining).[9] In order that uranium mills may be granted a source material license prior to the publication of the generic statement, the NRC requires the address of "five criteria" for a uranium milling operation.[9]

While the proposed solution mining project does not contain all of the components utilized in a "normal" uranium milling operation, the primary product, yellow cake, is the same. For this reason, the staff has followed the June 1976 statement of the NRC and considered the "five criteria" as follows:

1. It is likely that each individual licensing action of this type would have a utility that is independent of the utility of other licensing actions of this type.

This statement is true for this project, since the uranium ore will not be removed from its natural underground location and would not be available for transport to another mill for processing.

2. It is not likely that the taking of any particular licensing action of this type during the time frame under consideration would constitute a commitment of resources that would tend to foreclose significantly the alternatives available with respect to any other individual licensing action of this type.

None of the materials involved in the construction or operation of this project are unique or in short supply. Air, water, and land resources will be locally affected but not to an extent that would preclude later beneficial use of the local environment. The project will, in addition to providing yellow cake, supply operational and restoration data helpful in improving responsible licensing requirements for other individual licensing actions of this type.

3. It is likely that any environmental impacts associated with any individual licensing action of this type would be such that they could adequately be addressed within the context of the individual license application without overlooking any cumulative environmental impact.

This Environmental Statement contains an evaluation of environmental impacts associated with the proposed licensing action and their severity and includes requirements for monitoring programs and other actions to mitigate the impacts. Cumulative impacts have been considered within the context of the individual license. The relative isolation of the proposed site virtually ensures that all appropriate environmental impacts can be adequately discussed in a site-specific Environmental Impact Statement.

Restoration of the groundwater contained in the ore-bearing sandstone after the extraction of uranium is yet undemonstrated. The staff proposes to limit the scope of the applicant's solution mining project until restoration is demonstrated on a production-scale mining unit and the results are evaluated. The limited authorization minimizes the potential for any cumulative impacts.

4. It is likely that any technical issues that may arise in the course of a review of an individual license application can be resolved within that context.

The staff has reviewed the applicant's evaluations and, in addition, has evaluated other technical issues. All of these evaluations and, presumably, any further technical issues that may arise during review are resolvable within the context of the individual licensing action, inasmuch as this project is independent of other projects.

5. A deferral on licensing actions of this type would result in substantial harm to the public interest as indicated above because of uranium fuel requirements of the operating reactors and reactors now under construction.

As stated in the June 1976 statement[9] by the NRC, "the full capacity of the existing mills will be required to support presently operating nuclear power reactors and those expected to begin operation in 1977." Therefore an increase in uranium production as proposed by this project is in the public interest, since present national policy is to increase the production of electric power by construction of new nuclear reactors.

REFERENCES FOR SECTION 1

1. Wyoming Mineral Corporation, *Environmental Survey for Irigaray Uranium Mine Site, Jonnson County, Wyoming*, Docket No. 40-8502, January 1976.

2. Wyoming Mineral Corporation, *Amplification of Wyoming Mineral Corporation Environmental Survey; Irigaray Uranium Solution Mine Site, Johnson County, Wyoming*, Docket No. 40-8502, Nov. 16, 1976.

3. Wyoming Mineral Corporation, Draft Answers to NRC Questions, Docket No. 40-8502, April 1977.

4. Wyoming Mineral Corporation, *Environmental Report — Irigaray Project, Johnson County, Wyoming*, Docket No. 40-8502, July 1977.

5. Wyoming Mineral Corporation, *Clarification and Information, Wyoming Mineral Corporation Revised Environmental Report*, Docket No. 40-8502, Oct. 17, 1977.

6. Wyoming Mineral Corporation, *Requested Answer Clarifications, NRC Questions, Revised Irigaray Environmental Report*, Docket No. 40-8502, Oct. 28, 1977.

7. Wyoming Mineral Corporation, "Irigaray Restoration Demonstration Program, Final Report," Lakewood, Colo., Mar. 13, 1978.

8. Wyoming Mineral Corporation, "Irigaray Restoration Data Package," Lakewood, Colo., March 1978.

9. "Uranium Milling, Intent to Prepare a Generic Environmental Impact Statement," *Fed. Regist.* 41: 22430-22431 (June 3, 1976).

2. THE EXISTING ENVIRONMENT

2.1 CLIMATE

2.1.1 General influences

The climate is semiarid; the mean annual precipitation is 12.0 in. More than 50% of the annual precipitation is received during the months of May, June, and July, in the form of wet snow and rain. Temperatures vary from summer highs near 38°C (100°F) to winter lows near -40°C (-40°F). The seasons are distinct, with mild summers and harsh winters. Spring and fall are transition seasons with warm days and cold nights. Heavy snowfalls can be expected during both of these seasons.[1]

2.1.2 Winds

The prevailing wind direction at the site is expected to be westerly, based on annual average surface wind flow measurements from Sheridan and Casper as shown in Fig. 2.1. Strong winds are fairly frequent. Winds of 50 mph or more have been reported at Casper in every month of the year except November.[2] The local topography strongly influences the micrometeorological conditions.

2.1.3 Precipitation

Cooperative weather station data over the period 1970-1974 for four stations 48 to 64 km (30 to 40 miles) from the site in the prevailing wind pattern gave an "averaged" annual precipitation of 30.9 cm (12.2 in.). These stations, at Kaycee, Billy Creek, Buffalo, and Reno (Table 2.1), showed a low of 28.9 cm (11.4 in.) and a high of 33.2 cm (13.1 in.) of precipitation per year. Late spring and summer precipitation is normally derived from scattered thunderstorms, and the monthly extremes from each station vary widely. Fifty-three percent of the measured precipitation occurred in the period April-July, 12% occurred in October, and only 12% occurred in the period November-January. Table 2.1 shows the 1970-1974 average values for both precipitation and snow for each of the four stations. The last column contains the maximum and minimum values observed for all years and all stations and demonstrates the large variability that may be observed.[3]

2.1.4 Storms

Winter storms, with attendant snowfall, low temperatures, and high winds, are common. Thunderstorms, occasionally spawning tornadoes, are frequent in spring and summer.

2.2 AIR QUALITY

As a result of fairly constant daily winds, air dispersal capabilities in the Powder River Basin are relatively good. Because of the clear skies and rapid nighttime cooling, low-level nocturnal inversions are common. These inversions are usually dissipated shortly after sunrise by rising surface temperatures and increased wind speeds. Upper-level inversions [above 150 m (492 ft)], resulting in stagnant air, may be expected an average of 40 episode days per year.[4] Episodes lasting at least five days occur on an average of four times a year.[4]

There has been no site-specific air quality monitoring near the proposed WMC site. However, because of the distance of the WMC site from any urban or industrial emission sources, the air quality may be expected to be very good, with concentrations of major pollutants at very low background levels. Fugitive dust from oil fields, gravel borrow pits, and unpaved roads may occasionally affect air quality in the WMC vicinity. At sites within the Powder River Basin removed from localized dust sources, background suspended particulate concentrations range from 13 to 21 $\mu g/m^3$.[4] The Wyoming State ambient air quality standards are listed in Table 2.2.

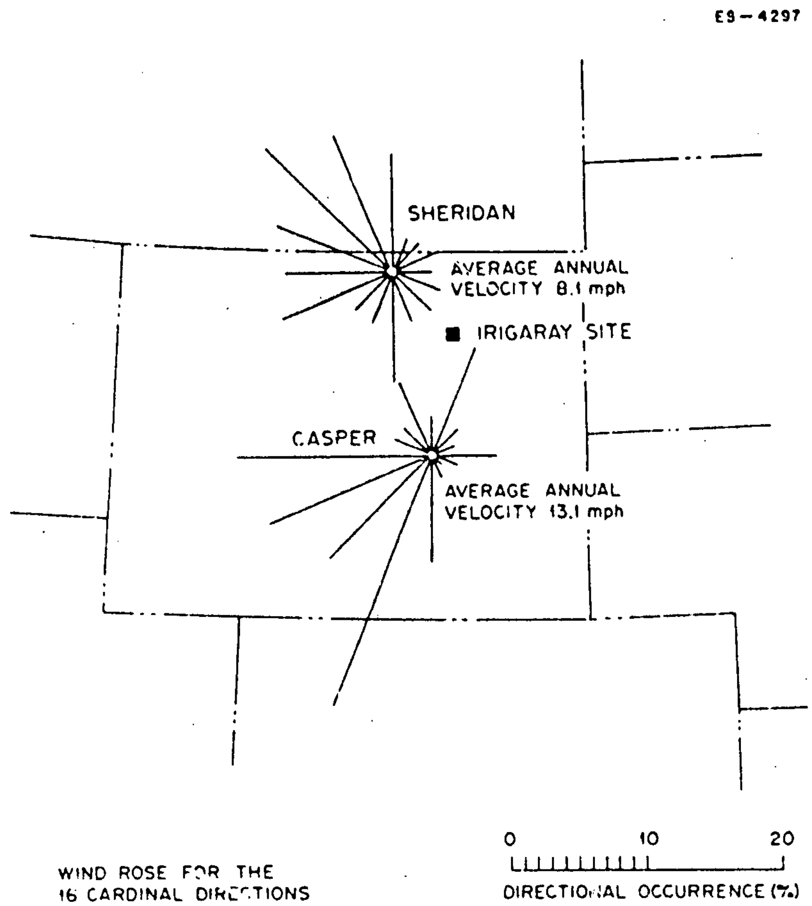

Fig. 2.1. Annual surface wind flow at Sheridan and Casper, Wyoming. Source: U.S. Department of Commerce, *Local Climatological Data – Summary with Comparative Data, 1973, Casper, Wyoming.*

Table 2.1. Average precipitation 1970–1974

All values in inches

Month	Kaycee		Billy Creek		Buffalo		Reno		All stations	
	Precip	Snow	Precip	Snow	Precip	Snow	Precip	Snow	Max	Min
January	0.54	6.4	0.33	5.2	0.42	4.5	0.34	4.6	1.28	0.03
February	0.27	3.0	0.30	3.7	0.52	6.5	0.16	1.0	1.26	0.01
March	0.82	7.4	0.75	8.6	1.39	9.4	0.59	4.7	1.75	0.00
April	2.51	11.9	1.37	6.2	1.91	2.2	1.22	7.3	4.62	0.92
May	1.98	1.0	1.37	Trace	1.73	0.4	1.96	Trace	3.88	0.37
June	1.80	0	1.21	Trace	1.55	0	1.99	0	3.53	0.58
July	1.02	0	1.55	0	1.04	0	1.49	0	3.30	0.15
August	0.76	0	1.08	0	1.07	0	1.04	0	2.90	0.00
September	0.88	5.5	0.75	1.0	1.14	Trace	0.85	Trace	2.65	0.28
October	1.41	4.0	1.68	6.1	1.64	2.0	1.14	8.3	3.58	0.37
November	0.45	3.4	0.42	5.2	0.52	9.0	0.16	0.3	0.92	0.01
December	0.37	4.7	0.27	4.2	0.17	3.3	0.47	5.4	0.45	0.00
Yearly	12.81	47.3	11.49	40.2	13.10	37.3	11.41	31.6		

Source: Cooperative Weather Station Data, National Weather Service Station Data, National Climatic Center, Asheville, N.C., 1970–1974, U.S. Department of Commerce.

Table 2.2. Wyoming State ambient air quality standards

Pollutant	Averaging period	Maximum acceptable concentration
Total suspended particulates	Annual (geometric mean)	60 $\mu g/m^3$
	24 hr	150 $\mu g/m^3$ [a]
Total settleable particulates	30 days	5 g/m^2 per month (residential areas)[a]
	30 days	10 g/m^2 per month (industrial areas)[a]
Sulfur dioxide	Annual (arithmetic mean)	60 $\mu g/m^3$
	24 hr	260 $\mu g/m^3$ [a]
	3 hr	1300 $\mu g/m^3$ [a]
Sulfation rate	Annual	0.25 mg SO_3 per 100 cm^2 per day
	30 days	0.50 mg SO_3 per 100 cm^2 per day[a]
Hydrogen sulfide	0.5 hr	70 $\mu g/m^3$ [b]
	0.5 hr	40 $\mu g/m^3$ [c]
Photochemical oxidants	1 hr	160 $\mu g/m^3$ [a]
Nonmethane hydrocarbons	3 hr (6 AM–9 AM)	160 $\mu g/m^3$ [a]
Nitrogen dioxide	Annual	100 $\mu g/m^3$
Carbon monoxide	8 hr	40 mg/m^3 [a]
	1 hr	10 mg/m^3 [a]

[a] Not to be exceeded more than once a year.

[b] Not to be exceeded more than twice a year.

[c] Not to be exceeded more than two times during any five day period.

Source: Wyoming Environmental Quality Act (1975), Chapter 1, Sections 3 through 12, Air Quality Standards and Regulations, amended January 31, 1975.

2.3 TOPOGRAPHY

The Irigaray property is located in the southern portion of the Powder River Basin, which is a part of the Great Plains physiographic province. The Powder River Basin is a structural and topographic basin covering approximately 64,750 km^2 (25,000 sq miles) in eastern Wyoming and southern Montana.[4] The basin is bounded on the east by the Black Hills and on the west by the Bighorn Mountains and Casper arch (Fig. 2.12). The Laramie Range and Hartville uplift serve as the southern boundary, while the Miles City arch, in Montana, demarcates the northern extent of the basin.

The surface configuration in the Irigaray property area is characterized by gently rolling uplands, which have been extensively dissected, and broad valleys. The Powder River valley is from 1/2 to 1 mile wide, and the valley of Willow Creek is from 1/4 to 1/2 mile wide on the Irigaray property. Elevations range from 1280 m (4200 ft) along the Powder River in the northern section of the property to 1433 m (4700 ft) near the southeast property boundary.

The topography in the vicinity of both the existing pilot-scale test activities and the proposed initial well field areas is shown in Fig. 2.2.

2.4 REGIONAL DEMOGRAPHY AND SOCIOECONOMIC PROFILE

2.4.1 Demography

2.4.1.1 Current population and distribution

Because of accessibility to the site, the proposed project work force would be expected to reside primarily in Buffalo, the county seat of Johnson County, approximately 68 km (42 miles) from the site. In 1970, Buffalo had a population of 3394 people, out of about 5600 people residing in the county. The populations of other nearby ranches and towns are shown in Table 2.3. The locations of the towns are shown in Fig. 2.3. In 1976 the population of Buffalo was reported as 4200, and the total population of Johnson County was 5300.[5] The population density for Johnson County is 1.29 persons per square mile.

The applicant reports 1403 housing units in Buffalo and a vacancy rate of 8% or 112 units (ER, p. 46). The permanent project work force is expected to be less than 60; many are already residents of Buffalo.

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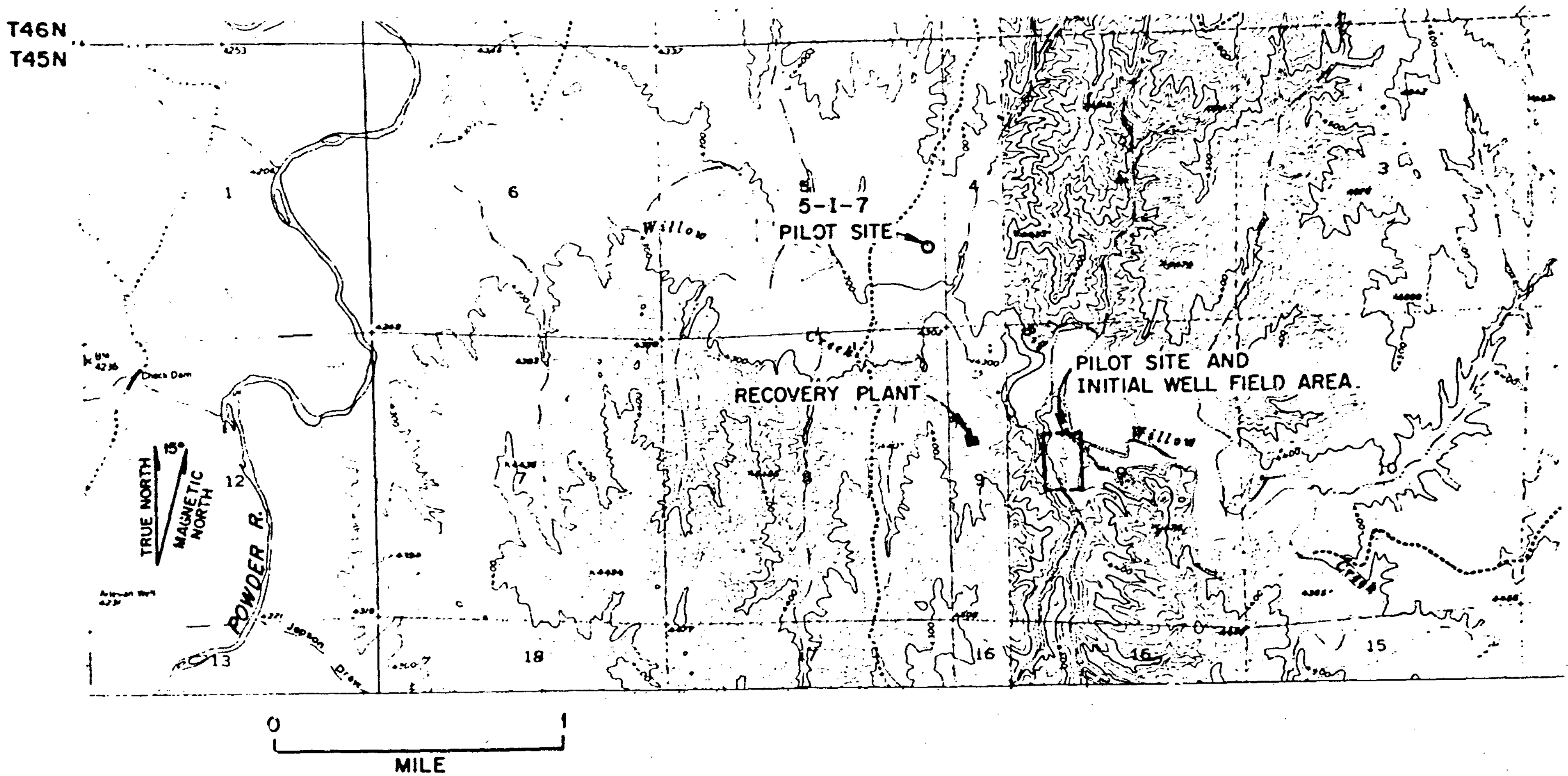

Fig. 2.2. Topographic map with the location of solution mining activities on the Irigaray property. Note: Scale, 1:24,000. Source: U.S. Department of the Interior Geological Survey, Topographic maps of the Nipple Quadrangle and the Hoe Ranch Quadrangle, 7.5 Minute Series, 1953.

Table 2.3. Ranch and town populations near Irigaray property

Ranch or town	Distance from site (miles)	Population
Reculusa Ranch	4.1	8–10
Irigaray Ranch	4.4	6
ZL Bar Ranch	5.6	12
Falxa Camp	5.7	2
Urruty Ranch	7.2	4–5
Sussex	15.0	30
Linch	20.0	300
Kaycee	28.0	272
Buffalo	42.0	3394
Gillette	42.0	7194

2.4.1.2 Projected population and distribution

Population growth in the Powder River Basin was 39% from 1940 through 1970. The Johnson County population increased only 12% during these 30 years. At present, coal and uranium mining in the region is increasing the employment opportunities, and the population is growing. The new residents migrate to communities such as Buffalo, which increased in population by 24% from 1970 to 1976.[5] This increase in urban population is expected to continue.

2.4.1.3 Transient population

Interstate highway 25, a major tourist route, passes through Buffalo 68 km (42 miles) away from the site. Few tourist accommodations are present, and this transient population has almost no effect on the community.

2.4.2 Socioeconomic profile

2.4.2.1 Social profile

Privately owned homes in Buffalo comprise 79% of the dwelling units. There are no public housing units. There is a police force of seven and a volunteer fire department. Buffalo has a high school and an elementary school, whose enrollments are 410 and 680 respectively. The ratio of students to teachers is 18.8, and the total expenditure per student was about $1300 in 1976. Buffalo is served by five physicians and three dentists. The local hospital has 24 beds and an occupancy rate of 66%.

2.4.2.2 Economic profile

Buffalo has a combined labor force of 2810 workers, of whom 1913 (68%) are male and 897 (32%) are female. The unemployment rate is 2.8% for the total work force.

Statistics on the distribution of employment are tabulated in Table 2.4.

The total assessed tax value of Johnson County is $42,975,195, of which $4,231,289 lies within the city of Buffalo.

The bonded indebtedness for the city is $113,000 and for the school district $140,000. The total tax revenue collected in 1975 by Johnson County was $2,287,437, and the city of Buffalo collected $299,389.

The distribution of the tax levy for the county, city, and school district for 1970, 1974, and 1975 is tabulated in Table 2.5.

2.5 LAND USE

2.5.1 Land resources

Cattle and sheep ranching are the major land uses in the region surrounding the proposed project site. About 94% of the land in the Powder River Basin is classified as rangeland.[6] Native rangeland vegetation provides the majority of the livestock forage in the region. Major native forage species are blue grama grass (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), needlegrasses (*Stipa* spp.), prairie june grass (*Koeleria cristata*), and numerous forbs. Crested wheatgrass (*Agropyron desertorum*), the principal introduced forage plant, is often planted on reclaimed disturbed land.

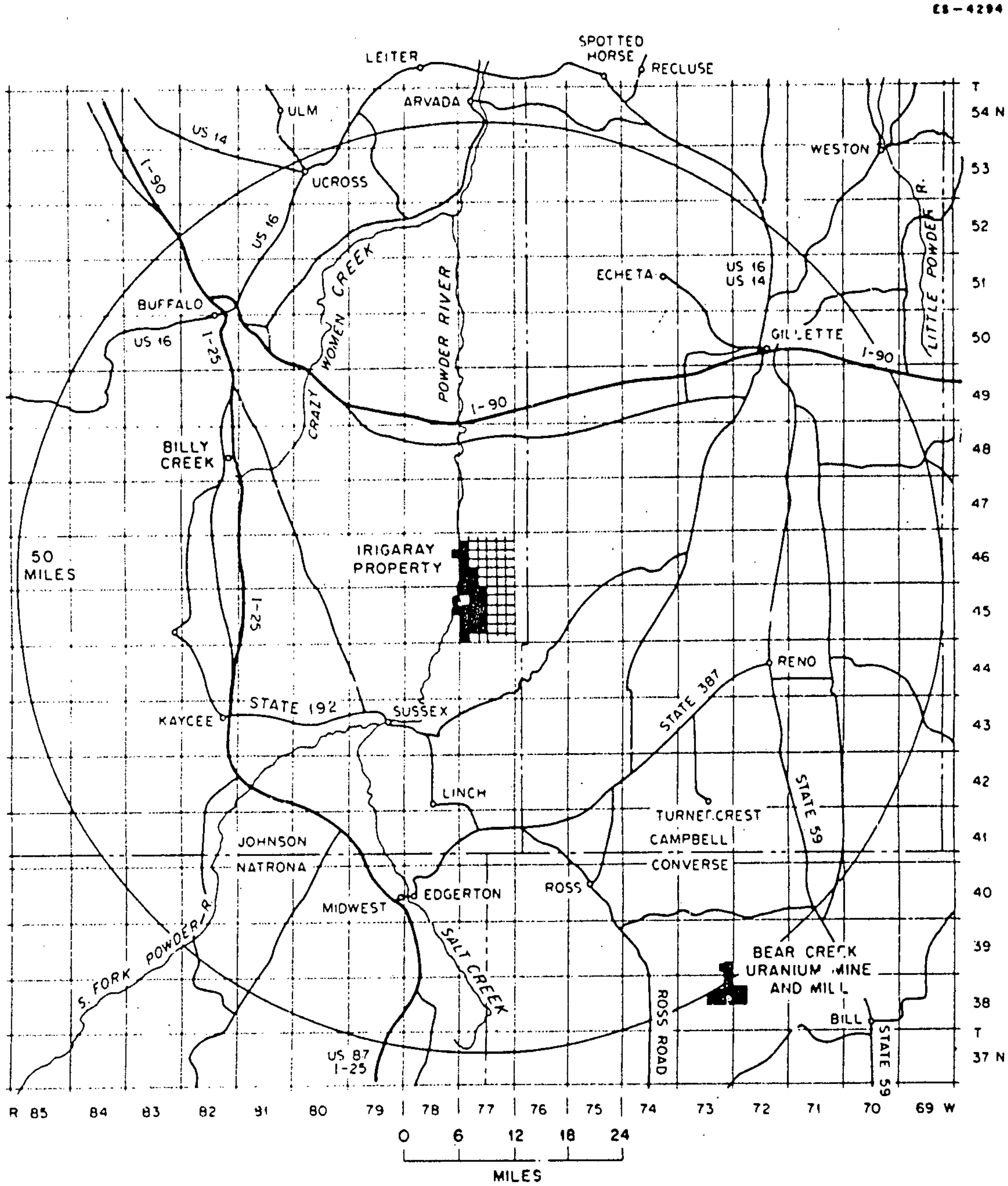

Fig. 2.3. Irigaray property and the surrounding area.

Table 2.4. Distribution of labor force

Contract construction	236
Transportation, communications, and utilities	85
Finance, insurance, and real estate	55
Service with local government	218
Mining	205
Manufacturing	96
Wholesale trade	11
Retail trade	365
Federal government	35
Agriculture	640
Nonagricultural	720
Other	144
Total	2810

Table 2.5. Tax levy

Unit	Tax levy (mills)		
	1970	1974	1975
City	7.7	17.6	17.09
County	29.5	9.5	12.56
School	18.3	40.6	41.10
Total	55.76	68.5	70.76

The area within a 15-km (9-mile) radius of the WMC site includes portions of five ranches. Table 2.3 lists the populations at the headquarters of these ranches and their distances from the WMC site. All of the Irigaray site is currently grazed. According to . generalized land use map of Johnson County,[7] the majority of the land on the proposed site is classified as fair to poor rangeland. From past grazing records of the site filed with the Bureau of Land Management District Office in Buffalo, the grazing capacity of the land is estimated to be 3.5 ha (9 acres) per animal unit month (ER, p. 89). The land along the floodplains of Willow Creek and the Powder River, with its denser cover of perennial grasses, is better rangeland and may have a grazing capacity of 0.8 to 1.5 ha (2 to 4 acres) per animal unit month.[6]

Major transportation routes in Johnson County are shown in Fig. 2.3. Access to the proposed WMC site is from Wyoming Highway 192 just west of Sussex via a graveled light-duty road.

Extraction of energy-related minerals is the major industrial land use in the Powder River Basin. Mineral resources of the region are discussed in detail in Sect. 2.7.2. Oil and gas production and, more recently, coal and uranium mining have been significant factors in the economy of the Powder River Basin. Future trends in land use point to more land being committed to minerals production.[6,8]

Since the land is privately owned, recreational uses of the WMC site and adjacent lands are limited. Hunting is permitted by some landowners. Pronghorn antelope and mule deer are the most important game species. Upland game birds, primarily sage grouse, and small game such as cottontail rabbits are a minor hunting resource.

2.5.2 Historical and archaeological sites and natural landmarks

The archaeologic and paleontologic resources of the Powder River Basin remain largely uninvestigated. Most known archaeologic sites in the region were found as a result of surveys connected with recent minerals-related development in Campbell County, 65 km (40 miles) to the east of the WMC site. The nearest known sites of paleontologic value are located approximately 8 km (5 miles) west of the WMC site at the Reculusa blowout.[6] Mammalian fossils of Eocene age have been collected from the Reculusa sites.[6] Since no major excavation is anticipated at the proposed project, no survey of archaeologic and paleontologic resources has been conducted on the WMC site.

There are no sites within the WMC site boundaries that are currently listed on the National Register of Historic Places, nor any that have been determined to be eligible for inclusion, nor any that have been nominated for consideration of eligibility. This statement is based on a search of the latest listing of the National Register[9] and all weekly and monthly supplements. The Hoe Ranch, located within the WMC site boundaries (Fig. 2.4), is not a National Register site but has some historic value as a ranch headquarters that entered into the history of the Johnson County range wars.[6] The site consists of a massive stone chimney and other ruins of the old ranch. The Hoe Ranch has not been nominated for consideration of eligibility for inclusion into the National Register. The locations of National Register sites near the WMC site are shown in Fig. 2.4. Fort Reno and Cantonment Reno are currently included in the National Register.[9,10] The Portuguese Houses site has been determined as eligible for inclusion into the National Register.[11]

Based on a search of the National Registry of Natural Landmarks and all current supplements, there are no natural landmarks in the vicinity of the WMC project area.[12]

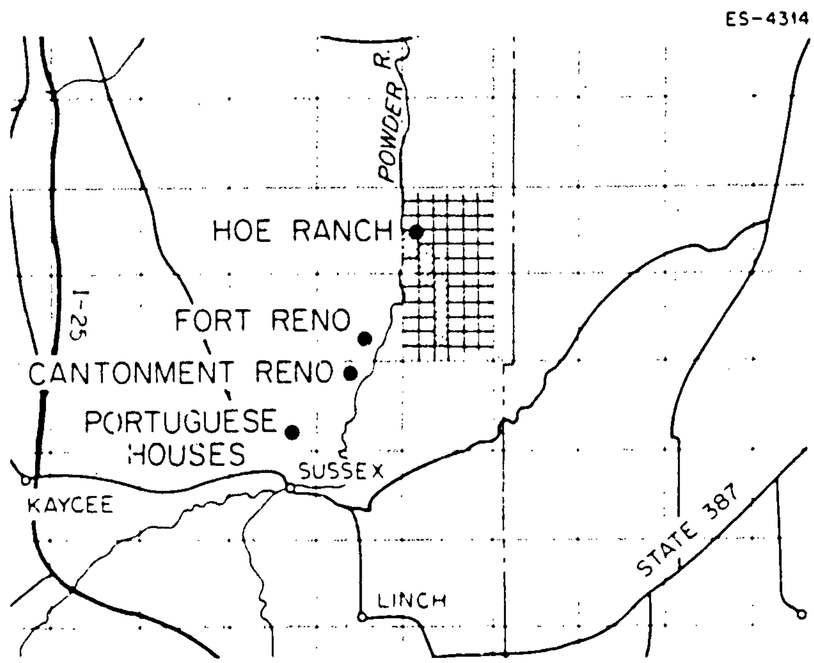

Fig. 2.4. Historic sites in the vicinity of the WMC site.

2.6 WATER

2.6.1 Surface water

The Powder River rises near the center of Wyoming and flows northward, draining 8% of Wyoming's area. WMC's Irigaray site is adjacent to the Powder River (Fig. 2.5). Willow Creek, which flows intermittently westward across the central part of WMC's site, is a tributary of the Powder River. The WMC plant and several well fields lie near the Willow Creek streambed (Figs. 2.7 and 4.4).

The surface waters of Johnson County are described by Wendell et al.[13] The Powder River is fed by both surface flows and groundwater. Most of the streams feeding the Powder River rise in the Bighorn Mountains, where precipitation is highest. As shown in Fig. 2.6, most of the runoff occurs during the months of March through July, due to heavy winter snowpacks and rainfall caused by air rising over the Bighorn Mountains.

The flow and character of surface streams depend on geology, topography, vegetation, and climate. Nonmountain streams have low flows and high sediment loads. Soil erosion is a problem in the basin area due to sparse cover, easily eroded soils, and nonresistant rock units. Some surface streamflows are apparently lost to groundwater recharge as they cross carbonate rocks in the mountains, but most of the streamflows emerge as springs and seeps in the foothills.[13]

The U.S. Geological Survey gaging stations on streams near the WMC site are listed in Table 2.6 and shown in Fig. 2.5. Data regarding discharge and water quality at these stations are summarized in Tables 2.6 and 2.7. WMC provided data regarding water quality in the Powder River at two points near the plant (ER, p. 83). WMC's "upstream" station is located about 9 km (5.7 miles) southwest of WMC's plant. WMC's "downstream" station is located about 5 km (3 miles) northwest of the plant site at the Irigaray Ranch. These sampling locations are shown in Fig. 2.7. Water quality data from these stations are presented in Table 2.8.

Water quality in the Powder River varies greatly, as indicated in Table 2.7. The pattern described by Kittrell often applies,[14] namely, the concentrations of many parameters, such as alkalinity and hardness, often vary inversely with streamflows. During periods of low flow, most streamflow is water that has entered the stream from groundwater (ER, p. 79). Water in shallow aquifers generally has a higher dissolved solids concentration than the runoff from precipitation. At lower streamflows, higher dissolved solids concentrations generally occur and often exceed that of the aquifer source, due to the evaporative concentration in stream channels.[15]

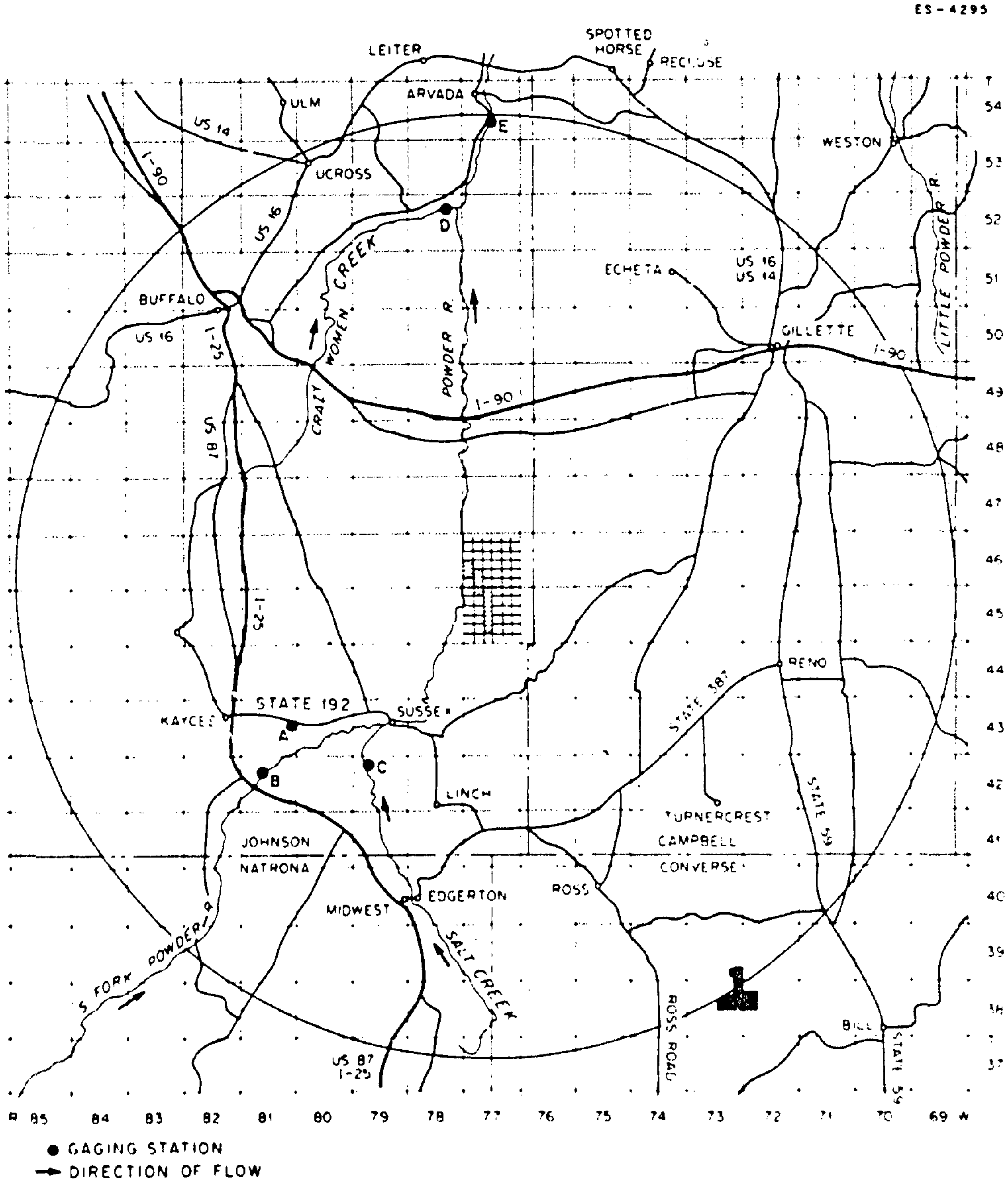

Fig. 2.5. U.S. Geological Survey stream gaging stations near the Irigaray site.

In the Powder River the total dissolved solids concentrations usually exceed the recommended drinking water criteria for chloride and sulfate of 250 mg/liter.[16] Total dissolved solids concentrations frequently exceed 3000 mg/liter, and such water may produce undesirable effects when used for livestock watering or irrigation.[17]

The Wyoming Department of Environmental Quality considers the Powder River at Salt Creek and Arvada to contain "problem segments." Below its confluence with Salt Creek, the Powder River shows high salt concentrations. Salt Creek consists mainly of wastewater from oil field operations. Flows from Salt Creek added 47% of the salinity recorded in the Powder River at Sussex during water year 1976.[18] The Powder River at Arvada exceeds standards and criteria for many parameters, including fecal coliforms, chromium, mercury, iron, and cadmium. Dissolved oxygen concentrations below the recommended level are also found.[18] The Department of Environmental Quality believes that diffuse nonpoint sources are responsible for high metal concentrations. Oxygen depletion is a result of low flow conditions in the summer; runoff from grazing areas produces occasional excesses of fecal coliforms.[18]

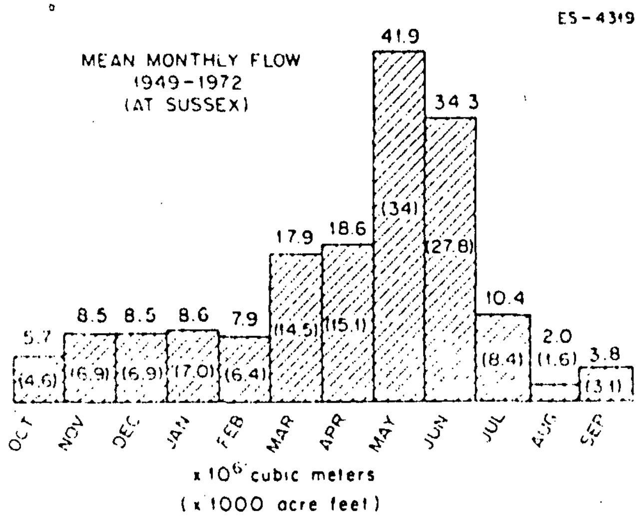

Fig. 2.6. Mean monthly flows on the Powder River at Sussex, 1949-1972. Source: W. G. Wendell et al., *Johnson County, Wyoming, Geologic Map, Atlas, and Summary of Land, Water, and Mineral Resources*, County Resource Series No. 4, Geologic Survey of Wyoming, 1976.

Table 2.6. U.S. Geological Survey stream gaging stations near the Irigaray site

Figures are for water years 1972, 1973, and 1974

Map code	Station No.[a]	Station name	Drainage area (sq miles)	Discharge (cfs) Range	Discharge (cfs) Average
A	3125	Powder River near Kaycee	980	0.68 920	126.6
B	3130	South Fork Powder River near Kaycee	1150	0 165	23.9
C	3134	Salt Creek near Sussex	765	5.9 110	29.0
D	3164	Crazy Woman Creek at upper station near Arvada	945	0.2 770	45.6
E	3170	Powder River near Arvada	6050	9.1 2050	350.7

[a] Locations of stations are shown in Fig. 2.5. Listed in downstream order.

Source: U.S. Geological Survey, *Water Resources Data for Wyoming*, Part 2, *Water Quality Records 1972, 1973, and 1974*.

Willow Creek is normally dry (ER, p. 84). During the spring, snowmelt and discharge from high water tables may produce flow for periods of several weeks. Runoff from convective storms may also cause temporary flow in Willow Creek. The applicant uses analyses from the U.S. Geological Survey[17] to calculate flood risk. Willow Creek's drainage is approximately 250 km^2 (96 sq miles). The mean annual flood discharge is predicted to be 19,255 liters/sec (680 cfs). A flood with a 50-year recurrence interval would have a discharge of 168,310 liters/sec (5944 cfs) (ER, p. 84). Floods could interrupt project operations.

There are no data available that describe the water quality in Willow Creek.

2.6.2 Groundwater

2.6.2.1 Hydrologic units

Hydrologic units on the Irigaray site include surface alluvium, the Wasatch Formation, and the Fort Union Formation, both of Cenozoic age. Older rocks are at least 1219 m (4000 ft) below the Irigaray site, and little is known of their hydrologic characteristics. Solution mining will be limited to the Wasatch Formation, which is about 480 m (1575 ft) thick in the Pumpkin Buttes area (see Sect. 2.7.1).

The following description of the major hydrologic units comes from Hodson and others[18] and is not site-specific unless so indicated.

Table 2.7. Summary of monthly water quality data for the years 1972–1974 for Powder River and tributaries near the Irigaray site

Station[a] code	Dissolved solids (sum of constituents) (mg/liter)	Dissolved Fe[b] (μg/liter)	Dissolved bicarbonate (mg/liter)	Dissolved sulfate (mg/liter)	Dissolved nitrate (mg/liter)	Specific conductance (micromhos)	pH
A (Powder River)							
Range	263–1306	0–200	119–287	100–672	0–2.9	421–1750	7.6–8.3
Average	827	68	244	265	1.2	1190	8.09
Min discharge (6/20/74)	1220		262	632	0.2	1710	8.1
Max discharge (5/17/72)	263	50	119	100	2.8	421	7.9
B (South Fork)							
Range	1590–4390	0–470	104–345	990–2300	0–19	2040–5460	7.7–8.4
Average	2310	97	182	1560	2.96	3099	7.99
Min discharge (12/15/71)	3790	10	345	2300	3.3	4570	7.8
Max discharge (4/12/73)	2280	470	162	1500	4.0	2760	8.0
C (Salt Creek)							
Range	3070–5660	0–440	453–1410	93–1790	0–34	4440–8370	7.5–8.4
Average	4710	141	862	1279	1.3	6843	8.0
Min discharge (11/20/73)	5650		1180	1300	0.7	7820	7.9
Max discharge (4/21/72)	3710	50	453	1700	0.2	5140	7.8
D (Crazy Woman)							
Range	300–2360	0–1000	74–360	130–2000	0.2–3.7	508–3340	7.2–8.4
Average	1208	166	229	748	0.69	1551	8.03
Min discharge (8/7/74)	2360		360	1500	0.7	2670	7.9
Max discharge (2/29/72)	289	20	74	150	3.7	443	7.5
E (Powder River)							
Range	766–3207	0–590	145–620	380–1500	0.02–2.3	1110–4430	7.4–8.4
Average	1903	137	278	1122	0.83	2639	7.92
Min discharge (7/17/73)	2600	90	256	1300	0.4	3430	7.7
Max discharge (4/23/74)	2060		150	1300	1.4	2580	8.1

[a] Locations are shown in Fig. 2.5.

[b] Data regarding concentration of Fe were collected only in 1972–1973.

Alluvium

The alluvial aquifer consists of thin, unconsolidated clay, silt, sand, and gravel. Its thickness varies from less than 0.3 m (1 ft) on topographically high areas to as much as 30 m (100 ft) along the major river valleys. Well yields range from a few to 1000 gallons per minute (gpm), depending on the saturated thickness of the alluvium, grain sorting, well construction, and development methods. Total dissolved solids range from about 100 to over 4000 mg/liter but are more commonly 500 to 1500 mg/ liter. Water in the alluvium from the Powder River valley and central Powder River Basin is generally of a poorer quality than elsewhere in the basin.

Wasatch Formation

The Wasatch Formation yields water from lenticular sandstone bodies. Smaller volumes are derived from jointed coal and clinker beds. Well yields range from 10 to 15 gpm in the northern part of the basin but may be over 500 gpm in the southern Powder River Basin. The specific capacity of wells varies from 5 to 14 gpm per foot of drawdown. Total dissolved solids range from less than 200 to more than 8000 mg/liter but are more commonly 500 to 1500 mg/liter. There is no apparent relationship between depth and water quality, but total dissolved solids concentration generally decreases to the south.

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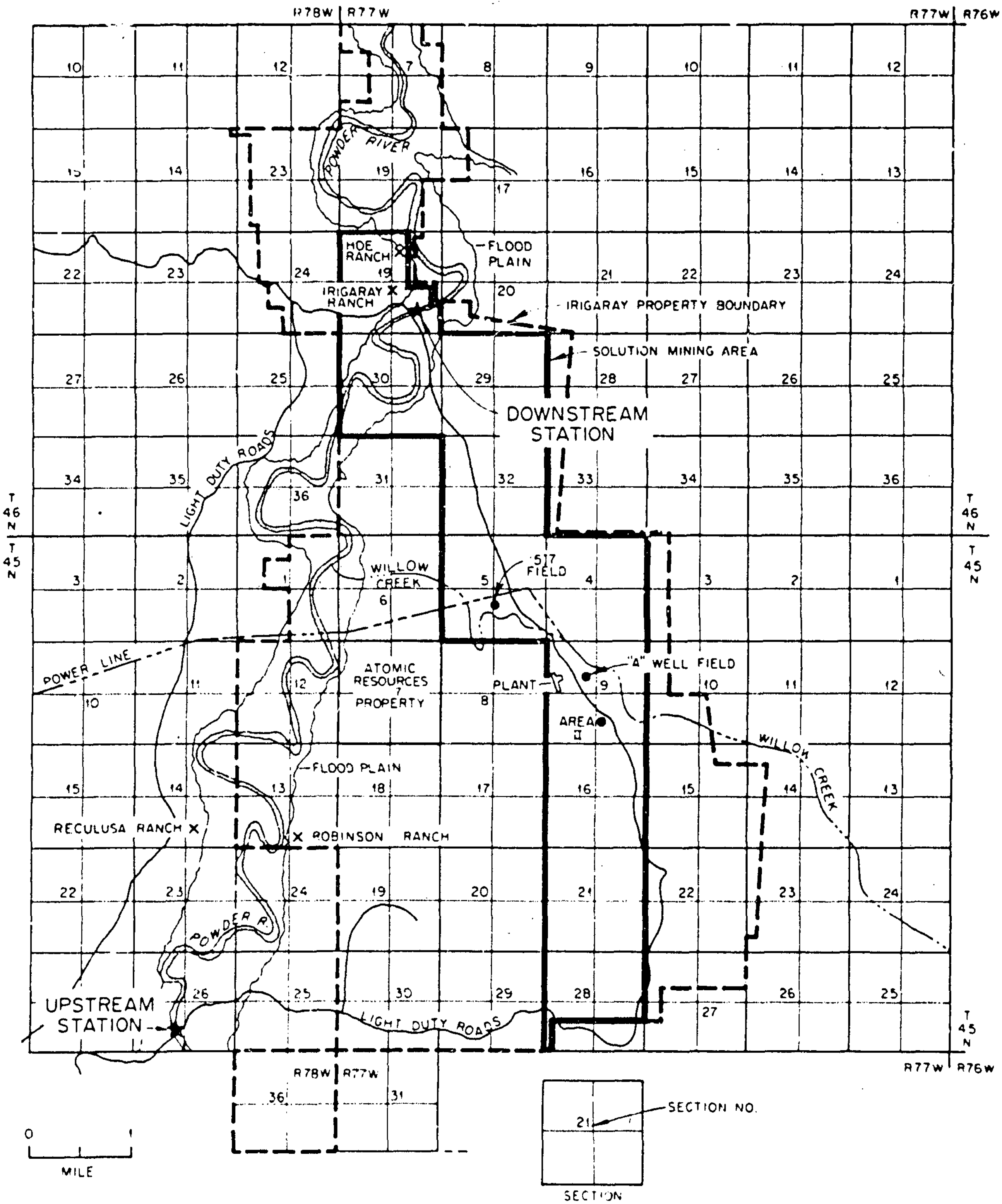

Fig. 2.7. Locations of WMC's sampling points in the Powder River.

Table 2.8. Water quality data for the Powder River upstream and downstream from WMC Irigaray plant site

Analysis	Unit	Station[a]	
		Upstream	Downstream
As	ppb[b]	5.0	6.5
Ba	ppm[c]	0.30	0.33
B	ppm	0.71	0.60
Cd	ppb	7.0	7.0
Cr	ppb	14	36
Cu	ppb	12	28
Mn	ppm	0.05	0.27
Hg	ppb	0.40	0.27
Ni	ppb	30	52
Se	ppb	<5	<5
Ag	ppb	6	<5
Zn	ppb	0.03	0.09
Pb	ppb	42	62
Total dissolved solids	ppm	2,090	2,110
Ra-226	pCi/liter	0.9 ± 0.5	1.0 ± 0.5
Gross alpha	pCi/liter	19 ± 7	13 ± 6
Gross beta	pCi/liter	46 ± 17	42 ± 17

[a]Station locations are shown in Fig. 2.6. Upstream station is located adjacent to the river in the southwest quarter of Section 26, T45N, R78W; downstream station is located at Irigaray bridge near the Irigaray Ranch, Section 19, T46N, R77W.

[b]ppb is parts per billion.

[c]ppm is parts per million (equivalent to mg/liter).

Source: ER, p. 83.

Fort Union Formation

The Fort Union Formation yields water from fine-grained sandstone and jointed coal and clinker beds. Maximum yields are about 150 gpm. The specific capacity varies from 0.3 to 0.9 gpm per foot of drawdown. Total dissolved solids range from about 200 to over 3000 mg/liter but are usually between 500 and 1500 mg/liter. The water type is primarily sodium bicarbonate and secondarily sodium sulfate.

2.6.2.2 General characteristics

The Powder River Basin is a relatively independent groundwater system. Recharge to both the Wasatch and Fort Union formations in most of the Powder River Basin is by precipitation.[19] Discharge is by evaporation, springs, transpiration by plants, and well pumpage. Annual water-level fluctuations in observation wells are small, indicating a balance between recharge and discharge.[19] The water table for the Wasatch Formation is relatively shallow in the western part of the basin.

A regional potentiometric surface map of the Wasatch Formation aquifer, as provided by the applicant, is shown in Fig. 2.8. The equipotential lines are based on water level readings in wells taken by WMC in 1974. The regional hydraulic gradient is approximately 0.005 ft per foot to the north-northwest, and the estimated groundwater flow rate is 5 to 8 ft/year. The groundwater moves approximately parallel to the long axis of the ore body. Beneath the Powder River floodplain, however, groundwater moves upward through the Wasatch Formation and discharges into the Powder River[20] (Fig. 2.9).

2.6.2.3 Site-specific groundwater characteristics

Local variations in the groundwater flow rate are to be expected in the fluvial sedimentary deposits underlying the Irigaray site (Sect. 2.7.1.2). At Irigaray pilot-scale test site 517 (Fig. 2.10) the hydraulic gradient averages 0.033 ft per foot to the west and the groundwater flow rate as calculated by the staff, is about 60 ft/year. Groundwater level monitoring data, gathered from June 1976 through October 1976, indicate at least 3 m (10 ft) of fluctuation in groundwater levels; water levels were high in June and low in October.

Aquifer tests of the Upper Irigaray sandstone were conducted by the applicant at three locations from 1975 to 1977 (Fig. 2.10). Test analyses indicate that transmissivities ranged from 373 to 1410 gpd/ft. Storage coefficients varied from 1.85×10^{-4} to 7.44×10^{-5}, indicating that the aquifer system is under artesian head. The primary direction of groundwater flow and major hydraulic conductivity is to the northwest.

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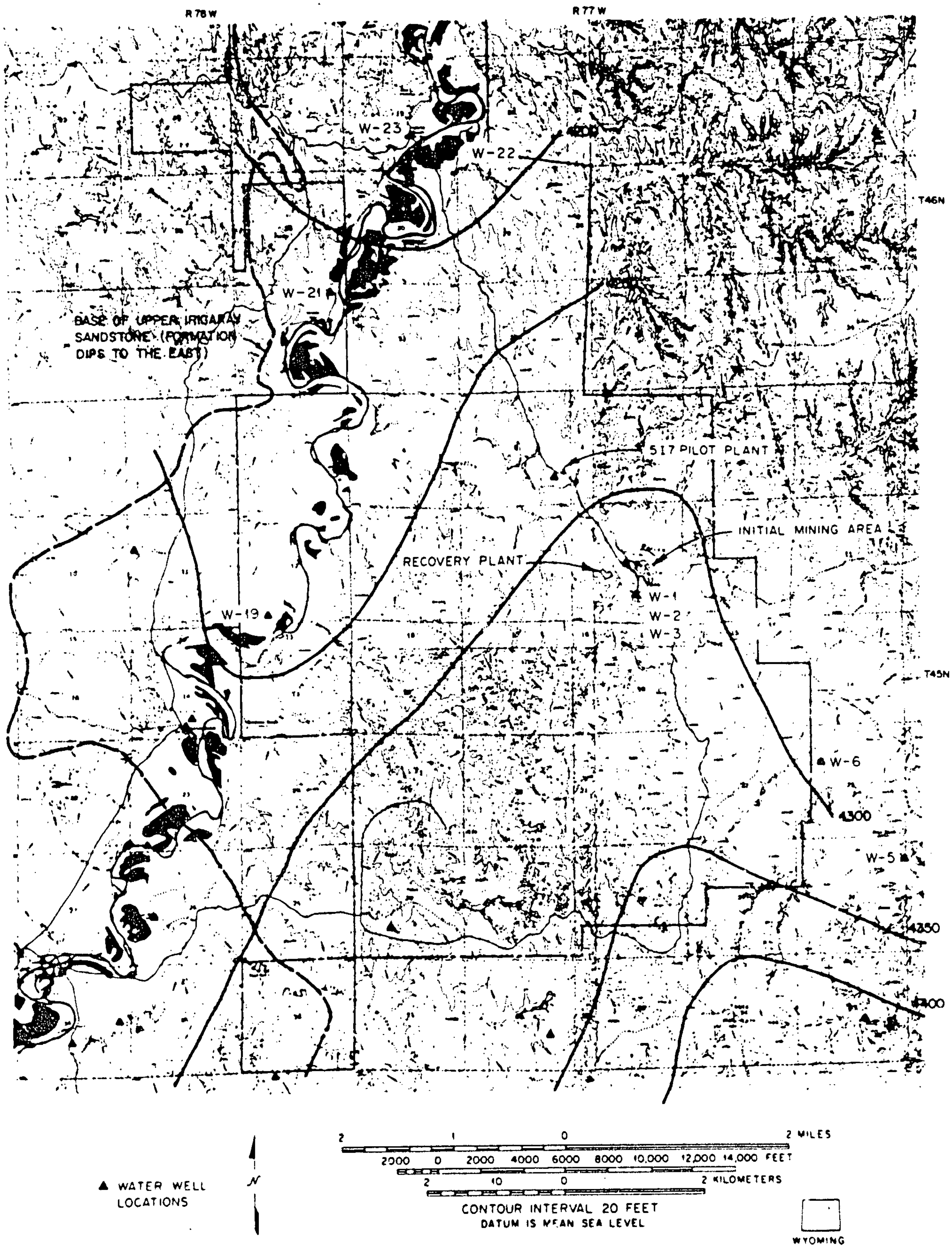

Fig. 2.8. Elevation contour map of potentiometric surface, Wasatch Formation, Irigaray, Wyoming. W-1, W-2, etc., indicate the location of wells listed in Appendix B, Table B.1. Note: W-1, W-2, and W-3 are WMC test wells, and the nearest private wells are W-6, W-22 and W-23.

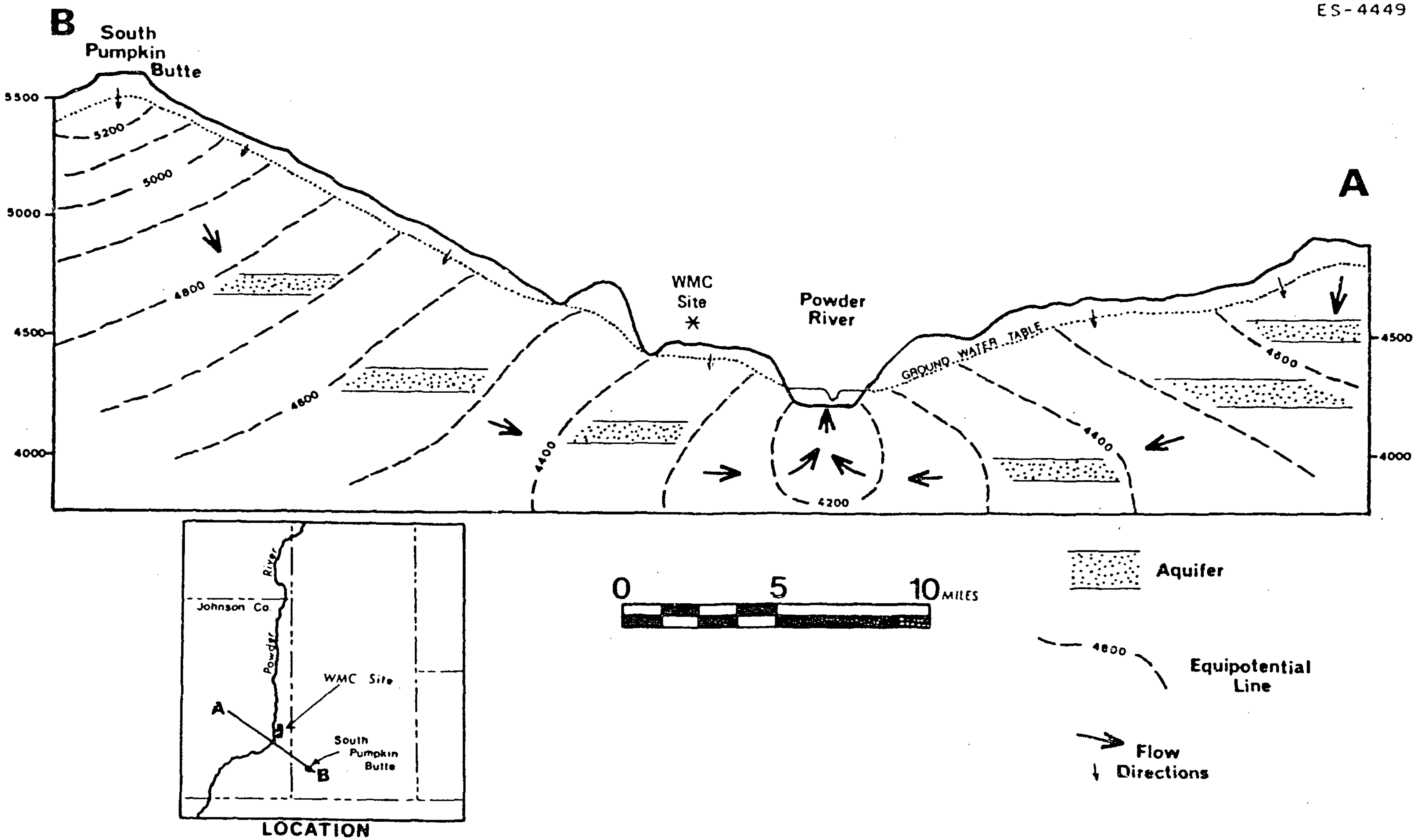

Fig. 2.9. Regional groundwater flow pattern in the vicinity of the Irigaray site. Note the orientation of the insert. Source: Modified from J. Faqmaier, *Groundwater Flow, Hydrochemistry, and Uranium Deposition in the Powder River Basin, Wyoming*, Ph.D. dissertation, University of North Dakota, 1971.

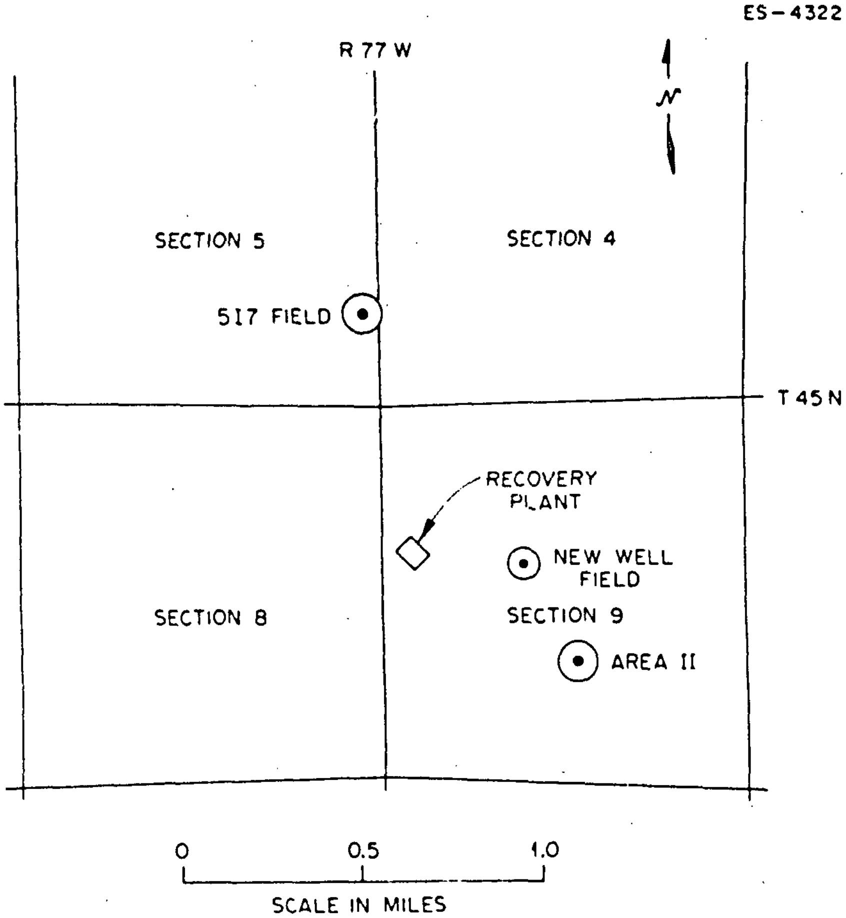

Fig. 2.10. Locations of pump test sites (circles).

The area II site was tested in August 1975, using two observation wells in addition to the pumped well. This continuous-drawdown test was conducted for 27 hr at a pumping rate of approximately 20 gpm. The drawdown at the end of the test was 30 m (100 ft), indicating that the pumped well's specific capacity is about 0.2 gpm per foot of drawdown. Transmissivities ranged from 925 gpd/ft for the pumped well and 1035 and 1100 gpd/ft for the two observation wells. Calculated storage coefficients were 3.6×10^{-5} and 6.7×10^{-5}.

An aquifer test was conducted at the 517 pilot-scale test field during November 1975. The test consisted of a 19-hr continuous-drawdown test at a pumping rate of 15 gpm. There were eight observation wells in addition to the pumped well. The drawdown at the conclusion of the test was 49 ft; the specific capacity of the pumped well was therefore approximately 0.3 gpm per foot of drawdown. The 37-m (120-ft) aquifer was only partially penetrated; however, no partial penetration corrections were deemed necessary by the applicant in the test analyses. Transmissivity values derived from observation well data ranged from 1030 to 1410 gpd/ft. Storage coefficients varied between 1.85×10^{-4} and 7.44×10^{-5}. Major and minor hydraulic conductivities were 11.6 and 6.7 gpd/ft^2 (566 and 327 ft/year), and the hydraulic gradient was 0.033 to the west-northwest.

The proposed production area site was tested in February 1977. The 15-hr continuous-drawdown test was conducted by pumping one well at a rate of 10 gpm and noting the effects on four observation wells. All wells partially penetrated the aquifer thickness. Transmissivity values ranged from 373 to 770 gpd/ft. Storage coefficients varied between 1.0×10^{-5} and 2.6×10^{-4}. The hydraulic gradient at the proposed production site was approximately 0.009, due west.

Limited data were supplied to analyze accurately the groundwater environment at the Irigaray site. From the information contained in the applicant's pump tests, however, some tentative conclusions can be made. The various field tests indicate that the aquifer is anisotropic and heterogeneous in nature. Furthermore, the range in values of calculated storage coefficients suggests a leaky (locally unconfined) artesian system.

Conclusions based on the above described aquifer tests can be misleading. While they may be used to generalize the hydraulic characteristics of the aquifer, individual lenses or channels within the aquifer may behave quite differently. If the production test and observation wells do not penetrate a particular channel sand, its hydraulic characteristics cannot be measured directly. Parameters such as hydraulic conductivity may be an order of magnitude too low, for example, if good hydraulic connection between wells is not established through the main channel of a buried channel sand. The penetration of high permeability lenses or channels is often a matter of chance.

2.6.2.4 Groundwater quality

The applicant initiated groundwater quality studies in 1974 with sampling and analysis of surrounding private wells. Additional site-specific groundwater studies have been conducted at both pilot-scale test sites, and groundwater sampling is continuing in the proposed initial well field. Groundwater data supplied by the applicant are contained in Appendix B.

In general, waterwells in the area supply water from the Wasatch Formation, which also contains the uranium deposit to be mined. Most of these wells are used for domestic and stock-watering purposes. Groundwater from wells within an 8-km (5-mile) radius of the site generally meets EPA drinking water standards. One private well on the Irigaray site (W-6, Appendix B, Table B.1) exceeded the standards with a selenium level of 0.07 ppm (EPA and USPHS drinking water standard is 0.01 ppm and the State of Wyoming wildlife and livestock limit is 0.05 ppm).[21-24] Total dissolved solids are low (less than 500 ppm), and the predominant cation and anion are sodium and sulfate. Water quality data (Appendix B, Table B.1) can be compared with the various water quality criteria and toxic concentrations listed in Table 6.2.

Groundwater has also been sampled and analyzed by the applicant in the immediate vicinity of the uranium ore deposits (mineralized zone). The pilot scale-test area in Section 9 is near the center of the proposed initial well field. Water samples were taken from November 1976 to February 1977 from wells in the mineralized zone and from wells located at distances of 61 and 137 m (200 and 450 ft) from the test well field (see Table B.3, Appendix B, for complete data and Fig. 4.4 for well locations). Some of these wells, however, may be located in the mineralized zone because they encircle the test well field. As shown in Table 2.9, the groundwater chemistry from these wells exhibits considerable variability. Groundwater in the mineralized zone (production well zone) generally exceeds drinking water standards for radium, uranium, and gross alpha (Table 2.9). At distances of a few hundred feet from mineralized areas (depending on rock structure and configuration of the ore body) the groundwater generally meets drinking water standards. Complete water quality data from wells in the vicinity of the mineralized zone are contained in Appendix B and include wells W-1, W-2, and W-3 in Table B.1, Table B.2, and Table B.3.

Table 2.9. Selected groundwater chemistry data from wells on the site and relevant water standards

Species	Concentration: Production well zone	Concentration: Monitor well zone	Drinking water standards[a]	Wyoming wildlife and livestock standards[b]
As, ppm	<0.01–0.10	<0.01–0.01	0.05	0.20
Cl, ppm	9.7–12.5	12.1–17.0	250	2,000
NO_3 (as N), ppm	0.32–0.58	0.42–0.78	10.0	
NH_4, ppm	<0.2–0.18	<0.2–0.24		
Th-230, (pCi/liter)	0.2–9.0	0.08–0.9		
U, ppm	0.34–11.96	0.02–0.09	5.0	
Ra-226, (pCi/liter)	23.5–144.3	0.3–6.8	5.0	
Gross alpha, (pCi/liter)	122.4–6,341	2.9–19.4	15	
Gross beta, (pCi/liter)	117.8–1,644	63.2–102.0	1,000	

[a]Drinking water standards are from: U.S. Public Health Service, *Drinking Water Standards*, PHS Publication 956, 1962. U.S. EPA, "National Interim Primary Drinking Water Regulations," *Fed. Regist.* 40 (248): 59566–59577 (1975). U.S. EPA, "Proposed National Secondary Drinking Water Standards," *Fed. Regist.* 42 (62): 17143–47 (1977).

[b]Wyoming Department of Environmental Quality, Land Quality Division, Guideline No. 4 (Revised), Part II: Water Quality Criteria for Wildlife and Livestock Impoundments, Nov. 9, 1977.

Premining (baseline) groundwater quality values for the proposed well fields will be obtained as discussed in Sect. 8.1.5.2.

2.6.3 Water use

Availability of water is a major factor influencing activity in the Powder River Basin of Wyoming. Surface and groundwaters are used primarily to support ranching. Irrigation accounts for the largest part of consumptive water use in the region. Most of the irrigated acreage is used to produce hay for winter feeding.[25] Municipal, domestic, and industrial uses of water are relatively minor, but these usages are expected to increase, particularly industrial usage associated with energy development.[26] Based on data obtained in 1974 from the Wyoming State Engineer's office, the Bureau of Land Management tabulated the average annual streamflow and water use from the Powder River in Wyoming,[27] as shown by the following:

	Acre-feet per year	
State live streamflow under natural conditions		419,100
Man's depletions of streamflow in Wyoming:		
Irrigation	66,100	
Municipal, domestic, and stock	2,100	
Industrial	700	
Reservoir evaporation	27,600	-96,500
Depleted streamflow leaving Wyoming		322,600

Near the WMC site, water is used only for livestock watering and private water supply. The applicant states that there is no irrigation farming within the area (ER, p. 69). Although there are no quantitative data describing water use near the WMC site, it is assumed to be small due to the low densities of people and livestock. Figure 2.8 shows the locations of private wells in the area. Wells are located mostly on the floodplain of the Powder River, with the nearest wells used for drinking water located 6.5 km (4.4 miles) northwest (Irigaray Ranch) and southwest (Reculusa Ranch) of the plant site.

2.7 GEOLOGY, MINERAL RESOURCES, AND SEISMICITY

2.7.1 Geology

2.7.1.1 Regional geology

The stratigraphic succession in the western Powder River Basin is shown in Fig. 2.11. The uranium-bearing unit to be mined is in the Wasatch Formation, of Eocene age.

2.7.1.2 Wasatch Formation

Sediments of the Wasatch Formation were deposited approximately 40,000,000 years ago after late Paleocene uplift caused erosion and locally tilted the Fort Union Formation.[28] The resulting increased stream gradient in early Eocene time caused rapid erosion of the mountains, and powerful streams carrying coarse debris flowed far into the Powder River Basin. Based on sediment coarseness, cross bedding, and mineralogy, Sharp and Gibbon indicate a source area to the south exposing Precambrian igneous and metamorphic rocks.[29] Figure 2.12 is a map showing the Eocene paleography of northeast Wyoming.

During flood stage the rivers overflowed their banks and, depending on local topography, deposited thick to thin layers of silt and clay over extensive areas of the basin. The contemporaneous deposition of coarse channel sands and fine floodplain deposits resulted in rapid lateral changes in lithology over short distances. Figure 2.13 is a generalized geologic map of northeast Wyoming and shows the general distribution of coarse- and fine-grained clastic rocks in the Wasatch Formation. Sharp and others indicate that the sandstone units are restricted to the central part of the basin but that in this area sandstones occur erratically throughout the Wasatch Formation.[28] Along the periphery of the basin, thick coal beds accumulated where deposition of clay predominated. The predominance of gray and generally drab-colored fine-grained flood deposits, plus peripheral coal beds, suggests deposition in a reducing environment during Wasatch time.

In the Pumpkin Buttes area, a few miles southeast of the Irigaray site, the Wasatch Formation is about 480 m (1575 ft) thick and consists of claystone, some marlstone, siltstone, carbonaceous shale, thin lignite, and fine to very coarse, poorly sorted sandstone. The following brief descriptions of the major lithologic units in the Wasatch Formation are from Sharp and others[28] from their studies in the Pumpkin Buttes area.

Stratigraphic Column

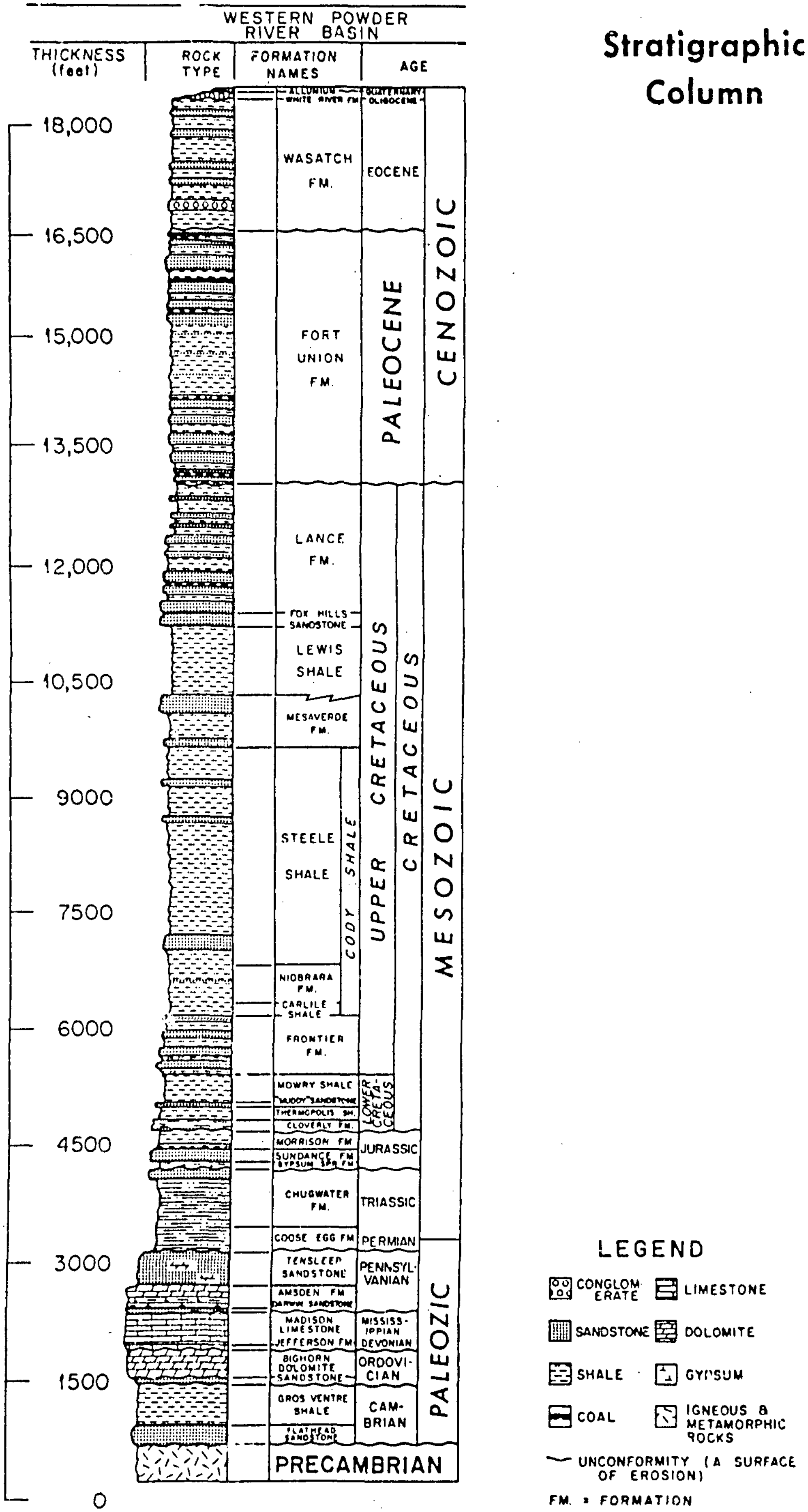

Fig. 2.11. Stratigraphic succession in the western Powder River Basin, Wyoming. Source: W. M. Sharp, E. J. McKay, F. A. McKeown, and A. M. White, *Geology and uranium deposits of the Pumpkin Buttes area of the Powder River Basin, Wyoming*, U.S. Geol. Survey Bull. 1107-H, 1964.

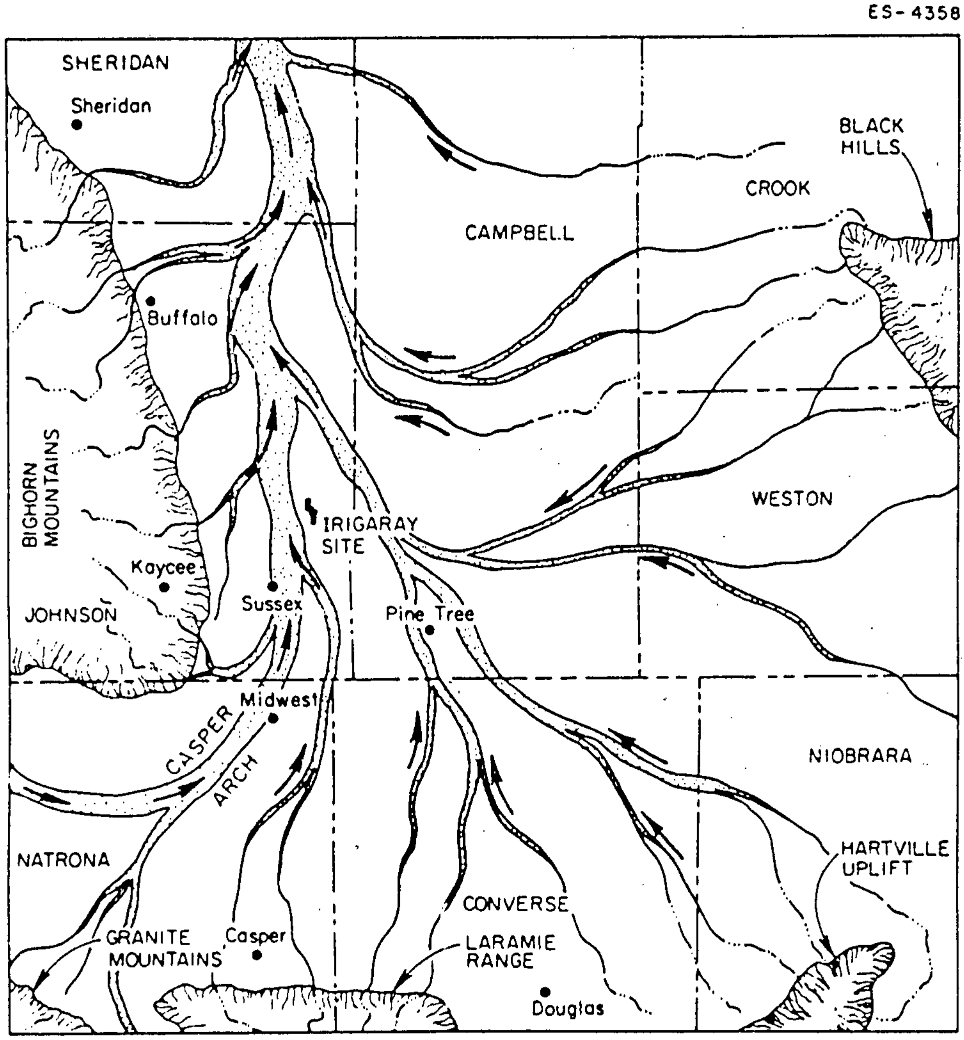

Fig. 2.12. Eocene paleogeography of northeast Wyoming. Source: Modified from David A. Seeland, "Relationships Between Early Tertiary Sedimentation Patterns and Uranium Mineralization in the Powder River Basin, Wyoming," in *Geology and Energy Resources of the Powder River, Wyoming Geological Assoc. 28th Annual Field Conference Guidebook,* Casper, Wyo., 1976.

The claystone is medium-dark gray to dark greenish gray in beds 1.5 to 3.0 m (5 to 10 ft) thick. Some claystone beds are up to 9 m (30 ft) thick and can be traced laterally into siltstone or carbonaceous shale or are cut by channels of coarse-grained sandstone. Siltstone is the most abundant rock type in the Wasatch Formation and is drab yellowish brown to pale yellowish gray in thin to thick beds. Carbonaceous shale beds several feet thick and containing coarsely crystalline gypsum are numerous, and some can be traced more than 16 km (10 miles). Sandstone constitutes one-third of the thickness of the Wasatch Formation at Pumpkin Buttes, and solution mining at the Irigaray site will be within a channel sandstone. Therefore the characteristics of these deposits will be discussed in more detail.

Sandstone units in the Pumpkin Buttes area vary from a few feet to over 30 m (100 ft) thick but are commonly 0 to 9 m (20 to 30 ft) thick. Because most of the sandstone deposits are of fluvial origin, they fill distinct channels and are elongate in shape. Some sandstone lenses are 30 to 61 m (100 to 200 ft) across and 12 m (40 ft) thick at midchannel and were probably the result of coalescing channels of a braided stream. Many channel remnants, however, are as much as 10 to 13 km (6 to 8 miles) by 6 to 8 km (4 to 5 miles) in extent and up to 15 m (50 ft) thick. In some places at least two subparallel channels lie several hundred ft apart in the same stratigraphic horizon. Cross lamination is common; it is typically 1-1/2 to 2 ft thick and overlain by as many as 12 similar sets. Most sandstones show intervals of graded bedding, the coarsest particles being less than 1/2 in. in diameter. Calcium carbonate concretions, about 6 to 10 in. in diameter, occur sporadically in thick sandstone units, but otherwise the sandstone is only slightly calcareous.

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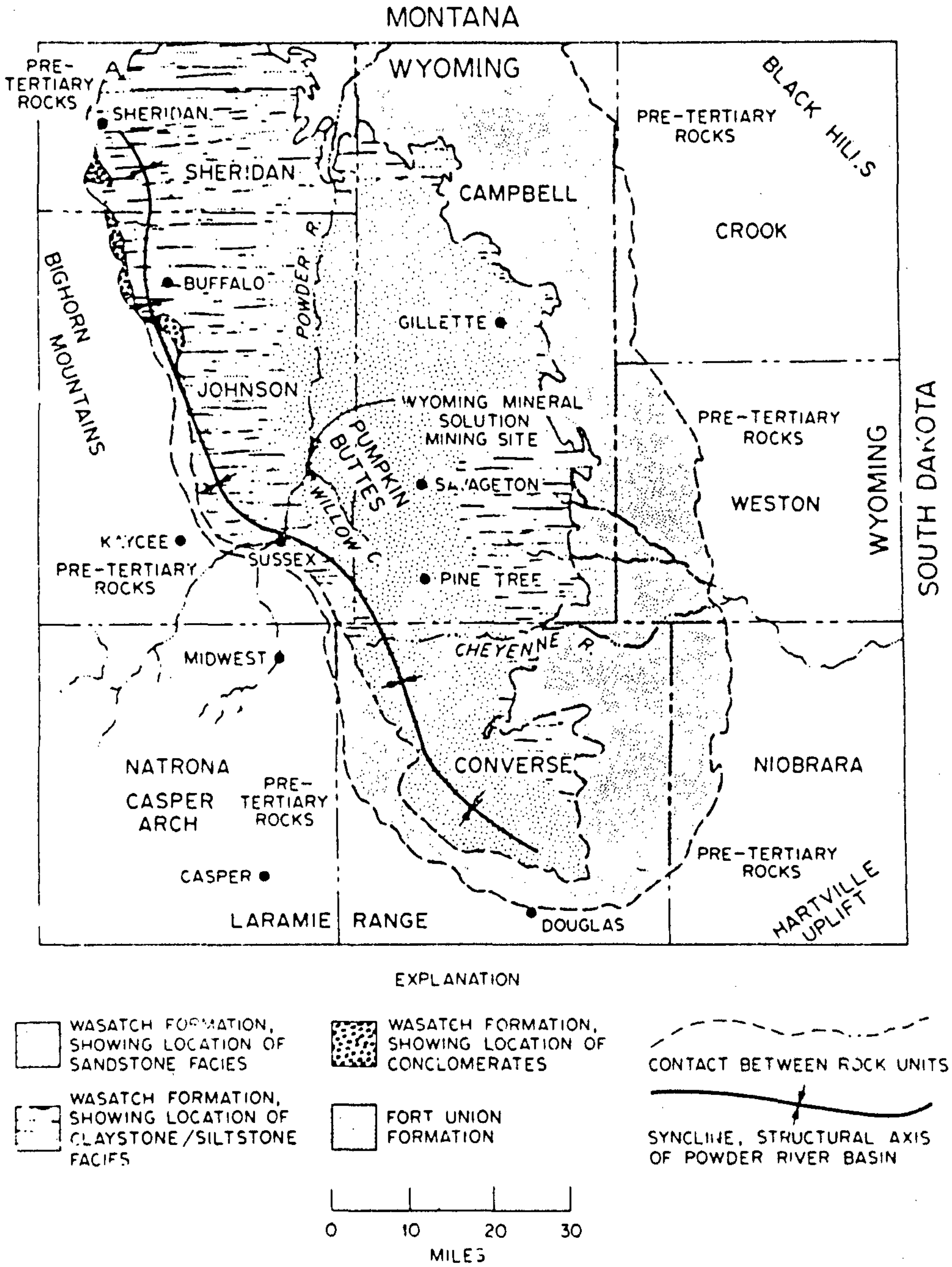

Fig. 2.13. Generalized geologic map of the Powder River Basin, showing the location of coarse-, medium-, and fine-grained rocks in the Wasatch Formation. Source. Modified from W. M. Sharp and A. B. Gibbon, *Geology and Uranium Deposits of the Southern Part of the Powder River Basin, Wyoming*, U.S. Geol. Survey Bull. 1147-D, 1964.

2.7.1.3 Structure

Structurally, the Powder River Basin is an asymmetric syncline, the deepest part lying close to the Bighorn Mountains. The outcrop width of the Fort Union Formation clearly reflects this structure (Fig. 2.13). The structural axis projected to the surface from the Precambrian basement is approximately parallel to the front of the Bighorn Mountains and is about 40 km (25 miles) west of the Irigaray site (Fig. 2.13). Dips of pre-Tertiary strata on the east side of the Bighorn Mountains vary from 30° east to locally overturned. The dip of the Wasatch Formation in the Pumpkin Buttes area is generally less than 3° northwest.

Although the Powder River Basin is less deformed than other Wyoming basins, the Precambrian basement is nonetheless over 4572 m (15,000 ft) below sea level. The middle of the basin is characterized by gentle folding and minor faulting. In the Pumpkin Buttes area, Sharp and others report two slight anticlines in surface rocks trending north-southeast and east-west, which are superimposed on a broad southwest-plunging anticline in Precambrian rocks.[28] The folds in the Wasatch Formation are not reflected in the overlying White River Formation and are therefore pre-White River, post-Wasatch in age.

No faults have been recognized in the Pumpkin Buttes area, but a few minor reverse faults offset coal beds along the Powder River.[28] Jointing in calcareous sandstone and 1- to 2-ft-wide clastic dikes cutting claystone and siltstone occur sporadically and trend from north 40° east to north 80° east.

2.7.1.4 Site geology

The Wasatch Formation is exposed at the surface and dips to the west from 1° to 2°. Figure 2.14 is a composite section of a part of the Wasatch Formation at the site. Uranium mineralization occurs within the applicant's designated Upper Irigaray sandstone (UISS), which was deposited by a north-flowing stream with a channel width of approximately 11 km (7 miles). The host sandstone is 23 to 46 m (75 to 150 ft) thick and from 23 to 152 m (75 to 500 ft) below the surface (Figs. 2.15-2.18). The UISS shows a series of vertically graded sands from coarse at the bottom to fine at the top and at least two periods of downcutting and subsequent filling. Because of the mainly fluvial depositional environment of the Wasatch Formation, horizontal and vertical facies changes occur rapidly, making it difficult to correlate the highly lenticular beds across the site.

Figure 2.15 shows the locations of the cross sections shown in Figs. 2.16 and 2.17. It is not known whether the Lower Irigaray sandstone (LISS) extends into the southern part of the permit area (cross section A-B-C, Fig. 2.16). On cross section D-B-E (Fig. 2.17) the claystone unit separating the UISS and LISS is believed to pinch out to the east, thus connecting the UISS and LISS in this area. To date, drilling below the LISS has shown discontinuous beds of sandstone interbedded with siltstone, claystone, and shale (Fig. 2.17).

2.7.2 Mineral resources

Uranium occurrences in the Powder River Basin were first reported by Love in the Pumpkin Buttes area.[30] Mining in this district from 1953 to 1964, however, yielded only 2,408 tons of uranium from numerous small surface mines.[13] Since the mid-1960s, when uranium ore was discovered at depth, drilling has defined many large deposits in a wide zone south from the Irigaray site into the southern Powder River Basin. Most of these deposits occur in the Fort Union and Wasatch formations of Early Tertiary age. From the standpoint of drilling, the Powder River Basin is the most active area in the United States for uranium exploration.[31]

According to Monsson, oil accounted for nearly 98% of the mineral valuation in Johnson County in 1975; production was about 5,561,500 m^3 (3,500,000 bbl) per year.[32] Currently producing oil and gas fields near the Irigaray site are Heldt Draw (T46N, R77W), Jepson Draw (T45N, R77W), and Heller Draw (T44N, R76W). The fields were discovered in 1973-1974 and produce from Upper Cretaceous rocks at depths between 2743 and 3048 m (9000 and 10,000 ft) below the surface. As of December 1974 the three fields had a cumulative production of 286,644 m^3 (180,393 bbl) of oil and 1.437×10^9 m^3 (50,731 million cubic feet) of gas.[13]

Coal production in the Powder River Basin is centered in Campbell County; the main belt of strippable coal is about 56 km (35 miles) east of the Irigaray site. Campbell County should become the leading coal producer in the State, having 50% of Wyoming's remaining coal resources and 84% of its known strippable coals.[33] In contrast, Glass estimates that Johnson County has 9% of Wyoming's identified coal resources and only 4% of its known strippable coal,[34] located at least 32 km (20 miles) west and north of the Irigaray site. Most of the thick coal beds, some up to 37 m (120 ft) thick, occur in the upper member of the Fort Union Formation east of Gillette. At the site, two thin [1 m (3 ft)] coal beds in the Wasatch Formation occur between 18 and 146 m (60 and 480 ft) below the surface (Figs. 2.14, 2.16, and 2.17). Because of the more abundant and easily strippable coal elsewhere in the basin, the coal underlying the Irigaray site is not considered presently to be economically important.

Gold, copper, manganese, and rare earth minerals are reported in small quantities along the east flank of the Bighorn Mountains. These deposits are 48 km (30 miles) west of the Irigaray site, and no production has been reported since 1942.[13]

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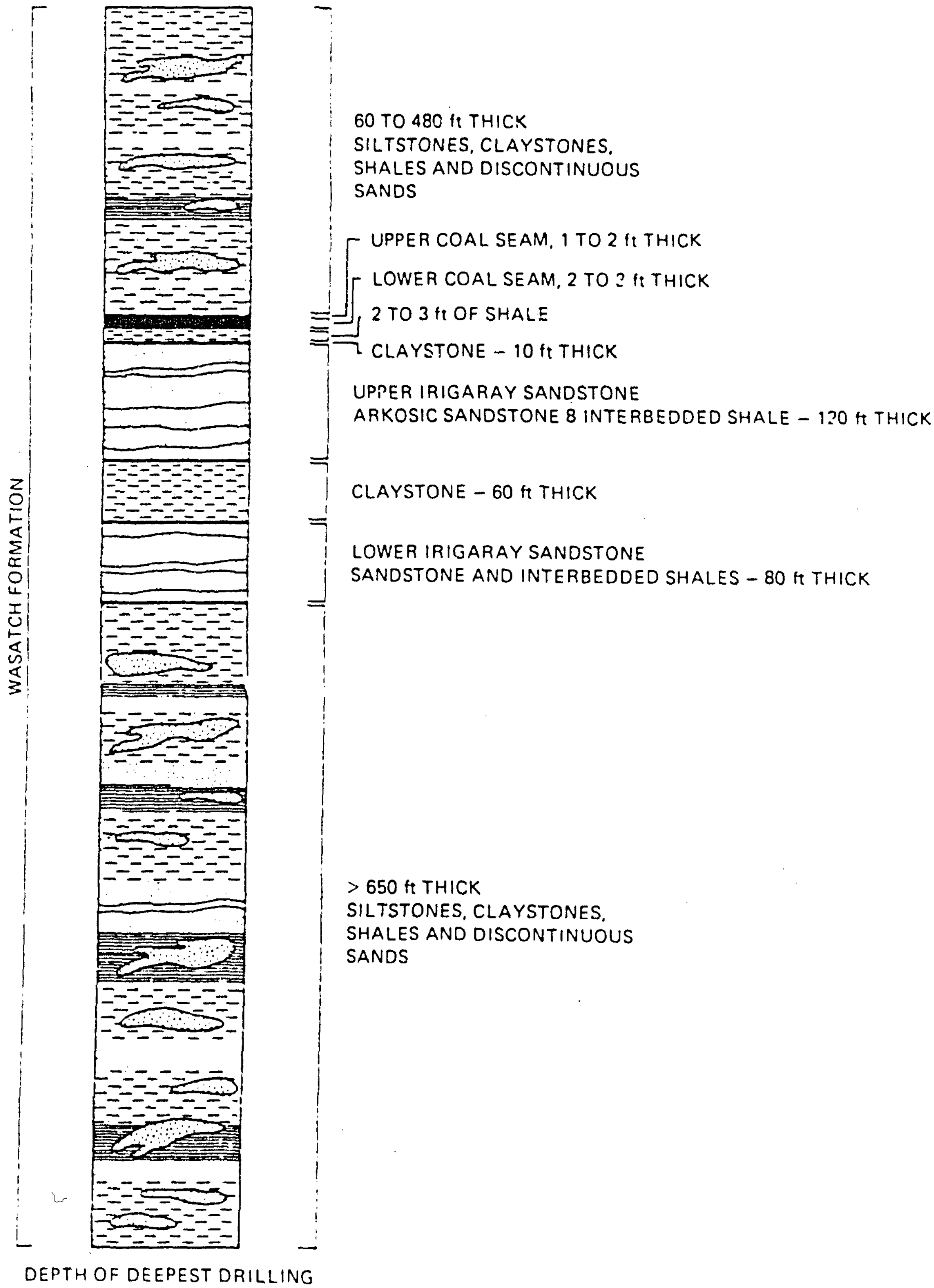

Fig. 2.14. Composite section of the Wasatch Formation at the Irigaray site. Source: ER, Fig. 3-2.

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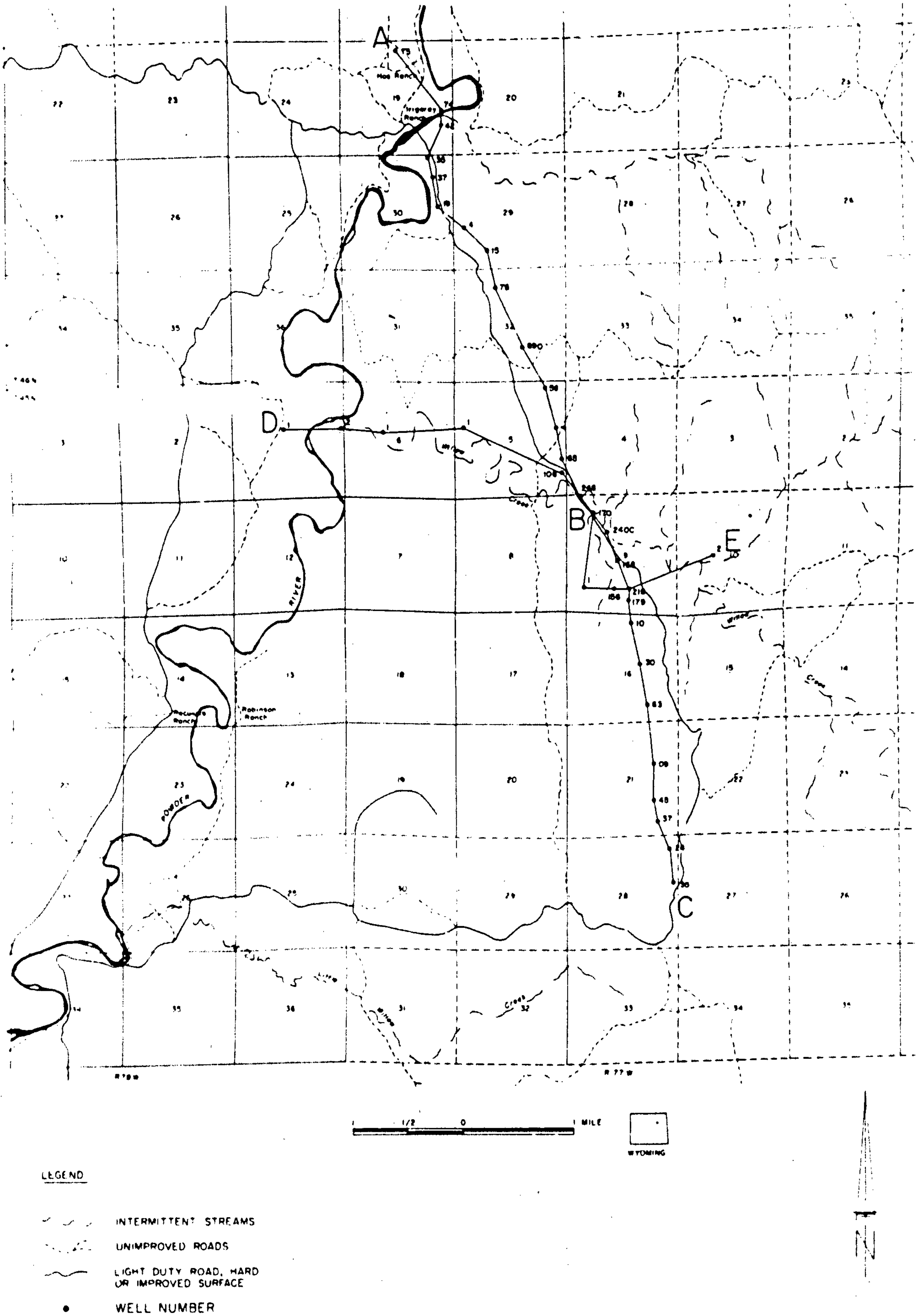

Fig. 2.15. Locations of geologic cross sections (Figs. 2.16 and 2.17) at the Irigaray site.
Source: ER, Fig. 3-3.

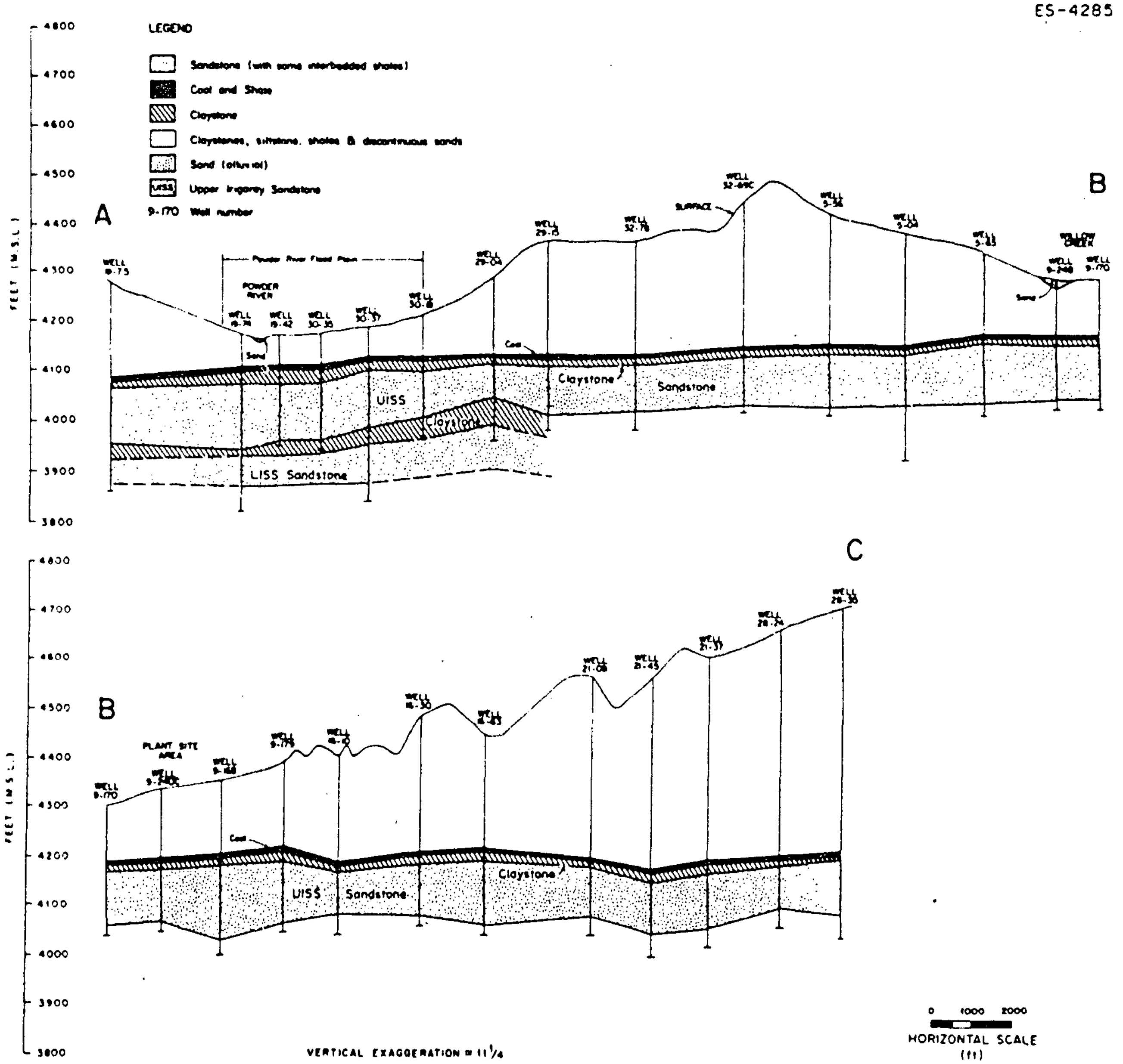

Fig. 2.16. Geologic cross sections A-B and B-C (Fig. 2.15) at the Irigaray site. Source: ER, Figs. 3-4 and 3-5.

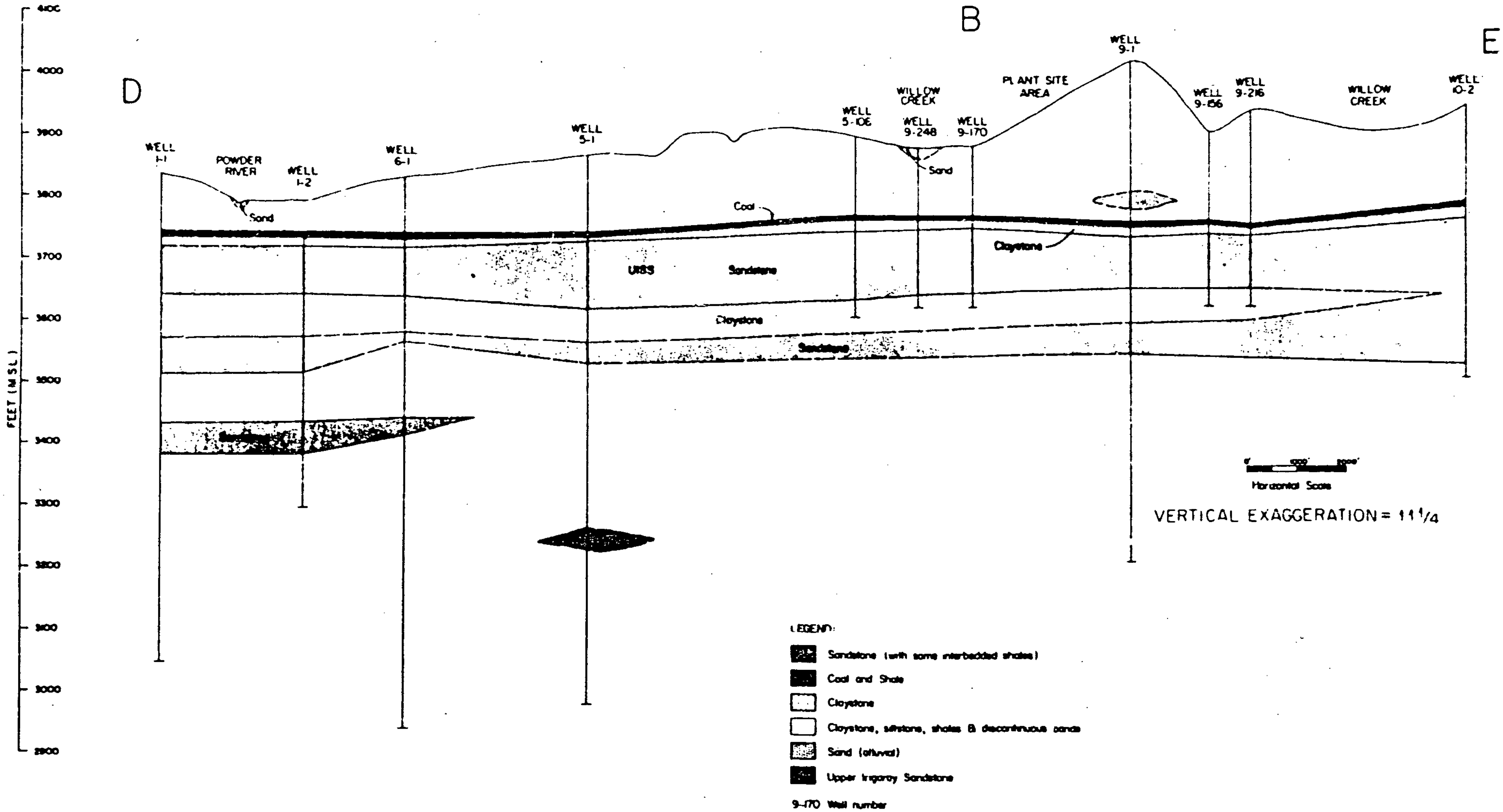

Fig. 2.17. Geologic cross section D-B-E (Fig. 2.15) at the Irigaray site. Source: ER, Fig. 3-6.

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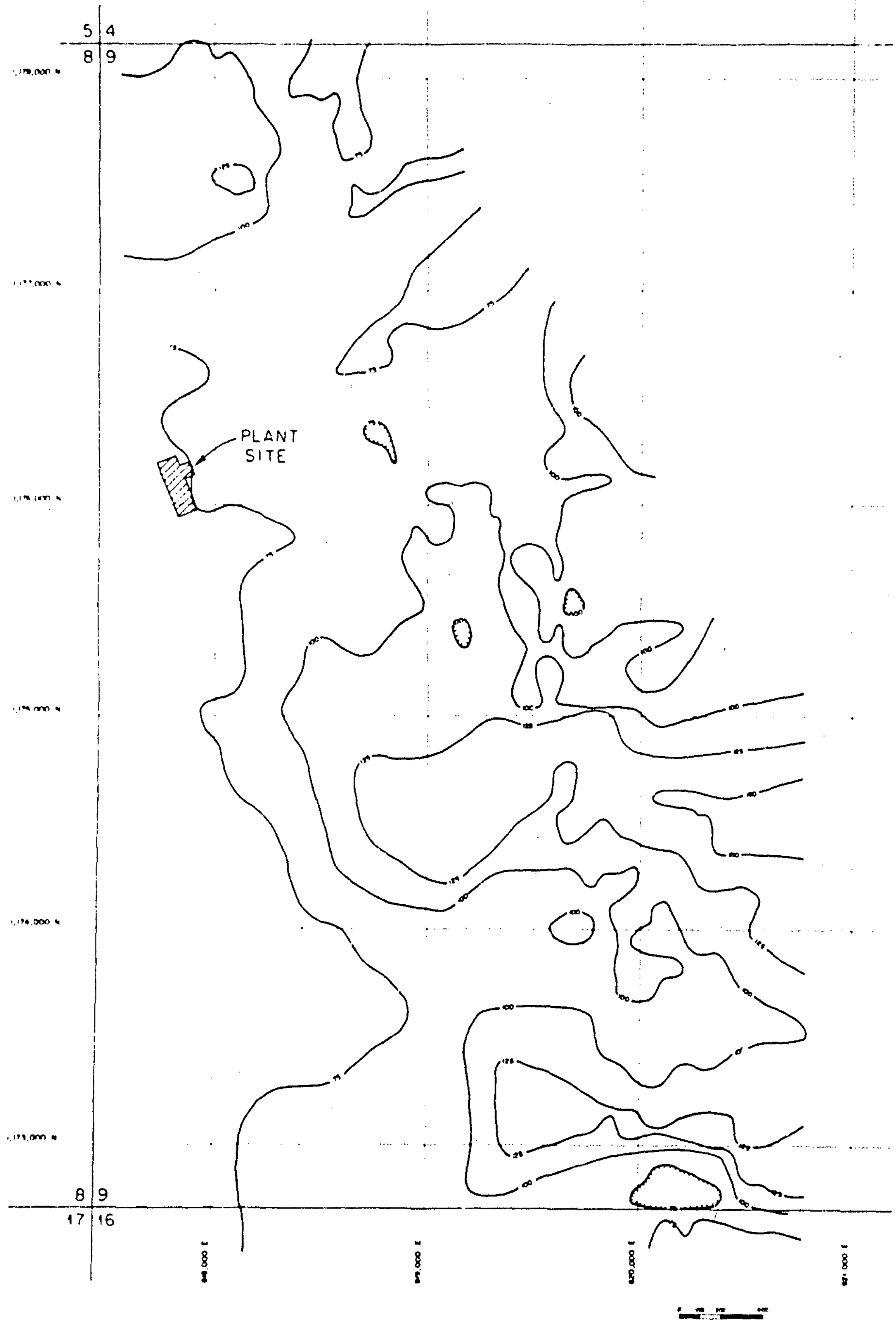

Fig. 2.18. Isopachs (thickness) of the Upper Irigaray sandstone in Section 9. Source: Modified from ER, Fig. 3-7.

2.7.3 Seismicity

The Intermountain seismic belt (including Yellowstone Park) is continuous from western Montana to north-central Utah. Earthquakes with epicenters in or near Yellowstone Park are likely to create some of the strongest motions to be experienced in the Powder River Basin; only locations within about 30 km (19 miles) of the epicenter of an earthquake occurring within the basin will experience stronger motion. The local intensity of distant earthquakes will nevertheless be low. For example, the Irigaray site lies near the boundary of the felt area for the Hebgen Lake earthquake of 1959.[35]

Although distant earthquakes may produce shocks strong enough to be felt in the Powder River Basin, the region is considered to be one of minor seismic risk (Fig. 2.19).[36] In the past 80 years only four earthquakes having epicenters within 160 km (100 miles) of the Irigaray site were strong enough to be felt.[37] The 1897 earthquake (intensity VII on the modified Mercalli scale) near Casper, Wyoming, was strong enough to cause significant damage. In the same region only five earthquakes (all of magnitude less than 5 on the Richter scale) have been instrumentally recorded since 1965.[37] These data are too limited to establish reliable recurrence intervals, but they suggest that a magnitude 6 earthquake is a rare event. Magnitude 6 (intensity VII-VIII) earthquakes occur perhaps an order of magnitude less frequently than magnitude 5 (intensity VI-VII) earthquakes.[38] Historical records indicate that magnitude 5.0 to 6.0 earthquakes occur about once every 20 years within 160 km (100 miles) of the Irigaray site. Therefore an earthquake between 6.0 and 7.0 can be expected to recur once in 200 years (ER, p. 68). The Irigaray site would have to be in the epicentral area [8-km (5-mile) radius] of a maximum credible intensity Powder River Basin earthquake to experience slight damage. The historical record of seismicity in the Powder River Basin suggests that the probability of the occurrence of such an event during the lifetime of the Irigaray plant is vanishingly small.

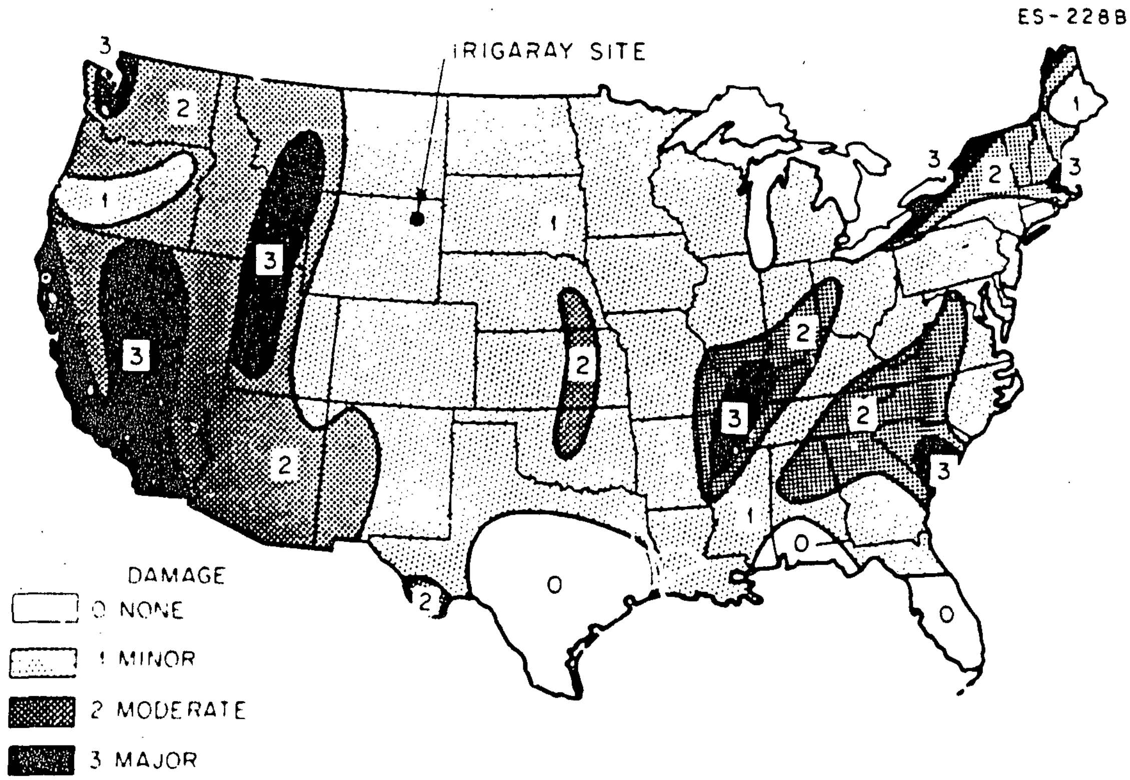

Fig. 2.19. Seismic risk map of the United States. Source: Modified from S. T. Algermissen, *United States Earthquakes*, U.S. Government Printing Office, Washington, D.C., 1968.

2.8 SOILS

The following discussion of soils is based on a recently published soil survey of southern Johnson County by the U.S. Soil Conservation Service.[39]

The upland soils of the WMC site belong to the Shingle and Stoneham series. The upland soils are generally suitable only for range and wildlife habitat. The Shingle series, which covers a majority of the site, occurs on hillsides and ridgetops. It consists of relatively thin and poorly developed soils formed from residuum weathered from sandstone and siltstone bedrock. Effective rooting depth is limited, since bedrock occurs at 20 to 25 cm (8 to 10 in.). Shingle soils are moderately alkaline loams with moderate permeability and low available water capacity. Runoff from these soils is rapid and erosion hazard is high. Vegetative cover supported by Shingle soils is predominantly shortgrasses such as blue grama.

Soils of the Stoneham series develop on alluvial fans that form along lower slopes, mainly adjacent to the Powder River and Willow Creek. Stoneham soils are better developed and deeper than Shingle soils. Effective rooting depth may be down to 150 cm (60 in.). Permeability is moderate and available water capacity is high. These soils generally support stands of sagebrush and grasses such as western wheatgrass. If cover is removed, the hazard of wind erosion is high on Stoneham soils.

Soils along the floodplains of the Powder River and Willow Creek are a complex of a number of soil associations and material that is classified as alluvial land. The majority of the soil associations belong to the broader category of the Haversen series, which consists of well-drained soils formed in alluvium. The soils in this series are moderately alkaline loams with moderate permeabilities and high available water capacity. The effective rooting depth may be down to 150 cm (60 in.). Haversen soils are suitable for irrigated hay, pasture, and small grain, as well as for range and wildlife habitat.

Alluvial land consists of materials that comprise old gravel bars and meanders along the Powder River and Willow Creek. The soil material is depositional in origin, is highly stratified, and ranges from loam to sand in texture. Alluvial land is subject to frequent flooding and generally supports stands of cottonwood and willow. It is suitable only as range and wildlife habitat.

2.9 ECOLOGY

2.9.1 Terrestrial ecology

The following discussion of terrestrial ecology is based on a search of the literature and on a biologic study conducted for the applicant near the Irigaray site (included here as Appendix C).

2.9.1.1 Vegetation

The Irigaray site is located within the Powder River Basin of northeast Wyoming. Vegetation in the basin exhibits a broad transition between two major vegetation types – the grasslands of the northern Great Plains to the east and the sagebrush steppe that occurs over much of the rangeland of the western basins. Big sagebrush (*Artemisia tridentata*) is the most prevalent and important shrub species in the Powder River Basin. Characteristic and dominant grasses include blue grama grass (*Bouteloua gracilis*), western wheatgrass ((*Agropyron smithii*), prairie June grass (*Koeleria cristata*), and needlegrasses (*Stipa* spp.). The composition and structure of the sagebrush-shortgra's community vary with localized soil and moisture conditions and past use, resulting in intergrading sagebrush and shortgrass-sagebrush associations. In general, dense stands of big sagebrush and other shrubs occur on the moister slopes of draws and drainages. On the drier and more exposed uplands, however, the community has a grassland aspect, and big sagebrush occurs only as low and widely scattered individual plants.

A list of major plant species observed near the WMC site is available in Appendix C. The majority of the site (over 95%) is covered by the shortgrass-sagebrush association typical of the Powder River Basin. Except in the draws and drainages where shrub cover is relatively dense, most of the site has a shortgrass prairie aspect. A generalized vegetation map of Johnson County lists the vegetation of the WMC site as primarily annual grasses and weeds with western wheatgrass, prairie June grass, and needle-and-thread grass (*Stipa comaea*) as the dominant species.[40] Big sagebrush and other shrubs such as Douglas rabbitbrush (*Chrysothamnus viscidiflorus*), silver sagebrush (*Artemisia cana*), and fringed sagewort (*Artemisia frigida*) occur as low and widely scattered individuals. Common forbs include prickly pear (*Opuntia polyacantha*), soapweed (*Yucca glauca*), and a number of species of wild buckwheat (*Eriogonum* spp.). With the exception of the floodplains of Willow Creek and the Powder River, vegetation cover on the majority of the WMC site ranges from 5 to 25%.[40]

A riparian vegetation type exists along the floodplains of Willow Creek and the Powder River. In moist areas adjacent to the water, there is a dense, meadow-like cover of perennial grasses, sedges, and rushes. Trees, primarily plains cottonwood (*Populus sargenti*) and willows (*Salix* sp.), are limited to the floodplains. Where soils are moist but not saturated along Willow Creek and the Powder River and along tributary drainages and draws, there is a fairly dense shrub cover. Shrubs such as big sagebrush, silver sage, wild rose (*Rosa woodsii*), skunkbush sumac (*Rhus trilobata*), and serviceberry (*Amelanchier* sp.), which occur in this habitat, provide excellent wildlife browse. The riparian habitat along the Powder River and Willow Creek is important wildlife habitat. The trees, shrubs, and moist meadows provide food, shelter, and breeding areas for a variety of wildlife species that would not otherwise occur on the site. Studies have shown that the density and diversity of wildlife species associated with riparian habitats may be five to ten times those in the surrounding grasslands.[41]

2.9.1.2 Wildlife

Wildlife species that occur on the WMC site are those characteristic of the sagebrush grasslands of the Powder River Basin and, indeed, most of the sagebrush rangelands of the western United States. The fauna of the Powder River Basin has been described in recent environmental impact statements and other documents concerning energy-related development in the basin.[42-44] The most abundant animals are rodents, such as the deer mouse (*Peromyscus maniculatis*) and thirteen-lined ground squirrel (*Spermophilus tridecemlineatus*), and a number of species of grassland passerine birds. Predators that are common in the region near the WMC site include badgers (*Taxidea taxus*), long-tailed weasels (*Mustela frenata*), coyotes (*Canis latrans*), and red foxes (*Vulpes vulpes*). A number of raptor species occur in the area. Waterfowl utilize the stock watering ponds and reservoirs of the area as resting places during migration, and some individuals remain through the summer to breed.

Game species

The Powder River Basin is nationally known for its outstanding hunting resource of pronghorn antelope (*Antilocapra americana*). It is estimated that 45 to 50% of the world's pronghorn population occurs in Wyoming.[45] Pronghorn prefer open, rolling topography such as that in the Powder River Basin. The animals depend primarily upon big sagebrush for winter browse, and sagebrush stands are important for concealment of the fawns during spring and early summer. The region in which the WMC site is located is classified by the Wyoming Game and Fish Department as year-round pronghorn habitat. Estimates of pronghorn density on habitat similar to that on the WMC site range from 2 to 4 animals per square kilometer (5 to 10 per square mile).[42-44]

Another popular big game species that occurs on the WMC site is mule deer (*Odocoileus hemionus*). Deer frequent the riparian habitats along Willow Creek and the Powder River and the draws, where dense shrub cover provides browse and concealment. The areas along the Powder River and Willow Creek could represent important mule deer winter habitat. During winter field studies near the WMC site, from 7 to 22 deer were sighted per day (Appendix C).

Compared to large game, upland small game are a minor hunting resource in the Powder River Basin. The most important small game species occurring in the vicinity of the WMC site is sage grouse (*Centrocercus urophasianus*). No estimate of grouse density on the WMC site was available, but the site apparently has all the components of good sage grouse habitat. From late fall to early spring sage grouse are solely dependent upon big sagebrush for food. Strutting grounds are usually within relatively open areas surrounded by sagebrush. The dense sagebrush cover and the moist, meadowlike vegetation in draws and drainages and along Willow Creek and Powder River represent good brood-rearing habitat.

Other common small game species that would occur on the WMC site include mourning doves (*Zenaida macroura*) and cottontails (*Sylvilagus audubonii*). Doves are migratory and their densities on the site fluctuate seasonally. Cottontail populations are somewhat cyclic; rabbit densities in habitat similar to that on the site may vary from 20 to 150 per square kilometer (50 to 375 per square mile).[42,44] Wild turkeys (*Meleagris gallopavo*) occur in Johnson County. The Powder River in the vicinity of the WMC site would be good turkey habitat, and the species likely occurs there. A number of species of waterfowl nest in the many small stockwater impoundments scattered through the Powder River Basin. Common species include mallard (*Anas platyrhynchos*), blue-winged teal (*A. discors*), gadwall (*A. strepera*), and pintail (*A. acuta*).

Rare and endangered species

A number of proposed endangered plants occur in Wyoming.[46] However, according to Mr. Robert Dorn, of the Wyoming Department of Environmental Quality, who is familiar with Wyoming's rare plants, none of the endangered plant species occur in the Powder River Basin of eastern Wyoming.

Of the species currently on the Federal list of endangered species,[47] only the black-footed ferret (*Mustela nigripes*) and the peregrine falcon (*Falco peregrinus*) could potentially occur in the Powder River Basin. Breeding pairs of peregrine falcons are not likely to occur near the WMC site, since the required breeding habitat of cliffs is lacking. The black-footed ferret is closely associated with prairie dog towns. According to the applicant, there are no prairie dog towns known to occur on or near the WMC site, so it is unlikely that ferrets occur on or near the site.

The State of Wyoming has no state endangered species law. In the recent publication of the current status of wildlife in Wyoming,[48] there is a list of animals considered rare in Wyoming. According to the ranges and habitat preferences listed for the rare species, two could potentially occur near the WMC site, the burrowing owl (*Speotyto cunicularia*) and the milk snake (*Lampropeltis triangulum*). The burrowing owl is seldom found in the absence of active colonies of burrowing mammals such as prairie dogs.[48] Since, according to the applicant, there are no prairie dog towns on the WMC site, it is unlikely that the owls would occur on the site. Milk snakes have been collected from central Sheridan County and are thought to inhabit other portions of eastern Wyoming.[48] The species inhabits a variety of habitats, including riparian areas, shrub woodlands, and rocky hillsides. The species apparently prefers habitats in which there is sufficient cover in the form of rocks, rotting logs, dense shrubs. Since habitat suitable for milk snakes is present on the WMC site, this species could potentially occur on the site.

2.9.2 Aquatic ecology

The aquatic habitats that might be affected by WMC's operations are the Powder River and Willow Creek. These areas are described below.

Near WMC's site the Powder River meanders across its floodplain with a gentle gradient of less than 2 m/km (10 ft/mile). The arid plains in the area are composed mostly of erodible shales, silstones, and sandstones.[15] This land contributes substantial sediments to the Powder River and tributaries, especially if land is overgrazed. The Powder River has generally high levels of suspended sediments; 80 km (50 miles) downstream from the WMC site (station E, Arvada, Fig. 2.5) the suspended sediment concentration varied from 172 to 39,800 mg/liter and averaged 6419 mg/liter for water years 1972-1974.[49-51]

Near the WMC site the Powder River provides poor habitat for game fish due to high turbidity, low water quality, and, in summer, low streamflows and excessive water temperatures (see Sect. 2.6.1). The Wyoming Game and Fish Department classifies all of the Powder River below Kaycee (station A, Fig. 2.5) as "very low production waters — often incapable of sustaining a fishery."[52]

There has apparently been little sampling of fish populations in the Powder River near the WMC site. However, the Wyoming Game and Fish Department has sampled nearby drainage systems, including the Little Powder and the Belle Fourche rivers.[53] Based primarily on this, the Department of the Interior listed the following nongame species as present or suspected present in the Powder River:[6] flathead chub (*Hybopsis gracilis*); carp (*Cyprinus carpio*); goldeye (*Hiodon alosoides*); Northern redhorse (*Moxostoma macrolepidotum*); white, longnose, and mountain sucker (*Catostomus commersoni, C. catastomus, C. platyrhynchus*); fathead minnow (*Pimephales promelas*); longnose dace (*Rhinichthys cataractae*); sturgeon chub (*Hybopsis gelida*); river carpsucker (*Carpiodes carpio*); plains minnow (*Hybognathus placitus*); and silvery minnow (*Hybognathus nuchalis*).

The Bureau of Land Mangement indicates that bullheads (*Ictalurus* sp.) and stonecats (*Noturus flavus*) are present in the stretch between Kaycee and Barnum and that "shovelnose sturgeon and sturgeon chub are known to inhabit the silty currents of the lower Powder River."[54] The Wyoming Game and Fish Department reports that a rough fishery of nongame species is maintained in deep water areas below Arvada.[55] Recently, the Wyoming Game and Fish Department has found young-of-the-year channel catfish (*Ictalurus punctatus*) at the bridge where Interstate 90 crosses the Powder River, approximately 30 km (20 miles) north of the WMC site.[56] In the Powder River north of Arvada, especially in southern Montana, a healthy fishery of channel catfish has apparently developed, including individuals up to 5.5 kg (12 lb). Channel catfish may be migrating upstream during periods of high flow, and the Powder River near WMC's site could provide habitat for this species.

The Wyoming Game and Fish Department considers 13 species of fish to be "rare" in Wyoming.[48] The four species that have been reported from the Powder River are described in Table 2.10.

Three nationally listed endangered aquatic species, the humpback chub (*Gila cypha*), Colorado River squawfish (*Ptychocheilus lucius*), and Kendall warm springs dace (*Rhinichthys osculus thermalis*), occur in Wyoming.[45] However, none of these are believed to occur in the eastern Powder River Basin.[57]

Very little is known about Willow Creek and any aquatic biota that may inhabit it. (The Environmental Report makes no mention of biota in Willow Creek or the Powder River.) Although Willow Creek is intermittent, it may provide breeding habitat for fish during parts of the year. Hynes

Table 2.10. Rare fish species of the Powder River

Common name	Scientific name	Distribution	Comment
Shovelnose sturgeon	*Scaphirhynchus platorhynchus*	Powder River	May be extinct in Wyoming
Goldeye	*Hiodon alosoides*	Lower Powder River Crazy Woman Creek Lower Clear Creek Little Missouri River	Tolerant of high turbidity
Sturgeon chub	*Hybopsis gelida*	Powder River in Sheridan County Lower Big Horn River	Adapted to areas of gravel bottom in large silty river
Silvery minnow	*Hybognathus nuchalis*	Lower Powder River Belle Fourche River Lower Little Missouri River	Prefers larger rivers

Source: Wyoming Game and Fish Department, *Current Status and Inventory of Wildlife in Wyoming*, Cheyenne, Wyo., 1977.

notes that intermittent streams frequently support suprisingly diverse aquatic communities, especially if there are pools of standing water.[58] Some organisms survive in pools despite high temperatures and low oxygen concentrations. Other species have eggs that can survive long dry periods, and some species survive by aestivating or burrowing into a continually moist substratum. In addition, when streamflow does occur, the stream may be reinvaded by fish from downstream waters. If pools exist in Willow Creek for extended periods, they may develop biotic communities typical of stock watering ponds, as shown in Fig. 2.20.

2.10 RADIATION ENVIRONMENT

2.10.1 Surface

The intensity of cosmic radiation is a function of altitude and at the Irigaray site would be approximately 50 millirems per year to the whole body.[59] The total natural radiation background is estimated to be 150 millirems per year.[60] The whole-body dose rate from domestic and industrial sources in Wyoming is estimated to be 25 millirems per year. The medical whole-body dose is estimated to be 75 millirems per year.[60,61]

The radon flux to the atmosphere from a dry, sandy soil containing 1 pCi/g of radium-226 (Table 8.1) is estimated to be 1.6 $pCi/m^2 \cdot sec$.[62,63] The concentration of Ra-226 in sedimentary soil is about 0.5 pCi/g, which would give a radon-222 flux of 0.8 $pCi/m^2 \cdot sec$.[62,63] Although this general estimate does not take into account all of the variations of radium-226 concentrations and soil conditions at the Irigaray site, the staff believes that this estimate does show the magnitude of natural radon emanation in and around the Irigaray property. The annual quantity of radon released from a 21,000 acre (8500 ha) area, an area about equal to that occupied by the Irigaray property, is estimated to be less than 2200 Ci. Concentration of radon in air is estimated to be in the range of 500 to 1000 pCi/m^3. Exposure to a radon concentration of 1000 pCi/m^3 on a continuous basis would result in a dose of 625 millirems per year to the bronchial epithelium.

The annual average concentration (20 mg/m^3) of particulates in Wyoming air will contain about 4×10^{-5} pCi/m^3 of radium-226, 8×10^{-5} pCi/m^3 of thorium-232, and 4×10^{-5} pCi/m^3 of thorium-230. The dose from these particulates to the lungs under normal conditions would be about 2 millirems per year. The dose to the bone would be less than 1 millirem per year.

2.10.2 Subsurface

The concentration of radioactive materials in groundwater is influenced by the chemistry and nature of the aquifer in the zone of interest. Wells located in the mineralized trend (i.e., well P4, Appendix B, Table B.3) may exceed the EPA drinking water standards (Table 2.9) for gross alpha, gross beta, radium-226, and natural uranium by factors of at least 400, 1.6, 30, and 2.7 respectively. Wells located outside of the mineralized zone (wells M4 and M5, Appendix B, Table B.3) show gross alpha, gross beta, radium-226, and natural uranium levels well below the standards (see Sect. 2.6.2.4 on groundwater quality).

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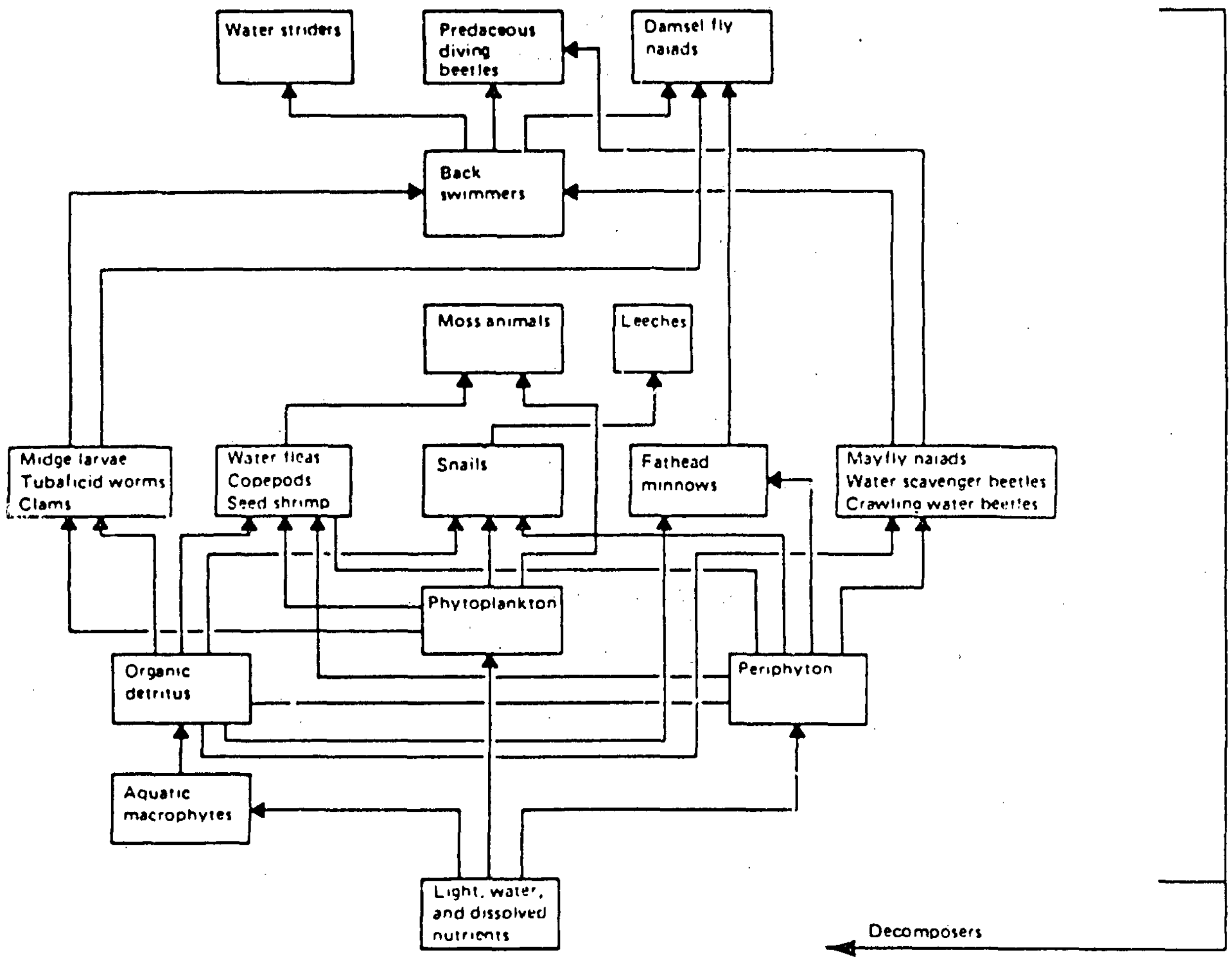

Fig. 2.20. Typical food web of livestock ponds in Campbell and Converse counties. Source: *Applicant's Environmental Assessment for a Proposed Gasification Project in Campbell and Converse Counties, Wyoming,* prepared for Wyoming Coal Gas Company and Rochelle Coal Company by SERNCO, Inc., 1974.

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3. SOLUTION MINING (IN SITU LEACHING) OF URANIUM

This section provides background information on solution mining (in situ leaching) of uranium. A glossary of terms abstracted from the International Glossary of Hydrology[1] as well as a selected bibliography on this subject are also included.

3.1 INTRODUCTION

In situ leaching (solution mining) of uranium is a potential addition to the list of conventional mining methods currently used to extract uranium. Basically, the in situ leaching method involves (1) the injection of a leach solution (lixiviant) into a uranium-bearing ore body to complex the contained uranium, (2) mobilization of the uranium complex formed, and (3) surface recovery of the solution bearing the uranium complex via production wells. Uranium is then separated from the leach solution by conventional milling unit operations (ion exchange).

The environmental advantages of in situ leaching of uranium appear to be significant. While the conventional extraction of minerals produces significant impact on the environment, the solution mining method appears potentially to result in a lesser impact. Compared with the conventional uranium mining and milling operations, in situ leaching will also permit economical recovery of currently unrecoverable low-grade uranium deposits, thereby enhancing the nation's uranium reserves.

In conventional uranium recovery techniques, the ore is mined (open pit or underground), crushed, ground in mills, and subsequently leached, using either an acidic or basic oxidizing solution to extract the uranium. In solution mining, an acidic or basic oxidizing solution is injected into and produced from the naturally situated ore body via wells to extract the uranium. The chemical technology is about the same in both cases. In solution mining, however, no ore mining, transporting, and grinding operations are needed before chemical processing to recover the uranium. Moreover, there are no mill tailings to be disposed of, although solid wastes are generated that would require controlled disposal.

In conventional uranium mining, for each ton of mined ore, more than 1900 lb of solid waste (tailings) are produced, containing essentially all of the associated radium-226 and other daughter products. With solution mining, less than 5% of the radium from an ore body would be brought to the surface.

Since the technology for in situ solution mining of uranium is still actively developing, variations among the different operations are not unusual. Thus, the following background discussion is general. Specific procedures proposed by the applicant are described and discussed in later sections of this Statement.

For consistency and clarification, two major terms are defined.

3.1.1 Solution mining

Solution mining is a general term describing the extraction of minerals in liquid form. The solution may only contain the mineral sought from the natural source (e.g., salt, sulfur) or may include other materials such as excess chemicals that have been added to aid in the dissolution of the resource from its source host, reaction by-products, and other materials associated with the mineral deposit co-dissolved in the process.

The mineral-bearing solution can be obtained from its source in several ways. A fluid can be injected and recovered through wells from the mineralized host beneath the surface (borehole mining) or sprayed over mineral-bearing materials that have been brought to the surface (e.g., dump or heap leaching). In all cases, a solution containing the mineral sought is produced.

3.1.2 <u>In situ leaching</u>

In situ leaching is one of the many types of solution mining. In this technique, the mineral sought is dissolved from its host source *in place* (in situ) and extracted as a liquid, while leaving the solid host material in its natural position. The basic unit operations of in situ leaching of uranium involve (1) the introduction of a leach solution via injection wells into a uranium-bearing ore body, (2) mobilization of the uranium from the host material via creation of a soluble complex salt,, and (3) removal of the complexed uranium-bearing solution via production wells. The uranium in the uranium-bearing solution is recovered in a conventional surface facility where, generally, an ion exchange process is used for recovery.

3.2 PROCESS DESCRIPTION

Uranium in situ solution mining involves the following basic components and associated processing activities: (1) the ore body, (2) the well field, (3) the lixiviant or leach liquor, (4) the uranium recovery process, (5) the waste treatment process(es), (6) waste management process(es), and (7) aquifer restoration and land reclamation process(es). The interrelationships of these are discussed in the following.

3.2.1 <u>Ore body</u>

Roll-type uranium deposits are generally associated with fluvial sandstones and conglomerates. The mineral in the ore is concentrated by a liquid oxidizing front moving down the hydrologic gradient in the reduced host zone (sands). Uranium is thereby precipitated along the interface of the oxidizing and reducing sides of the front. The physical shape of an ore roll is dependent on the local permeability of the matrix material and its continuity and distribution in the geologic unit (Fig. 3.1). Such ore bodies are prevalent in most of the established uranium mining districts in the western United States. In situ leaching, however, can be conducted only on those ore deposits that meet certain criteria. These generally include: (1) the ore deposit must be located in a saturated zone, (2) the ore deposit must be confined both above and below by impervious layers, (3) the deposit must have adequate permeability, and (4) the deposit must be amenable to chemical leaching.

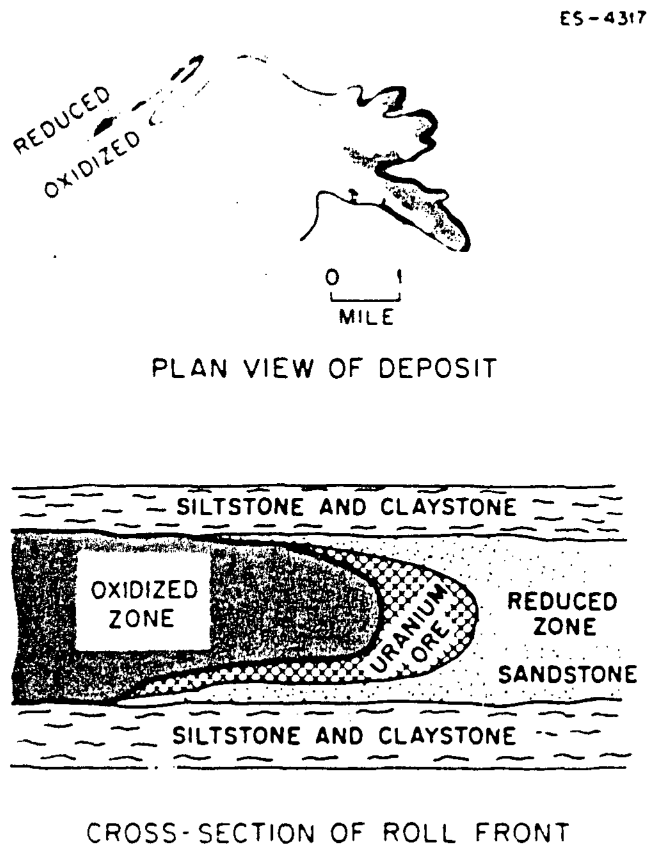

Fig. 3.1. Plan view of uranium ore deposit and cross section of geochemical cell or roll front. <u>Source</u>: A. R. Dahl and J. L. Hagmaier, "Genesis and Characteristics of the Southern Powder River Basin Uranium Deposits, Wyoming, USA," *Formation of Uranium Ore Deposits*, pp. 201-218 in *Proc. Symp., Athens, 6-10 May 1974*, International Atomic Energy Agency, Vienna, Austria, 1974.

The ore body is a basic part of the process circuit in in situ leaching. Additionally, the mineralogic and hydraulic properties of the ore body are pertinent factors in the engineering design of the total operation.

3.2.2 Well field

The well field provides the means by which leach solution (lixiviant) is circulated through the ore body to extract the uranium. Therefore the well field design determines the effectiveness of lixiviant circulation, confinement, and utilization. It also affects the efficiency of uranium extraction. Principal engineering considerations in well field design are the well spacing, the injection and production patterns, the well completion methods, and the number of wells to be used. Well spacing is determined by the hydrologic characteristics of the formation. These influence the rate and efficiency of lixiviant circulation. The pattern of injection and production wells is determined by the injectivity rate(s) to the formation and the horizontal hydraulic sweep efficiency through the mineralized well field zone. The well completion method and local permeability determine the vertical confinement and vertical sweep efficiency of the lixiviant through the mineralized zone.

The applicant's proposed well field(s) is discussed in Sect. 4.3.

3.2.3 Lixiviant chemistry

Initially, in situ solution mining of uranium utilized a dilute sulfuric acid lixiviant enhanced by an oxidizing agent such as sodium chlorate. Such a lixiviant is suitable in working low-alkaline (low-carbonate) ore deposits. However, acidic solutions also tend to dissolve other trace minerals associated with such an ore and, therefore, are less specific for uranium. As a result, basic (ammonium or sodium bicarbonate-carbonate) lixiviants with an oxidizing agent are now generally used in most in situ activities where carbonate minerals are known to be associated with the ores (Table 3.1).

Table 3.1. Typical concentrations of major constituents in basic lixiviant solutions used in solution mining of uranium

Constituent	Concentration (mg/liter)	
	Pawnee project[a]	Palangana project[b]
Ammonium bicarbonate-carbonate	2,000–10,000	8,000
Hydrogen peroxide	100–800	1,500
Sodium	150–200	250
Chloride	200–350	200
Sulfate	75–350	1,500

[a]Texas Water Quality Board, "Permit to Dispose of Wastes under Provisions of Article 7621 d-1, Vernon's Texas Civil Statutes. Permit No. 02050, January 1977, Intercontinental Energy Corporation."

[b]Texas Water Quality Board, "Permit to Dispose of Wastes under Provisions of Article 7621 d-1, Vernon's Texas Civil Statutes. Permit No. 02051, January 1977, Union Carbide Corporation."

At startup, the necessary chemicals are added to water drawn from the ore zone aquifer. This solution is then recirculated through the localized ore zone (well field). Typically, the desired concentration of a basic lixiviant (e.g., ammonium bicarbonate) is maintained by chemical reconstitution operations and by controlling the pH (about 8). Carbon dioxide and ammonia or other soluble basic carbonate salt may be used to adjust concentrations. An oxidant (oxygen, air, or hydrogen peroxide) is normally added to the lixiviant at the well field prior to its injection into the ore zone.

The applicant's lixiviant is listed in Table 4.2.

3.2.4 Uranium recovery process

As depicted in Fig. 3.2, a generalized solution mining process has four main processing circuits or units: (1) a lixiviant sorption circuit, (2) a resin transfer circuit, (3) an elution and precipitation circuit, and (4) a product drying and packaging unit. The movement of uranium through these circuits and the relationships of various process components are discussed in the following sections. The applicant's proposed process is discussed in Sect. 4.4.

3.2.4.1 Lixiviant sorption circuit

The lixiviant sorption circuit consists of the ore body, the well field, the uranium adsorption column(s), lixiviant bleed, lixiviant makeup unit, and calcium control unit. The process begins with the injection of lixiviant into the ore body. This solution oxidizes the uranium in the localized ore zone and forms a soluble uranium ion complex. The complexed uranium, mobilized reaction by-products, and unreacted reagents in the lixiviant flow to a production well and are pumped to the surface (produced from the ore zone). This uranium-bearing solution then passes through a uranium sorption column (near the well field or in the recovery plant) via the use of an ion exchange resin that preferentially extracts the uranium ion complex from the pregnant solution. The solution leaving this resin column is essentially barren of uranium. It also contains residual lixiviant chemicals. This barren solution is passed to the makeup unit, where it is reconstituted with the necessary lixiviant chemicals and is recycled to the well field for reinjection.

A solution bleed in the plant enables some control of groundwater flow. By diverting part of the barren solution leaving the uranium sorption column, less recycle solution is reinjected. This reduces the water level in the localized ore zone, permitting water from the surrounding aquifer to migrate into the mined zone. The rate of the groundwater incursion should be equal to the bleed rate. This groundwater influx would tend to limit the excursion of lixiviant out of the localized well field area.

The presence of calcium compounds in the lixiviant or barren solution is generally disadvantageous in the processing. Calcium could precipitate as calcite ($CaCO_3$) in basic leach solutions or as gypsum ($CaSO_4$) in sulfuric acid leach solutions. Either precipitate could plug injection and production wells or interfere with the ion exchange process. Calcium removal units utilizing either ion exchange (water softening) or solution pH control techniques may be placed in the lixiviant sorption circuit to mitigate potential calcium-related problems.

3.2.4.2 Resin transfer circuit

The ion exchange resin used in the uranium extraction column is eluted periodically to recover the sorbed uranium and to regenerate the resin before it is returned to the sorption circuit. The resin transfer circuit cycles the ion exchange resin between the sorption and elution circuits. Most solution mining operations house the ion exchange columns in a recovery building. Alternatively, the ion exchange columns may be located near the active well fields and the resin trucked to a central recovery facility (satellite recovery system).

The resin transfer circuit also allows the flushing of the uranium-loaded resin and rinsing of the regenerated (eluted) resin to control other contaminants that may affect the efficiencies of the elution and the extraction process respectively.

3.2.4.3 Elution and precipitation circuit

The elution and precipitation circuit consists of the elution column, the precipitator, and the contaminant control and eluant makeup units. Uranium-loaded resin from the column is the feed for this circuit. After transfer of the loaded resin to the elution column, the uranium-loaded resin is eluted with a moderately concentrated chloride salt solution (1 to 2 M Cl). The chloride ion in this solution displaces the uranium ion complex sorbed on the resin and thus regenerates the resin. The regenerated resin is returned to the uranium extraction column, and the uranium-rich eluate is transferred to the precipitation unit.

In the precipitation unit, the desorbed uranium ion complex is destroyed by acidification. The resultant uranium ion is precipitated with ammonia as ammonium diuranate [$(NH_4)_2U_2O_7$], which is commonly known as ADU. The ammonium diuranate, in slurry form, is transferred to the drying and packaging unit. The barren eluate is recycled through the contaminant control unit and eluant makeup unit to the elution column.

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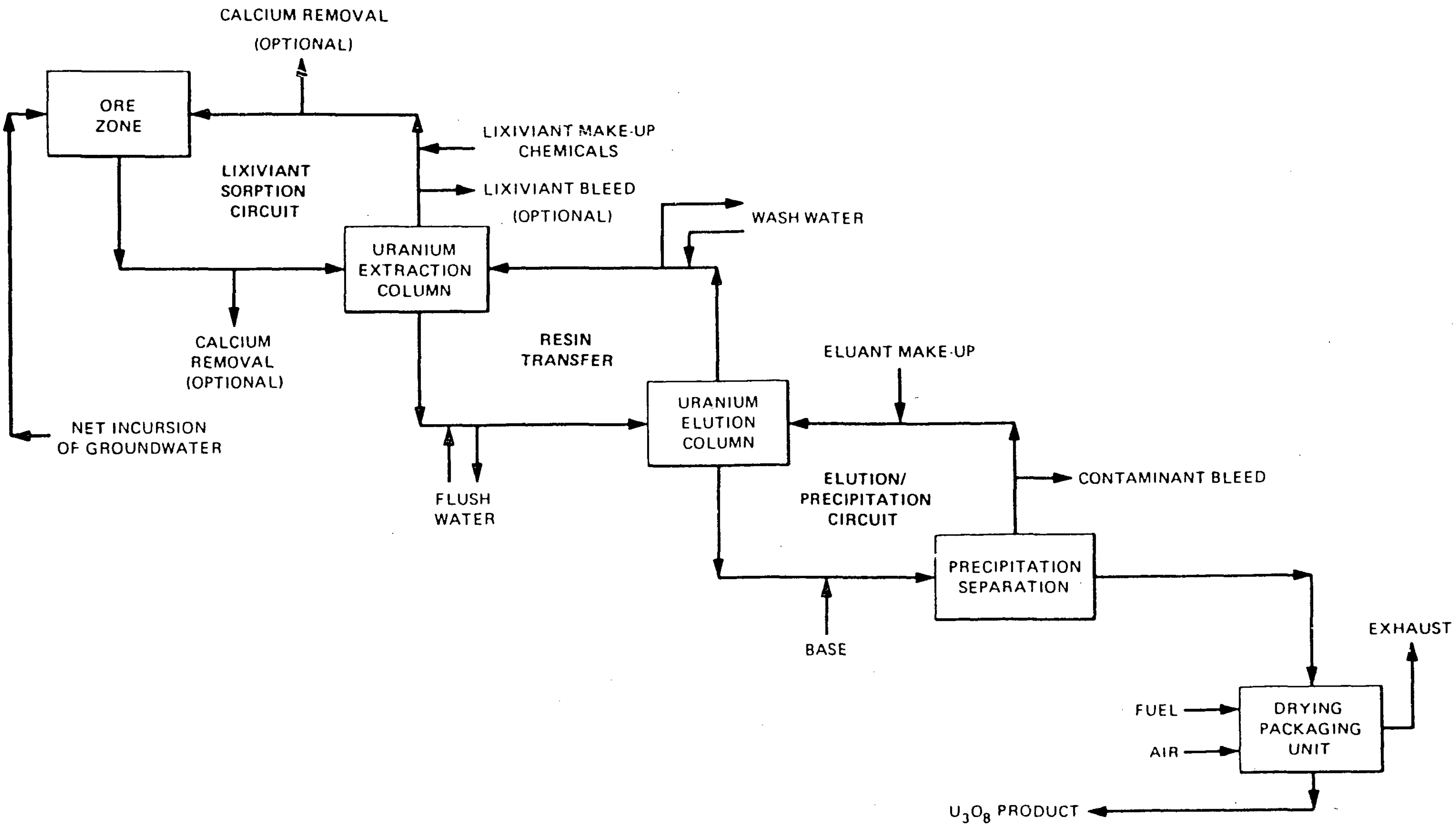

Fig. 3.2. Generalized uranium recovery process.

In the uranium recovery process, contaminants such as sulfate and vanadium are also sorbed on the ion exchange resin and stripped into the elution and precipitation circuit along with uranium. In the absence of any control, the concentration of such contaminants could build up to affect the product purity and/or elution process efficiency. For contaminant control, a bleed-off of some of the contaminated recycle eluant is effected by replacing a bled volume with an equal amount of fresh eluant. This controls the contamination level but requires the increased use of makeup water and elution chemicals and the discharge of a concentrated liquid waste stream to a holding pond that must be ultimately managed.

Water consumption can be reduced through the use of precipitation and physical adsorption processes in contaminant control. For example, sulfate levels can be controlled by the addition of barium chloride ($BaCl_2$) to the recycle eluant, precipitating insoluble barium sulfate ($BaSO_4$). This can be stored in an interim solid waste impoundment; vanadium can be adsorbed on activated carbon and recovered as a by-product or disposed of with the carbon as a solid waste.

The nature, level, and even the need of contaminant control depend on the composition of the ore body and the chemistry of the specific solution mining process. The prevailing conditions in the solution mine field, the chemical reagent costs, and the wastewater disposal techniques employed will determine what contaminant control measures will be used.

Prior to entering the elution column, the recycle eluant passes through an eluant makeup unit. In this unit, the chloride ion concentration, depleted during elution and contaminant control operations, is restored by the addition of a chloride salt. Makeup water may also be added here to maintain the system flow.

3.2.4.4 Product drying and packaging unit

The uranium leaves the elution and precipitation unit as a slurry of ammonium diuranate and may be dried prior to packaging for shipment. Upon entering the product drying and packaging unit, the slurry is washed and dewatered. The rinse water, which contains some soluble uranium, is returned to the elution and precipitation unit. The moist diuranate cake enters a dryer and calciner, where it is converted to U_3O_8 and the by-products (water and ammonia) are driven off. Following drying and calcining, the oxide product (yellow cake) is crushed and placed in drums for shipment.

To mitigate particulate uranium releases in this unit process, the exhausts from the dryer and calciner, crusher, and packaging equipment areas are treated in Venturi scrubbers (see Sect. 3.2.5). The spent scrubber solution is recycled to the elution and precipitation circuit to recover any entrained uranium.

3.2.5 Waste effluent treatment processes

In general, liquid and solid waste and atmospheric effluents will result from the solution mining activities. Liquid wastes from well field overpumping (i.e., production flow in excess of injection flow), elution and precipitation circuit bleeds, and subsequent aquifer restoration represent the major waste streams to be managed from solution mining activities. Since the dissolved solids content of the wastewater precludes any uncontrolled releases, some form(s) of waste management is necessary. Generally, for liquid waste management, evaporation ponds are utilized; however, deep well disposal has been used in Texas. The ponds vary in size depending on the flow rate of liquid waste streams to the pond and the rate(s) of water evaporation and seepage from the pond. To minimize unwanted seepage of the wastewater, the ponds are lined during construction with clay, asphalt, or continuous plastic membranes. The specific method(s) used is dependent on the conditions at each solution mining operation.

Solar evaporation is a consumptive use of water. When recycle of wastewater is desirable, water reclamation by reverse osmosis, ion exchange, chemical treatment, or multieffect distillation may be attempted.

Solid wastes generated, for example, from the calcium control unit in the lixiviant sorption circuit and from the contaminant control unit in the elution and precipitation circuit also require controlled management. During the life of a solution mining operation, solids may be impounded in specific storage ponds as a slurry and be maintained and monitored under a liquid seal to minimize particulate emissions and radon gas evolution. Permanent disposal techniques, in accord with NRC and/or responsible State agency regulations, will subsequently isolate the solids from the environment.

Sources of atmospheric emissions include the open surfaces of ponds and tanks, the product drying and packaging unit, the internal combustion engines in vehicles and drilling rigs used at the site, dust due to vehicular movement on unimproved roads, and processes using ammonia. Tank emissions can be limited by venting them through liquid or solid absorbents before release to the atmosphere. Venturi or impingement scrubbers are used to control both particulate and gaseous emissions from drying and packaging operations. Exhaust emission controls are presently provided for internal combustion engines.

3.2.6 Groundwater quality restoration process

After termination of solution mining operations, procedures are implemented to restore the water quality of the affected aquifer. Restoration will remove or immobilize chemical species injected into or mobilized as a result of chemical actions in the ore body during mining. The restoration process is intended to reduce the mobilized solids content and composition of the groundwater to levels set by appropriate regulatory agencies.

Groundwater restoration technology is still in the development stage. A process that requires the pumping of large quantities of water from the aquifer (groundwater sweeping) is currently in general use. By this technique, the contaminated water removed from the aquifer is replaced by groundwater entering the localized ore zone from the surrounding area or is replaced by purifying (for example, by reverse osmosis) the contaminated water and recycling it into the aquifer. The water entering this ore zone aquifer will gradually sweep the residual impurities from the solution mining operations toward the production wells, where they will be withdrawn to the surface for management. The efficiency of the sweeping action may not be very high. Impurities, e.g., ammonia, are chemically sorbed on clay minerals within the aquifer host formation and are only removed slowly, because their migration rate is retarded by repeated sorption and desorption from the clays. Unless some efficient elution or immobilization techniques are developed, long-term aquifer pumping may be the only method of ore zone groundwater restoration. Water produced by such a restoration process or other processes under development should be managed by the methods discussed in Sect. 3.2.5.

3.3 GLOSSARY OF TERMS RELATED TO SOLUTION MINING OF URANIUM

Adsorptive capacity. Physical limit of adhesion of ions in solution to the surfaces of solids with which they are in contact.

ADU. Ammonium diuranate. Approximate chemical composition is given as $[UO_2 (OH)_2 \, x \, H_2O \, NH_4^+]$ salt. ADU is not the oxide form of uranium, namely, U_3O_8 (triuranium octaoxide).

Alkalinity. A measure of the power of a solution to neutralize hydrogen ions expressed in terms of an equivalent amount of calcium carbonate.

Alluvium. Clay, silt, sand, gravel, or other rock materials transported by flowing water and deposited in comparatively recent geologic time as sorted or semisorted sediments.

Annular space (annulus). The space between casing or well screen and the wall of the drilled hole.

Aquiclude. Formation that, although porous and capable of absorbing water, does not transmit it at rates sufficient to furnish an appreciable supply for a well or spring.

Aquifer. Porous water-bearing formation (bed or stratum) of permeable rock, sand, or gravel capable of yielding significant quantities of water.

Aquifer, leaky. Aquifer overlain and/or underlain by a thin semipervious layer through which flow into or out of the aquifer can take place.

Aquitard. Geological formation of a rather impervious and semiconfining nature which transmits water at a very slow rate compared with an aquifer.

Area of influence. Area around a pumping well in which the water table or the piezometric surface (in confined aquifers) is lowered by pumping.

Artesian. The occurrence of groundwater under greater than atmospheric pressure.

Artesian (confined) aquifer. An aquifer overlain by confining beds containing water under artesian conditions.

Artesian well. Well tapping a confined artesian aquifer in which the static water level stands above the surface of the ground.

Assessment actions. Those actions taken during or after an accident to obtain and process information that is necessary to make decisions to implement specific emergency measures.

Backblowing. Reversal of flow of water under pressure, for example, in a well to free the screen or strainer and the aquifer of clogging material.

Baseline. The environmental condition that existed prior to mining as determined by physical and/or chemical parameters and their natural variability.

Bleed system. A production adjustment technique whereby more fluids are pumped from the production zone than are injected, creating an inflow of groundwater into the production area.

Borehole. An uncased drilled hole.

Boundary, geohydrologic. Lateral discontinuity in geologic material, making the transition from the permeable material of an aquifer to a material of significantly different geohydrologic properties.

Boundary, impervious. Boundary of a flow domain through which no flow can take place because of greatly reduced permeability at the other side of the boundary.

Brine. A highly mineralized solution (usually greater than 100,000 mg/liter), especially of chloride salts.

Capacity. Volume that can be contained by a tank, pond, etc.; rate of flow that can be carried by any conveying structure.

Capacity, specific. Ratio of discharge of a well to drawdown at equilibrium.

Capillary diffusion. Movement of water by capillarity in a porous medium.

Capillary water. Water held in the soil above the water table by capillarity; soil water above hygroscopic moisture and below the field capacity.

Casing. Steel or plastic pipe or tubing that is placed in a borehole to prevent entry of loose rock, gas, or liquid or to prevent loss of drilling fluid.

Chemical water quality. The nature of water as determined by the concentration of chemical and biological constituents.

Clogging. Deposition of fine particles such as clay or silt at the surface and in the pores of a permeable porous medium, e.g., soil, resulting in the reduction of permeability.

Concentration. The weight of solute dissolved in a unit volume of solution.

Conductivity, hydraulic. Combined property of a porous medium and the fluid moving through it in saturated flow, which determines the relationship, called Darcy's law, between the specific discharge and the head gradient causing it.

Cone of depression. The depression, ideally conical in shape, that is formed in a water table or potentiometric surface when water is removed from a well.

Confining bed. Formation overlying or underlying a much more permeable aquifer.

Consumptive use. That part of the water withdrawn that is no longer available because it has been evaporated, transferred, incorporated into products or crops, or otherwise removed from the immediate water environment.

Contamination. The degradation of natural water quality as a result of man's activities to the extent that its usefulness is impaired. There is no implication of any specific limits, since the degree of permissible contamination depends upon the intended end use, or uses, of the water.

Corrective actions. Those measures taken to ameliorate or terminate a situation at or near the source of the problem in order to prevent an uncontrolled release of radioactive or toxic material or to reduce the magnitude of a release, e.g., shutting down equipment, repair and damage control, or reorganizing pumping arrangements.

Curie. The quantity of any radioactive material giving 3.7×10^{10} disintegrations per second. A picocurie is one trillionth (10^{-12}) of a Curie, or a quantity of radioactive material giving 2.22 disintegrations per minute.

Darcy. Unit of intrinsic permeability defined as the permeability of a medium in which a liquid of dynamic viscosity of 1 centipoise discharges 1 cm^3/sec through a cross section of 1 cm^2 under a gradient normal to the section of 1 atm/cm.

Darcy's law. Law expressing the proportionality of the specific discharge of a liquid flowing through a porous medium to a hydraulic gradient in laminar flow (low Reynolds numbers).

Degradable. Capable of being decomposed, deteriorated, or decayed into simpler forms with characteristics different from the original; also referred to as biodegradable when readily decomposed by organisms.

Degradation of water quality. The act or process of reducing the level of water quality so as to impair its original usefulness.

Depletion. Continued withdrawal of water from groundwater at a rate greater than the rate of replenishment; reduction of groundwater storage in an aquifer or of the flow of a stream or spring caused by discharge exceeding natural recharge.

Dewatering. Removing water by gravity or by pumping.

Dewatering coefficient. Amount of water removed per unit horizontal area and unit drawdown.

Diffusivity (of an aquifer). Coefficient of transmissivity of an aquifer divided by its coefficient of storage.

Dispersivity. Property of a porous matrix to cause spreading of a tracer traveling through it.

Dissolved solids, total (TDS). Total weight of dissolved material constituents in water per unit volume or weight of water in the sample.

Dominant direction of groundwater movement. The principal expected direction of groundwater flow. This dominant direction of movement is a result of three major variables: the transmissivity of the aquifer, the hydraulic gradient, and the differential applied hydraulic pressure.

Downstream. In the direction of the current.

Drawdown. Lowering of the water table or piezometric surface caused by the extraction of groundwater by pumping, by artesian flow from a borehole, or by a spring emerging from an aquifer.

Drawdown, equilibrium. Drawdown of the water table or of the piezometric surface near a pumping well, at constant discharge, after a stationary condition has been reached.

Effluent. A waste liquid, solid, or gas, in its natural state or partially or completely treated, that discharges into the environment.

Eluant. The solution that removes (elutes) a material (uranium) adsorbed on ion exchange resin.

Emergency action levels. Specific contamination levels of airborne, water-borne, or surface-deposited concentrations of radioactive or toxic materials; or specific instrument indications that may be used as thresholds for initiating such specific emergency measures as designating a particular class of emergency, initiating a notification procedure, or initiating a particular protective action.

Excursion. The movement of lixiviant (leachate solution) out of a mine zone as evidenced by measured movement past a trend or monitor well. Measurement is by an increase of selected parameter values above their established upper control limits.

Freeboard. Vertical distance between the normal maximum level of the surface of the liquid in a conduit, reservoir, tank, canal, etc., and the top of the sides of an open conduit, the top of a dam or levee, etc.

Groundwater. Water beneath the land surface in the saturated zone that is under atmospheric or artesian pressure; the water that enters wells and issues from springs.

Groundwater management. The development and utilization of the underground resources (water, storage capacity, and transmission capacity), frequently in conjunction with surface resources, in a rational and optimal manner to achieve defined and accepted water resource development objectives. Quality as well as quantity must be considered. The surface water resources involved may include imported and reclaimed water as well as tributary streams.

Groundwater, mining of. Withdrawal from a groundwater reservoir in excess of the average rate of replenishment.

Groundwater recession. Natural lowering of the groundwater level in an area.

Grout. To fill, or the material filling, the space around the pipe in a well, usually between the pipe and the drilled hole. The material is ordinarily a mixture of portland cement and water.

Hardness, carbonate. Hardness of water resulting from the presence of dissolved calcium and magnesium bicarbonates (temporary hardness).

Hardness, noncarbonate. Hardness of water resulting from the presence of dissolved calcium and magnesium salts other than carbonates (permanent hardness).

Hardness of water. That property of water, due mainly to bicarbonates, chlorides, and sulfates of calcium and magnesium, which prevents the production of abundant lather with soap.

Hazardous waste. Any waste or combination of wastes (which pose a substantial present or potential hazard to human health or living organisms) whose properties include flammability, evolution of toxic or irritating vapors, contact irritation, or human or animal toxicity.

Heads grade. The uranium content of recovered lixiviant, normally expressed in parts per million.

Heavy metals. Metallic elements, including the transition series, which include many elements required for plant and animal nutrition in trace concentrations but which become toxic at higher concentrations. Examples are mercury, chromium, cadmium, and lead.

Hydraulic gradient. The change in static head per unit of distance along a flow path.

Impoundment. A body of water formed by collecting water, as by a dam.

Infiltration. The flow of a liquid into soil or rock through pores or small openings.

Injection well. A well used for injecting fluids into an underground stratum or ore body by gravity flow or under pressure.

Ion exchange. Reversible exchange of ions absorbed on a mineral or synthetic polymer surface with ions in solution in contact with the surface. In the case of clay minerals, polyvalent ions tend to exchange for monovalent ions.

In situ. In its original or natural position.

Isopach. A line on a map drawn through points of equal thickness of a designated geological unit.

Leachate. The liquid that has percolated through solid ore, waste, or other man-emplaced medium and has extracted dissolved or suspended material from it.

Leakage. In groundwater, the flow of water from or into an aquifer through an underlying or overlying semipervious layer.

Lignite. A brownish-black coal in which the alteration of vegetal material has proceeded farther than in peat but not so far as in subbituminous coal.

Lixiviant. Leachate solution pumped underground to a uranium ore body; it may be alkaline or acid in character.

Mine field. Refers to the well-field area(s) and affected surface associated with solution mining. The term is often used interchangeably with well field.

Mine zone. The area from which uranium is extracted, including related buildings and structures. In this instance, it would include the ore body, all associated surface areas, and related well fields, process equipment, and buildings.

Mining unit (production unit). A segment or portion of an ore body capable of economically supporting mineral extraction; the minable limits of an ore body, which would normally include several production fields.

Monitor well. A surveillance (observation) well located usually along the periphery of a well field. It is used to indicate containment and/or lixiviant migration beyond the well-field boundary. When the upper control limit of a monitor well is exceeded, corrective action is initiated.

Monitor well zone. The area of possible monitor well location. This zone is normally outside the limits of mineralization.

Nonpoint source. A source from which the contaminant enters the receiving water in an intermittent and/or diffuse manner.

Nonproduction zone(s). Those stratigraphic intervals underlying and overlying the production zone that are aquifers or that are relatively permeable.

Ore body. The mineralized portion of the sandstone formation where uranium is found in various grades and concentrations that can be extracted economically.

Osmosis. Passage of a solvent from a dilute solution to a more concentrated one through a semipermeable membrane (one that is permeable to the solvent only).

Oxidation. A chemical reaction in which there is an increase in positive valence of an element from a loss of electrons; in contrast to reduction.

Percolation. Movement under hydrostatic pressure of water through unsaturated interstices of rock or soil.

Permeability. Property of a porous medium to allow for the movement of liquids and gases through it under the combined action of gravity and pressure.

Permeable rock. Rock having a texture that permits water to move through it perceptibly under a head gradient ordinarily found in subsurface water (pervious rock).

pH. Minus the logarithm of the hydrogen ion concentration (activity). It is used as an indicator of acidity (pH less than 7) or alkalinity (pH greater than 7).

Phreatic divide (groundwater divide). Line on a water table along the sides of which the groundwater flows in opposite directions.

Piezometric surface. The surface defined by the levels to which water under artesian conditions will rise in tightly cased wells; also called potentio metric surface.

Plume. A body of contaminated groundwater originating from a specific source and influenced by such factors as the local groundwater flow pattern, density of contaminant, and character of the aquifer.

Point source. Any discernible confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, or concentrated animal feeding operation, from which contaminants are or may be discharged.

Pollutants (water). Substances that may become dissolved, suspended, absorbed, or otherwise contained in water and impair its usefulness.

Pollution (water). The degradation of natural water quality, as a result of man's activities, to the extent that its usefulness is impaired.

Ponds. Small storage reservoirs.

Population at risk. Those persons for whom protective actions are being or would be taken.

Pore. An open space in rock or soil.

Porosity. The relative volume of the pore spaces between mineral grains in a rock as compared with the total rock volume.

Porous medium. Solid body containing interconnected pores more or less evenly distributed.

Production area. The area of injection and production activity, which can be portrayed by a plan view of the well-field area and vertically by a cross section extending from the surface to at least 10 ft below the bottom of the lowest production zone.

Production cell. The grouping of injection wells about a production or recovery well arranged in various configurations and varying in number.

Production field (zone). Mine or well field(s) actively used for production. It could consist of two or more well fields.

Production module. A process plant that is modularized for ease of installation and removal and is capable of handling a given production flow and output.

Production well (recovery well). A well from which lixiviant is recovered for conveyance to a process plant.

Production zone. That stratigraphic interval into which leaching chemicals are introduced. This interval extends horizontally in all directions in and beyond the production area.

Pump test. Extraction of water from a well at one or more selected discharge rates, during which piezometric or phreatic levels are measured regularly at the pumped well and at nearby observation wells. The data are used for determining the aquifer parameters in the vicinity of the pumped well.

Purification. Treatment of water for the removal of harmful or undesirable physical properties, chemical substances, and living organisms.

Radius of influence. Distance from the axis of a pumped or recharged well at which the effect of the well on the piezometric or the phreatic surface is no longer perceptible.

Recharge. The addition of water to the groundwater system by natural or artificial processes.

Reclamation. The return of the surface environment to acceptable preexisting conditions. This normally includes equipment removal, well plugging, surface contouring, reseeding, etc.

Recovery actions. Those actions taken after an emergency to restore the plant or facility as nearly as possible to its preemergency condition.

Reduction. A chemical reaction in which there is a decrease in positive valence as a result of gaining of electrons.

Restoration. The returning of all affected groundwater to its premining use by employing the best practical technology.

Reynolds number. Defined as $R = av\rho/\eta$, where ρ is the fluid density, η is the fluid viscosity, a is a length characteristic of the porous structure, such as the average pore size, and v is the volume of fluid crossing unit area per unit time.

Roll front. Uranium deposition localized as a roll or interface separating an oxidized interior from a reduced exterior. The reduced side of this interface is significantly enriched in uranium.

Runoff. Direct or overland runoff is that portion of rainfall which is not absorbed by soil, evaporated, or transpired by plants but finds its way into streams as surface flow.

Saturated zone. The zone in which interconnected interstices are saturated with water under pressure equal to or greater than atmospheric.

Sedimentary rock. Rocks formed from the accumulation and compaction of sediment.

Seepage. Slow movement of water in unsaturated rock material; loss of water by infiltration into the soil from a canal or other body of water.

Semiconfining bed. Poorly pervious yet water-transmitting layer.

Solution channels (holes or cavities). Fractures, joints, bedding planes, or other openings in soluble rocks, through which flow can occur (especially in limestone).

Sorption. A general term used to encompass processes of adsorption, absorption, desorption, ion exchange, ion exclusion, ion retardation, chemisorption, and dialysis.

Specific conductance. The ability of a cubic centimeter of water to conduct electricity; varies directly with the amount of ionized minerals in the water.

Stratigraphy. Concerning the sequence of rock types formed on the earth's surface. Each stratum is defined by its composition, distribution, succession, and geologic era.

Subsidence. Surface caving or distortion brought about by collapse of deep mine workings or cavernous carbonate formations, or from overpumping of certain types of aquifers.

Surface water. That portion of water that appears on the land surface (oceans, lakes, rivers).

Toxicity. The ability of a material to produce injury or disease upon exposure, ingestion, inhalation, or assimilation by a living organism.

Transmissivity. Rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is expressed as the product of the hydraulic conductivity and the thickness of the saturated portion of the aquifer.

Trend well. Surveillance well for production control and/or monitoring located between the well field and the monitor wells.

Unsaturated zone. Consists of interstices occupied partially by water and partially by air and is limited above by the land surface and below by the water table.

Upconing. The upward migration of groundwater from underlying strata into an aquifer caused by a reduced hydrostatic pressure in the aquifer as a result of pumping.

Upper control limit (UCL). A concentration value for any designated chemical species (indicator species) that must not be exceeded in a monitor well. Corrective actions are initiated when the upper control limits are exceeded and are continued until migration is brought under control.

Upstream. In the direction opposite to the main current.

Waste. Solids or liquids from solution mining or associated processes of no further value and subject to no additional productive processing. These are normally stored for concentration and ultimate disposal. Some process streams may be waste streams.

Water, brackish. Water containing significantly less salt than seawater. The concentration of total dissolved solids is usually in the range of 1,000-10,000 mg/liter.

Water conservation. Measures introduced to reduce the amount of water used for any purpose and/or to protect it from pollution.

Water demand. Actual quantity of water required for various needs over a given period as conditioned by economic, social, and other factors to satisfy a known or estimated requirement.

Water, drinking. Water suitable for drinking.

Water, fresh. Water neither salty nor bitter to the taste and in general chemically suited for human consumption (having a low dissolved solids content).

Water quality. Pertaining to the chemical, physical, and biological constituents found in water and its suitability for a particular purpose.

Water resources. Supply of water in a given area or basin interpreted in terms of availability of surface and underground water.

Water supply system. All storage reservoirs, pumps, pipes, and works required for providing water of a desired quality to the different sectors of consumption.

Water table. That surface in an unconfined groundwater body at which the pressure is atmospheric. It defines the top of the saturated zone.

Water table aquifer. An aquifer containing water under atmospheric conditions.

Water yield. Total runoff from a drainage basin through surface channels and aquifers.

Well capacity. Maximum rate at which a well will yield water under a stipulated set of conditions, such as a given drawdown.

Well completion. Techniques used to control horizontal underground movement of injected fluids from a well and to maintain the integrity of over- and underlying layers.

Well, disposal. Well used for the disposal of polluted or drainage water brines, etc.

Well field (mine field). Several production cells capable of supplying a given feed to a process plant.

Well, fully penetrating. Well that extends through the whole saturated depth of an aquifer and is constructed in such a manner that water is permitted to enter the well throughout its length.

Well, partially penetrating. Well in which the length of water entry is less than the thickness of the saturated aquifer that it penetrates.

Well radius, effective. Horizontal distance from the axis of a well.

Yield of aquifer (economic). Maximum rate at which water can be artificially withdrawn from an aquifer in the foreseeable future without continuously lowering the water table, depleting the supply, or altering the chemical character of the water to such an extent that withdrawal at that rate is no longer economically possible.

Yield, optimal. Amount of water that can be withdrawn annually from an aquifer or from a basin according to some predetermined criterion of optimal exploitation.

Yield, safe. Amount of water (in general the long-term average amount) that can be withdrawn from a groundwater basin or surface water system without providing undesirable results.

Zone of saturation. That part of the lithosphere in which the pores are completely filled with water.

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4. PROPOSED OPERATIONS

4.1 DESCRIPTION OF ORE BODY

4.1.1 Physical shape and areal extent

Roll-type mineralization is present at the Irigaray site in the Wasatch Formation in units designated by WMC as the Upper Irigaray sandstone (UISS) and the Lower Irigaray sandstone (LISS). The UISS is the thickest and economically most important. Figure 4.1 shows the areal extent of mineralization of the UISS.

4.1.2 Mineralogy and geochemistry

Uranium has been deposited in the reducing environment of the ore roll front as uraninite, an oxide of uranium, and coffinite, a silicate. The content of calcite, $CaCO_3$, ranges from 1 to 3%, and pyrite, FeS_2, is generally less than 0.5%. In contrast to many uranium deposits of similar origin, no molybdenum mineralization has been found at the Irigaray site to date. Arsenic and selenium are present within and adjacent to the uranium mineralization. Barite, $BaSO_4$, is found with the uranium mineralization.

4.2 AMENABILITY TO SOLUTION MINING

Pilot-scale testing has been performed on the Irigaray deposit to determine its amenability to and the feasibility of recovering uranium by solution mining techniques. During the course of testing, data were collected on (1) solution circulation rates as a function of well spacing, completion methods, and lixiviant composition; (2) characteristics of the solution produced as a function of lixiviant composition; and (3) sustained well field and process plant operation.

The first test period lasted for 11 months, beginning in November 1975 and continuing until October 1976. During this period, testing was conducted on three adjoining patterns in Section 5, designated 5I7, and 5I7X, and 5I7S (Fig. 4.2). Restoration tests have been conducted at the 5I7 site.

Results from the 5I7 test to demonstrate the feasibility of solution mining are shown in Table 4.1. The data suggest that the well spacing (injection to production) best suited for the Irigaray deposit is near 12 m (40 ft). Because of limited injection flows and economic considerations, the proposed production cell configuration will be a seven-spot pattern (six injection wells around a central recovery well).

A pilot-scale test is being conducted in Section 9 at the site (Fig. 4.4) to develop design criteria for the proposed production-scale solution mining operation.

4.3 WELL FIELD

4.3.1 Description and location

Uranium will be mobilized by injecting a leach solution and an oxidizing agent into the ore body through injection wells and recovered by pumping the uranium-rich solution to the surface through nearby production or recovery wells. Figure 4.3 is a simplified cross section of a solution mining unit. The numbers of injection wells and recovery wells and their spacing depend on the hydrologic characteristics of the host rock. The initial well pattern to be used at the Irigaray site is called a seven-spot — six injection wells surrounding one central recovery well (Fig. 4.4, inset) — and is based on economic factors and limited injection flow rates. The distance between the injection and recovery wells will be about 12 m (40 ft). The seven wells are called a production cell. A number of production cells operating in one area constitute the well field. Numerous well fields will make up a mining unit (Fig. 4.4). The applicant's proposed mining and drilling schedule is shown in Fig. 4.1.

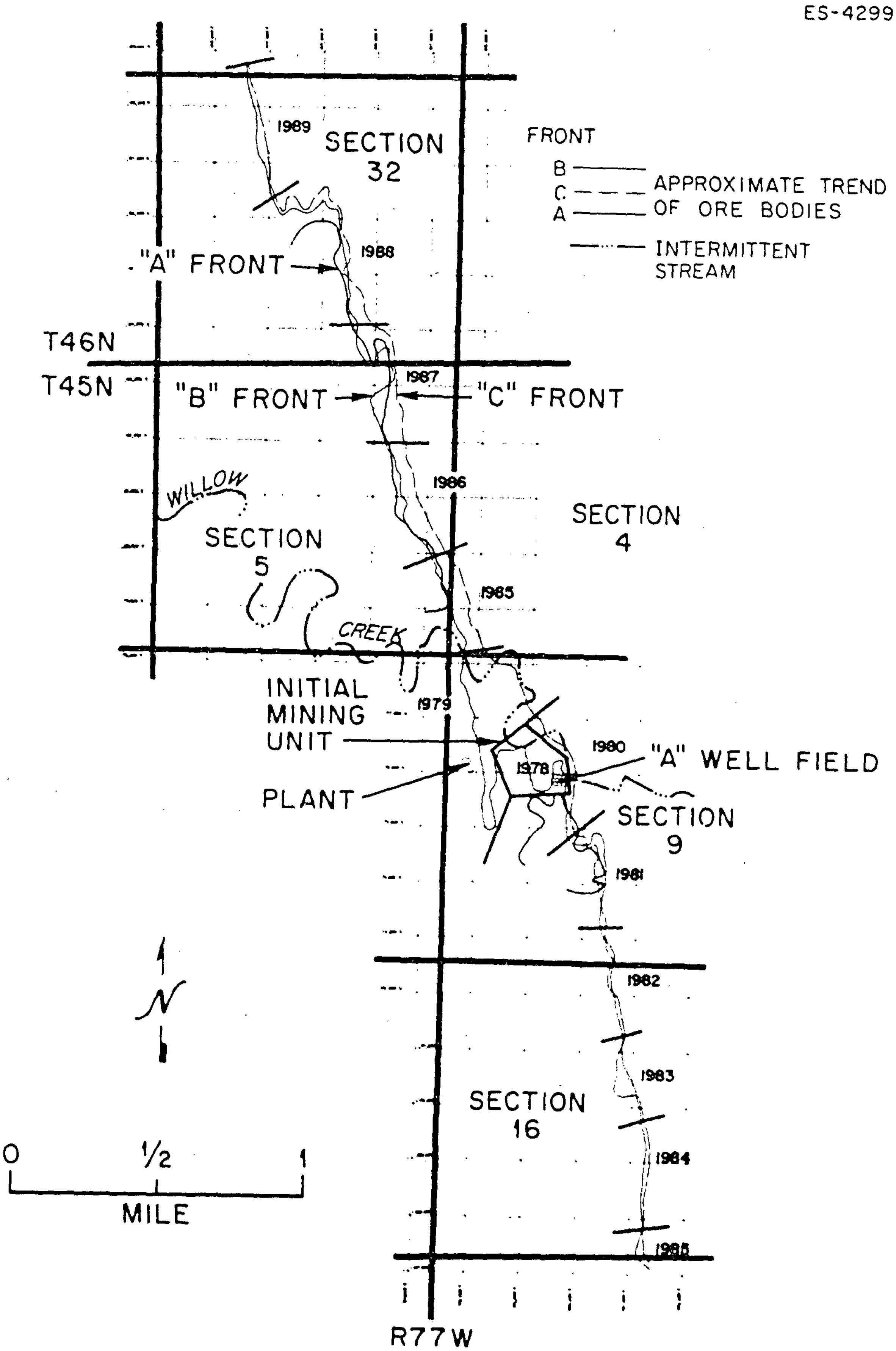

Fig. 4.1. Potential mining and drilling schedule for the Irigaray site. Source: Modified from ER, Fig. 4-1.

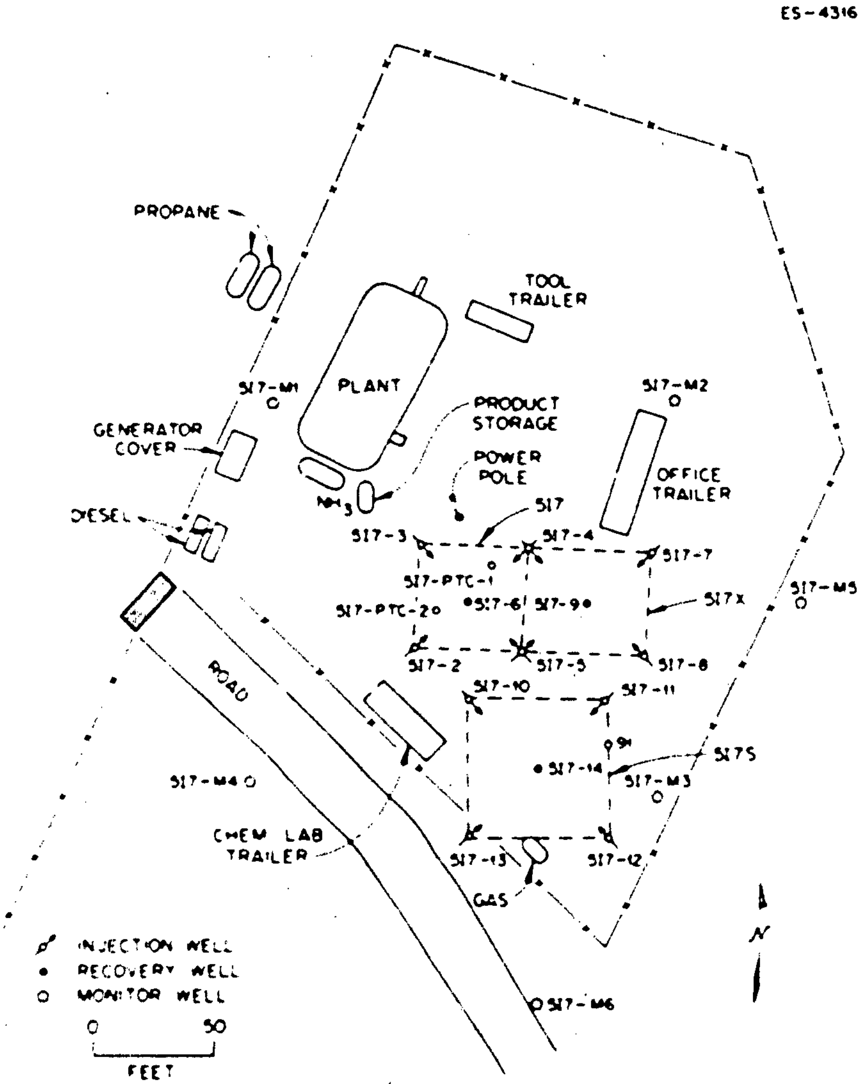

Fig. 4.2. 5I7 Irigaray research and development test layout. Source: ER, Fig. 2-7.

Table 4.1 Results from 517 pilot-scale test

Test	Surface area of test site (ft^2)	Duration of test (days)	Approximate percentage of U_3O_8 recovered[a]
517	1600	107	35
517X	2000	104	50
517S	3250	94	30 (approx)

[a]Test was only operational in nature; it was not intended to effect optimum recovery.

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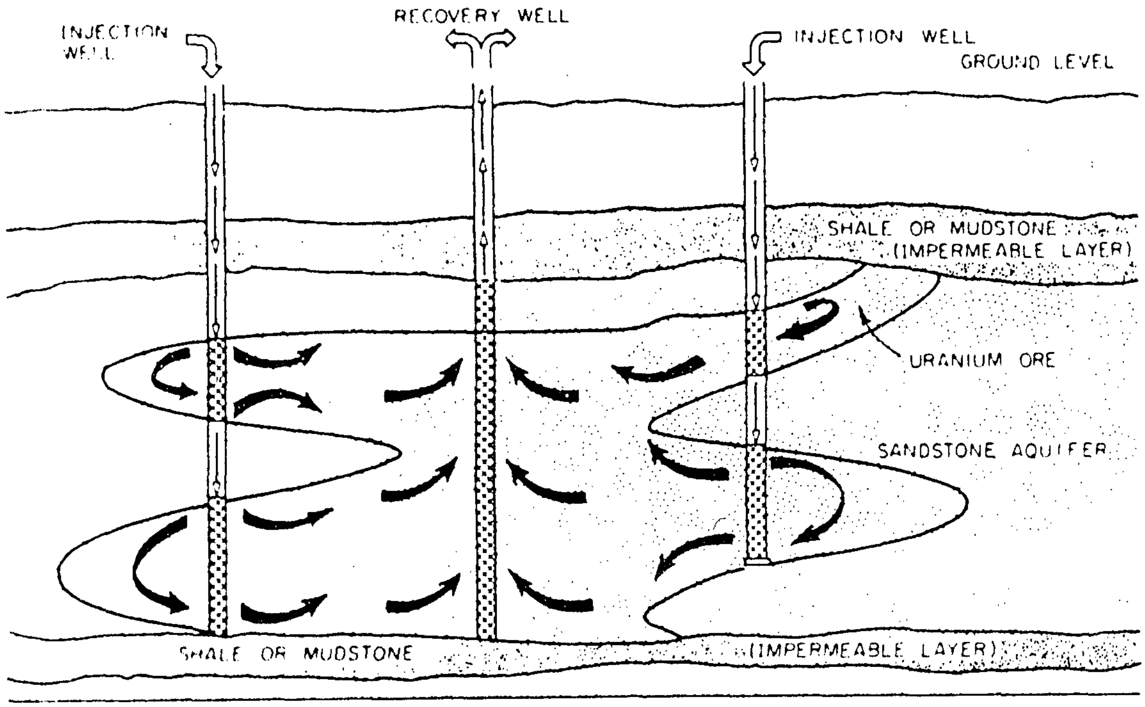

Fig. 4.3. Cross section of a typical uranium roll front deposit and the solution mining unit. Source: Modified from ER, Fig. 2-2.

The existing well field A (pilot-scale test area) is located in Section 9, T45N, R77W (Fig. 4.4). Proposed well fields for subsequent mining are also indicated in Fig. 4.4.

4.3.2 Well completion

Wells are drilled with a standard exploration-type water drill rig using a conventional bit and an inorganic drilling mud. The wells are usually 10 cm (4 in.) in diameter. The hole is logged (gamma, resistivity, etc.) to pinpoint the mineralized zones and the depths where open or screened holes are needed. The well is then cased. The bottom of the casing is assembled as shown in Fig. 4.5.

Cement is then pumped into the casing and through cementing holes into the annulus above the cement basket. Water is used to force most of the cement out of the casing and bring the cement level in the annulus to the surface. The well is then shut in and checked for leaks, and the cement is allowed to harden. After hardening, the cement remaining in the casing is drilled out along with the plug. The part of the well below the casing is then cleaned by circulating water, "produced," and steam-cleaned. Underreaming is used when the injectivity is not acceptable.

A cap is put on the injection well so that fluid can be injected into the open interval. Recovery wells are equipped with a down-hole pump suspended on a 1-in. pipe, which brings recovered solution to the surface.

4.3.3 Injection and production rates and pressures

Based on the hydraulic conductivity of the ore zone (Sect. 2.6.2.3), injection rates per well are expected to be 4 to 5 gpm at a pressure of 50 to 120 psi. Total injection rate in one production cell could be as much as 30 gpm. These figures are based on pilot-scale experience. Localized variations of the hydraulic characteristics in the ore body might increase or decrease selected injection rates. Other factors that may affect the maximum injection pressures and flow vs pressure relationships are hole interval, blinding of the injection well bore, and the quality

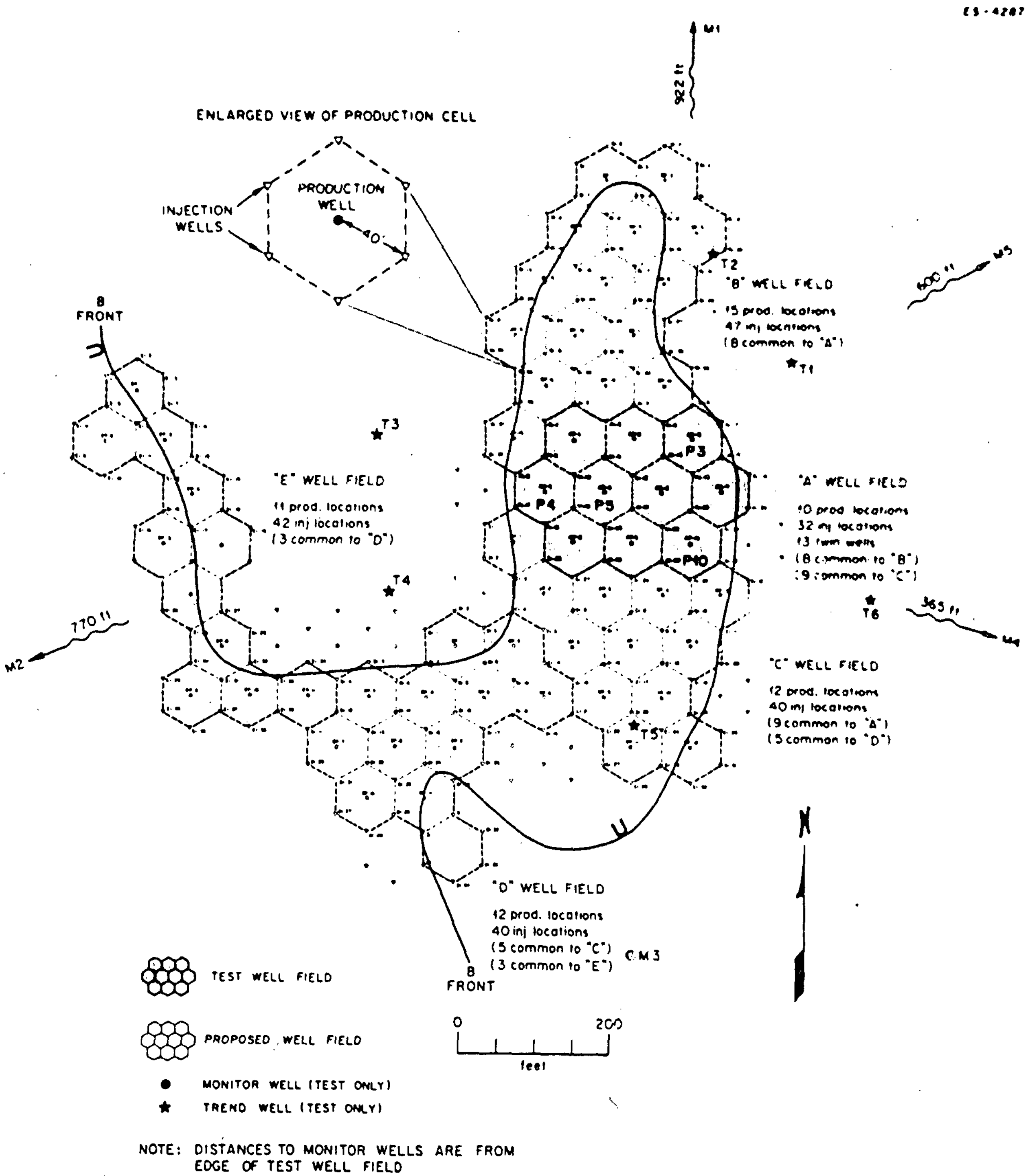

Fig. 4.4. Well field locations for the initial mining unit and pilot-scale test in Section 9. Source: Modified from ER, Fig. 2-10.

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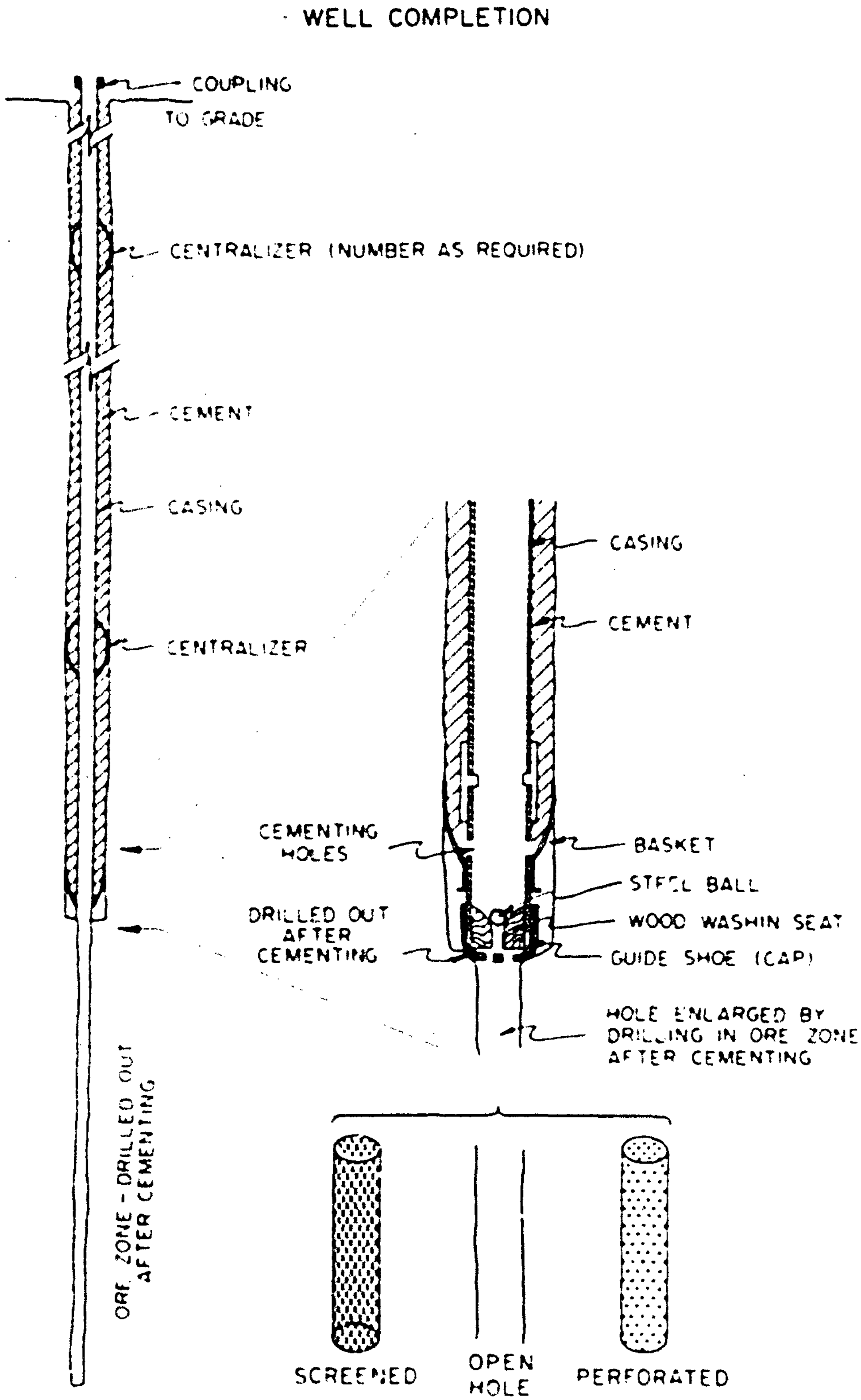

Fig. 4.5. Diagram of well completion methods. Provided by the applicant.

of well completion. The injection pressure is limited by the fracturing pressure of the formation, which is about 140 psi. Successful leaching of uranium could be markedly impeded if fracturing occurred.

Recovery wells will be pumped at a rate planned to confine the leach solution to the production cell or well field. Specific production rates from recovery wells are expected to range from 12 to 15 gpm based on a 3 to 1 ratio of injection wells to recovery wells.

4.3.4 Operating plans and schedules

4.3.4.1 Well field and plant

The recovery building shell has been constructed. It presently contains the pilot-scale test equipment, operating at a 100-gpm capacity under Nuclear Regulatory Commission Source Material License SUA-1204. The applicant proposes plant start-up at a capacity of 500,000 lb/year of U_3O_8 (800 gpm) in summer of 1978. Well field drilling is planned to stay approximately four to five months ahead of the mining operation.

4.3.4.2 Mining operation

Proposed annual progress of the mining and drilling operation is shown in Fig. 4.1. The general plan will be to start at the existing well field A in Section 9 and follow the ore body north toward Section 4. South of well field A, mining will move to the other side of the ore body and progress southward through Sections 9 and 16. As the mining operation moves away from the site of the present plant, other recovery plants may be required in the future.

4.3.4.3 Restoration

Restoration will begin after a well field has been mined out and the mining operation has moved far enough away [a distance of three production cell widths approximately 73 m (240 ft)], so there will be minimal interference with the restoration operation. For specifics, see Sect. 5.1.

4.4 RECOVERY FACILITY

4.4.1 Buildings: construction and appearance

According to the applicant, the Irigaray plant building will house a 500,000-lb/year recovery plant. The site and core building have been designed to permit expansion to a 1,000,000-lb facility either by replication of the currently planned recovery system or by the use of satellite systems (see Sect. 3.2.4.2).

The process building covers 2230 m^2 (24,000 ft^2) and is 91 m (300 ft) long, 24 m (80 ft) wide, and 6 m (20 ft) high except for a raised section that is 12 m (40 ft) high, 24 m (80 ft) wide, and 12 m (40 ft) long to accommodate the ion exchange columns.

The building is a standard steel structural framed unit, covered with prepainted 24-gage steel sheets, and has fiberglass-insulated walls and ceilings. The floors are a minimum of 15 cm (6 in.) of reinforced concrete with central drain and sump systems to reclaim all plant liquids used in processing and washing. The structure is designed to be expandable to accommodate modifications or process changes during the life of the plant. As mining progresses, new floors and foundations can be prepared elsewhere. The skid-mounted process units and the building can then be moved to that location.

Attached to the process building is a combined office, warehouse, and analytical laboratory of 446 m^2 (4,800 ft^2).

Well field control buildings will be located in each well field. The buildings will typically be 9 m (30 ft) long, 6 m (20 ft) wide, and 3 m (10 ft) high. The size may vary slightly depending on the number of wells serviced by each building. Floors and pump mounts are constructed of reinforced concrete. The floor is equipped with drains and sumps to control wash water and spills.

Septic systems have been built to State-approved plans for the process building to handle sanitary and laboratory wastes. Power is supplied by the Rural Electrification Administration on specially built power lines to meet service requirements. Water is supplied by onsite wells drilled specifically to supply plant and process water. The buildings are heated by propane space heaters to prevent freezing of equipment. The office, warehouse, and laboratories are served by a central heating and air conditioning unit to provide the required temperature levels to maintain comfort.

4.4.2 Process equipment

This discussion is centered on process components that produce or control effluents during operation and/or accidents. Figure 4.6 is a schematic representation of the applicant's recovery process.

4.4.2.1 Lixiviant sorption circuit

In the WMC lixiviant sorption circuit, the pregnant lixiviant solution will flow from the production wells to the uranium extraction column, then through the lixiviant solution makeup unit to the calcium control unit, and back to the ore zone through the injection wells. The production well pumps are centrifugal-type submersible electric pumps mounted at the bottom of the wells and will produce flows of 12 to 15 gpm at each production well. Flow rates will be limited to this range by manual control valves in the well field control buildings.

The production wells and control building will be connected by solution collection lines of polyvinyl chloride (PVC) and/or rubber pipe. The lines will be above ground except at road, ravine, and creek crossings, where suitable culverts or supports will be constructed. Aboveground piping simplifies leak detection and repair. According to the applicant, operation at planned flow rates should prevent pipeline freezes during cold weather.

At the well field control building, the uranium-rich lixiviant solution will pass through a manual flow control valve and a flowmeter into a surge tank (approximately 12,000 gal). It will be pumped to the main processing plant via the main trunk pipeline (PVC pipe) into another surge tank. The pregnant lixiviant solution will then pass through the uranium sorption column, where the complexed uranium displaces chloride ion from the ion exchange resin. The uranium-depleted solution will flow to the lixiviant makeup unit, where additional ammonia and carbon dioxide will be injected to reconstitute the ammonium bicarbonate concentration.

As a result of ammonium bicarbonate reconstitution, precipitation of calcite ($CaCO_3$) occurs. To prevent scale formation in pipes or plugging of injection wells, the calcite will be separated from the leach solution prior to recycling the lixiviant to the well field.

Calcite precipitation will be done in a large tank in which the lixiviant solution will remain long enough to permit calcite crystals to grow and settle. The product will be transferred to an external calcite storage pond.

The refortified lixiviant solution will be recycled to the well field. Surge tanks and PVC trunk pipelines will be used to transfer the solution to the well field control buildings. The solution will be pressurized prior to injection, metered, fortified with oxidant (0.25 to 1.0 g of hydrogen peroxide per liter of solution), and fed to the injection wells through rubber or PVC pipe.

4.4.2.2 Resin transfer circuit

Periodically a fixed quantity of uranium-loaded resin will be transferred from the sorption circuit to the elution circuit and a like quantity of eluted resin will be transferred in the opposite direction. The uranium-loaded resin will be flushed to remove contaminant solids, and the eluted resin will be washed to remove unabsorbed elution chemicals. These washing steps will minimize chemical communication between the sorption and elution circuits. A portion of the wash water waste will be used for process water, while the remainder will be sent to a liquid waste pond.

4.4.2.3 Elution and precipitation circuit

The elution column will receive uranium-loaded resin from the uranium extraction column. An eluant containing ammonium bicarbonate and ammonium chloride will elute the uranium complex from the resin. Hydrochloric acid will then be added to this eluate to decompose the complex and to drive off carbon dioxide (CO_2), converting the uranium to its uranyl form. The uranyl ion will be precipitated with ammonia to form ammonium diuranate (ADU). A thickener unit will be used to separate the ammonium diuranate slurry from the solution. The slurry will then be transferred to the drying and packaging unit for final processing.

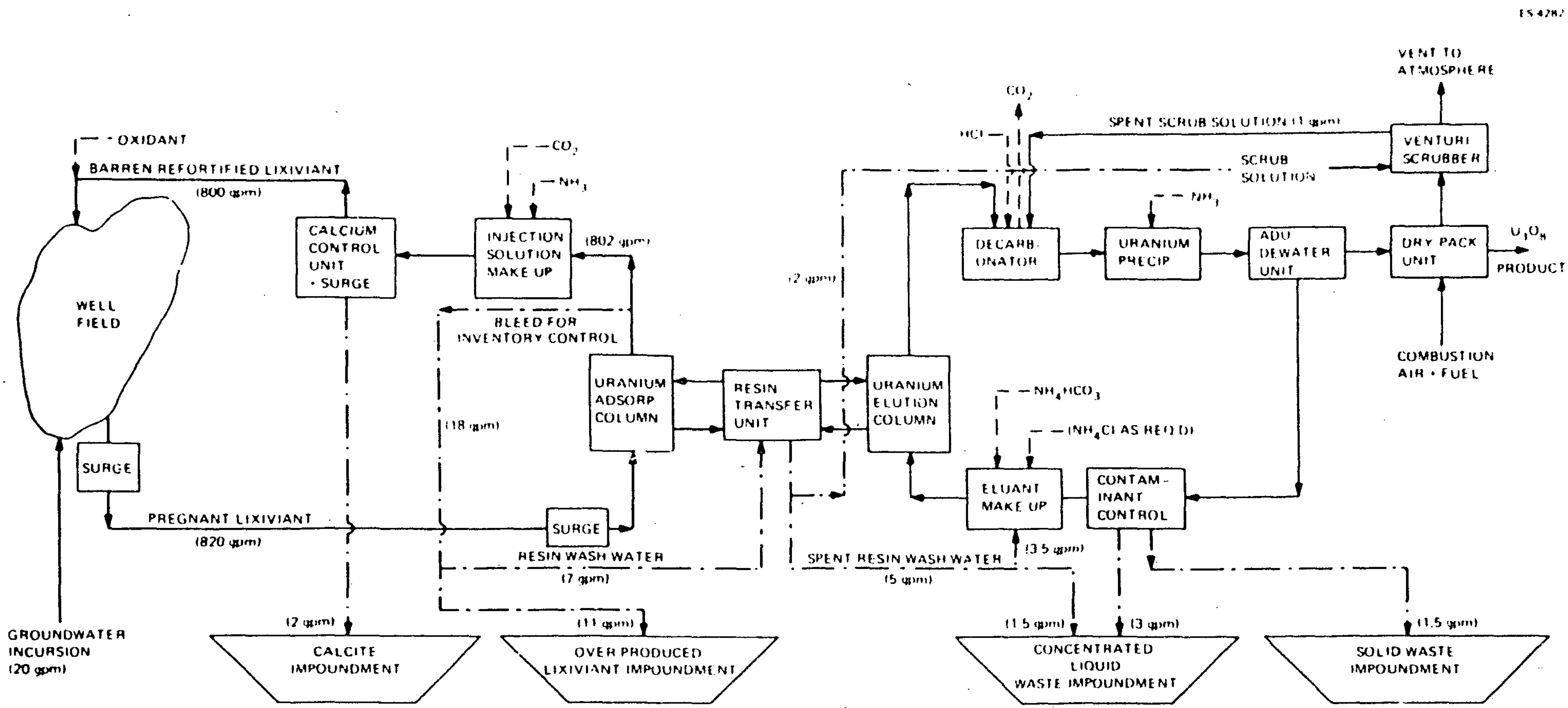

Fig. 4.6. Schematic diagram of the applicant's uranium recovery process, showing volume flow rates. Source: Modified from ER, Fig. 2-9.

The barren solution from the thickener will be refortified in chloride and bicarbonate ion before it is recycled to the elution column. If sulfate or vanadium levels increase above pilot-scale observations, vanadium adsorption on activated carbon or sulfate precipitation utilizing barium salts will be used to reduce their levels in the circuit. Vanadium-saturated activated carbon and barium sulfate would then be produced as solid wastes.

4.4.2.4 Drying and packaging unit

The ammonium diuranate slurry will enter a propane-fired kiln, where it will be dried and converted to U_3O_8 product (yellow cake). Upon cooling, the U_3O_8 will be packaged in drums. Airborne effluents from the drying and packaging unit operation will be controlled by Venturi scrubbers. Spent scrubber solution will be recycled to the elution precipitation unit to recover any particulate U_3O_8.

4.4.2.5 Wastewater treatment unit

Uranium recovery process liquid wastes consist mainly of ammonium chloride and carbonate solutions. They may contain sufficient radium, uranium, and other dissolved solids to warrant isolation from surrounding surface and groundwaters. Wastewater treatment is discussed in Sect. 4.6.2.

4.4.2.6 Chemical storage tanks

Onsite storage facilities will be maintained for chemical agents and fuels involved in mining and restoration operations. Corrosive or flammable liquids and pressurized gases will be stored away from buildings in tanks and pressure vessels meeting ASME standards. Materials to be stored would include liquified anhydrous ammonia (30,000 gal tank), liquified carbon dioxide (20,000 gal tank), concentrated hydrochloric acid (35 wt % HCl), hydrogen peroxide (50%), propane (5000 gal tank), diesel fuel (3000 gal), and gasoline (3000 gal).

Prefabricated fiberglass surge tanks will be employed in the recovery system to maintain flow to the uranium extraction column during temporary curtailments in production and injection flows, as indicated in Fig. 4.6.

4.4.3 Process operation

The WMC recovery plant is designed to produce 500,000 lb of U_3O_8 per year. The flow rate of lixiviant through the plant will be adjusted so that the scheduled yellow cake production can be met with the available heads grade or uranium concentration. The design plant flow rate is 800 gpm. The applicant's pilot-scale operating experience suggests that a plant flow rate of 800 gpm will be sufficient for initial plant production.

At the well field, a sufficient number of injection and production wells will be maintained to handle the flow requirements of the plant. Only a portion of all the wells in a well field would be in operation at any time. This will allow continuous operation, since new production cells could be brought on line as mined-out cells are retired. Also, production would not be affected by maintenance operations such as injection well cleaning.

4.4.4 Operating plans and schedules

Plant startup is anticipated for the summer of 1978. The plant's life expectancy is up to ten years or until mining operations require relocation of the recovery plant.

4.5 PLANT MATERIALS BALANCE AND FLOW RATES

The estimated volume flow rates for an 800-gpm plant to produce 500,000 lb of U_3O_8 per year are shown in Fig. 4.6. The anticipated chemical feed rates are listed in Table 4.2. The chemical feed ranges in Table 4.2 reflect the wide range of operating conditions that are possible. The introduction of sulfate precipitation and/or vanadium adsorption for contaminant control would reduce both the rate of bleed from the elution and precipitation circuit and the consumption of ammonium chloride and water.

Assuming 100% recovery of uranium from the lixiviant solution, the plant would be expected to operate on an average heads grade of at least 143 ppm (as U_3O_8) in the lixiviant to maintain scheduled production.[1]

Table 4.2. Estimated chemical feed rates for WMC Irigaray uranium recovery process

500,000 lb/year production

Compound	Feed rate	
	Pounds per hour	Tons per year
Lixiviant chemicals for 800 gpm injection		
Carbon dioxide (CO_2)	75–225	325–985
Ammonia (NH_3)	40–120	175–525
Hydrogen peroxide (H_2O_2) (50%)	75–250	325–1100
Elution and precipitation reagents for 4.5 gpm total eluant bleed		
Ammonium bicarbonate (NH_4HCO_3)	35–100	150–440
Ammonium chloride (NH_4Cl)	75–200	325–875
Hydrochloric acid (35% HCl)	25–70	110–305
Ammonia (NH_3)	5–20	22–90
Fuel		
Propane	20–60	90–260

4.6 WASTES AND EFFLUENTS

4.6.1 Liquid waste sources

The major effluent to be generated during solution mining and the subsequent groundwater restoration processing will be liquid wastes. A small volume of sanitary waste will also be generated.

Maximum water volumes affected in a solution mining operation of this scale under normal conditions, as estimated by the applicant, are summarized in Table 4.3 along with the bases for these estimates. The largest volume of effluent will be generated by groundwater restoration operations. This is discussed in Sect. 5.1.4.1.

The second major source of liquid waste will be well field overpumping. Here, more water is withdrawn from the well field than is injected. Overpumping helps to confine the lixiviant solution to the ore zone being mined. It will also serve to supply the wash and process water in the uranium recovery plant. This volume will be minimized by balancing the operational flows.

Another source of liquid waste will be associated with routine injection well cleaning to maintain necessary lixiviant flows. Present treatment to clean the injection well bore includes the withdrawal of about 10 well bore volumes to remove residual solids from the formation and well prior to resuming injection. Alternative well cleaning methods to reduce effluent volumes for this operation are being investigated in the applicant's pilot-scale tests.

Other sources of process liquid wastes will be the spent resin wash water and the eluant circuit bleed respectively. Alternative methods of contaminant control are under pilot-scale investigation by the applicant to reduce the rates of waste sources. Overproduced solution could be successively used for resin wash water and eluant makeup prior to being discharged as waste. Neither source will represent a major consumptive use of water. The remaining water requirement for sanitary use and monitor well sampling will be approximately 1 gpm.

4.6.2 Liquid waste disposal

Liquid wastes generated in mining and restoration processes will vary in composition and volume. Uranium recovery process liquid wastes, groundwater restoration liquid wastes, and sanitary wastes will be handled by separate systems.

4.6.2.1 Liquid wastes from mining

Uranium recovery process liquid wastes will consist of ammonium chloride and carbonate solutions. They will contain radium, uranium, and dissolved solids warranting isolation from surrounding surface and groundwaters.

Table 4.3 Estimated volumes of liquid effluents[a]

Estimated volumes of liquid wastes (in acre-feet per year) associated with 500 000 lb/year solution mining production facility (800 gpm)

Source[b]	Acre feet per year
1 Overproduction of the well field (basis: 1% of design production rate of 800 gpm for 500 000 lb/year facility)	12.5
2 Well cleaning to maintain injection flows (basis: 10 acres land on seven spot configuration, 40 ft spacings with 1500 gal per well twice a month required to accomplish cleaning)	7.6
3 Resin wash water for contaminant control (basis: field test data indicate a bleed of ≤7.0 gpm is required for control, or ≤10.5 acre-ft/year)	Included in item 1
4 Eluant bleed for contaminant control (basis: field test data indicate a bleed of ~4.5 gpm will be required)	Included in item 1
5 Plant and well field sanitary water use (basis: estimated consumption rate of 2 000 gpd)	2[c]
6 Mop for well sampling (basis: a withdrawal of 200 gal per well is necessary to obtain a representative sample and 50 wells sampled twice monthly)	[illegible]
Affected volume from mining operations (items 1, 2, and 6)	21.0

[a] Exclusive of groundwater restoration activities.
[b] All sources are presumed to be radioactive except for item 5.
[c] Goes to sanitary waste field.

As indicated in Table 4.3, approximately 21 acre-ft of this waste would be generated annually. Since the net annual evaporation rate in the Wyoming area is about 4 ft per year, solar evaporation ponds covering at least 5.3 acres could handle this liquid waste volume indefinitely.

The WMC solution mining process is still in the developmental stage. Future process developments may lead to decreased liquid waste volumes. On this basis, the applicant proposes the construction and use of the evaporation ponds listed in Table 4.4 to serve the dual function of liquid waste storage and concentration.

Table 4.4. Evaporation ponds for liquid wastes

Type	Number	Overall dimensions (ft)	Volume (acre-ft)	Surface area (acres)	
				Per pond	Total
Calcite waste	1	100 X 250 X 6	2.7	0.5	0.5
High TDS waste	1	250 X 250 X 6	6.3	1.4	1.4
Low TDS waste	3	250 X 250 X 6	18.9	1.4	4.2
Total			27.9		6.1

Figure 4.7 shows the locations of the proposed ponds. Although the calcite waste pond is designed primarily for solids containment, it will also serve as an evaporation pond, since a liquid seal will be maintained over the solids. The ponds should have sufficient capacity for liquid wastes from the recovery plant.

Figure 4.8 shows the details of pond construction as proposed by the applicant. The waste ponds will be constructed as rectangular basins excavated in relatively flat areas on high ground. A gravel bed and a system of perforated pipes will be placed under the base of each pond to

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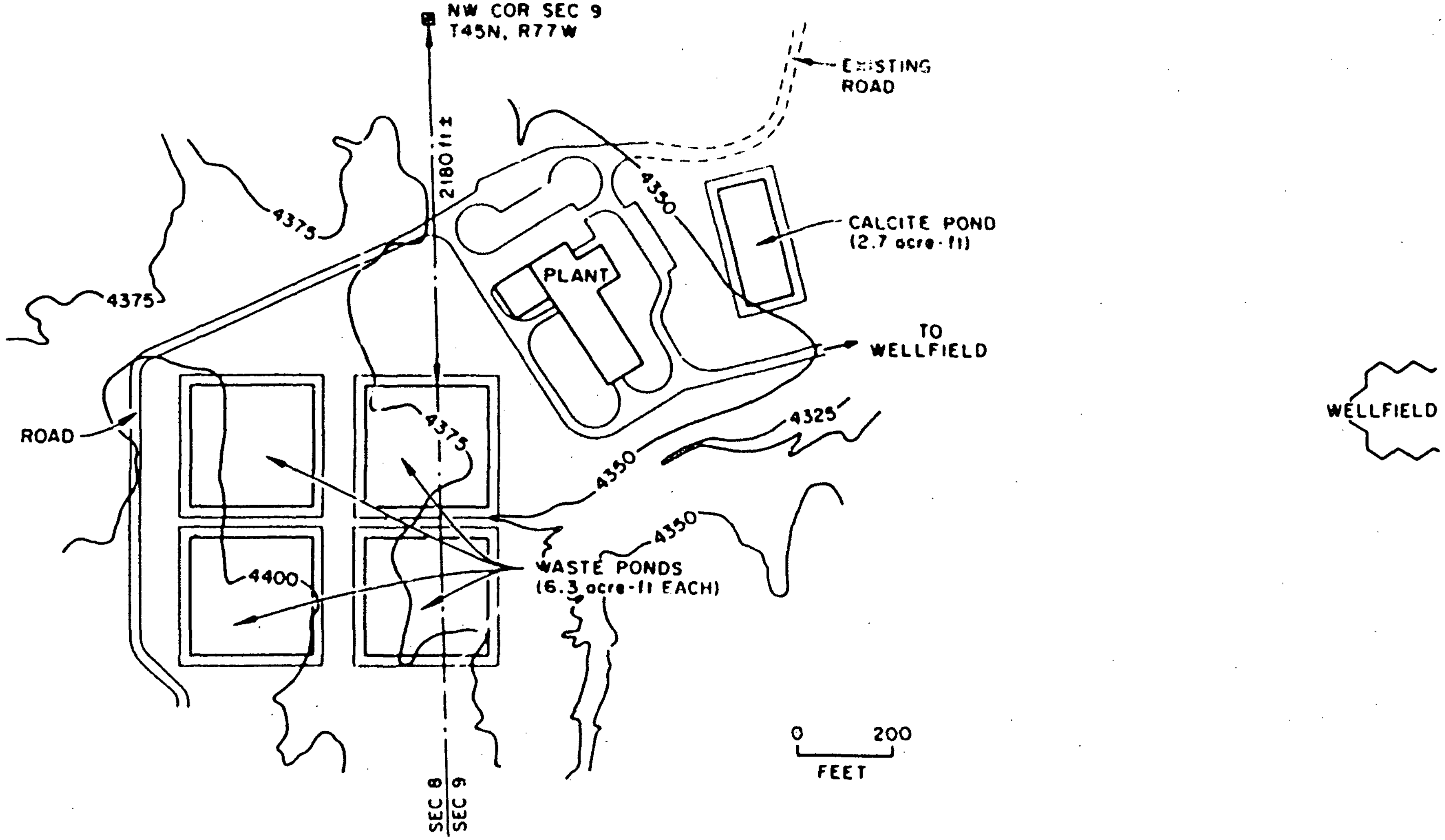

Fig. 4.7. Locations of evaporation ponds for process plant liquid wastes at the proposed Irigaray site. Provided by the applicant.

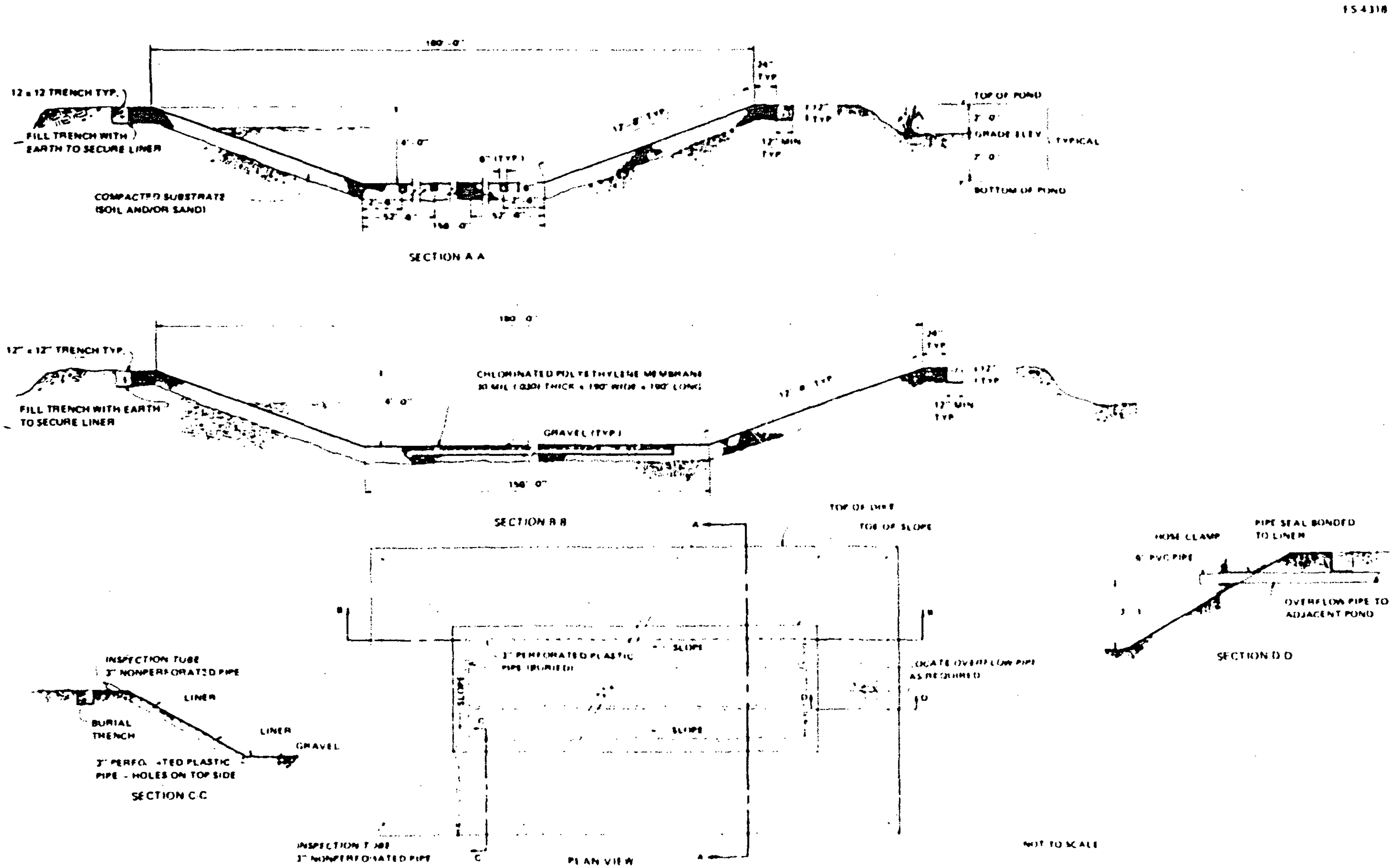

Fig. 4.8. Pond construction detail. Source: ER, Fig. 4-4.

collect seepage and serve as a leak detector. A thin layer of soil will be placed over the gravel and will be covered by an impermeable polyethylene liner. A thin layer of soil may also be placed over the liner to protect it from mechanical and weather damage. In normal operation at least 0.6 m (2 ft) of freeboard will be maintained in each pond. The plastic liner will normally preclude any seepage from the pond. However, should the liner fail, process wastes would seep into the gravel and piping underlying the pond. The presence of water and process chemicals in the leak detection system will readily indicate a leak. In this event, the contents of the leaking pond will be pumped to an adjacent pond to permit repair of the liner.

4.6.2.2 Liquid wastes from groundwater restoration

Restoration wastes are discussed in Sect. 5.1.4.

4.6.3 Solid waste sources

Solid wastes will be generated from three principal sources in the recovery process: (1) the calcium removal unit, (2) supplemental contaminant control incorporated in the elution and precipitation circuit of the recovery process, and (3) liquid waste concentration by evaporation during impoundment. Additional solid wastes will be produced in conjunction with the water treatment methods utilized to accomplish aquifer restoration. The latter would generally be similar to the solid wastes produced in the uranium recovery process.

Calcite ($CaCO_3$), which will be removed prior to injection of the refortified lixiviant, will be the principal solid waste produced in the solution mining process. Contaminants will be coprecipitated with the calcite prior to lixiviant reinjection. According to the applicant, the precipitated calcite could contain from 500 to 1200 pCi of radium-226 per gram (ER, p. 37). This corresponds to about 95 removal of the radium-226 that may be mobilized by the applicant's proposed lixiviant. The applicant estimated that for each pound of U_3O_8 recovered, 2 lb of calcite will be produced. Thus less than 500 tons of calcite would be generated per year that could contain about 0.5 Ci of radium.

Another source of solid wastes could be associated with supplemental contaminant control methods for sulfate and vanadium, as indicated in Sect. 4.4.2.3.

A third source of solid wastes from the recovery plant would be crystallized materials resulting from evaporative concentration of impounded waste solutions. These products would consist primarily of assorted ammonium and alkaline earth salts (e.g., ammonium chloride, ammonium sulfate, calcium carbonate, radium sulfate). The staff estimates that on the order of 500 tons per year of such material may be generated and would contain an indeterminate quantity of naturally radioactive materials.

4.6.4 Solid waste disposal

The solid wastes generated by mining and subsequent aquifer restoration could contain uranium, thorium, radium, and other toxic materials in varying amounts. Therefore, isolation of solid wastes will be necessary. The applicant plans to temporarily store these wastes in lined ponds under a liquid seal. A maximum of two years accumulation of the calcite wastes will be permitted prior to removal from the site. This will be a license condition. The applicant will transport these wastes to an active uranium mill tailings impoundment for disposal. Other radioactive or toxic wastes accumulated in the evaporation ponds will be removed and transferred to an active mill tailings impoundment as necessary (as ponds fill) or at the time of site reclamation. The staff recommends that any transportation method used for such wastes have provisions for minimizing dust releases to the environment. The staff also recommends that contract arrangements for the disposal of such solid wastes be obtained and maintained by the applicant and the operator of the licensed tailings pond. The maintenance and fulfillment of such a contract will be a license condition.

4.6.5 Atmospheric emissions

Atmospheric emissions from the proposed solution mining process will originate from three principal sources: (a) the uranium recovery process area, (b) the calcium removal unit, and (c) waste ponds. To reduce atmospheric releases within the uranium recovery process area, process components will be enclosed or vented where practicable. Ventilation and emission controls will be maintained at levels necessary to ensure safe working conditions and insignificant environmental impacts. In the plant building, there will be two principal atmospheric emission sources: the calcium removal unit (tanks) and the product drying and packing unit.

According to the applicant, the drying and packaging unit atmospheric release will consist of (1) by-products of combustion (1,000,000-Btu/hr product drying unit), (2) volatilized solution residuals (about 0.75 to 1.25 lb of barren eluant per pound of ammonium diuranate feed), and (3) U_3O_8 fines generated during product drying. The off-gases from the dryer will be scrubbed by a high-intensity Venturi scrubber (99.5 to 99.9% efficient) to reduce U_3O_8 losses to less than 1000 lb/year.

The storage ponds will also be a source of atmospheric ammonia, carbon dioxide, radon, and ammonium chloride emissions. The magnitude and composition of atmospheric emissions will be determined by the equilibria established between the prevailing evaporation rate, the feed rate, and the composition of solutions being impounded. Particulate emissions from impoundment areas will be minimized by a liquid seal over pond contents. The maintenance of a liquid seal on impoundments will be a license condition.

Radioactive atmospheric releases will originate in the ammonium diuranate drying unit, the calcium control unit, and the waste storage ponds. Releases of 1000 lb of U_3O_8 per year from dryer losses would correspond to a release of approximately 0.15 Ci of uranium-238 per year. A like amount of radioactivity release would be expected from the other natural uranium isotopes. Radium-226 mobilized during in situ leaching will coprecipitate with the calcite in the calcium control unit and will be deposited in the calcite storage pond. The staff estimates that about 1.4 Ci of radon-222 per year could be released from the calcite storage pond and calcium control unit as a result of decay of radium-226. Radon-222 mobilized from the ore zone during solution mining would be vented at the well field surge tanks. The staff estimates that approximately 76 Ci of radon-222 per year would be released from these tanks.

Table 4.5 contains a summary of the estimated emissions from each of the indicated sources. The cited estimates are based on the applicant's source composition and ambient temperature data and an assumed mean evaporation rate of 42 in./year.

Table 4.5. Estimated atmospheric emissions

Source	Emission rate[a] (thousands of pounds per year)				Radioactive releases[b] (Ci/year)	
	NH_3	CO_2	NH_4Cl	H_2O	U-238	Rn-222
Uranium recovery process facility (excluding the calcium control unit and waste storage ponds)	6–9	1500–3000	30–54		0.151	
Calcium control unit (basis: 1,000 ft^2 of exposed solution surface containing 0.75 g NH_4, 1.5 g total CO_3, and 0.75 g Cl per liter)	2–4	6–9	0.06–0.09	390–470		0.04
Calcite storage pond (basis: complete evaporation of 2.04 gpm of supernate containing 0.75 g NH_4, 1.5 g total CO_3, and 0.75 g Cl per liter)	2.5–3.5	9–10	0.5–10.5	~8000		1.36
Liquid waste storage ponds (basis: 1 acre of exposed solution surface containing about 7.0 g NH_4, 1.0 g total CO_3, and 16 g Cl per liter)	9–11	7–8	27–31	~9300		
Well field surge tanks						76

[a]Based on data supplied by applicant. Net evaporation rate of 42 in./year used in estimating releases.
[b]Staff estimates

REFERENCE FOR SECTION 4

1. W. C. Larson, "Nomograph for In-Situ Uranium Leaching," *Eng. Min. J.*, September 1977, p. 159.

5. RESTORATION, RECLAMATION, AND DECOMMISSIONING

This section discusses the measures that will be taken to return the mining area to its original use after mining has been completed. Restoration techniques will be applied to all contaminated groundwater. Reclamation will be conducted on all disturbed surface areas. Decommissioning of all structures will be accomplished when the project has been completed. A performance bond is required by the State of Wyoming for both reclamation and restoration.

5.1 RESTORATION

Restoration is defined as the returning of affected groundwater to a condition consistent with its premining use (or potential use) upon completion of leaching activities. Restoration is intended to reduce the concentration of toxic contaminants remaining in the groundwater to acceptable levels. Although restoration technology is currently in the developmental stage, test results to date indicate that satisfactory levels of restoration can be achieved.[1]

Currently, the most widely used restoration technique is groundwater sweeping. This technique involves the pumping of contaminated groundwater from the mineralized zone which then causes surrounding (uncontaminated) groundwater to flow through the affected area. The contaminated groundwater is eventually displaced by uncontaminated groundwater, thereby restoring the affected area. This technique has also been successfully demonstrated on contaminated groundwater in the oil industry.[2] Although a number of companies have demonstrated the feasibility of the groundwater sweeping technique on small test areas, it has not yet been tried or demonstrated on a production scale. Other groundwater restoration techniques involving chemical treatment methods and/or groundwater recycling are also under study by the industry and the U.S. Bureau of Mines.[3]

5.1.1 Restoration criteria

With continued sweeping over a sufficiently long term the affected mining zone will approach its original condition. However, the consumptive use of water, the disposition of solid wastes, and additional costs must be optimised against groundwater condition if solution mining is to be a viable technique for recovery of uranium resources. In line with this, the staff evaluation of the applicant's proposed restoration procedure is based on the requirement that any affected groundwater must be returned to a chemical condition consistent with its potential premining use.

The staff has recognized two water quality zones within the ore-bearing aquifer. The zones are defined as follows:

1. Mining zone — the area within the mineralized (ore deposit) portion of the aquifer. The perimeter of this zone is defined as one well spacing (approximately 40 ft) either beyond the outer injection wells or the limit of the ore deposit to be mined. At the Irigaray site, groundwater (as determined from the highest concentrations in wells) within this zone naturally contains excessive concentrations of radium-226 (144 pCi/liter vs 5 pCi/liter), arsenic (0.10 mg/liter vs 0.05 mg/liter), and selenium (0.73 mg/liter vs 0.01 mg/liter) compared with drinking water standards (Table 2.9). The quality of the groundwater is such that the water is unfit for either domestic or livestock consumption. Groundwater within this zone will be affected by in situ leaching operations.

2. Containment zone — the area, in the ore-bearing aquifer, from the perimeter of the mining zone to the nearest monitor well. The perimeter of this zone is defined by a line connecting the monitor wells surrounding the well field. Trend wells may be placed within this zone. At the Irigaray site, groundwater quality in this zone (excluding wells placed in mineralized areas) is generally suitable for drinking water. However, it is anticipated that water quality may be degraded in portions of this zone during solution mining operations.

   Because the groundwater in each of these zones is of different quality, each zone will require specific restoration criteria. The groundwater quality can be such that the water will meet standards for either drinking water or livestock watering purposes, or the natural quality may preclude its use for either animal or human consumption. Where the premining quality of the groundwater meets either drinking water or livestock watering standards, the appropriate established State or Federal criteria will be used to establish maximum permissible chemical concentrations for restoration purposes. If the premining groundwater chemistry exceeds either set of the criteria, the staff believes that a return to within ±20% of the baseline concentrations of each toxic element or complex ion would be a reasonable basis for establishing restoration criteria. If there are no applicable criteria, a level should be selected for restoration that is consistent with public health and safety.

The applicant's proposed lixiviant consists of ammonia carbonate/bicarbonate; residual ammonia concentrations will be present. Ammonia is discussed in detail in Sect. 6.3.2.2.

[illegible] The applicant's restoration demonstration test

As discussed in Sect. 4.2, the 517 test pattern was leached as part of the pilot-scale test program to determine the feasibility of recovering uranium. A restoration demonstration was initiated on a part of the 517 test area in May 1977, and reports have recently been submitted by the applicant.[illegible]

Average preleaching (Column A) and postleaching groundwater quality (Column B) are shown in Table 5.1. These values were obtained from a single sampling of wells and reflect average concentrations rather than fluid chemistry for any specific well. The applicant used the affected mineral zone in the vicinity of well 517-3 (Fig. 5.1) for the restoration demonstration tests. According to the applicant, these tests involved approximately 142 m³ (37,400 gal) of affected groundwater. The applicant's restoration demonstration was designed to provide preliminary evaluation of three restoration techniques: (1) groundwater sweeping, (2) water recycle (use of reverse osmosis unit), and (3) chemical treatment.

Groundwater sweep test

The applicant's groundwater sweep test involved the removal of affected groundwater from a part of the 517 test pattern. A hydraulic fence was used to isolate the restoration test area from the rest of the pattern, which permitted surrounding generally uncontaminated groundwater to flow into the leached zone thereby removing and replacing the affected groundwater. Approximately [illegible] m³ ([illegible] gal) of groundwater were pumped during this phase of the restoration test. As shown in Table 5.[illegible] (Columns [illegible] and [illegible]), this operation did lower the concentrations of most radioactive and toxic constituents.

Reverse osmosis unit test

Water removed from the aquifer during the groundwater sweep test [approximately 1710 m³ (450,000 gal)] was conveyed to a pond for storage. This water was used as feed for the testing of the reverse osmosis (RO) unit. At the start of the RO demonstration, natural evaporation had reduced the volume of water in the ponds to approximately 836 m³ (220,000 gal). This water was pumped to a surge tank, the pH was adjusted to 5.5, and the water was then pumped at high pressure to the RO unit. Approximately 670 m³ (176,000 gal) of permeate (clean water) and 170 m³ (44,000 gal) of concentrate were produced during the RO unit test. The performance of the RO unit is shown in Table 5.2, Column B. These results indicate that the unit is capable of producing water suitable for reinjection (recycling) into the aquifer.

Clean water recycle test

The applicant initiated a clean water recycle test in the vicinity of well 517-3 (Fig. 5.1). A small five-spot pattern was drilled with wells 517-3 and 517-6, 3A and 2A, serving as injection wells. Well 6A was used as the recovery well. The ponded premeate from the RO test [approximately 670 m³ (176,000 gal)] was injected via the four perimeter wells and pumped out through the central recovery well. Conductivity of the injected solution was maintained at a low level (650-700 micromhos/cm), and the injection rate was balanced with the recovery rate (8.0-8.5 gpm) during the test. The final levels of analyzed constituents are shown in Table 5.2, Column C. These results indicate that the clean water recycle method can probably reduce levels of the constituents listed, except for ammonia, more efficiently than groundwater sweeping.

Chemical restoration test

Both the groundwater sweep and clean water recycle tests were ineffective in reducing the concentration of residual ammonia. The applicant designed a chemical restoration test to demonstrate the enhanced removal of residual ammonia (NH_4^+) from the aquifer. This test involved the

Table 5.1. Water quality during restoration testing

Units are ppm except as noted

Constituent	Column A Preleaching groundwater quality[a]	Column B Postleaching groundwater quality[b]	Column C Postleaching groundwater quality – Well 517-3	Column D Groundwater quality after sweep test – Well 517-3	Column E Postrestoration testing of groundwater quality
Ammonia	<1.0	235	180	123	27 (as N)
Arsenic	<0.0025	0.021	0.033	0.017	0.02
Barium	0.12	0.069	0.09	0.03	0.05
Bicarbonate	139	805			0.60
Boron	0.16	0.283	8.3	0.26	0.11
Cadmium	<.005	0.014	0.30	<0.002	0.002
Calcium			58.5	13.5	37.8
Calcium carbonate	232		616	445	
Carbonate			4.2	4.7	
Chloride	10.75	524	531	229.9	159
Chromium	0.0135	0.002	<0.002	0.004	0.005
Copper	0.019	0.22	0.215	0.041	0.035
Fluoride			2.75	4.10	2.4
Iron			2.15	0.65	0.04
Lead	0.0035	0.110	0.32	0.058	0.015
Magnesium			19.5	5.4	3
Manganese	0.12	0.97	0.784	0.15	0.022
Mercury	0.0028	<0.0002	0.0002	<0.0002	0.0018
Molybdenum			<0.02	0.42	0.12
Nickel	0.018	0.218	1.79	<0.2	0.2
Nitrate			4.92	1.24	0.2
Nitrite			2.76	0.151	
Potassium			8.14	2.9	
Selenium	0.013	1.75	1.02	0.339	0.01
Silicon			5.3	3.3	
Silver	<0.005	0.015	<0.002	<0.005	0.002
Sodium			308	210.8	97
Sulfate			270	233	105
Vanadium			<0.05	0.21	0.33
Zinc	0.003	0.22	0.218	0.02	0.02
Total dissolved solids	793	1324	1302	712	460
pH, standard units			7.94	8.14	9.0
Conductivity, μmhos/cm			3300	1950	
Uranium	0.098	24.4	18	12.3	<1.0
Ra-226, pCi/liter	26.8 ± 5.2	371 ± 5.6	478 ± 9	105 ± 10	18.4
Th-230, pCi/liter			640 ± 21	1.5 ± 0.9	
Gross alpha, pCi/liter	168 ± 11	22815 ± 296	12317 ± 288	5412 ± 177	
Gross beta, pCi/liter	164 ± 19	21043 ± 441	5374 ± 115	2052 ± 85	

[a] Average of analyses for a single sampling from five wells at the 517 test site.

[b] Average of analyses for a single sampling.

Table 5.2 Concentration of selected constituents after completion of restoration demonstration tests

Constituent (ppm)	Initial[a]	Column A Groundwater sweeping	Column B Reverse osmosis[b]		Column C Clean water recycle	Column D Chemical treatment	Column E Residual TDS reduction
			Concentrate	Permeate (clean water)			
Ammonia (NH_4^+)	[illegible]	123	54	3	120	120	35
Chloride (Cl^-)	[illegible]	230	686	26	160	2800	150
Carbonate (CO_3)	[illegible]	267	300	4	40	40	60
Uranium (U_3O_8)	14	[illegible]	43	[illegible]	2	[illegible]	<1
Conductivity (micromhos/cm)	[illegible]	1950	3237	145	1400	9000	880

[a] [illegible]
[b] [illegible]

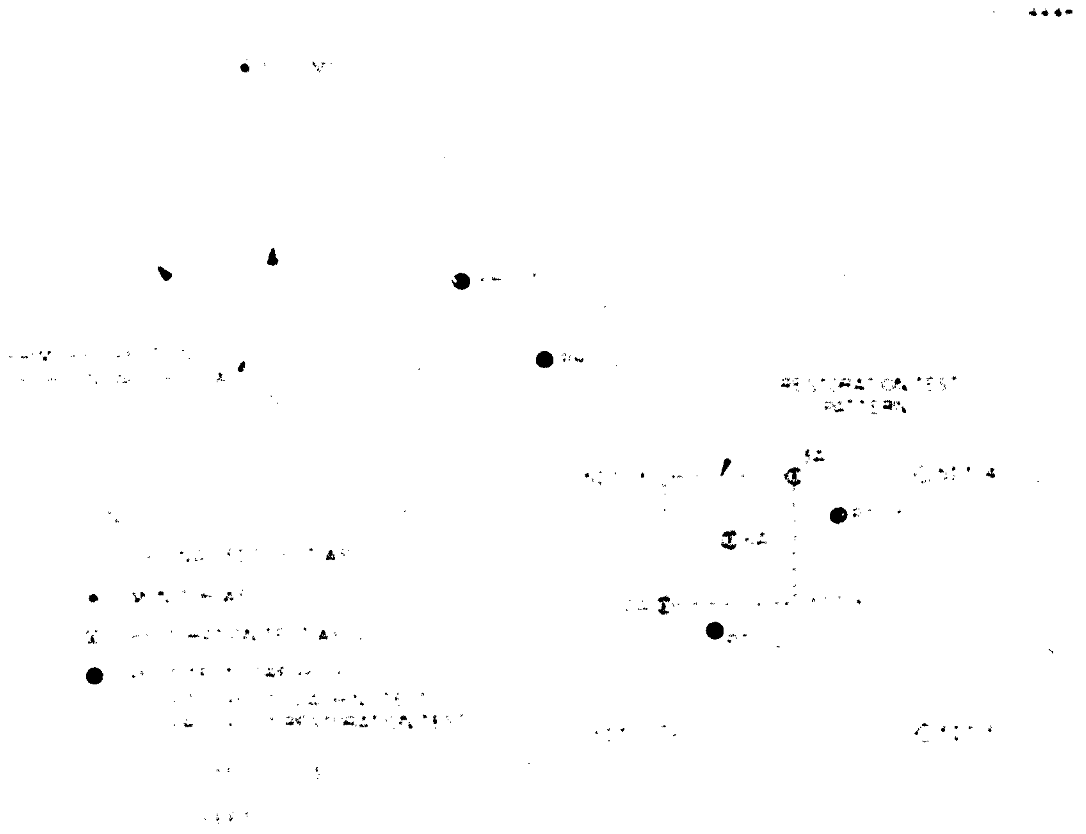

Fig. 5.1 Location of the 517 restoration demonstration well sites.

(1) circulation of a concentrated salt (Ca^{++}, Na^+, and/or Mg^{++}) solution through the formation to elute the ammonia from clays, and (2) removal of the ammonia from the solution in a surface treatment plant. Test results showed that ammonia was released from the clays as indicated by an initial increase in the concentration of ammonia from less than 120 ppm (Table 5.2, Column C) to 230 ppm in the produced fluid during this phase of the test. After further treatment the chemical restoration test was terminated when ammonia reached the level of 120 ppm, as shown in Table 5.2, Column D.

Residual total dissolved solids (TDS) reduction test

The final method tested by the applicant involved the addition of an RO unit to the well field, water treatment circuit. Groundwater in the test area after the chemical restoration test was recycled through the RO unit. The permeate (clean water) was recycled through the aquifer, and the concentrate was discharged into a waste pond. The resultant groundwater quality after completion of this test is shown in Column E in both Table 5.1 and 5.2. Most constituents have been reduced to preleaching levels or below accepted criteria, although ammonia (35 ppm) remained well above baseline.

In addition to the above experiments the applicant has conducted similar experimental pilot-scale tests near Bruni, Texas, and Grover, Colorado (ER, Appendix A). In general these restoration demonstration tests also indicate that restoration can be achieved using a combination of the techniques described above. From the various restoration demonstration tests, the applicant has developed a restoration program for the Irigaray site.

5.1.3 The applicant's restoration program

After mining has been completed in a given area, activities will be initiated to return the affected groundwater to the premining quality. The applicant's proposed restoration plan will be implemented on a sequential basis using a water recycle treatment process. Restoration will begin after the first well field has been mined out and the mining operation has moved far enough away so there will be minimal interference between concurrent mining and restoration operations.

Sequential restoration of the groundwater in a well field will be conducted concurrently with ongoing mining activities rather than at the termination of all mining operations. The restoration treatment process will begin on a mined-out unit and will continue until the groundwater in that mined-out unit is restored to its premining quality. This sequence will be repeated as additional units are mined out and new well field areas are brought into production until mining operations are completed.

The restoration treatment will incorporate water removal (groundwater sweeping), water treatment, and reinjection processing steps (Fig. 5.2). When a mining unit has been depleted of uranium and a buffer zone established, restoration will be initiated. The residual leach solution in the mined-out unit, which is usable, will be pumped out and reinjected into a new mining area. Natural groundwater from the new mining area will be pumped back into the mined-out unit. After most of the residual leach solution has been removed, the groundwater will be pumped from the mined-out area and ponded. This ponded water will be run through a hardness removal step (cold lime softening) and a reverse osmosis unit for additional removal of various contaminants if required. Prior to reinjection of this water into the mined-out aquifer, it will be chemically adjusted by the addition of ions such as calcium or magnesium to enhance the removal of ammonia adsorbed on clays in the mined ore zone before reinjection. This solution will be circulated with ammonia removed at the surface and replaced with an alkaline earth cation. This process will be repeated until the contaminated groundwater in the mined-out unit has reached a selected ammonia level. Then the RO unit will be placed in the circuit and operated until all ions have reached selected levels. The applicant estimates that the withdrawal of at least five pore volumes will be required to reach this point.

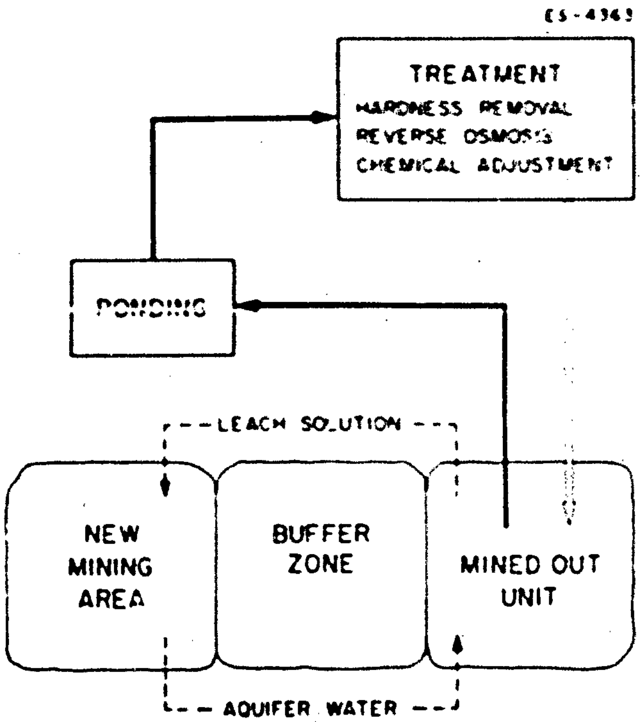

Fig. 5.2. Diagram of applicant's proposed restoration method for the Irigaray project. Note: For the treatment stage, operations will be done within the existing recovery plant.

5.1.4 Wastes from aquifer restoration

5.1.4.1 Liquid waste

The quantity of liquid waste generated by the applicant's proposed aquifer restoration process (Sect. 5.1.3) will depend on the affected aquifer volume and the characteristics of the host rock.

The applicant will mine a maximum of 20 ha (50 acres) under the initial licensing action. This area will be divided into approximately 4-ha (10-acre) units that will be mined and restored separately. The staff estimates, as a worst case, that the entire thickness of the host sandstone will be affected by in situ leaching. The resulting aquifer volume (pore volume) will be approximately 420,000 m^3 (340 acre-ft) for each 4-ha (10-acre) well field unit. The applicant estimates that at least five pore volumes [approximatley 2 x 10^6 m^3 (1700 acre-ft)] will have to be cycled through the field to effect restoration. Under the sequential restoration process (Sect. 5.1.3), approximately one pore volume or 20% of the total 2 x 10^6 m^3 (1700 acre-ft) will be exchanged with groundwater from a new, unmined, 4-ha (10-acre) unit. The other four pore volumes, approximately 1.7 x 10^6 m^3 (1360 acre-ft), would receive reverse osmosis (RO) treatment and be circulated through the mined-out 4-ha (10-acre) unit. Approximately 2.5 x 10^5 m^3 (205 acre-ft) or 15 percent of the water receiving RO treatment will be released as a concentrated brine. This wastewater will be discharged to evaporation ponds. The applicant estimates that additional ponding may be necessary for restoration wastes (ER, p. 117).

The waste production rate and required ponding area will be functions of the number of 4-ha (10-acre) units undergoing restoration and the time required to process the necessary volume of liquids. Assuming a one-year timetable for the treatment and/or circulation of five pore volumes, the staff estimates the necessary surface area of evaporation ponds to be about 24 ha (58 acres)* per 4-ha (10-acre) unit undergoing restoration. A reduced restoration rate would decrease the waste production rate and required pond area. The applicant is presently evaluating potential sites for restoration evaporation pond(s).

The chemical treatment pumping of five times the affected aquifer volume through the mined area will sweep out the major portion of the contaminant chemical species from the mined area. However, various amounts of contaminants may be left in the formation as ions absorbed on clays and sands. Reduction of contaminant concentrations in the water may cause gradual desorption of the ions from the clays and sands back into the water until equilibrium is obtained. This will be checked by postrestoration sampling. Should these concentrations exceed the pre-established water quality criteria, further restoration work would be necessary. This additional work may increase the volume of waste generated by the applicant's proposed restoration process.

5.1.4.2 Solid waste

According to the applicant, the reverse osmosis unit will produce a brine with a dissolved solids content of 15 g/liter (ER, p. 175). The brine will contain primarily salts such as ammonium chloride and sodium sulfate and will have a pH of about 6. The brine will also contain concentrations of radium exceeding 100 pCi/liter and small quantities of uranium, calcium, magnesium, selenium, arsenic, and other trace contaminants. As water evaporates from the brine, these chemicals will precipitate from solution as solid waste. Additionally, some calcite wastes will also be produced by the lime water-softening process.

The staff estimates that the maximum quantity of solid wastes resulting from the evaporated brine during restoration of a 4-ha (10-acre) mining unit will be approximately 4200 tons. However, the applicant also reports a TDS of 1324 ppm in the prerestoration mine water at the 517 test site (Table 6.1). If these solids were concentrated in 15% of the original liquid volume, the TDS content would be 9 g/liter, which would result in about 3000 tons of solid waste. In addition, the TDS content of the groundwater that is being restored will decrease during restoration activities. Therefore, the final quantity of solid wastes should be less than 3000 tons. The quantity of solid waste will be dependent on the amount of liquid waste. Any increase in liquid waste volume will result in an increase in solid waste.

Disposal of restoration solid waste will be accomplished as described in Sect. 4.6.4.

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*Assumes a net evaporation rate of 1.1 m (42 in.) per year.

5.1.5 Staff recommendations

The applicant has demonstrate that the various proposed restoration techniques can be used to reduce the concentrations of radioactive and toxic constituents in affected groundwater. There are, however, two areas which need further evaluation to determine the applicability of the applicant's proposed techniques to a production-scale mining unit. First, the reverse osmosis method is in a developmental stage.[6] The effectiveness and practicality of this unit on a large-scale restoration operation need to be established. Secondly, a primary area of concern is the potential environmental impact of ammonia. The remaining concentration of ammonia after completion of restoration by the applicant may result in ammonia migration and/or its possible conversion to nitrate and nitrite which will migrate.

The ammonia problem is present only with the use of an ammonium bicarbonate leach solution. The applicant proposes to restore the groundwater to an ammonia concentration of 20-50 ppm.[7] No present standard exists for ammonia concentration in groundwater. The staff recognizes that the proposed level of ammonia left in the groundwater may be controversial and that the applicant will be required to meet any ammonia standard promulgated later.

Currently, the applicant is examining alternative alkaline leach solutions for future use at the Irigaray site (ER, p. 107, ref. 7). Until the ammonia problem is resolved or alternative lixiviants are developed, the staff proposes that limitations be placed on the use of ammonium bicarbonate leach solution by the applicant.

The applicant's proposed recovery plant will have an annual production of about 500,000 lbs of yellow cake. The staff estimates that this amount will require an annual well field area (production unit) of up to 4 ha (10 acres) to maintain the anticipated production over the five-year duration of the requested license; thus, a maximum well field of 20 ha (50 acres) would be required. The staff proposes to limit the mining of not more than 20 ha (50 acres) with an ammonium carbonate-bicarbonate lixiviant, which will allow multiple production units to be developed while production-scale unit restoration can be demonstrated. Accordingly, the following license conditions are proposed:

1. The use of an ammonium bicarbonate lixiviant will be limited to a maximum well field area of 20 ha (50 acres). This area will include the well field used for the 100 gpm pilot-scale test.

2. Restoration of the first production unit [up to a 4-ha (10-acre) well field] must be initiated upon completion of mining of the unit. This production unit should be sufficiently isolated from any further operating well field within the 20-ha (50-acre) area to ensure that restoration operations will not be compromised by ongoing mining activities.

3. Restoration of at least the first production unit must be completed prior to mining any area beyond the maximum 20 ha (50 acres) with an ammonium bicarbonate lixiviant.

4. The applicant must provide a detailed mining plan that reflects these requirements prior to issuance of the source materials license.

The staff recognizes the potential of a small risk from the residual ammonia. However, a search of the literature by the staff indicates no significant risk to mammals from ingestion of water containing this concentration of ammonia (see Sect. 5.3.2.2). The ammonia is expected to be relatively immobile in the aquifer and remain within the mining zone. The possible conversion of this ammonia to nitrate (water quality standard of 10 ppm) appears unlikely under expected anerobic conditions. These aspects are discussed in detail in Sect. 6.3.2.2.

The staff concludes that with the above restrictions the risk of leaving a small region of contaminated groundwater is more than offset by opportunity to (1) continue development of a new uranium mining technology that appears to offer significant environmental advantages over conventional mining methods and (2) develop and improve restoration techniques for solution mining on a production scale. This conclusion is reinforced by the much smaller surface impacts of solution mining compared with conventional uranium mining and milling methods.

5.2 SURFACE RECLAMATION

5.2.1 Applicant's program

All land disturbed during WMC solution mining activities will be reclaimed in accordance with State regulations. According to the applicant, reclamation of a well field will be done after a field has been mined and the localized groundwater restored. Wells will be plugged and sealed below the surface according to State regulations. Disturbed soil will be prepared and seeded; fertilization and irrigation will be employed as necessary. After all solution mining and groundwater restoration activities are completed, the recovery facility will be decommissioned. The plant site and waste pond sites will be reclaimed. Residual solid wastes from evaporation ponds exhibiting sufficient radioactivity or toxicity will be removed and transferred to a licensed tailings pond or burial site. The ponds will be backfilled, shaped, and seeded.

5.2.2 Staff recommendations

The staff recommends that reclaimed land be seeded with a diverse mixture of native grasses, forbs, and shrubs. Some fast-growing introduced species such as yellow sweet clover, alfalfa, and crested wheatgrass may be used to help stabilize reclaimed areas rapidly. However, a diverse selection of native species should provide long-term stability of reclaimed land and ensure its future value as wildlife habitat. The staff suggests that seeding should take place in late fall (after October 15), because many native species require winter conditions to break dormancy. Winter and spring precipitation and melt-off will provide moisture for germination. If reseeding of shrub species, especially big sagebrush, does not prove successful, the staff recommends that shrubs from surrounding undisturbed land be transplated to reclaimed areas.

5.3 DECOMMISSIONING

All structures (pipelines, tanks, buildings, and foundations) will be removed from the site by the applicant upon completion of project operations. After the decommissioning, all disturbed areas will be reclaimed as described in Sect. 5.2.

REFERENCES FOR SECTION 5

1. Discussions with Texas Water Quality Board personnel (now Texas Department of Water Resources), Austin, Texas, Jan. 17, 1977, and subsequent discussions with other offices.

2. L. G. McMillion, "Groundwater Reclamation by Selective Pumping," *Trans. AIME* 250: 11-15 (March 1971).

3. W. C. Larson, *The State of the Art of in situ Leach Mining, FY 77*, prepared by Twin Cities Mining Research Center for the United States Department of the Interior, Bureau of Mines.

4. Wyoming Mineral Corporation, "Irigaray Restoration Demonstration Program, Final Report," Lakewood, Colo., Mar. 13, 1978.

5. Wyoming Mineral Corporation, "Irigaray Restoration Data Package," Lakewood, Colo., March 1978.

6. E. B. Besselievre and Max Schwartz, *The Treatment of Industrial Wastes*, 2d ed., McGraw Hill, New York, 1976, pp. 175-177.

7. K. R. Schendel, Wyoming Mineral Corporation, attachment to letter to L. C. Rouse, Nuclear Regulatory Commission, March 20, 1978, Docket No. 40-8502.

6. ENVIRONMENTAL IMPACTS

Environmental impacts from a solution mining operation result from both construction and operational activities. An attempt has been made to separate these two activities in the following discussions. In most cases, doing so proved difficult because development (construction) of some well fields will be concurrent with production (operation) from other well fields. The impacts from these activities are also quite similar. Therefore, assessment of many impacts associated with solution mining includes the combined effects of construction and operational activities.

Solution mining (in situ leaching) of uranium is a relatively new and developing technology. Operating experience as well as information on the subsurface environment is currently limited. Consequently, conservative assumptions and "worst case" examples have been used to assess many of the environmental impacts. Therefore, the magnitude of such impacts may be considerably smaller than those determined in this Statement.

The applicant is continually providing additional information from pilot-scale tests. Any significant information that becomes available will be incorporated in the Final Environmental Statement (FES).

6.1 IMPACTS ON AIR QUALITY

The proposed project could affect air quality near the WMC site by the formation of fugitive dust, the release of diesel emissions from drilling and construction equipment, and the release of atmospheric emissions from the recovery facility and waste ponds. Diesel emissions will be minor, of short duration, and should be readily dispersed.

Dust will be generated as a result of construction and drilling activities in connection with well field development. During project operation, disturbed areas on the roads and well fields will continue to be a source of fugitive dust. Wyoming's air quality regulations require that dust control measures be implemented for all potential sources of dust.[1] Adequate dust control measures, such as application of oil or water to graveled roads, wetting of exposed soil on well fields, and reseeding and stabilizing distrubed land, should minimize dust emissions. Localized degradation of air quality resulting from dust could occasionally occur at the WMC site on windy days, possibly causing the concentration of suspended particulates to exceed the State standard of 150 $\mu g/m^3$ (24-hr maximum). Other than such occasional, localized episodes, fugitive dust from WMC activities should not significantly affect air quality.

Air quality at the site and environs could be affected during operation of the proposed project by atmospheric releases from the recovery facility and from the waste storage and treatment ponds. Nonradioactive emissions from the recovery facility will include combustion products from the propane-fueled project drying unit and volatilized solution residuals (primarily ammonia). Ammonia and ammonium chloride will be released from the ponds.

Atmospheric releases from the combustion of propane will consist of hydrocarbons, nitrogen oxides, carbon monoxide, sulfur oxides, and particulates. The dryer has a relatively small capacity (1,000,000 Btu). Thus release of pollutants from combustion should be insignificant, and State and Federal ambient air quality standards for these pollutants (Sect. 2.6) are unlikely to be exceeded.

Estimated releases of ammonia vapors and ammonium chloride particulates from the recovery facility and waste ponds are detailed in Table 4.5. Particulate ammonium chloride formed over waste ponds should rapidly precipitate in the immediate vicinity of the ponds and should have no effect on air quality. Ammonium chloride particulates from the recovery facility should likewise not affect air quality beyond the immediate vicinity of the facility. An estimate of atmospheric ammonia concentrations resulting from release of ammonia vapors from the facility and ponds has been made using an atmospheric dispersion model. Atmospheric dilution factors were obtained using wind and stability data from Casper. Although the ponds and recovery facility will actually act as scattered and rather diffuse sources of ammonia, the model assumes

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all ponds to be one ground-level point source and, therefore, should result in conservative estimates of maximum ambient ammonia concentrations.

Maximum ammonia emissions from the ponds and recovery facility could total 12,500 kg (27,500 lb) of ammonia annually, or 0.4 g/sec. Using the point-source dispersion model, estimated maximum concentrations of ambient atmospheric ammonia could be 75 $\mu g/m^3$ at 100 m (328 ft) from the ponds and facility. At 500 m (1640 ft) from the ponds and recovery facility, maximum ammonia concentrations should be about 5 $\mu g/m^3$. By comparison, the recommended occupational threshold limiting value (TLV) for ammonia is 35,000 $\mu g/m^3$ (ref. 2), and the threshold for ammonia odor is 37,000 $\mu g/m^3$ (ref. 3). The lowest atmospheric concentration of ammonia known to affect vegetation is 1000 $\mu g/m^3$, which produced effects on photosynthesis.[4] There are no Federal or State ambient standards for atmospheric ammonia. Because anticipated ammonia concentrations in the vicinity of the ponds (75 $\mu g/m^3$ at 100 m) are over an order of magnitude below levels that affect vegetation and well over two orders of magnitude below the TLV, they should not have a significant effect on air quality.

6.2 IMPACTS ON LAND USE

6.2.1 Grazing

Grazing will be restricted on the project area proper. A total of approximately 400 ha (1000 acres) may be involved over the life of the project. Approximately 24 ha (60 acres) of land will be removed from grazing during the limited 20-ha (50-acre) well field operation. This land has an average grazing capacity of 3.5 ha (9 acres) per animal unit month. Therefore a total of seven animal unit months will be removed from use, a loss of grazing capacity that would support about five cows per year. With successful reclamation (Sect. 5.2), this grazing land could be returned to its original capacity.

6.2.2 Transportation

The applicant estimates that about 80 km (50 miles) of roads will be constructed or improved to serve the WMC site over the life of the project (ER, p. 118). These could improve access for the local ranchers to parts of their properties. The relatively small increase in traffic associated with the WMC project should not adversely affect neighboring ranching activities.

6.2.3 Recreation

Hunting will be restricted on the WMC site, which will result in the removal of an area of about 25 km^2 (10 sq miles) from hunting. The abundance of excellent hunting area available in the region leads to the conclusion that this removal should not result in a significant impact.

6.2.4 Impacts on historic, archaeologic, and natural landmark sites

Fort Reno and Cantonment Reno are the only sites located in the vicinity of the WMC site that are listed in the National Register of Historic Places (Sect. 2.5.2). These two sites are over 8 km (5 miles) from the project boundaries and should not be affected by project activities. The Portuguese Houses site, which has been determined as eligible for inclusion in the Register, is also over 8 km (5 miles) from the WMC site and should not be affected by the proposed project. The Hoe Ranch, a site of some historic value that has not currently been determined as eligible for inclusion in the National Register, is within the boundaries of the WMC site. The ranch ruins, however, are not within the area to be mined and thus should not be impacted by project activities.

No archaeological survey has been conducted on the WMC site. Because no major excavation will be involved in the proposed project, the staff cannot foresee any disturbance to any archaeologic resources that might be on the site. If any suspected archaeologic sites are discovered during project development, the office of the Wyoming State Archaeologist will be contacted before any disturbance of the site would occur.

No natural landmarks exist in the region of the WMC site.

6.3 WATER

6.3.1 Surface water

6.3.1.1 Impacts of construction

Impacts to aquatic systems from WMC construction activities will derive primarily from the release of sediments, oil, and grease. Land clearing during construction will increase the rates of erosion and discharge of sediments. WMC used the Universal Soil Loss Equation to predict that, with the disturbance of 40 ha (100 acres) at any one time, soil loss will increase from the normal 14 tons per year to 20 tons per year (ER, p. 118). U.S. Geological Survey data (1972-74) for the Powder River at Arvada indicate that the existing load of sediments has varied from 4.4 tons per day to 83,700 tons per day, with an average of 9285 tons per day. Apparently, even if WMC's estimate of increased erosion were low by a factor of 10, the increased sediment released by WMC activity would constitute a negligible addition to the Powder River.

Most of WMC's activities should have a small or negligible impact on Willow Creek. In addition to erosion, land clearing can cause more rapid runoff to occur during rainstorms, which can accelerate scouring and erosion of stream channels. The discharge of eroded sediments and oil and grease from heavy equipment and drilling rigs could affect any biota inhabiting Willow Creek or the pools in its normally dry streambed. However, WMC's operation will disturb only 2% of the Willow Creek drainage area (400 ha out of 25,000 ha, or 1000 acres out of 96 sq miles). Therefore, the majority of WMC's activities should produce only minor localized impacts on Willow Creek.

WMC plans to conduct solution mining in the streambed of Willow Creek, and this activity has the greatest potential for adverse impact. WMC is currently developing engineering designs and methods to (1) protect pipes and equipment in the streambed from flooding and (2) prevent adverse impacts to downstream water quality.

Operations in the streambed are scheduled to begin in 1979, and protective measures will be adopted prior to these operations. WMC has proposed several modifications of its operation for activity in the Willow Creek streambed.[5] These modifications include installing wells at a dry season and constructing temporary dikes while mining is in progress to contain any spills. WMC has also indicated that a temporary diversion of the Willow Creek channel might be constructed. Because such a channel modification could cause erosion problems and long-term disturbance of the stream, NRC will review WMC's proposed control and mitigation measures prior to initiation of operations in this sensitive area.

6.3.1.2 Impacts from operations

WMC's project operations are designed to produce no discharge to surface waters. Under normal operating conditions, there should be no impact on surface waters. There is, however, a potential for accidental release of contaminated fluids, which is discussed in Sect. 7.1. In addition, normal well field operating conditions will result in localized groundwater contamination. As discussed in Sect. 6.3.2.2, an uncontrolled excursion or incomplete restoration could possibly result in contaminated groundwater reaching the Powder River.

As the contaminated groundwater migrates through the aquifer, contaminating substances can be differentially adsorbed to clays and other materials. Presently, however, it is not possible to predict which constituents would be removed from the contaminated water movement through the aquifer. In addition to removal of contaminants by adsorption, the contaminated groundwater would also be diluted to some unknown extent by uncontaminated groundwater.

Due to the distance to the Powder River, contaminated groundwater from the initial 20-ha (50-acre) mining area would cause relatively minor adverse impacts to surface waters. Furthermore, the program of monitoring groundwater (Sect. 8.2.3) should reduce the probability of an uncontrolled excursion to a low level, and restoration should return any affected groundwater to its premining quality. These observations suggest that WMC can conduct solution mining with a low risk of adverse effects on the Powder River. Nevertheless, because knowledge of excursions and restoration is incomplete, a precautionary program for monitoring surface waters is proposed in Sect. 8.1.5.

6.3.2 Impacts on groundwater

6.3.2.1 Consumption

Maximum pumpage from the Wasatch Formation as a result of mining and restoration of 20 ha (50 acres) of well fields will be about 1000 acre-ft. This withdrawal of groundwater will occur over an extended period, and the impact of this pumpage is difficult to determine because of the limited available data on groundwater in the area and because of the complex geology (Sect. 2.7.1.2). Potential impacts, however, could include (1) temporary lowering of water levels in wells that are completed in the ore zone aquifer in the immediate vicinity of the well fields and (2) the lowering of water levels in wells completed in the alluvium overlying the Wasatch Formation, if leakage from the alluvium into the Wasatch Formation occurs as a result of pumping. The occurrence of these potential impacts should be readily identified by the applicant's monitoring of water levels.

Should the applicant's solution mining operation expand in the future, some significant impacts are anticipated.

6.3.2.2 Groundwater quality

Local groundwater quality will be lowered by in situ leaching of uranium. Potential groundwater quality impacts from the applicant's proposed operations are associated with (1) waste disposal ponds, (2) accidental leaks or spills of toxic liquids, (3) uncontrolled excursions, and (4) improper or incomplete groundwater restoration. The Upper Irigaray Sandstone will be the primary aquifer affected by in situ leaching. However, contaminated groundwater could also enter shallower and deeper aquifers in certain areas – especially from upward movement in the vicinity of the Powder River (see Sect. 2.6.2.2). Each of these potential impacts will be discussed below.

Waste disposal ponds

Liquid and solid wastes will be stored temporarily in polyethelene-lined ponds. Failure of the pond liners would permit some of the liquid wastes to seep into the ground. At the Irigaray site, this is expected to have an insignificant impact because of dry strata beneath the ponds. This type of accident is discussed in Sect. 7.2.1.

Leaks or spills

Accidental leaks or spills of toxic liquids could potentially infiltrate shallow aquifers and locally reduce groundwater quality. Accidental leaks and spills would probably not be of a sufficient volume to degrade significantly near-surface groundwater quality (see Sect. 7.1).

Excursions

Excursions of contaminated groundwater from the well field aquifer are possible because of large variations in aquifer permeability, less than optimal well spacings, and low pumping rates. The magnitude of an excursion and the degree to which the contaminants become attenuated once they have passed beyond the influence of the pumping well field is the primary and most difficult operational impact to predict at the Irigaray site. Consequently, worst case examples are used, and the magnitude of such impacts may be considerably less.

Initial concentrations of ammonia, bicarbonate, and hydrogen peroxide in the leach solution will range from 300-1500 ppm of ammonia, 1000-5000 ppm of bicarbonate, and 250-1000 ppm of hydrogen peroxide. As the leach solution circulates through the aquifer, many elements in addition to uranium will be oxidized and dissolved. Table 6.1 compares premining groundwater quality to postmining groundwater quality at the Irigaray 517 test site (see Figs. 1.2 and 4.2 for location). This leaching test consisted of four injection wells surrounding one recovery well and was conducted for 107 days. Longer periods of leaching over a much larger area could possibly result in higher concentrations of toxic substances in the groundwater. These concentrations, however, will depend on the initial concentrations of toxic substances in the ore zone and the extent to which they are mobilized by in situ leaching.

Elements associated with the ore zone: Uranium, arsenic, selenium, vanadium, and molybdenum were originally transported into the ore zone as complex anions in oxidizing groundwater having a slightly alkaline pH. The anions remained mobile until the oxidation potential (Eh) was reduced. This condition occurred at the Irigaray site and uranium, arsenic, selenium, vanadium, and molybdenum precipitated out of solution as relatively insoluble oxides (U, V), silicates (U, V), or native elements (As, Se). The molybdenum concentration was too low to form any minerals. During in situ leaching, these elements are expected to be remobilized by a similar, although more reactive, geochemical environment. In the event of an excursion, they will remain mobile as long as the groundwater remains oxidized.

Uranium occurs in the ore zone as the minerals uraninite and coffinite. During in situ leaching, uranium will be transported in solution as the uranyl dicarbonate complex $[UO_2(CO_3)_2 2H_2O]^{2-}$. In

Table 6.1. Comparison of premining groundwater and prerestoration groundwater quality, Irigaray test site 517

Analysis	Premining groundwater quality	Prerestoration production zone values
	(ppm)	(ppm)
As	< 0.0025	0.021
Ba	0.12	0.069
B	0.16	0.283
Cd	< 0.005	0.014
Cr	0.0135	0.002
Cu	0.019	0.220
Mn	0.12	0.97
Hg	0.0028	< 0.0002
Ni	0.018	0.218
Se	0.013	1.75
Ag	< 0.005	0.015
Zn	0.003	0.22
Pb	0.0035	0.110
U_3O_8	0.098	24.4
NH_3	< 1.0	235
Cl^-	10.75	524
	(mg/liter)	(mg/liter)
HCO_3^-	139	805
Total dissolved solids	793	1,324
	(pCi/liter)	(pCi/liter)
Gross α	168 ± 11	22,815 ± 296
Gross β	164 ± 19	21,043 ± 441
Ra-226	26.8 ± 5.2	371 ± 5.6

Source: ER, p. 168.

the event of an excursion, uranium will remain mobile until the Eh is sufficiently lowered, at which time UO_2 (uraninite) or $USiO_4$ (coffinite) will begin to precipitate out of solution.

Arsenic occurs in the ore zone as either native arsenic or possibly arsenide minerals. During in situ leaching, arsenic will be transported in solution as the anion AsO_4^{3-}. In the event of an excursion, arsenic will be deposited as native arsenic if there is a decrease in the Eh.

Selenium occurs in the ore zone as native selenium and possibly as ferroselinite. During in situ leaching, selenium will be transported in solution as the anion SeO_3^{2-}. In the event of an excursion, selenium will be deposited as native selenium or $FeSe_2$ (ferroselinite), if the Eh is lowered at some distance from the well field.

Molybdenum occurs in the ore zone in very small concentrations. During in situ leaching, molybdenum will probably be carried in solution as the anion MoO_4^-.

Substances injected into the aquifer: The concentrations of ammonia, bicarbonate, and chloride increase significantly in postmining groundwater at the Irigaray test site 517 (Table 6.1). Although chloride is not an essential part of the leach solution, large concentrations are injected into the aquifer as a result of elution from the ion-exchange resin.

The concentration of un-ionized ammonia (NH_3) and ammonium ion (NH_4^+) in the well field groundwater will equilibrate according to the pH. In general, the higher the pH, the more un-ionized ammonia will be present.[6]

At the surface and near-surface environment, with oxygen present, ammonia can be converted to nitrate and nitrite by bacteria. Some of the appropriate bacteria could conceivably be incorporated into the leach solution and then injected into the well field aquifer. Whether these bacteria, which normally thrive in acidic soils, would survive in the alkaline groundwater environment at the site is not known.

Other elements: Increases in the concentration of other elements in the groundwater as shown on Table 6.1 result from changes in the geochemical environment induced by in situ leaching. Elements such as manganese, iron, and small amounts of boron occur in the ore zone in a variety of detrital heavy and authigenic minerals. Other elements which show increased concentrations in the groundwater (Table 6.1), such as cadmium, copper, nickel, silver, zinc, and lead, are not associated with any identifiable minerals. These elements probably occur at concentrations of less than a few parts per million within the rock and show no relationship to uranium mineralization.

Table 6.2 summarizes information regarding water quality criteria and toxicity for many of the constituents that might be released during an excursion. Criteria and standards for irrigation water, drinking water, and aquatic life, and the Wyoming Department of Environmental Quality criteria for wildlife and livestock are also included in Table 6.2. Two indications of toxicity of trace elements to aquatic organisms are derived from a data base assembled by Cushman et al.[7]

Table 6.2. Water quality criteria and toxic concentrations for potential contaminants from solution mining

All units in mg/liter, unless indicated otherwise

Parameter	Wyoming DEQ water quality criteria for wildlife and livestock[a]	NAS criteria for irrigation water[b]	Recommended limit for protection of aquatic life	Drinking water standard	Toxic concentrations[c]	
					Mean toxic concentration[d]	Lowest toxic concentration[e]
NH_3[f]			0.02[b,g] (for un-ionized ammonia)	0.5[h]		
Cl^-	2000			250[i,j]		
SO_4	3000			250[i,j]		
Ag				0.05[i,k]		
Al	5.0		5.0		18.9	0.07
As	0.2	0.1		0.05[i,k]	13.6	0.022
B	0.5	0.75			900	0.69
Ba				1.0[i,k]	1080	8.0
Cd	0.05		0.003–0.03[b,g] 0.001–0.012[g] (for hard water)	0.01[i,k]	7.4	0.0009
Co		0.05			21	0.021
Cr	1.0	0.1	0.05[b]–0.1[g]	0.05[i,k]	80.7	0.008
Cu	0.5	0.2		1.0[i]	1.6	0.006
Fe		5.0	1.0[g]	0.3[j]	1235	0.02
Hg	0.01		0.05[g]	0.002[k]	0.2	0.003
Mn		0.2		0.05[i]	2259	17
Mo		0.01			.147	47
Ni		0.20		1.0[l]	13.0	0.05
Pb	0.1	5.0	0.03[b]	0.05[k]	69.8	0.007
Se	0.05	0.02		0.01[k]	11.2	1.0
U					36.2	1.7
V		0.1			27.3	4.8
Zn	25	2.0		5[j]	7.9	0.0001
F	2.0	1.0		0.7–1.2[i]		
Total dissolved solids	5000			500[i,j]		
pH	6–9			6.5–8.5[j]		
Ra-226, pCi/liter				5.0[j]		
Gross α, pCi/liter				15.0[j]		
Gross β, pCi/liter				1000.0[j]		

[a] Data obtained from Wyoming Department of Environmental Quality, Land Quality Division, Guideline No. 4 (Revised), Nov. 9, 1976, p. 3-41.

[b] Data obtained from National Academy of Sciences, Environmental Studies Board, *Water Quality Criteria 1972*, EPA/R3/73-033, March 1973.

[c] R. M. Cushman, S. G. Hildebrand, R. H. Strand, and R. Anderson, *The Toxicity of 35 Trace Elements in Coal to Freshwater Biota: A Data Base with Automatic Retrieval Capabilities*, Report ORNL/TM-5793, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1977.

[d] Mean of all concentrations (ppm) found to be lethal to fish in experiments lasting 96 hr or longer.

[e] Lowest concentration (ppm) found to be lethal to any aquatic organism.

[f] The toxicity of ammonia is discussed in detail in the text.

[g] Data obtained from U.S. Environmental Protection Agency, *Quality Criteria for Water*, EPA-440/9-76-023, 1976.

[h] Data obtained from World Health Organization, *European Standards for Drinking Water*, Geneva, Switzerland, 1961.

[i] Data obtained from U.S. Public Health Service, *Drinking Water Standards*, PHS Publication 956, 1962.

[j] Data obtained from "Proposed National Secondary Drinking Water Standards," *Fed. Regist.* 42(62): 17143-17147 (March 31, 1977).

[k] Data obtained from "National Interim Primary Drinking Water Regulations," *Fed. Regist.* 40(248): 59566-59577 (Dec. 24, 1975).

[l] Data obtained from T. Kirkor "Protecting public waters from pollution in the USSR" *Sewage Ind. Wastes*, 23(7): 938–940 (1951).

In general, the size, shape, and concentration of an excursion will depend on the following variables:

1. the effectiveness of pumping to confine and then remove these contaminants from the groundwater;
2. the direction of groundwater flow;
3. how mobile and physically and chemically reactive each substance is;
4. the geochemical characteristics of the aquifer, such as its capacity to dilute, dispense, and diffuse contaminants, and the adsorptive and ion exchange capacity of minerals in the aquifer;
5. the physical characteristics of the aquifer such as abrupt changes in permeability and porosity; and
6. how quickly the applicant detects the excursion and the methods that are used to remove these contaminants from the groundwater.

At the Irigaray site, hydrologic and lithologic characteristics of the aquifer are not known well enough to predict, and along what specific layers, the contaminants might travel. There is a possibility that fractures are present in the upper Irigaray sandstone. As reported by Grisak and Cherry,[7] groundwater velocities in fractured rock (or channelized sands) can be orders of magnitude greater.

The shape of an excursion can be quite variable, as indicated by Legrade.[9] Little is known, however, about the three dimensional shape of an excursion. The concentration of a continuous excursion will usually decrease with increasing distance from a well field until a quasi-equilibrium is reached between contaminants added to the excursion from leaching, and attenuation of the contaminants at the periphery of the excursion by physical and chemical mechanisms. At this point, the contaminated zone would remain somewhat stationary, although individual contaminants such as selenium, chloride, uranium, etc., would establish their own quasi-equilibrium at some unknown distance within the excursion. At the Irigaray site, however, a continuous excursion is not anticipated. Contaminants in the groundwater would therefore be expected to attenuate more rapidly as they travel down the hydraulic gradient toward the Powder River — about 5.6 km (3.5 miles) away. Furthermore, because normal well field production should remove some percentage of the mobilized ore-associated contaminants, concentrations of these elements in successive excursions would be expected to decrease.

Cations and ammonia are less mobile than the anions because of their tendency for the cations to be absorbed onto clays, especially montmorillonite. However, the distance each ion will travel during an excursion is not known. Because in situ leaching for uranium is a new and evolving technology, past experience cannot always be used to predict future groundwater contamination problems because of the site-specific nature of these operations. Based on the preceding qualitative analysis, the staff concludes that some contaminants could potentially enter the Powder River through groundwater recharge. The concentration of these contaminants upon entering the Powder River, however, would probably be very low. The monitoring program for groundwater should ensure that any impacts from excursions will be minimal (see Section 8.2.3).

Restoration

Groundwater restoration will include the following cycle: (1) groundwater removal, (2) treatment of the groundwater to remove contaminants, and (3) reinjection of the treated groundwater (see Sect. 5.1.3). Should restoration be incomplete for any mobilized constituents, groundwater quality will be degraded. As mentioned in Sect. 5.1.4, the use of an ammonium carbonate/bicarbonate leach solution may result in significant residual ammonia concentrations after restoration.

After WMC's mining operation, ammonia will be present in the Upper Irigaray Sandstone (UISS) in at least two states: (1) in solution and (2) adsorbed on clays and other minerals which form the aquifer. Restoration will remove ammonia from the groundwater; this will alter the equilibrium and cause some ammonia to be desorbed from bonding sites in minerals and clays. However, ammonia adsorbs tightly to clays, and WMC's restoration tests indicate that the desorption of ammonia proceeds slowly. Table 5.2, which shows the decline of ammonia during WMC's restoration tests, indicates that the rate of desorption declines as restoration progresses; that is, it becomes increasingly difficult to remove ammonia from the aquifer. Because of this, WMC has proposed a restoration criterion for ammonia of "a minimum value in the 20-50 ppm (average) range."[10] Ammonia concentrations of 20-50 ppm represent a substantial degradation of groundwater quality when compared with premining levels. In evaluating the significance of this degradation of groundwater quality, the staff considered (1) transformation of the contaminants; (2) mobility; (3) water quality standards for all forms of nitrogen for humans, livestock, and other organisms; and (4) water uses — past, present, and potential.

Transformations: Ammonia cannot be considered alone as a water quality constituent. In the presence of oxygen, nitrifying bacteria convert NH_3 to NO_2^+ and NO_3^-. As mentioned in Sect. 6.3.2.2 it is difficult to predict whether nitrification will occur in the aquifer. A lack of oxygen, high pH, or other factors may inhibit formation of nitrites or nitrates.

The basic stoichiometry of the conversion process is

$$NH_3 + 2O_2 \rightarrow HNO_3 + H_2O \ .$$

Several different paths and mechanisms may be involved, but all involve driving forces not available in the underground mining zone except under leaching conditions. Other formation constituents compete for the available oxidant even then, so only minimal nitrate formation would be expected. This fact is confirmed by reported data as shown in Table 5.1, Column C, where a total of 7.68 ppm of combined nitrate and nitrite have apparently been formed in the presence of 180 ppm of ammonia. Restoration techniques effectively remove this nitrate (Table 5.1, Column E).

After restoration the only oxygen available for ammonia conversion would be from air dissolved in the water returned to the aquifer. At one atmosphere pressure, the saturation value is 9 to 14 ppm of dissolved oxygen (dependent on temperature). If the water was fully saturated and 100% conversion to nitrate occurred, neither of which the staff considers likely, no more than 14 ppm of nitrate could be formed. When reported as nitrogen, this concentration amounts to only 3.2 ppm which is well below the allowable drinking water standard of 10 ppm for nitrate (as nitrogen).

Mobility: As noted previously, the presence of clays in the UISS should make ammonia relatively immobile. Ammonia can migrate through parts of the aquifer where absorptive capacity is saturated, but in parts of the aquifer that are unaffected by solution mining, ammonia should travel only short distances. Nitrite and nitrate, on the other hand, are relatively mobile and are expected to migrate with the flow of groundwater.

The large amounts of ammonia left in the mining zone, both in the groundwater and aquifer (sand and clays), and the subsequent difficulty in eluting this ammonia from the aquifer by groundwater sweeping indicates chemical exchange. The ability to elute ammonia from the aquifer by alkaline earths in solution confirms that a true chemical exchange is occurring.

From this evidence the staff concludes that any ammonia transported by the slowly moving groundwater will equilibrate with the sands and clays outside the mining zone. This exchange is probably with the calcium associated with the clay (approximately 15%) in the aquifer.

The overall effect will be to decrease the rate of ammonia transport and concentration in the groundwater system as it leaves the mining site. The applicant estimates the groundwater flow as 5 to 8 ft per year. The staff estimate is about a factor of 10 higher; however, exchange reactions with the aquifer will reduce the effective ammonia transport rate to less than 10 ft per year, although ions such as chloride and nitrate can be expected to move with groundwater velocity.

The staff concludes that this slow transport and effective dilution will make potential offsite consequences neglible but recommends continued monitoring as a precaution. Furthermore, the staff considers that the "restored" section of the 517 pilot test area provides a unique opportunity to study ammonia movement caused by groundwater flow and/or conversion to nitrate.

One week after completion of the TDS reduction experiment, the central recovery well showed 27 ppm of ammonia (as nitrogen). The injection wells, about 4.3 m (14 ft) distant, showed values below 0.5 ppm. Nitrate values were below 0.5 ppm. Groundwater flow is to the northwest of the "restored" plot (Fig. 5.1). Unrestored mined areas bound the "restored" region on the sides bounded by wells 2A, 517-6, and 3A. In addition, wells PRC-1, PRC-2, and M-1 lie about 12, 18, and 32 m (40, 60, and 105 ft) down gradient from the recovery well (No. 6A). The applicant has reported that the water in PRC-1 has contained small quantities of ammonia, but its present condition is unknown.

If the above described physical system is sampled for ammonia and nitrate routinely over a long time period, the staff believes that the relative importance of ammonia transport and nitrate conversion can be demonstrated.

As a license condition the applicant will be required to submit an experimental plan to demonstrate whether significant ammonia transport occurs and if nitrate is formed in the "restored" formation. The actual demonstration will be the responsibility of the applicant as a license condition.

Standards and criteria: Ammonia is identified as an objectionable constituent in water supplies, but it appears that rather little is known about the toxicity of ammonia to humans. The NAS[6] recommends a low limit for NH_3 in public water supply stating:

- Because ammonia may be indicative of pollution and because of its significant effect on chlorination, it is recommended that ammonia nitrogen in public water supply sources not exceed 0.5 mg/liter.

With respect to livestock it appears that 40 ppm of ammonia in drinking water will not pose a hazard to cattle.[11] Ammonia is toxic to fish at low concentrations, and, as shown in Table 6.2, a very low limit for ammonia is recommended for protection of aquatic life.

While there is uncertainly about nitrification in the aquifer, it is clear that nitrification will occur as soon as any water from the aquifer reaches the surface and is exposed to oxygen. Because nitrate and nitrite can cause methemoglobinemia in infants, NAS[6] recommended as follows:

- On the basis of adverse physiological effects on infants and because the defined treatment process has no effect on the removal of nitrate, it is recommended that the nitrate-nitrogen concentration in public water supply sources not exceed 10 mg/liter.
- On the basis of its high toxicity and more pronounced effect than nitrate, it is recommended that the nitrite-nitrogen concentration in public water supply sources not exceed 1 mg/liter.

With respect to livestock, the NAS concluded "that all classes of livestock and poultry that have been studied under controlled experimental conditions can tolerate the continued ingestion of waters containing up to 300 mg/liter of NO_3N to 100 mg/liter of NO_2N." Nevertheless, NAS[6] recommended:

- In order to provide a reasonable margin of safety to allow for unusual situation such as extremely high water intake or nitrite formation in slurries, the NO_3N plus NO_2N content in drinking waters for livestock and poultry should be limited to 100 ppm or less, and the NO_2N content alone be limited to 10 ppm or less.

Water use: Water from the UISS aquifer is used predominantly for livestock watering. This aquifer is also the water source for the Irigaray ranch, although moderate levels of selenium were present (Appendix B, Table B-1, W-23). Natural radiological contamination is also present in many areas of the aquifer. It is difficult to predict future use of the UISS aquifer. Ranching seems likely to remain the predominant land use near WMC's operations, but uranium mining may greatly increase in the area. WMC's degradation of aquifer water quality would be initially limited to the mining zone [approximately 20 ha (50 acres) of well fields]. If nitrification occurs in the aquifer, those "downstream" portions of the aquifer into which nitrates and nitrites could migrate would also be degraded. Currently the water quality in these potentially affected areas is naturally degraded by the radioactive materials associated with uranium deposits. Thus, water from much of the potentially affected areas is already unacceptable for public water supply.

Conclusions

The WMC's proposed action will degrade groundwater in the mining zone (Sect. 5.1.1). The extent of degradation depends significantly on an unknown factor: whether nitrates and nitrites are formed in the aquifer. Degradation would be limited to a relatively small area in which groundwater quality is already naturally degraded. If WMC leaves 20-50 ppm of NH_4 in the UISS aquifer, this groundwater would be unacceptable for human consumption due to (1) possible presence of nitrites and nitrates, (2) the odor of ammonia, and (3) potential toxicity of ammonia. The water would probably be marginally acceptable for livestock water, unless partial nitrification resulted in concentrations of nitrite-nitrogen greater than 10 mg/liter. Finally, if water from the contaminated aquifer reached any aquatic ecosystems (i.e., Powder River), it could adversely affect fish and other aquatic life. Livestock ponds filled with water from the contaminated aquifer would not support fish due to (1) ammonia toxicity, and (2) possible algal blooms stimulated by ammonia or nitrate.

The WMC's restoration does not pose a large or imminent threat to public health because the degradation of groundwater quality would occur in a small area where groundwater is currently not used for human consumption. Pumping from the contaminated area could probably be controlled or eliminated in the immediate future, and adverse impacts to public health, livestock, and aquatic life could be avoided in the near and mid-term. However, contamination of an aquifer under any circumstances is a serious matter because it is essentially irreversible. The restoration plan does involve potential risks, for example, in the event of unforeseen circumstances or perhaps at some future time. Thus, the proposed action is considered acceptable because of the small area involved and the extensive monitoring that will be undertaken.

6.4 MINERAL RESOURCES

Coal deposits underlying the Irigaray site are of limited quantity and are not considered presently to be economically recoverable. Any oil and gas that may exist beneath the site would be thousands of feet below the depths at which solution mining will take place and could not be affected by the proposed operation. Solution mining should not interfere with later potential resource recovery at the Irigaray site.

Uranium recovery using the solution mining method may not be as efficient as recovery by conventional underground or open pit mining methods since the technology is in a developmental stage. However, solution mining is conducted on uranium deposits that may not be of sufficient mineral grade or quantity to be economically mined by conventional methods. Such deposits would be lost as a resource.

6.5 SOILS

The removal of natural vegetative cover from construction sites and much of the well field areas will expose surface materials to accelerated wind and water erosion. Soil compaction due to operation of drilling rigs and other equipment in the well fields will also increase erosion and sedimentation. Extensive destruction of the soil system characteristics (physical, chemical, and biological) is not anticipated since no stripping or excavation will occur during proposed project operations.

6.6 ECOLOGICAL IMPACTS

6.6.1 Impacts on the terrestrial environment

Impacts on terrestrial biota will accrue from vegetation disturbance and related loss of wildlife habitat during well field development as well as possible effects on wildlife from increased human activity associated with the project. Atmospheric emissions from the project have been discussed in Sect. 6.1 and will have no effect on terrestrial biota. Traffic associated with the project may result in an increase in road-killed animals. Such losses, however, should not significantly affect local populations. Increased human activity may cause some wildlife species that are particularly intolerant of human presence to leave the immediate area. Because increased human activity will be limited to a small area around the recovery facility and the specific well field, this factor should not be significant.

Vegetation will be disturbed during development and operation of the proposed project in connection with construction of the recovery facility [2 ha (5 acres)], roads, and well fields. Well field development will produce the great majority of land disturbance. Drilling wells and subsequent maintenance activities will destroy natural vegetation present on the well fields and will involve an estimated 24 ha (60 acres) for the limited operation and may involve a total of 400 ha (1000 acres) over the lifetime of the project. WMC will reclaim and revegetate all land disturbed and is required to post a reclamation bond with the Wyoming Department of Environmental Quality.

Most of the land to be disturbed by well field development is within the sagebrush/grassland vegetation type, which is abundant and widely distributed over the entire Powder River Basin. Although wildlife will be displaced from the land disturbed, the animals that may be expected to occur on the sagebrush/grassland type are common and relatively abundant in the region of the site. The land that is disturbed will be lost as wildlife habitat until revegetation is accomplished. However, disturbance of about 400 ha (1000 acres) of the sagebrush/grassland vegetation type will not result in significant adverse impacts.

Disturbance of riparian habitat along Willow Creek and the Powder River could have a significant impact depending upon the extent of disturbance. Vegetation in riparian habitats is difficult to reclaim adequately,[12] and the vegetation type is not widely distributed in the region of the site. Furthermore, riparian areas near the site represent important habitat to a number of wildlife species including game species such as mule deer, sage grouse, and wild turkeys. Plans for the initial well field development should not include any riparian habitat along Willow Creek. However, because maps of the ore body show that it passes under Willow Creek and closely approaches the Powder River in Section 30 of the site, it is possible that future mining activities could involve riparian areas. The staff therefore recommends that disturbance in riparian habitats be kept to a minimum. In particular, the staff will require that trees and large shrubs, which could take over 100 years to be replaced, should not be destroyed. Vegetation along streams should not be removed because it stabilizes stream banks.

6.6.2 Impacts on endangered species

No endangered plant or animal species are expected to occur on the WMC site (Sect. 2.7). Of the wildlife species listed by the Wyoming Game and Fish Department as rare in Wyoming, only the milk snake would be likely to occur on the site. Construction and development of the proposed project should disturb only a small percentage of the habitat available for milk snakes on the site.

6.6.3 Impacts on aquatic environments

Potential impacts to surface aquatic environments through construction and operation of the WMC project are directly related to potential impacts on water quality, discussed in Sect. 6.3.1. Two aquatic environments are of concern: Willow Creek and the Powder River. Willow Creek has not been characterized ecologically except for the theoretical analysis presented in Sect. 2.9.2. Routine construction activities associated with the applicant's in situ mining operation near

Willow Creek should have a negligible impact on aquatic biota that may be present during periods of flow (Sect. 6.3.1.1). Solution mining proposed within the Willow Creek streambed itself could potentially disrupt aquatic habitat that may be present. WMC is currently developing methods to minimize any adverse impacts (Sect. 6.3.1.1). As a condition to license consideration, the staff requires that WMC, prior to any solution mining in the Willow Creek streambed, submit and obtain approval of mitigating measures to be used at Willow Creek. Potential construction impacts on aquatic systems in the Powder River should not significantly affect aquatic biota (Sect. 6.3.1.1).

Potential impacts of solution mining operation on aquatic environments may result from accidental surface releases of contaminated fluids onsite to Willow Creek or the Powder River (Sect. 7.1) and from contaminated groundwater ultimately reaching the Powder River (Sect. 6.3.2.1). The probability of an event of such magnitude cannot be predicted accurately. Monitoring programs required as a condition to this license should reduce the probability of an excursion significantly affecting aquatic biota in the Powder River (Sect. 8.2.3).

6.7 RADIOLOGICAL IMPACTS OF ROUTINE OPERATIONS

6.7.1 Introduction

Estimates of radiation doses resulting from routine operations of the Irigaray solution mining and uranium recovery process facilities are considered in this section. Individuals living in the area of the Irigaray project will be exposed to the airborne radionuclides and the subsequent deposition of these materials on the land surface.

Estimates of radiation doses from the exposures involve many complex considerations. In the absence of complete information, estimates were made using the best current knowledge. Conservative assumptions were made where there was insufficient knowledge; for example, estimates of doses from atmospheric releases assumed exposure to contaminated air and ground 100% of the time with no shielding and consumption of food that was produced entirely at the location of dose calculation.

The radiological impact of the routine release of radionuclides during normal operations at the well field and processing facilities was assessed by estimating radiation dose commitments to individuals and population from the resultant exposure. Since radioactive materials taken into the body by innalation and ingestion continuously irradiate the body until removed by processes of metabolism and radioactive decay, the estimate of the total dose an individual will receive from one year's intake is integrated over 50 years (remaining lifetime of the individual) and is called a dose commitment. All of the internal doses estimated in this report represent 50-year dose commitments. For those materials which have a short radioactive half-life or those, such as uranium, which are eliminated rapidly from the body, essentially all of the dose is received in the same year that the materials enter the body; that is, the annual dose rate is about the same as the dose commitment.

6.7.2 Airborne effluents

The release of radioactive materials to the atmosphere was assumed to be the principal mode of environmental contamination from the uranium solution mining and processing facility. Releases from solution mining will be substantially lower than those attributable to a conventional uranium mining-milling operation.

6.7.2.1 Models and assumptions

AIRDOS-II, a FORTRAN computer code,[13] was used to estimate individual and population radiation doses resulting from continuous atmospheric release of airborne radioactive materials from the uranium mining and processing operation. Pathways to man include the inhalation of radionuclides in air, immersion in air containing radionuclides, exposure to ground and surfaces contaminated by deposited radionuclides, and the ingestion of food produced in the area.

The area around the operating facility was divided into 16 sectors. Each sector was bounded by radial distances of 0.5, 1.0, 2.0, 3.0, 4.0, 5.0, 10, 20, 30, 40, and 50 miles from the point of release. Factors used as input data were (1) human population (Table 6.3), (2) numbers of beef and dairy cattle, and (3) specifications as to whether each of the areas lying outside the facility boundary was used for producing vegetable crops or is a water area.

A portion of the AIRDOS-II computer code[13] is an atmospheric dispersion model (AIRMOD) which estimates concentrations of radionuclides in air at ground level and their rates of deposition on ground and surfaces as a function of distance and direction from the point of release. Annual average meteorological data for the site area are supplied as input for AIRMOD.

Table 6.3. Population distribution within 50 miles of the Irigaray project site

Sector	Population									
	0–1 mile	1–2 miles	2–3 miles	3–4 miles	4–5 miles	5–10 miles	10–20 miles	20–30 miles	30–40 miles	40–50 miles
N	0	0	0	0	0	0	0	0	0	0
NNE	0	0	0	0	0	0	0	0	0	152
NE	0	0	0	0	0	0	1,813	0	0	7,194
ENE	0	0	0	0	0	0	0	0	0	797
E	0	0	0	0	0	0	0	0	0	175
ESE	0	0	0	0	0	0	0	200	0	86
SE	0	0	0	0	0	0	0	0	0	0
SSE	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	501	0
SSW	0	0	0	0	0	0	0	0	635	0
SW	0	0	0	0	0	17	0	0	0	0
WSW	0	0	0	0	10	0	0	272	0	0
W	0	0	0	0	0	0	0	0	572	0
WNW	0	0	0	0	0	0	173	0	0	0
NW	0	0	0	0	0	0	0	0	480	3,394
NNW	0	0	0	0	6	5	0	0	340	0
Total	0	0	0	0	16	22	1,986	472	2,528	11,798

AIRMOD is interfaced with environmental models within the AIRDOS-II computer code to estimate doses to man through the various pathways. A terrestrial model, TERMOD,[14] which estimates the radionuclide intakes via ingestion of radionuclides deposited on crops, soil, and pastures, is included. The intakes result from eating beef and vegetable crops and from drinking milk. The dose conversion factors for most radionuclides are based on ICRP-2[15] and the report of the Task Group on Lung Dynamics for Committee II of the International Commission on Radiological Protection (ICRP).[16] Methods used in estimating radiation doses have been published in a reference handbook, ORNL-4992.[17]

6.7.2.2 Atmospheric dispersion (meteorology)

In the absence of site-specific meteorological data for the proposed project, the staff used the meteorological data from the nearest weather station (Casper, Wyoming), approximately 113 km (70 miles) away, which should be quite similar to that of the project site. Values of χ/Q at the nearest residence (the Reculusa Ranch, where the highest individual dose occurred) was 2.31×10^{-8} sec/m^3 for particulates and 3.67×10^{-8} sec/m^3 for radon-222. The χ/Q values at the Irigaray Ranch were 5.65×10^{-9} sec/m^3 for particulates and 1.26×10^{-8} sec/m^3 for radon-222.

Atmospheric dispersion and deposition models and computations used are discussed in ref. 13.

6.7.3 Radiation dose commitments from airborne effluents

The radiation dose commitments from airborne effluents are based on the estimated emission rates shown in Table 6.4.

6.7.3.1 Maximum dose to the individual

Reculusa Ranch

The maximum annual dose commitments were received by individuals living at the Reculusa Ranch, the nearest residence to the plant site. The ranch is 6.6 km (4.1 miles) west-southwest of the recovery plant and 7.1 km (4.4 miles) west-southwest of the initial well field (Fig. 6.1). The doses are shown in Table 6.5.

The highest organ dose is estimated to be 1.1 millirems per year to the lung resulting from the release of uranium from the yellow cake drying and packaging operation. As shown in Table 6.5, other organ doses and the total body dose are much lower. The contribution of the various radionuclides is shown in Table 6.6.

Table 6.4. Release rates for radionuclides from the well field and recovery plant

Radionuclide	Release rate (Ci/year)
Recovery plant	
U-238	1.5×10^{-1}
U-234	1.5×10^{-1}
U-235	7.0×10^{-3}
Th-230	2.6×10^{-3}
Ra-226	1.0×10^{-4}
Pb-210	1.0×10^{-4}
Bi-210	1.0×10^{-4}
Po-210	1.0×10^{-4}
Well field	
Rn-222	7.6×10^{1}

Source: Estimates based on information contained in *Environmental Report, Irigaray Project, Johnson County, Wyoming,* Docket No. 40-8502, Wyoming Mineral Corp., Lakewood, Colo., July 1977.

These predicted annual individual dose commitments resulting from the normal operations are only a small fraction of the present NRC dose limits for members of the public outside restricted areas, as specified in 10 CFR Part 20, Standards for Protection against Radiation. Table 6.7 presents a comparison of the predicted annual dose commitments to individuals from operations of the Irigaray Project with present NRC limits and can be compared with the future Environmental Protection Agency's (EPA) Radiation Protection Standard (40 CFR Part 190),[18] which becomes effective for some uranium fuel cycle facilities in December 1979 and uranium mills in December 1980.

Irigaray Ranch

The maximum annual dose commitments are also shown for individuals living at the Irigaray Ranch, which is 7.1 km (4.4 miles) north-northwest of both the plant and well field. These dose commitments are shown in Table 6.8. The doses are about one-fourth of the similar doses received by individuals at the Reculusa Ranch and are also well below applicable standards.

6.7.3.2 Dose to the population

The annual dose commitments from the airborne effluents to the population living within 80 km (50 miles) of the operating facility are summarized in Table 6.9. The population total-body dose was 0.006 man-rem. The comparable dose from natural background in the area was 2.4×10^3 man-rems.[19] The highest population organ dose of 1.4 man-rems was to the lung (includes dose to bronchial epithelium) and was only 0.009% of the similar dose resulting from area background. All population doses are quite low due to the relative isolation of the project facilities from the nearest residences and, additionally, to the fact that the population density for the area adjacent to the site is very low (only 16,819 persons living within 80 km (50 miles) of the project site).

6.7.4 Liquid effluents

There are no planned discharges of radioactive pollutants into uncontrolled areas of the Irigaray project and no anticipated seepage from waste ponds into the local groundwater.

The required groundwater monitoring and corrective action program should effectively contain any contaminated groundwater. Therefore, any adverse impact resulting from contaminated groundwater is expected to be minimal.

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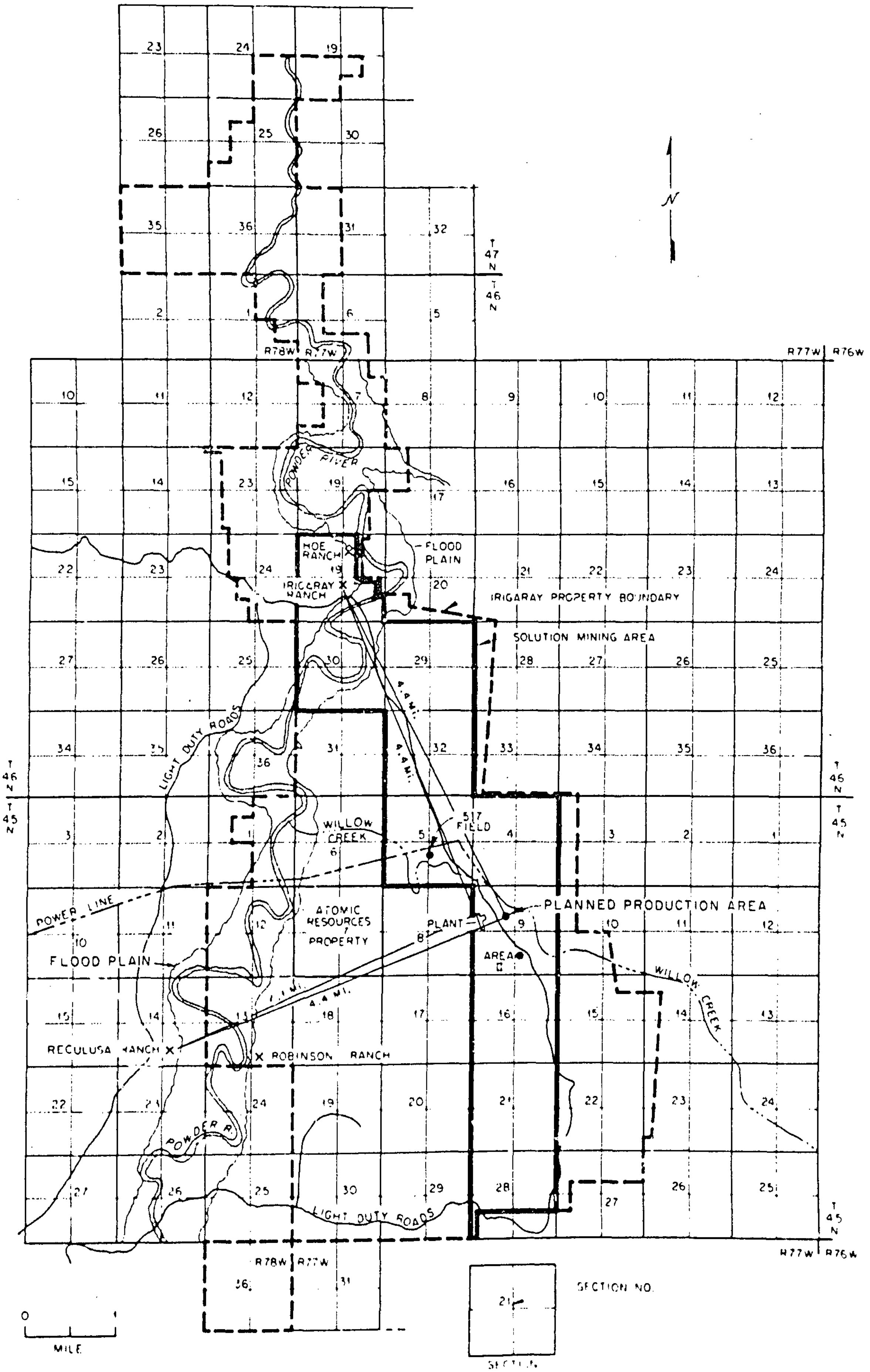

Fig. 6.1. Distances to nearest residences from the recovery facility and well fields.

Table 6.5. Estimated maximum annual doses from the airborne effluents to an individual living at the Reculusa Ranch[a]

Figures are for 50-year dose commitments from one year of intake of radionuclides

Pathway	Maximum annual dose (millirems)				
	Total body	Bone	Lung	Kidney	Bronchial epithelium
Submersion in air	8.2E-5[b]	1.2E-4	7.4E-5	6.5E-5	
Inhalation[c]	1.2E-3	2.7E-2	1.1	1.2E-2	8.9E-2
Ingestion[d]	5.0E-3	8.1E-2	5.1E-3	1.9E-2	
Exposure to ground	2.8E-3	4.5E-3	2.3E-3	1.0E-3	
Total	9.1E-3	1.1E-1	1.1	3.3E-2	8.9E-2

[a] The nearest residence to the plant and well field; located 4.1 miles west-southwest of the plant and 4.4 miles west-southwest of the well field.

[b] Read as 8.2×10^{-5}.

[c] Daily intake assumed to be 23 m^3 of air.

[d] Daily intake assumed to be 0.30 kg of beef and 0.25 kg of vegetables.

Table 6.6. Contribution of radionuclides to dose from airborne effluents at the Reculusa Ranch, the nearest residence

Radionuclide	Percent contribution			
	Total body	Bone	Kidney	Lung[a]
Po-210	0.1	<0.1	0.8	<0.1
Pb-210	0.2	0.4	1.2	<0.1
Rn-222[b]	5.4	2.3	16.6	7.8
Ra-226	3.2	2.6	0.9	<0.1
Th-230	6.0	15.6	16.1	0.8
U-234	31.7	38.6	31.1	47.4
U-235	11.1	2.9	3.2	2.2
U-238	42.3	37.5	30.1	41.8

[a] Includes dose to bronchial epithelium.

[b] Includes dose from daughters Pb-214 and Po-218.

Table 6.7. Comparison of annual dose commitments to the nearest residence (Reculusa Ranch) with radiation protection standards

Receptor organ	Estimated annual dose commitments	Radiation protection standards	Fraction of standard
Present NRC Regulation (10 CFR Part 20)			
Total body	9.1E-3 millirems per year	500 millirems per year	1.8E-5
Lung	1.1 millirems per year	1500 millirems per year	7.3E-4
Bone	1.1E-1 millirems per year	3000 millirems per year	3.7E-5
Bronchial epithelium	4.5E-7 WL[a]	3.3E-2 WL[a]	1.4E-5
Future EPA Standard (40 CFR Part 190)			
Total body	9.1E-3 millirems per year	25 millirems per year	3.6E-4
Lung	1.1 millirems per year	25 millirems per year	4.4E-2
Bone	1.1E-1 millirems per year	25 millirems per year	4.4E-3
Bronchial epithelium	4.5E-7 WL[a]	NA[b]	NA[b]

[a] Radiation standards for exposure to Rn-222 and daughter products are expressed in Working Level (WL). WL means the amount of any combination of short-lived radioactive decay products of Rn-222 in one liter of air that will release 1.3×10^5 mega electron volts of alpha particle energy during their decay to Pb-210.

[b] Not applicable; 40 CFR Part 190 does not include doses from Rn-222 daughters.

Table 6.8. The estimated maximum annual doses[a] from airborne effluents to an individual living at the Irigaray Ranch, 4.4 miles north-northwest of the plant

Pathway	Maximum annual dose (millirems)				
	Total body	Bone	Lung	Kidney	Bronchial epithelium
Submersion in air	2.1E−5[b]	3.0E−5	1.9E−5	1.7E−4	
Inhalation[c]	3.1E−4	6.7E−3	2.6E−1	3.1E−3	3.1E−2
Ingestion[d]	1.3E−3	2.1E−2	1.3E−3	5.0E−3	
Exposure to ground	7.2E−4	1.2E−3	5.9E−4	5.0E−4	
Total	2.3E−3	2.9E−2	2.6E−1	8.8E−3	3.1E−2

[a]50-year dose commitments from one year of intake of radionuclides.
[b]Read as 2.1×10^{-5}.
[c]Daily intake assumed to be 23 m^3 of air.
[d]Daily intake assumed to be 0.3 kg of beef and 0.25 of vegetables.

Table 6.9. Annual doses[a] to the population from airborne effluents of the solution mining facilities

Organ	Population dose (man-rems)	
	Project effluents	Natural background
Total body[b]	5.76E −3[c]	2.42E3
Lung[d]	1.39	1.51E4
Bone	4.31E−2	2.96E3

[a]Based on 1970 population of 1.68×10^4 persons.
[b]Total-body dose from normal background from all sources for the State of Wyoming is 144 millirems per year (D. T. Oakley, *Natural Radiation Exposure in the United States*, ORP/SID 72-1, USEPA, 1972).
[c]Read as 5.76×10^{-3}.
[d]Dose to lung includes dose to bronchial epithelium from Rn-222 daughters. With normal background conditions continuous exposure to the mean concentration (500–1000 pCi/m^3) of Rn-222 in the air would deliver a dose of 500 to 1000 millirems per year to the broncnial epithelium (National Academy of Science – National Research Council, *The Effects on Populations of Exposures to Low Levels of Ionizing Radiation, Report of the Advisory Committee on the Biological Effects of Ionizing Radiation, (BEIR)*, U.S. Government Printing Office, 1972.

6.8 SOCIOECONOMIC IMPACTS

The proposed project will require 60 employees during operation (ER, p. 184). Approximately 40 of these individuals are WMC employees working at the pilot-scale test facilities on the Irigaray site. Most of these employees currently reside in Buffalo. The 20 additional employees could result in an increase of 70 residents (3.5 persons per household) in the town of Buffalo. This small increase in population should be readily accommodated by the town of Buffalo. Therefore, no significant impact on the community is anticipated.

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7. ENVIRONMENTAL EFFECTS OF ACCIDENTS

Accidents in the operation of the Irigaray project can be minimized through (1) the proper design, manufacture, and operation of the process equipment, (2) adherence to adopted solution mining and radiation safety procedures, and (3) incorporation of a quality assurance program designed to establish and maintain safe operations in accordance with NRC Regulatory Guide 3.5. The NRC will maintain surveillance over the facility and its individual safety systems by conducting periodic inspections and by requiring reports of effluent releases and deviations from normal operations.

Accidents involving the release of radioactive materials or harmful chemicals have occurred in operations similar to those proposed by the applicant. Therefore, in this assessment, accidents that might occur during operation have been postulated and their potential environmental impacts evaluated.

Solution mining of uranium is currently developing. Operating experience is limited, thus restricting the application of probabilities of occurrence for most types of accidents. Where adequate information for realistic evaluations was unavailable, conservative assumptions were used to assess environmental impacts resulting from accidents. Thus the environmental effects of such accidents may be less than the potential effects determined by this assessment.

7.1 SURFACE ACCIDENTS

7.1.1 Surface pipe failures

The bulk of the piping at the Irigaray site will be surface piping to permit ready detection and repair of leaks. Polyvinyl chloride (PVC) and rubber piping will be used extensively to minimize corrosion and costs. This, however, introduces problems of low impact strength at freezing temperatures and gradual deterioration due to weathering. Pipe failures could result from vehicle and personnel movement near the pipelines and from freezing of the pipe.

7.1.1.1 Causes of leaks

In places, well field access roads will parallel or cross the main trunk pipelines. At crossings, a suitable pipeline casing protection will be provided. Vehicles may inadvertently slide off the road during icy or muddy conditions and hit the pipeline. Also, on passing another vehicle at a crossing, a vehicle may drive over the pipeline. Within the well field, vehicles and personnel may inadvertently break smaller injection or production lines.

During winter, temperatures at the Irigaray site will fall well below freezing. The salts in the lixiviant are too dilute to significantly lower the solution's freezing point. The applicant contends that freezing will be prevented by operating at relatively high flow velocities in the pipelines. However, the addition of thermal insulation to increase pipeline reliability during cold weather may be incorporated if needed.

Flow interruption in cold weather may result in the freezing and possible cracking of lines. Occasionally leaks can be expected in normal operations as a result of defective materials, construction practice, chemical degradation, vibration, or stress. The applicant will be required to document pipe breaks that result in any significant release to the surface. A report describing the nature of the event and corrective actions taken will be made available for review by NRC inspectors.

7.1.1.2 Estimated releases

Breaks in trunk lines will be detected by low-flow and low-pressure alarms installed by the applicant, probably limiting such spills to a worst-case loss of 12,000 gal (complete drawdown on a surge tank). Since the barren lixiviant solution grossly resembles irrigation water containing ammonia fertilizer (ER, p. 161), the immediate chemical effect of such a spill would be small. However, with the pregnant lixiviant containing 150 ppm U_3O_8 and 370 pCi/liter of radium-226, a 12,000-gal spill would release approximately 4,550 μCi of uranium and 16.8 μCi of radium-226 to a localized area. The area affected by such an event would be readily identified and decontaminated.

Leaks in production or injection well field lines would generally be smaller. However, should an unobserved leak develop in a line from a production well operating at 10 gpm, up to 2 hr (the period between flowmeter readings) may pass before the leak is detected. A total of 1,200 gal containing 455 μCi of uranium and 1.68 μCi of radium-226 could thereby be released to the surface of the well field. It, too, would be readily identified and decontaminated, resulting in an insignificant environmental impact.

7.1.2 Failure of chemical storage tanks

At the Irigaray project, chemical storage facilities will be maintained both inside and around the plant building and in the well field area. Leaks from tanks within the plant building will be collected by the building sump and pumped to an appropriate receiving tank.

External tanks will be of two types: (1) pressurized gas storage tanks and (2) liquid storage tanks. Pressurized gases such as ammonia, propane, and carbon dioxide are used in the plant. Leaks in ammonia tanks may present a short-term toxic hazard to personnel at the facility. Carbon dioxide leaks would present no apparent hazard. Both ammonia and propane tank leaks could result in the occurrence of an explosion and fire (Sect. 7.1.3).

Liquid storage tanks will contain concentrated hydrochloric acid, hydrogen peroxide, production and injection surge fluids, gasoline, and diesel fuel. Fiberglass, stainless steel, and carbon steel tanks will be used to store the appropriate fluids (Sect. 4.4.2). All external storage tanks will be diked or bermed to contain a mimimum of twice the specific tank's capacity. If a leak or rupture occurred in a liquid storage tank, readily accessible shutoff valves would be closed and pumps turned off to prevent additional fluid loss. The failure would be repaired and the affected area cleaned up. Storage liquid releases to the environment would be insignificant.

7.1.3 Explosions and fire

Explosion(s) and/or fires at the Irigaray plant would be unlikely due to the limited use of combustible materials in the operations. The bulk of the plant construction and equipment is made of metal, fiberglass, polyvinyl chloride, or concrete. Fire sources would be limited to waste receptacles, electrical equipment, and fuel storage tanks. An adequate supply of properly serviced and appropriate portable fire extinguishers will be maintained at the site at all times. Personnel will be adequately trained in fire prevention and fire fighting techniques to limit and confine any fire that might occur. All electrical equipment will be properly wired and grounded in accordance with the National Electric Safety Code (ANSI C2). Diesel fuel and gasoline storage tanks will be properly labeled ("No Smoking," etc.) and will be diked or bermed.

Hydrogen peroxide storage tanks will be designed with pressure release vents to prevent the buildup of pressure within the vessels should unexpected oxidation occur (excessive heat, combustible material in contact with contents, etc.). The only other potential explosive sources on the site would be the ammonia and propane gas storage tanks, maintained in the open. Should either of these types of tank rupture releasing their contents, the concentrations in the vicinity of the tanks would not remain within the explosive limits of the respective gases (16 – 27% in air for ammonia and 2 – 10% in air for propane), due to their rapid dispersion. The environmental impacts from such occurrences are expected to be insignificant.

7.2 SUBSURFACE ACCIDENTS

7.2.1 Waste pond leakage

The description, size, and location of waste ponds are discussed in Sect. 4.6. The volume of liquid waste seeping into the ground through a ripped or corroded polyethylene liner would depend on the area exposed to infiltration and the time elapsed until repairs are made. Such leaks will be detected by a monthly monitoring program. Upon detection, liquid wastes from the leaking pond will be pumped to adjacent ponds, and the damaged plastic liner will be repaired. As a worst case, all four liquid waste ponds could develop leaks, and seepage into the ground could occur for one month without detection. As the liquid waste infiltrates into the ground, the variable lithologies below the pond will very slowly disperse the liquid waste, thereby limiting its mobility to a localized area around the ponds.

The effect of seepage will be mitigated by several factors: (1) The seepage will be passing through soils containing clays. Such clays (especially montmorillonite clay) have a cation exchange capacity of about 100 milliequivalents per 100 g of clay.[1] The clays will absorb radium, ammonium ion, and other toxic compounds contained in the seeped liquid. (2) The seepage would have to traverse several hundred yards to reach Willow Creek. The dispersion of the seepage over this distance will aid in the absorption of toxic elements by the soil materials. The result of these effects is to reduce the volume and later the composition of the wastes, so that the impact on Willow Creek would be insignificant.

7.2.2 Failure of well casing

A casing failure in a production or recovery well could permit injected leach solution or the uranium-rich leach solution to escape into units overlying the Upper Irigaray sandstone. The applicant reports that there is no water above the Upper Irigaray sandstone, except for a perched water table in the Willow Creek area. Therefore most leakage resulting from a failed well casing would seep into dry strata. The leakage would migrate down dip until it seeped from an outcrop or infiltrated a perched aquifer.

The applicant states that such failures would usually occur during the initial operation of a newly completed well due to improper completion. Close monitoring of injection flow and pressure will allow early detection of such a leak.

During normal operations, injection well pressure and flow rate will be monitored every 2 hours. Marked increases in flow rate at constant pressure would indicate a leak. Under such conditions the leakage rate would equal the flow rate increase over the normal value for the well. If the incremental changes are small, the leak might not be detected until lixiviant showed up at the shallow monitor well.

In the case of early leak detection, relatively small volumes of solution (1,000-10,000 gal) would be involved. Detection by a shallow monitor well would indicate a large spill. No practical method exists for reclaiming the dry strata contaminated by such a leak. However, the overall effect of such a leak would be small and comparable to a waste pond leak (see Sect. 7.2.1).

7.2.3 Well field excursions

Well field excursions are considered as potentially normal events during operation. As such, they have been discussed in Sect. 6.3.2.2. Considering the degree of monitoring and/or corrective actions that will be implemented to mitigate such events, the staff has concluded that such occurrences would result in minimal environmental impacts.

7.3 TRANSPORTATION ACCIDENTS

Transportation of materials to and from the Irigaray site can be categorized under three headings: (1) shipments of yellow cake from the plant to a uranium hexafluoride conversion facility, (2) shipments of process chemicals (nonradioactive) from suppliers to the project, and (3) shipments of naturally radioactive solid wastes from the site to existing tailings ponds or a licensed solid waste repository.

7.3.1 Shipments of yellow cake

The applicant proposes to ship the yellow cake product by truck to a uranium hexaflouride conversion plant. Refined yellow cake product is generally packaged in 0.208-m^3 (55-gal), 18-gauge drums holding an average of 364 kg (800 lb) and classified by the Department of Transportation (DOT) as type A packaging (49 CFR Parts 171-189 and 10 CFR Part 71). It is shipped by truck an average of 2200 km (1370 miles) to a conversion plant, which transforms the yellow cake to uranium hexafluoride for the enrichment step of the light water-cooled reactor fuel cycle. An average truck shipment contains approximately 45 drums, or 16 metric tons (17.5 tons) of yellow cake. Based upon an annual production of 227,000 kg (500,000 lb) of yellow cake, approximately 15 such shipments will be required annually.

From published accident statistics,[2-5] the probability of a truck accident is in the range of 1.0×10^{-6} to 1.6×10^{-6} per kilometer (1.6×10^{-6} to 2.6×10^{-6} per mile). Truck accident statistics include three categories of traffic accidents: collisions, noncollisions, and other events. Collisions involve interactions of the transport vehicle with other objects, whether moving vehicles or fixed objects. Noncollisions are accidents in which the transport vehicle leaves the transport path or deviates from normal operation in some way, such as by rolling over on its top and side. Accidents classified as other events include personal injuries suffered on the vehicle, records of persons falling from or being thrown against a standing vehicle, cases of stolen vehicles, and fires occurring on a standing vehicle. The likelihood of a truck shipment of yellow cake from the Irigaray site being involved in an accident of any type during a one-year period is approximately 0.03 to 0.05.

The ability of the materials and structures in the shipping package to resist the combined physical forces arising from impact, puncture, crush, vibration, and fire depends on the magnitude of the forces. These magnitudes vary with the severity of the accident, as does the frequency with which they occur. A generalized evaluation of accident risks by NRC classifies accidents into eight categories, depending upon the combined stresses of impact, puncture, crush, and fire. On the basis of this classification scheme, conditional probabilities (i.e., given an accident, the probabilities that the accident is of a certain magnitude) of the occurrence of the eight accident severities were developed. These fractional probabilities of occurrence for truck accidents are given in Column 2 of Table 7.1. In order to assess the risk of a transportation accident, it is necessary to know the fraction of radioactive material that is released when involved in an accident of a given severity. Two models are postulated for this analysis, and the fractional releases for each model are shown in Columns 3 and 4 of Table 7.1. Model I assumes complete loss of the drum contents; Model II, based upon actual tests, assumes partial loss of the drum contents. The packaging is assumed to be type A drums containing low specific activity (LSA) radioactive materials. Considering the fractional occurrence and the release fraction (loss) for Model I and Model II, the expected fractional release in any given accident is approximately 0.45 and 0.03 respectively.

Table 7.1. Fractional probabilities of occurrence and corresponding package release fractions for each of the release models for LSA and type A containers involved in truck accidents

Accident severity category	Fractional occurrence of accident	Model I	Model II
I	0.55	0	0
II	0.36	1.0	0.01
III	0.07	1.0	0.1
IV	0.016	1.0	1.0
V	0.0028	1.0	1.0
VI	0.0011	1.0	1.0
VII	8.5E-5	1.0	1.0
VIII	1.5E-5	1.0	1.0

Source: U.S. Nuclear Regulatory Commission, *Final Environmental Statement on the Transportation of Radioactive Materials by Air and Other Models*, Report NUREG-0170, Office of Standards Development, February 1977 (draft).

For Model I and Model II, the quantity of yellow cake releases to the atmosphere in the event of a truck accident is estimated to be roughly 7400 kg (16,200 lb) and 500 kg (1100 lb) respectively. Most of the yellow cake released from the container would be deposited directly on the ground in the immediate vicinity of the accident. Some fraction of the released material, however, would be dispersed to the atmosphere. Expressions for the dispersal of similar material to the environment based on actual laboratory and field measurements over several years have been developed.[3] The following empirical expression was derived for the dispersal of the material to the environment via the air following an accident involving a release from the container:

$$f = 0.001 + 4.6 \times 10^{-4} \, [1 - \exp(-0.15ut)]u^{1.78} \, ,$$

where

f = the fractional airborne release,

u = the wind speed at 15.2 m (50 ft) expressed in m/sec ,

t = the duration of the release, in hours .

In this expression, the first term represents the initial "puff" immediately airborne when the container is failed in an accident. Assuming that the wind speed is 5 m/sec (10 mph) and that 24 hr are available for the release, the environmental release fraction is estimated to be 9×10^{-3}. Assuming insoluble uranium, all particles of which are in the respirable size range, and a population density of 160 people per square mile characteristic of the eastern United States,[6] the consequences of a truck accident involving a shipment of yellow cake from the mill would be a 50-year dose commitment to the general population of approximately 13 and 0.9 man-rems to the lungs for Models I and II respectively.

A recent accident (September 1977) involving a commercial carrier, carrying 50 steel drums of uranium concentrate, overturned and spilled an estimated 6800 kg (15,000 lb) of concentrate on the ground and in the truck trailer. Approximately 3 hr after the accident, the material was covered with plastic to prevent further release to the atmosphere. Using the above formula and values of wind speed for a fractional airborne release for this 3-hr duration of release, approximately 56 kg (123 lb) of U_3O_8 would be released to the atmosphere. The consequence of this accident would be a 50-year dose commitment to the general population of 11 man-rems for a population density of 160 people per square mile. The consequences for the accident area where the population density is estimated to be 2.13 people per square mile would be a 50-year dose commitment of 0.146 man-rem. This dosage can be compared to a 50-year integrated lung dose of 19 man-rems from natural background.

The applicant has committed to submit to the NRC an emergency action plan for yellow cake transportation accidents. This emergency action plan is intended to assure that personnel, equipment, and materials are available to contain and decontaminate the accident area. Submittal of this plan will be a license condition.

7.3.2 Shipments of chemicals to the site

Truck shipments of anhydrous ammonia to the Irigaray site, if involved in a severe accident, could conceivably result in an environmental impact. Approximately 36 shipments of anhydrous ammonia will be made annually in 5,000-gal tank trucks from Cheyenne, Wyoming, a distance of approximately 250 miles from the site.

The annual amount of anhydrous ammonia shipped in that form is approximately 7,600,000 tons. About 26% of the ammonia produced is shipped by truck. Assuming that the average truck shipment is 21 tons, approximately 93,000 truck shipments of anhydrous ammonia are made annually. From Department of Transportation accident data, there are about 140 accidents per year involving truck shipments of anhydrous ammonia.[7] For an estimated average shipping distance of 250 miles, the resulting accident frequency is roughly 4.3×10^{-6} per mile. According to DOT data, an average release of 1,700 lb of ammonia resulted from approximately 80% of the reported incidents. Injury to the general public occurred in roughly 15% of the reported incidents involving a release. The injured were mainly the drivers (17 persons).

The probability of an injury to the general public resulting from an accident involving an average shipment of anhydrous ammonia is roughly 4.8×10^{-7} per mile (3×10^{-7} per kilometer). This is an overestimate for shipments in the Powder River Basin, which has a very low population density. Accepting this estimate, the likelihood of an injury to the general public from shipments of ammonia to the proposed site would be about 5×10^{-3} per year.

7.3.3 Shipment of naturally radioactive solid wastes

Low-level naturally radioactive solid wastes generated during the applicant's solution mining operations will be transported by truck to a licensed tailings pond (Sect. 4.6.4). Because of the low radioactive concentration involved, these shipments are considered to have minimum potential for significant effects as a result of transportation accidents. The applicant's emergency action plan (Sect. 7.3.1) can be initiated should unusual circumstances occur.

REFERENCES FOR SECTION 7

1. R. E. Grim, *Clay Mineralogy*, McGraw-Hill, New York, 1953, pp. 126-159.
2. USAEC, Directorate of Regulatory Standards, *Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Plants*, Report WASH-1846, Washington, D.C., December 1972.
3. Battelle Northwest Laboratories, *An Assessment of the Risk of Transporting Plutonium Oxide and Liquid Plutonium Nitrate by Truck*, Report BNWL-1846, Richland, Wash., August 1975.
4. R. K. Clarke et al., *Severity of Transportation Accidents*, Report SLA-74-0001, Sandia Laboratory, Albuquerque, N. Mex., 4 vols., unpublished.
5. J. L. Russell, "An Evaluation of Risk Models for Radioactive Material Shipments," in *Proceedings of the 4th International Symposium on Packaging and Transportation of Radioactive Materials, September 22-27, 1974, Miami Beach, Florida,* Report CONF-740901, 1974.
6. U.S. Bureau of the Census, *Statistical Abstract of the United States; 1976*, 97th ed., U.S. Government Printing Office, Washington, D.C., 1976.
7. Unpublished incident reports, 1971-1975, Office of Hazardous Materials, Department of Transportation.

The applicant has also determined the radioactivity in the ore zone aquifer where solution mining will be conducted. The aquifer contained 63 ± 8 pCi/liter of radium-226, 3.4 ± 1.2 pCi/liter of thorium-230, and about 4 mg/liter of natural uranium. This water exceeds the drinking water standard of 5 pCi/liter for radium.[1] Measurements in the same aquifer formation outside the mineralized zone showed values reduced by more than an order of magnitude.

Recent water samples from the Powder River obtained by the State of Wyoming Department of Environmental Quality and analyzed for radium-226 by U.S. EPA Region VIII in Denver are shown in Table 8.2. They indicate that radium-226 concentrations in the Powder River may be lower than the levels measured by the applicant, which are shown in Table 2.8. Variations may be due to the time of sampling, analytical techniques employed, and/or sampling techniques used.

Table 8.2. Radium-226 concentrations in the Powder River

Station	Location	Radium 226 (pCi/liter)
PR-1	Powder River upstream from Willow Creek	0.20
PR-2	Powder River downstream from Willow Creek	0.25
PR-3	Powder River at Interstate 90 bridge	0.36
PR-4	Powder River at Arvada	0.48
PR-5	Powder River north of Arvada	0.45

Samples collected by D. Harp, Wyoming DEQ, June 7-8, 1977.

Willow Creek, an intermittent stream on the site, was not sampled. No discharges to surface waters are planned by the applicant during project operations.

8.1.5 Staff recommendations

An effective monitoring program should be initiated with preoperational monitoring and continue throughout the operational and postoperational phases of a project. The locations of sampling points and the data obtained during preoperational monitoring or surveys must be sufficient to characterize the existing environment. Operational (and postoperational) monitoring should indicate any changes from preoperational values and initiate measures to reduce or mitigate environmental impacts. On this basis, some aspects of the applicant's preoperational monitoring for the proposed operation are deficient, and the staff makes the following recommendations.

8.1.5.1 Surface water baseline

WMC's preoperational monitoring of surface waters consisted of chemical analyses at two stations on the Powder River; the results are summarized in Table 2.8. These data, however, do not adequately define baseline water quality conditions in the Powder River. The NRC staff recommends that WMC pursue as soon as possible an expanded baseline survey of surface water quality near its facilities. In addition to the two stations already established, WMC should sample at a third station located farther downstream from the Irigaray Ranch. Currently, WMC's "downstream" station is located at the Irigaray Ranch. As discussed in Sect. 6, if a lixiviant excursion occurred, the direction of groundwater flow might bring the excursion to the Powder River somewhere near the Irigaray Ranch. Later sampling at this station might not fully reveal contamination of surface waters. Thus a sampling point farther downstream is necessary. The water quality of the Powder River should be sampled once each quarter for one year. The water quality in Willow Creek should be sampled during the period of spring flow. Constituents and characteristics that should be sampled for are listed in Table 8.3. In presenting the results, the dates of sampling, analytical techniques, and numbers of samples taken should be specified.

8. MONITORING PROGRAMS AND OTHER MITIGATING MEASURES

8.1 PREOPERATIONAL SURVEYS

This section discusses the surveys conducted by the applicant to document the preoperation characteristics of the site environment.

8.1.1 Hydrological surveys

The applicant conducted one-time sampling in the Powder River at two locations (see Sect. 2.6.1). No sampling was done for Willow Creek.

Groundwater sampling by the applicant was initiated for private wells in the area in 1974 (see Sect. 2.6.2.4). Onsite groundwater sampling has been conducted in association with the development of the two pilot-scale test operations (see Sect. 2.6.2.4).

8.1.2 Meteorological survey

An onsite weather station was established by the applicant in September 1975 to record temperature, precipitation, relative humidity, and wind speed and direction. Insufficient time has elapsed to collect a representative data base (minimum of five years of record).

8.1.3 Ecological surveys

A baseline ecological study was conducted for the applicant on T44N, R77W, just south of the Irigaray lease area, from late November 1974 to mid-April 1975 (Appendix C). The study consisted of transect trapping for rodents and visual counts of other terrestrial vertebrate species. Vegetation studies consisted of determination of vegetative cover by stratified sampling in three 10-ha plots. The study did not include sampling of aquatic habitats.

8.1.4 Radiological surveys

The applicant collected samples of soils and vegetation from the immediate site environment in November 1976. The results of the subsequent analyses for radioactivity and selected radionuclides are given in Table 8.1.

Table 8.1. Radiological baselines for soil and vegetation as provided by the applicant

Sample[a]	Gross alpha (pCi/g)	Gross beta (pCi/g)	Ra-226 (pCi/g)	U_3O_8 (%)	Air dry loss (%)	Ash 550°C (%)
			Soil			
IRSI-1	4.8 ± 3.8	46 ± 15	1.0 ± 1.5	<0.0003	<0.4	
IRSI-2	24 ± 8	19 ± 16	0.6 ± 1.2	<0.0003	<0.1	
			Vegetation			
IRV-1	1.3 ± 2.6	18 ± 14	0.34 ± 0.47	<0.0001	<2	34
IRV-2	1.9 ± 2.8	43 ± 15	0.46 ± 0.63	<0.0001	<4	42

[a] IRSI-1, soil sample taken just off dirt road adjacent to test site well field, IRSI-2, soil sample taken approximately 50 yd northeast of center of production plant construction site, IRV-1, vegetation taken as IRSI-1 above, IRV-2, vegetation taken as IRSI-2 above.

Table 8.3. Physical and chemical parameters for baseline survey of surface water and groundwater[a]

Ammonia (as NH_4)	Gross alpha and beta	Potassium
Arsenic	Hardness (as $CaCO_3$)	Radium 226
Barium	Iron	Selenium
Bicarbonate (HCO_3)	Lead	Silica
Boron	Magnesium	Silver
Cadmium	Manganese	Sodium
Calcium	Mercury	Sulfate
Carbonate (as CO_3)	Molybdenum	Total dissolved solids
Chloride	Nickel	Thorium 230
Chromium, hexavalent	Nitrate (NO_3)	Vanadium
Conductivity	Nitrite (NO_2)	Uranium (U_3O_8)
Copper	pH	Zinc
Fluoride		

[a]*Discharge should be determined for surface water, water level should be determined for groundwater.*

8.1.5.2 Groundwater baseline

The establishment of groundwater baseline is a prerequisite for both the groundwater monitoring program and identification of restoration requirements for a uranium in situ leaching operation. Therefore, considerable importance is placed on the establishment of a baseline which thoroughly characterizes the site premining groundwater environment. This objective can be attained only when detailed information is available on the hydrogeologic environment at the site (see Sect. 8.2.3.1).

The staff recommends that baseline determination for the proposed mining units should be conducted initially as follows:

Sample points

Sample points will consist of monitor wells and wells located within the proposed well field. Each monitor well, including shallow and deep monitor wells, should be sampled for baseline determination. A minimum of one well per each 0.8 ha (2 acres) of well field should be sampled to determine the initial baseline in well fields (mining zone). These wells should be randomly distributed within the planned production unit, and the sampled wells should be identified for future reference. In addition to the establishment of baseline, sample wells in the well field area will be used during restoration verification and monitor wells will be used during operational monitoring.

Sampling frequency

For the initial production units, sampling should include a minimum of three water samples from each monitoring and designated production unit well. These samples should be obtained at intervals of no less than two weeks.

Sample parameters

A list of parameters for analysis during baseline determination is shown in Table 8.3. As a basis for verification of restoration, the applicant should provide a quality control procedure for the sampling and analytical methods to be used during all phases of the project. To ensure that a representative sample of formation water is obtained, it is recommended that at least one bore hole volume be withdrawn before sampling. Furthermore, the sample for laboratory analysis should not be drawn until the electrical conductivity of the well water has stabilized. Proof of stabilization may be defined as no significant change in electrical conductivity for three successively drawn preliminary samples. During operation, selected parameters will be analyzed as part of the operational monitoring program (see Sect. 8.2.3.4).

Baseline sampling and analysis will establish the chemistry of groundwater and provide the necessary values to determine the quality of the groundwater. As discussed in Sect. 5.1, available groundwater chemistry data from the Irigaray site indicate the presence of two distinct areas. Groundwater within the mineralized portion of the host aquifer is generally unfit for consumption because of high concentrations of natural radioactivity and possibly other toxic elements (e.g., arsenic and selenium). In nonmineralized areas of the host aquifer, groundwater is generally of a quality that is suitable for either domestic or livestock use. The staff also recognized that the values obtained during baseline establishment are subject to considerable variation as a result of sampling procedures, analytical methods, and the natural variability of the groundwater both spatially and temporally. However, as the proposed limited operation develops, additional hydrogeologic data will become available. This data will be made available to the appropriate agencies, and refinements to the groundwater baseline program can be made within the hydrogeologic framework of the specific site.

8.2 OPERATIONAL MONITORING

8.2.1 Waste pond monitoring

Under mining and restoration plans, all liquid and solid waste streams will be contained in lined solar evaporation ponds. These ponds will be monitored monthly to detect leaks (Sect. 4.6.2).

8.2.2 Radiological monitoring

Solution mining eliminates the radioactive tailings that are generated in conventional uranium mining and milling operations. To produce 500,000 lb of yellow cake from 0.15% uranium ore by usual mining and milling methods would generate about 170,000 dry tons of radioactive waste.[2] The same production from a solution mining operation is expected to produce about 1% as much waste (see Sect. 4.6.3). The wastes from solution mining operations will be stored in evaporation ponds for later transfer to an active mill and tailings pond (Sect. 4.6.4).

The radiological monitoring program shown in Table 8.4 is considered adequate in view of the relatively low releases. In addition, the applicant will be requested to develop a sampling program that will enable better estimates of radon released from well field surge tanks. These will be license conditions.

Table 8.4. Minimum radiological monitoring program

Environmental element	Sampling location	Sampling frequency	Type of measurement
Air	Yellow cake dryer stack	Continuous (weekly analysis)	Natural uranium
Surface water	Surface impoundments	Quarterly	Uranium, Ra-226, Th-230
Sediment	Surface impoundments and affected drainage	Quarterly	Uranium, Ra-226, Th-230
Air	In enclosed buildings	Monthly	Rn-222 or radon daughters, uranium
Air	Air quality monitoring sites	24-hr sampling at monthly intervals	Particulates, Ra-226, Rn-222, Th-230, uranium
Soils	At the air quality monitoring sites	Annually	Uranium, Ra-226, Th-230, Pb-210

In addition the water quality in the ore zone aquifer will be monitored as discussed in Sect. 8.2.3.

8.2.3 Well field monitoring

Well field monitoring procedures will define an area of containment for leachate injected during the mining operation. Well field monitoring will be the surveillance technique for initiating corrective actions in the event of leachate migration. It will be effected through the use of monitor wells and may be supplemented by trend wells installed by the applicant for production control purposes.

8.2.3.1 Monitor wells

Monitor well location involves both surface spacing and subsurface placement in order to effectively determine the containment of the leach solution. On the surface, wells will be spaced around the perimeter of the well field so that any migrating leach solution (excursion) will be detected. Subsurface emplacement involves the location of monitor wells in the aquifers above and below the production zone aquifer. The locations of monitor wells should be optimized to assure that the injected leach solution is effectively confined to the production zone.

The applicant proposes to place monitor wells no closer than 400 ft from the limit of mineralization and no further than 1,000 ft from the well field (ER, p. 141). The State of Wyoming desires that monitor wells should not be located more than 200 ft from the perimeter of the production area (well field).[3]

Monitor wells must effectively act as a control to contain the leach solution within the production zone to minimize environmental impact. To accomplish effective containment, a number of factors must be considered in the surface spacing of monitor wells. These include the following:

1. Site geological and hydrological variations must be evaluated, including (a) local variations in groundwater flow rates and direction, (b) local variations in permeability or zones of significant hydraulic conductivity, and (C) presence of subsurface geologic features (channels, clay lenses, facies changes, etc.).

2. Monitor wells should be spaced so that their respective zones of influence overlap.

3. Monitor wells should be located at a distance from the well field so as not to intercept normal operating fluid flows: (a) the zone of influence during monitor well sampling must be considered, and (b) sufficient distance should be available so that trend wells can be installed for normal operational controls.

The State of Wyoming's monitor well location requirement will be adhered to by the applicant until further site-specific data have been developed and evaluated.

8.2.3.2 Trend wells

Trend wells may be drilled within the monitor well ring at the operator's discretion. These wells would be for production control and will not necessarily be analyzed for the same parameters as required for monitor wells. Changes in the water quality of samples from trend wells would not signal the need for corrective action by the operator. Rather, they would initiate a production evaluation by the operator to determine the cause of this occurrence. Appropriate adjustment action by the operator would then take place. The staff believes that the use of trend wells by an operator will reduce the potential for leach solution to migrate to a monitor well. Therefore, their use is recommended but not required.

8.2.3.3 Shallow and deep monitor wells

These wells will be installed to permit monitoring of the aquifer or dry formation immediately above or below the confining mudstone or shale that overlies or underlies the mineralized formation. These wells shall be placed within the well field area, and a minimum of one shallow and one deep monitor well for each 2 ha (5 acres) of well field should be required.

8.2.3.4 Monitor well sampling

Monitor wells will be sampled every two weeks during project operations. The staff believes that the monitoring parameters should reflect both operational and environmental (public health and safety) considerations. For the proposed Irigaray project, the following parameters should be monitored in the groundwater: (1) ammonia, (2) arsenic, (3) bicarbonate, (4) chloride, (5) selenium, (6) uranium, (7) pH, (8) total dissolved solids (and/or conductivity), and (9) water level.

8.2.3.5 Upper control limit

An upper control limit (UCL) shall be used to indicate a deviation in groundwater chemistry from the baseline concentrations. This deviation would indicate that migration (excursion) of lixiviant may be occurring and would initiate the appropriate corrective action(s). Ammonia, arsenic, chloride, selenium, and uranium will be present in the ore zone groundwater (leach solution) in concentrations usually much higher than the baseline values. In the event of an excursion, these concentrations would be diluted and dispersed as the leach solution flows through the aquifer. As a result of dispersion, small quantities of leach chemicals will arrive at the trend and/or monitor wells in advance of the main body of leach solution. The staff recommends that upper control limits should be set low enough to be sensitive to such lead indications. In addition, the UCL for each parameter at a monitor well should approximate the concentration consistent with the potential use of the groundwater. Therefore, the UCL for the various parameters should be the maximum concentration observed at each monitor well as determined during baseline sampling. A UCL will be established for each parameter listed in Sect. 8.2.3.4 for each monitor well.

8.2.3.6 Corrective actions

A corrective action procedure will ensure the containment of the leach solution. For maximum effectiveness, the corrective action requires consideration of a number of factors including (1) spacing of monitor wells (Sect. 8.2.3.1), (2) relative mobilities of the various contaminants, (3) uniform measurement and reporting procedures, and (4) response measures consistent with the detected release.

The mobility of contaminant ions in the aquifer will be a function of the ion solubility, local groundwater chemistry, and absorbing materials such as clay. As a result, during an excursion, some contaminant species might lag behind, such that only one or two parameters would exceed the UCL. Therefore the staff recommends that an alert mode be initiated when only one nontoxic parameter (e.g., chloride or bicarbonate) exceeds the UCL. The alert mode would involve (1) a verification of the initial analysis by taking a second sample and (2) an evaluation of possible sources by the operator. Another complete sample will be obtained within seven days of the verifying sample. If the nontoxic constituent (chloride or bicarbonate) exceeds the UCL, sampling and analysis will continue every seven days until the cause is determined. If the assays exceed the UCL for ammonia, arsenic, selenium, or uranium, corrective action shall be initiated to reduce the parameter value(s) to levels below the UCL.

If an excursion is verified, the plant supervisor will have several alternative methods for containing and correcting the migration of leach solution. The principal corrective action procedures are overpumping, reordering the pumping balance of the well field, reducing or stopping injection, ceasing both injection and recovery pumping, injecting a solution of reduced concentrations, establishing a water fence, or the beginning of restoration procedures. These methods may be applied locally to a few wells within a cell, to the entire cell, to several cells, or to the entire well field as the situation dictates. Current methods are as follows:

1. Overpumping. This method involves adjusting pumping so that the rate of flow into the injection wells is exceeded by the flow from the recovery wells. The net result is a general inward movement of native water.

2. Reordering. This is a variation of overpumping in that different ratios are applied to different areas in the well field. Hence the inward movement of native water may be emphasized at one point or another. Reordering may further include direct pumping from one part of the field to another.

3. Reducing injection. This is the second way to adjust the ratio of recovery flow to injection flow. At the same time it reduces the amount of leach solution introduced into the production zone in the vicinity of the wells concerned.

4. Ceasing pumping. This method stops both the injection and recovery flows. Exclusive of the effects of natural forces (e.g., natural migration of groundwater), which are orders of magnitude less, this should arrest the further migration of leach solution beyond the established boundaries.

5. Beginning restoration. This step can be utilized when all other efforts have failed to halt the migration of leach solution beyond the farthest allowable limits.

As part of the corrective action procedure, the operator will be required, by the drilling of a detection well(s), to locate the extent of migration beyond the monitor well. The detection well(s) will be sampled during corrective action to verify that the excursion is being controlled and/or corrected.

The applicant will be required to report in writing to the NRC within 30 days after an excursion has been detected. The report will describe the corrective action taken and an evaluation of the results achieved. If corrective action is continuing at the time of the report, a subsequent report shall be filed that describes and evaluates the final results. (Depending on the nature of the event, the NRC may require periodic reporting on the status of the corrective action.) The applicant will also notify the appropriate Wyoming State agency in accord with their requirements.

8.2.3.7 Postrestoration monitoring

After completion of restoration of the first production unit, the applicant will be required to conduct a postrestoration monitoring program. This program will be used to evaluate the effectiveness of the proposed restoration plan. The staff recommends the following: a minimum of two wells to establish baseline in the mining zone, a minimum of two monitor wells in the direction of maximum hydraulic conductivity, and a minimum of two trend wells (if used) to form the basis for postrestoration monitoring. If trend wells are not used, then at least two wells should be drilled between the well field and monitor well for this purpose. These wells should be sampled quarterly to evaluate restoration effectiveness.

Using the results of the experimental plans for the 517 test area discussed in Sect. 6.3.2.2 as a basis, the applicant will provide a postrestoration monitoring program prior to the beginning of restoration. This monitoring will be required as a license condition.

8.2.3.8 Postmining monitoring

The staff recommends that at least one monitor well per production unit, and a shallow and a deep monitor well from a production unit, be made available for monitoring use throughout the life of the Irigaray project. Annual sampling and analysis should be conducted on each of the wells.

8.2.3.9 Record keeping and reporting

All officially transmitted monitor well records will be prepared at the WMC office in Denver and returned to the Irigaray site for reporting requirements and site cumulative records. Required reporting will be to both the State of Wyoming and NRC unless otherwise specified.

8.2.4 Ecological monitoring

The WMC's plans for hydrological monitoring and erosion control measures should prevent the release of sediments or other constituents harmful to biota. No ecological monitoring of aquatic environments should be necessary during operation of WMC's facility. However, if significant releases of sediments or other constituents occur, WMC should undertake an ecological survey of Willow Creek or the Powder River in order to assess the extent of any damage to biota.

REFERENCES FOR SECTION 8

1. U.S. Environmental Protection Agency, *"National Interim Primary Drinking Water Regulations,"* as amended by 41 FR 28402, July 1976.

2. M. B. Sears et al., *Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing "as Low as Practicable" Guides — Milling of Uranium Ores*, Report ORNL/TM-4903, vol. 1, May 1975, p. 135.

3. Wyoming Department of Environmental Quality, Land Quality Division, "In Situ Mining Application — Supportive Information Handout," Mar. 18, 1977, pp. 5-6.

9. UNAVOIDABLE ADVERSE ENVIRONMENTAL IMPACTS

9.1 AIR QUALITY

The unavoidable impacts of solution mining activities upon the air quality in the area will be minimal. Some increase in suspended particulates from vehicular traffic on roads will occur, but the resulting impact upon the air quality will be minor. The anticipated small chemical emissions from the recovery facility and evaporation ponds will have a negligible impact on the air quality of the area.

9.2 LAND USE

There will be a temporary change in land use of about 24 ha (60 acres) from livestock grazing to mineral extraction during the limited project operations as proposed by the staff (Sect. 5.1.5). Ranchers will be inconvenienced by changes in land-use patterns.

The project area is presently of low potential for intensive recreation use and development, and no unique scenic or natural features are present. There are no existing recreation facilities within the project area. For these reasons, it is considered unlikely that any unavoidable adverse environmental impacts will occur, except some possible loss of hunting opportunities.

If archaeological sites exist, they may be damaged or destroyed during project activities, and possibly more losses will occur due to increased human activity in the vicinity of the project site.

9.3 WATER

9.3.1 Surface water

Some local deterioration of water quality may occur, although no surface discharges are planned during project operations. Additionally, removal of protective vegetative cover and other soil disturbance will cause increased sedimentation during development and mining activities.

9.3.2 Groundwater

Approximately 1.2×10^6 m^3 (1000 acre-ft) of groundwater will be permanently removed from the aquifer, mostly during restoration activities. Some project-induced degradation of groundwater quality may occur. This loss will be in addition to localized naturally contaminated groundwater.

9.4 MINERAL RESOURCES

No unavoidable adverse effects on mineral resources are expected, other than the extraction of the uranium. In addition to the environmental effects of solution mining of uranium discussed herein, other subsequent and related impacts will occur, the kind and intensity of such impacts being dependent on disposition of the refined ore. Assuming that the uranium will be used to fuel steam-electric systems, the environmental effects associated with the production of uranium hexafluoride, isotopic enrichment, fuel fabrication, reprocessing of irradiated fuel, transport of radioactive materials, and management of radioactive wastes are relevant to the proposed project. The nature of these environmental effects is presented within the scope of the AEC report entitled "Environmental Survey of the Uranium Fuel Cycle" and in NUREG-0116 "Supp. 1 to WASH-1248," October 1976.[1]

9.5 SOILS

The alteration of near-surface soil characteristics which have developed over long periods of geologic time cannot be avoided. Disturbance of soils may lower the natural soil productivity to some degree because of soil compaction and accelerated erosion.

Soil disturbance on the 24 ha (60 acres) used for the recovery process building site, evaporation ponds, and well fields cannot be avoided. The soil disturbance will not be severe, since only a few inches of soil material will be affected. A total of 400 ha (1000 acres) may be disturbed over the life of the project.

9.6 ECOLOGICAL

9.6.1 Terrestrial

Vegetation on approximately 400 ha (1000 acres) may be disturbed over the life of the project; about 24 ha (60 acres) will be disturbed during the limited operation proposed by the staff. Plant species composition and diversity will be altered due to the disruption of the natural vegetation and subsequent revegetation.

Loss of habitat for most wildlife populations will occur as a result of project operations. Habitat removal is expected to be temporary.

The evaporation ponds may contain radioactive and other contaminants that will, to some extent, harm all forms of wildlife that may come in contact with them.

9.6.2 Aquatic

Some minor impact on the aquatic system is expected. This impact will primarily result from increased sedimentation caused by well field operations.

9.7 RADIOLOGICAL

Radioactive emissions from excavated ore will not result from solution mining. The local environment will continue to be shielded by earth materials overlying the radioactive ore deposits. However, some small increase in the level of radioactivity is expected from emissions from the recovery plant and well field facilities.

9.8 SOCIOECONOMIC

No unavoidable adverse socioeconomic impacts on the local community are expected.

REFERENCE FOR SECTION 9

1. "Environmental Survey of the Uranium Fuel Cycle," U.S. Atomic Energy Commission, Directorate of Licensing, Fuels, and Materials, WASH-1248, April 1974 and Supp. to WASH-1248, October 1976.

10. RELATIONSHIP BETWEEN SHORT-TERM USES OF THE ENVIRONMENT AND LONG-TERM PRODUCTIVITY

10.1 THE ENVIRONMENT

10.1.1 Surface elements

The short-term increases in suspended particulates and chemical emissions associated with project activities are expected to have no effect upon the long-term quality of the atmosphere in the project area.

Project operations will cause a short-term reduction in carrying capacity of the local grazing resource and some reduction in hunting opportunities.

Well field development will result in not over 20 ha (50 acres) of vegetative cover lost during the limited operation proposed by the staff (Sect. 5.1.4).

Waste ponds, pipelines, access roads, and plant buildings will occupy only a small portion [2 to 4 ha (5 to 10 acres)] of the site.

Proposed monitoring and mitigating measures will assure that minimal short-term effects from project operations will occur.

After reclamation there should be no long-term effects on surface productivity.

10.1.2 Underground effects

The extraction of uranium (short-term usage) will not preclude extracting other minerals of current or future economic importance at a later date.

The short-term extraction of groundwater at up to 1.2×10^6 m^3 (1000 acre-ft) during the limited operation, mostly during well field restoration, should not adversely affect other users of the aquifer.

Restoration of the mined aquifer region to the available level of use prior to mining has not yet been completely demonstrated. Restoration techniques are under test. If unsuccessful, the mined aquifer region (mining zone) would be unavailable for irrigation or stock water wells. This zone is currently contaminated due to natural radioactivity. With the addition of contaminants from solution mining, however, this would represent a long-term impact for about 20 ha (50 acres) of aquifer area.

10.2 SOCIETY

No significant short-term or long-term impacts on the local communities can be expected from this project, since it will not be a large factor in the local economy.

11. IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

11.1 LAND AND MINERAL RESOURCES

After reclamation, no land resources are considered lost, although a different grouping of flora and fauna will probably occur.

The uranium produced is irreversibly and irretrievably lost when used to produce power from a nuclear reactor.

11.2 WATER AND AIR RESOURCES

Water used in the project, primarily during aquifer restoration, is recycled to the atmosphere for distribution elsewhere. The aquifer will eventually become recharged from natural sources. Air is self-cleaning of pollutants at the low concentrations expected. The displacement of these resources is small in comparison with the benefits derived from the mined uranium.

11.3 VEGETATION AND WILDLIFE

These resources are renewable, and while some irreversible and irretrievable commitment is required, it is relatively small. Reclamation will require a commitment of human and financial resources for an undetermined period of time.

11.4 MATERIAL RESOURCES

Irreversible and irretrievable commitments of construction materials will be made for well completions, plant buildings, and other activities.

Chemicals and reagents used during solution mining will also not be recoverable for reuse. The fuels used for vehicles, heating, and plant processing will also be irretrievably committed.

These materials are not in short supply and are common to many industrial processes.

12. ALTERNATIVES

12.1 MINING ALTERNATIVES

Selection of a mining technique to recover a mineral resource is based upon several complex and interrelated factors, including (1) the spatial characteristics of the deposit (size, shape, and depth), (2) the physical (or mechanical) properties of the mineral deposit and surrounding geological structure, (3) groundwater and surface water conditions, (4) economic factors, including ore, grade, comparative mining costs, and desired production rates, and (5) environmental factors, such as preservation and reclamation of the environment and the prevention of air and water pollution. The two most commonly used methods for mining uranium deposits are open-pit (surface mining) and underground mining. Other mining methods, such as solution mining (in situ leaching and bore hole), are currently in the developmental stage.

12.1.1 Open-pit mining

Open-pit mining is used for relatively shallow ore deposits. A pit is created when the overburden and topsoil overlying the ore body are removed to permit mining of the ore. The overburden and topsoil are stored and stabilized to meet future reclamation requirements. The mining depth is determined by economic factors: the point where the cost of mining a ton of ore is equal to the market value plus profit. To recover the uranium, the extracted ore must be processed in a mill (Sect. 12.2).

Although the applicant has initially decided to use in situ leaching methods to mine the ore, the eventual use of open-pit mining has not been precluded. As additional data are gathered during the development drilling that precedes solution mining activities, the applicant will be evaluating the economic viability of using other mining methods, such as open-pit mining, for ore extraction.[1] The decision to use alternative mining methods will be dependent on encountered ore grade and thickness, geological configurations, and other relevant decision parameters. Applications will be submitted to appropriate licensing authorities for necessary approval if any decisions are made to implement alternative mining methods.[1]

The environmental impacts associated with uranium open-pit mining operations are well documented.[2-4] For example, the Bear Creek open-pit mining and milling project located in the Powder River Basin has a comparable U_3O_8 production rate and will disturb about 650 ha (1600 acres) of surface area, with up to 1000 gpm (2000 acre-ft per year) of local groundwater being removed during pit dewatering for approximately 15 years.[3] Long-term impacts are primarily associated with changes in topography resulting from overburden dumps and pits which remain after mining operations are completed. Since conventional milling methods must be used to process the ore, measures to alleviate the short-term and long-term environmental impacts associated with the disposal of mill tailings must be determined and evaluated. Because greater numbers of mill and mine personnel would be needed for a conventional milling/open-pit mining operation (compared to solution mining), more significant socioeconomic impacts would occur. Open-pit mining (as shown by the Bear Creek example) would disturb a much larger surface area and completely alter the underlying geologic material. Additionally, the proximity of the ore deposits to the Powder River could result in more significant impacts to the river from open-pit mining and milling activities.

Many alternatives exist for the reclamation of uranium surface mines. Generally, overburden and topsoil are stored in dumps during mining, with the overburden being used to refill the pit (perhaps partially) and the surface being shaped to a rolling topography with slopes ranging from 0 to 30°. Salvaged topsoil is then distributed over the contoured surface. The restored surfaces are revegetated with plant species, using the necessary fertilizers and soil amendments to ensure plant growth. Precautions are taken to stabilize the soil against erosion and to provide watershed protection.

12.1.2 Underground mining

Underground mining is the method generally used for deeper, relatively high-grade ore deposits in structurally stable host rock. Basically, a vertical mine shaft is constructed to the depth of the ore body, with horizontal tunnels being utilized to remove the ore. Air shafts ventilate the mine, and extensive dewatering facilities are usually required. After mining operations have ceased, the equipment and buildings at the mine shaft and the mining equipment are removed. Air shafts and the mine shaft are sealed (probably with concrete), covered with topsoil, with the area being revegetated with appropriate plant species to stabilize the soil.

The applicant has rejected the underground mining alternative due to geologic conditions and economic factors (ER, p. 190). The relatively low-grade ore and the nature of the host sandstone rock at the Irigaray site make this alternative impractical for the present. To recover the uranium, the ore must be mill-processed (Sect. 12.2).

12.1.3 Solution mining (in situ leaching)

A general discussion of solution mining (in situ leaching) is presented in Sect. 3, while specific details of the applicant's proposed activities are addressed in other sections of this Statement. As noted throughout this document, in situ leaching is a developing technology and considerable variation exists from one operation to another.[6]

In situ leaching is a relatively new technique for uranium extraction on a commercial scale, with both operational and environmental considerations being very site specific. The disposal of waste solutions and/or contamination of the aquifers represent the major areas of environmental risk which must be examined carefully.

Uranium deposits which are small, isolated, and unsuitable for mining by other methods may be recovered by in situ leaching under the following general conditions:

1. The ore is generally horizontal and is confined by impervious layers such as shales, siltstones, or mudstones.
2. The ore is in a saturated stratum below the static water table.
3. The ore body must possess suitable mineralogic and hydraulic properties, that is, adequate permeability and amenability to chemical leaching.
4. A maximum recovery of the acidic or alkaline leach solution is possible. A primary impact of concern involves the possibility of incomplete recovery of the leachate.

The applicant conducted pilot-scale testing on the Irigaray deposit to ascertain the feasibility of uranium recovery by solution mining, concluding that, initially, utilization of in situ leaching was the most suitable mining alternative. However, according to the applicant, the mining plan is a "living plan"; that is, the plan will change as changes in environmental, economic, or regulatory circumstances are altered.[1] Initially, the applicant proposes a solution mining facility utilizing an ammonium bicarbonate and hydrogen peroxide lixiviant. As pointed out in Sect. 12.1.1, the applicant may later use open-pit mining techniques.

12.1.3.1 Alternative leach solutions

Both alkaline and acidic leach solutions may be used in uranium in situ leaching operations depending on formation constituents. An acidic lixiviant generally results in higher concentrations of mobilized constituents, such as selenium, arsenic, vanadium, and molybdenum, which may be present in the ore. The use of an alkaline leach solution may result in a lower uranium recovery rate than if the acidic lixiviant is used; however, lower mobilized concentrations of other ore constituents would result. Additionally, alkaline lixiviants are favorable for ore deposits having high carbonate content; such ores will neutralize substantial quantities of an acid lixiviant, increasing operating costs.

The applicant has determined that an alkaline leach solution is the better lixiviant for extracting uranium from the Irigaray ore deposits (ER, p. 107). An alkaline lixiviant could include a sodium, magnesium, calcium, or ammonium carbonate/bicarbonate solution as the mobilizing reagent in the presence of an oxidant (hydrogen peroxide). Because test results indicate that ammonium bicarbonate is suitable as a mobilizing compound, the applicant will utilize an ammonium bicarbonate and hydrogen peroxide lixiviant. However, as is the case for alternative mining methods, changes in the environmental, economic, and regulatory climate may require changes within the solution mining alternative. The applicant has indicated that it may apply for permission to change lixiviant chemistry within the first two-year period of operations.[1]

12.1.3.2 Comparison of impacts of in situ leaching of uranium with underground and open-pit methods

Impacts associated with in situ leaching of uranium are generally less severe than the impacts associated with conventional open-pit and underground uranium mining. Environmental advantages of the in situ leaching method include the following:

1. minimal surface disturbance,
2. less solid wastes, no mill tailings,
3. less air pollution compared with conventional uranium mining and milling,
4. minimal surface subsidence from in situ leaching,
5. possible restoration of the mine site to an "unrestricted use" status within a relatively short time, providing that the solid wastes are removed from the site or are otherwise restricted from contaminating the surface and subsurface environment, and
6. smaller radiological releases than in conventional mining and milling, particularly the release of radon-222.

Socioeconomic advantages of in situ leaching include the following:

1. ability to mine a lower grade of ore,
2. a minimum capital investment,
3. less risk to the miner,
4. short lead time before production begins, and
5. lower manpower requirements.

The primary disadvantage of in situ leaching of uranium is groundwater contamination, which however, does not imply that conventional uranium mining necessarily has an advantage in regard to groundwater pollution. On the contrary, in situ leaching may prove to have a less severe impact on groundwater than does conventional mining. Nevertheless, excursions of leach solution from the well field aquifer have the potential to enter surface waters and to contaminate nearby well water. To confine the leach solution and mobilized ore zone elements to the well field aquifer, the operator must maintain a proper balance between injection and production. In the event of an excursion, monitor wells must be adequately spaced and screened to detect the advancing contaminant plume. These wells can be properly placed only if the hydrologic characteristics of the aquifer are adequately known. If an excursion is detected, the operator has the choice of implementing one or more methods to reduce its impact on the groundwater, such as stopping the entire operation and then pumping all wells. Some of the contaminants, however, will invariably escape the influence of the pumping wells and will travel in the direction of the groundwater flow. This impact is unavoidable and in most cases negligible, considering the potential for most aquifers to attenuate contaminants as they move away from the source.

12.2 MILL PROCESSES REQUIRED FOR AN ALTERNATIVE OPEN-PIT OR UNDERGROUND MINE

There are eight main steps in the milling of uranium ore from open-pit or underground mines. They are (1) crushing of ore (primary), (2) grinding of ore (secondary), (3) production of water-ore slurry (sometimes combined with grinding), (4) leaching of ore, (5) separation of leach liquor from tailings (waste), (6) concentration and purification of leach liquor, (7) precipitation of uranium from leach liquor, (8) drying and calcining of precipitate to form U_3O_8.

The manner in which these steps are accomplished is ore- and site-specific. Decisions are based on process economics plus the costs of controlling chemical and radiological effluents to water, air, and land.

Crushing and grinding prepare run-of-mine ore for slurry formation and reduce the overall particle size so that efficient contact is made with the reagent that dissolves the uranium.

Leaching reagents are dependent on ore characteristics. Basic ores are leached with bicarbonate-carbonate solutions, while acid ores are leached with sulfuric acid. In each case an oxidant is added to the leach liquid.

The separation of the leach liquor (which contains over 90% of the uranium in the ore) from the undissolved waste (tailings) can be accomplished by thickening, filtration, settling, or countercurrent decantation.

The leach liquor is then concentrated and purified using ion exchange resins or solvent extraction.

The final step in the process is precipitation of the uranium from acid solution by the addition of ammonia or hydrogen peroxide. The precipitate is then filtered, washed, dried, and calcined to U_3O_8.

The solution mining project proposed by the applicant avoids steps 1 through 3 by leaching the ore in situ. In addition, no tailings are generated, and the gross quantity of solid waste expected in solution mining is about 1% of that remaining from the above alternatives.

12.3 ALTERNATIVE METHODS FOR WASTE MANAGEMENT

12.3.1 Introduction

For the purposes of this section, waste management is defined as the disposition of the solids and waste leach solutions following extraction (separation) of the uranium-bearing solutions and aquifer restoration activities. Engineering techniques to control pollutants from waste storage during both operational and postoperational stages of a conventional uranium milling project have been demonstrated. Such techniques are applicable to the control of liquid and solid wastes produced by a solution mining (in situ leaching) project. Because no tailings are generated by the in situ leaching process, the surface area required for storage of wastes would be significantly less than the area needed for the retention of tailings generated by processing the same ore by conventional mining and milling. In addition, waste disposal methods technically or economically infeasible for large-scale tailings facilities may be viable for the smaller quantities of wastes produced by in situ leaching. The method chosen for the control of solution mining wastes must match the unique characteristics of each facility and minimize potential environmental effects. The staff has examined alternatives considered by the applicant in preparing this section. Alternatives presently available or feasible (i.e., potentially available with existing technology and within legal constraints) are described in Sect. 12.3.2 and evaluated in Sect. 12.3.3.

Each alternative waste management plan has been evaluated against the following set of performance objectives developed by the staff and designed to ensure that potential public health hazards that otherwise could occur in the operation of the project are avoided or minimized. These criteria have been established for conventional uranium mill tailings disposal methods and are applied, where appropriate, to the methods proposed for this project.

Siting and design

1. Locate the waste isolation area remote from people so that population exposures would be reduced to the maximum extent reasonably achievable.

2. Locate the waste isolation area so that disruption and dispersion by natural forces is eliminated or reduced to the maximum extent reasonably achievable.

3. Design the isolation area so that the seepage of toxic materials into the groundwater system would be eliminated or reduced to the maximum extent reasonably achievable.

During operations

4. Eliminate the blowing of solid wastes to unrestricted areas during normal operating conditions.

Postreclamation

5. Reduce direct gamma radiation from the impoundment area to essentially background.

6. Reduce the radon emanation rate from the impoundment area to about twice the emanation rate in the surrounding environs.

7. Eliminate the need for an ongoing monitoring and maintenance program following successful reclamation.

8. Provide surety arrangements to assure that sufficient funds are available to complete the full reclamation plan.

12.3.2 Viable alternatives

Alternative 1: Onsite disposal using calcite settling pond and chemical waste evaporation ponds (ponds lined with plastic membrane)

This alternative consists of constructing above-grade calcite and liquid waste impoundments to the immediate northeast and southwest of the main plant building. The waste ponds will be constructed in square or rectangular basins excavated in relatively flat areas. To minimize seepage, the ponds will be lined with a 30-mil (0.08-cm) impermeable polyethylene liner. Leaks in the liner will be detected through the collection of seepage by a gravel bed and drain pipe system constructed beneath the pond. During operation, solids in the ponds will be stabilized against dusting by the maintenance of a liquid seal over the solids.

Long-term stabilization for each pond would be accomplished by applying a cover of clayey soil and topsoil which will be sufficiently thick to reduce gamma radiation levels to background and radon diffusion to twice background levels. The radium-226 concentration in the waste solids will be the most significant factor in the cover thickness. Therefore, the necessary cover thickness will vary from pond to pond according to radium content. The cover would be sufficiently impermeable to restrict the percolation of rainwater through the solids.

This alternative offers adequate isolation of radioactive and toxic wastes during operation and disposal. The use of a polyethylene pond liner, if installed and maintained properly, would eliminate the possibility of adverse impacts caused by seepage during operation. Long-term loss of pond liner integrity would not greatly affect the leaching of wastes, because the slightly permeable clayey soil cover would minimize groundwater percolation through the wastes.

Disadvantages of this alternative would be the loss of the waste impoundment areas from general land usage and the necessity of monitoring the impoundment for erosion and/or loss of vegetative cover.

Alternative 2: Onsite disposal using calcite settling pond and chemical waste evaporation ponds (ponds unlined)

This alternative is similar to Alternative 1 except there is no pond liner provided. Because the quantity of slimy solids relative to liquid waste volumes is small, no sealing of the pond bottom is expected. The ensuing seepage of chemical wastes and radionuclides for this alternative would be unacceptable.

Alternative 3: Onsite disposal with solidification of solid wastes

This alternative is similar to Alternative 1, except that, prior to application of the soil cover, the solids are stabilized in cement or asphalt. The major advantages of solidification are (1) leaching resistance is increased, (2) in asphalt-fixed solids, radon release is reduced, and (3) wind erosion is eliminated. However, as in Alternative 1, restricted land use and monitoring would be necessary.

Alternative 4: Temporary storage of solid wastes in calcite storage pond and chemical wastes evaporation pond with transport of solid wastes to an active uranium mill tailings impoundment

This alternative utilizes the plastic-lined ponds described in Alternative 1 for disposal of liquid wastes (by evaporation) and temporary storage of solids wastes. However, rather than stabilizing the solids for disposal onsite, all radioactive and/or toxic solid wastes will be removed to an active uranium mill tailings impoundment for disposal. The applicant would enter into a contractual agreement with the owner of the active uranium mill tailings impoundment for the disposal of these wastes. Calcite wastes containing higher than background concentrations of radium would be periodically removed from the calcite settling pond. Other solid chemical wastes will be removed when either the solid waste inventory approaches the holding capacity of the evaporation ponds or when reclamation procedures begin. Reclamation would consist of removing solid wastes, pond liners, and soils contaminated by radionuclides and/or process chemicals to the licensed tailings impoundment, followed by grading the temporary pond area to its natural contour, application of a topsoil cover, and revegetation with native plant species and suitable grasses approved by the Wyoming Department of Environmental Quality.

The advantage of this alternative is the safe disposal of both liquid and solid wastes so that there is no permanent land requirement for a disposal area. This benefit will become especially apparent in the later stages of project development, when the main recovery facility is moved or satellite facilities constructed. Such relocation would require construction of additional calcite settling ponds and solar evaporation ponds at the new sites. Should stabilization and onsite disposal be permitted, the net result would be proliferation of small solid waste impoundments within the project area. Such dispersed disposal would incur increased monitoring requirements, larger total land requirements, and greater risk of radionuclide and toxic material release. Removal of such materials to an active uranium mill tailings pond would eliminate such problems. Transfer of the relatively minor amounts of solids to an active tailings pond will have an insignificant impact on the environmental effects of the mill tailings facility. Disadvantages center on the increased cost of solids handling, the cost of the disposal agreement, and the risk of dispersion of the waste during transportation.

12.3.3 Evaluation of alternatives

Alternatives 1, 3, and 4 utilize waste ponds constructed with impermeable polyethylene liners. With the maintenance of a liquid seal over deposited solids and the continued monitoring of the ponds for leakage (Sect. 8.2.1), these alternatives offer adequate isolation of liquid and solid wastes during the operational phase of the project. The unlined ponds proposed in Alternative 2 would allow uncontrolled seepage of chemicals and radionuclides and are therefore unacceptable.

Alternatives 1 and 3 offer adequate stabilization of waste solids and reduction of gamma exposure and radon release to acceptable levels. However, these onsite disposal alternatives would require permanent land use restrictions on the waste impoundment areas and would require continued monitoring against erosion and loss of protective plant cover. The indicated future mode of project operation (i.e., relocation of main uranium recovery plant and/or construction of satellite uranium recovery facilities) would require construction of waste impoundment areas at additional sites. The resulting proliferation of waste impoundment areas would be undesirable.

Alternative 4 is the applicant's proposed waste management plan. Under this plan, radioactive and toxic wastes would be removed from the site to an active uranium mill tailings pond for disposal. The quantity of waste would be small relative to the tailings produced by the conventional mill [less than 10 metric tons (11 tons) per day (3000-4000 tons/year) for the proposed in situ facility (Sect. 4.6.3) compared to more than 910 metric tons (1000 tons) per day for a conventional mill]. The staff feels that the disposal of such relatively small quantities of process wastes would not significantly affect the safety or storage capacity of a conventional mill tailings pond. Stabilization of the disposed wastes would be accomplished according to the NRC license and State permit conditions applying to the uranium mill receiving the wastes.

Waste impoundment areas on the Irigaray project site would be reclaimed by grading the impoundment to its original contour, followed by application of topsoil and revegetating the area. Because no hazardous wastes would be present, there would be no restrictions against deep-rooted native plant species. The staff recommends that a diverse selection of native species should be used to provide long-term stability of the reclaimed land and to ensure its future value as a wildlife habitat (Sect. 5.2.2). The result of such actions would be the return of all disturbed lands to their original usage. Therefore, there would be no restrictions on future human usage.

Alternative 4 would incur additional solids handling, transportation, and disposal costs and risks associated with the transport of the wastes. However, due to the limited number of shipments, the mild chemical nature of the wastes, and the low population densities along roads from the project to potential disposal sites, the risks are minimal.

12.4 ALTERNATIVE ENERGY SOURCES

12.4.1 Fossil and nuclear fuels

The use of uranium to fuel reactors for generating electric power is relatively new historically. Coal was the first fuel used in quantity for electrical power generation. Coal use was reduced because of the ready availability and low price of oil and natural gas, which are cleaner-burning than coal and easier to use. Uranium fuel is even cleaner (chemically) than oil or gas and at present is less expensive, on a thermal basis, than all other fuels used to generate electric power. The following discussion concerns the relative availability of fuels for power generation over the next 10 to 15 years, since availability will be the key factor in the choice of fuel to be used.

Table 12.1 shows the disparity between availability and usage of energy resources in the United States. Although these data are for 1974 (final figures for 1975 are not yet available), estimates for 1975 indicate little difference. Gas usage in 1975 decreased slightly (about 1%); oil, coal, and nuclear usage increased slightly.

Table 12.1. Reserves and current consumption of energy sources

	Percent of proven U.S. energy reserves economically recoverable with existing technology (1974)	Percent of total U.S. energy consumption contributed by each energy resource (1974)
Coal	90	18
Oil	3	46
Gas	4	30
Nuclear	3	2
Other	0	4

Source: "National Energy Outlook," Federal Energy Administration, February 1976.

In 1975, the United States consumed about 71 q of energy (1 q = 10^{15} Btu); of this total, 20 q consisted of electric energy. An estimated 8.6% of this electric energy was generated using nuclear fuels, but within ten years the percentage is expected to increase to 26%.

Coal was used for producing 59% of the electric energy generated by combustion of fossil fuel in 1975; the percentages for oil and gas were 20 and 21, respectively. Use of oil and gas to generate electric power has decreased about 10% over the last three years, a reflection of high oil prices and gas unavailability.

Current and projected requirements for electric energy (1975-1985) and relative changes in resources used for generation, as estimated in "Project Independence," are shown in Table 12.2. All information available to date indicates that coal and uranium must be used to generate an increasing share of future U.S. energy needs, because of decreasing supplies of oil and gas available for electric power generation. The United States does not have sufficient oil and gas reserves to ensure a long-run supply, but coal and uranium resources are adequate for foreseeable needs. Currently rising prices for oil and gas are a reflection of increasing competition for these two resources, which will be severely depleted in the next few decades.

Expanding industrial capacity for increasing coal production to meet projected requirements must occur in the next decade (total requirement is 1040 million tons in 1985 vs 603 million tons in 1974). The major expansion of coal production will likely be in the West (from 92 million tons in 1974 to 380 millions tons in 1985) because of the low sulfur (low air pollutant) content of most Western coals. The potential for environmental damage (due to disturbance of generally fragile ecosystems) in the western United States will be increased. Since the major markets for the coal produced are located hundreds of miles from the mines, transportation costs will be high, as will the environmental impacts associated with transportation systems. Transportation costs for bringing Western coal to the eastern United States currently account for the major portion of the market price.

Table 12.2. Estimated relative changes in resources to be used for generation of projected energy requirements

Fuel resource used	Percent of thermal energy required in year:			
	1970[a]	1974[b]	1980[b]	1985
Coal	45	45	45	46[c]
Oil and gas	38	34	25	16
Nuclear	2	4[d]	17	26
Hydro, waste, etc.	15	17	13	12
Total q's of energy required	15.6	20	25.5	34

[a]Actual.

[b]Estimated ("National Energy Outlook," Federal Energy Administration, February 1976.

[c]Coal usage must increase 77% by 1985 to attain this level.

[d]Uranium-fueled reactors furnished 9.9% of the total U.S. production in January 1976.

Source: "Project Independence," Federal Energy Administration, November 1974.

For a given thermal content, transport facilities for U_3O_8 are minimal compared with those for coal because of the much higher energy content of uranium fuel. Approximately 250 tons of U_3O_8 per year are required for a 1000-MW nuclear plant operating at a plant factor of 80%. Annual Western coal requirements for an equivalent 1000-MW coal plant would be more than 3 million tons, or the load capacity of at least one unit train (100 cars of 100 tons each) per day of plant operation.

The evidence available at this time indicates that, of the resources currently used in electric power generating stations (coal, uranium, oil, gas, and hydro), only coal and uranium have the potential for increasing long-range reliability in domestic energy production. Because of the time lag between initial extraction and the consumption of the resource for energy production (3-5 years from mine to generation plant for uranium and coal, 5-7 years for construction of a coal generating plant, and 7-10 years for construction of a nuclear generating plant), the exploitation of both coal and uranium resources must be integrated with contemporary energy needs. Neither the coal nor uranium producing industries are considered capable of singly supporting the energy requirements projected over the next few decades; major expansion of both industries will be required to fill projected needs.

The determination of availability of uranium in large enough quantities to fuel the projected nuclear generating capacity (for 1985) is currently a matter of study.[7] Results of those studies are given below.

Estimates presented in the "National Energy Outlook"[8] indicate that 140,000 to 150,000 MWe of nuclear generating capacity will be needed to supply 26% of the total electrical energy used in 1985. The first "Project Independence" report[9] indicated that nuclear capacity could increase to more than 200,000 MWe by 1985. A more recent and lower estimate resulted from lower projections of electricity demand, financial problems experienced by utilities, uncertainty about government policy, and continued siting and licensing problems. The more recent projections of uranium requirements are given in Table 12.3.

Table 12.3. Uranium requirements

MWe operating by 1985	Lifetime U_3O_8 requirements (tons)	
	At P.F. of 0.8[a]	At P.F. of 0.6
142,000	960,000	704,000

[a]P.F. = plant factor, or capacity factor.

Source: "National Energy Outlook," Federal Energy Administration, February 1976.

Known reserves of uranium (as U_3O_8), as of January 1976, were an estimated 640,000 tons, as compared with 600,000 tons estimated in January 1975.[7] These reserves could be mined and milled at a cost of $30 per pound of U_3O_8 produced. The price of U_3O_8 in April of 1976 was $40 per pound for delivery in 1976 and $48 per pound for delivery in 1980.

ERDA has estimated total U.S. uranium resources as shown in Table 12.4.[7] The total of all variously known categories of uranium resources is equivalent to 3,560,000 tons of U_3O_8. Reserves are in known deposits; drilling and sampling have established the existence of these deposits beyond reasonable doubt. Probable resources have not been drilled and sampled as extensively as reserves. The speculative and possible resource categories have been estimated by inference from geologic evidence and limited sampling.

Table 12.4. United States uranium resources

Cost (dollars per pound of U_3O_8)	Tons U_3O_8			
	Reserves	Resources		
		Probable	Possible	Speculative
$30	640,000	1,060,000	1,270,000	590,000

Source: "Mineral Resources and the Environment," Supplementary Report: "Reserves and Resources of Uranium in the U.S.," National Academy of Sciences, 1975.

Historically, resources of uncertain potential have become established reserves at an average rate of 7% per year since 1955.[7] If this rate were to persist over the next decade, total reserves would exceed requirements (1,250,000 tons of reserves vs a maximum 960,000 tons required for lifetime nuclear generating capacity rated at 142,000 MWe) by about 300,000 tons. Assuming no transfer of possible resources into the probable category, probable resources would still contain 450,000 tons.

12.4.2 Solar, geothermal, and synthetic fuels

Estimates reported in the "National Energy Outlook"[8] indicate that solar and geothermal sources will each supply about 1% of U.S. energy requirements by 1985 and about 2% by 1990. Supplies of synthetic gas and oil derived from coal will probably not exceed 1% of U.S. energy requirements as of year 1990. These projections are based on many considerations. The technology exists in all cases, but not in a proven, commercially viable manner. The potential for proving these technologies on a commercial scale is great, but timely development will require a favorable market as well as governmental incentives. A maximum of 6% of projected 1990 energy requirements is expected to be derived from solar, geothermal, and synthetic fuel resources combined.

12.4.3 By-product uranium

Uranium reserves recoverable as a by-product of phosphate fertilizer and copper production are expected to increase from 90,000 tons (U_3O_8) in 1974 to 140,000 tons in 1976. These reserves are in addition to the 640,000 tons available from conventional mining and milling sources.

Quoting from ref. 7 (p. 106):

> Like all byproducts commodities, byproduct uranium is entirely dependent upon production of the primary commodity, is limited in amount by the level of production of the primary commodity, and is unresponsive to the demand for uranium. Byproduct uranium could be obtained from the mining of phosphate, copper, and lignite.
>
> Much phosphate is treated with sulfuric acid to produce fertilizer and goes through a phosphoric acid step. Uranium in the phosphate can be recovered from the phosphoric acid. . . .It has been estimated that about 2,500 ST U_3O_8 per year could be recovered from Florida phosphate mined for fertilizer. The Bureau of Mines studied the sulfuric acid leaching of flow grade dumps at 14 porphyry copper mines and concluded that about 750 ST U_3O_8 per year could be recovered. This would be recovered from rocks whose uranium content ranges from 1 to 12 ppm.

It was al.. thought that other porphyry copper deposits might also be possible sources of by-product uranium.

> This possible byproduct uranium totals 3,250 ST U_3O_8 per year which is only slightly less than the initial annual production planned for the Rossing deposit in South West Africa.
>
> Another source of byproduct uranium could be mine-mouth electric generating plants that burn uranium-bearing lignite as fuel. The uranium is concentrated in the ash. Some lignite contains as much as 0.30 percent U_3O_8. Bieniewski estimates that about 1500 ST of U_3O_8 is contained in about 500,000 ST of high grade lignite. More recently reserves in lignite were estimated to be less than 5,000 ST of U_3O_8 and resources to be about 50,000 ST. Low-Btu lignites seem to be richest in uranium. Good-quality coals usually contain less than 0.001 percent U_3O_8. If lignite is burned at too high a temperature, the uranium enters the ash in a form that is not easily leachable and for which an economic recovery system has not yet been developed.

12.4.4 Energy conservation

The NRC staff has examined available information concerning the potential reduction in energy usage that could be achieved by 1985 and concludes that incremental savings in *total* energy consumption could be achieved in all major consumption sectors: residential, commercial, industrial, and transportation. Actions which improve the thermal efficiency of automobiles, homes, and office buildings would have the greatest conserving effect. However, in the case of electrical energy, demand is expected to increase (during the next decade) at a rate about twice as great as that for total energy.[8] It will be more difficult to conserve electrical energy since it will probably be a viable alternative for oil and gas use in residential

REFERENCES FOR SECTION 12

1. Karl R. Schendel, Wyoming Mineral Corporation, attachment to letter to L. C. Rouse, Nuclear Regulatory Commission, March 20, 1978, Docket No. 40-8502.

2. U.S. Environmental Protection Agency, *State-of-the-Art: Uranium Mining, Milling, and Refining Industry*, Report EPA-660/2-74-038, U.S. Government Printing Office, Washington, D.C., June 1974.

3. U.S. Nuclear Regulatory Commission, *Final Environmental Statement Related to Operation of Bear Creek Project*, Docket No. 40-8452, NUREG-0129, June 1977.

4. U.S. Nuclear Regulatory Commission, *Draft Environmental Statement Related to the Minerals Exploration Company's Sweetwater Uranium Project, Sweetwater County, Wyoming*, Docket No. 40-8584, NUREG-0403, December 1977.

5. U.S. Atomic Energy Commission, *Environmental Survey of the Uranium Fuel Cycle*, Report WASH-1284, U.S. Government Printing Office, Washington, D.C., April 1974.

6. William C. Larson, *The State of the Art of In Situ Leach Mining, FY 77*, prepared by Twin Cities Mining Research Center for the United States Department of the Interior, Bureau of Mines.

7. "Mineral Resources and the Environment," Supplementary Report: "Reserves and Resources of Uranium in the U.S.," National Academy of Sciences, 1975.

8. "National Energy Outlook," Federal Energy Administration, February 1975.

9. "Project Independence," Federal Energy Administration, November 1974.

13. NRC BENEFIT-COST SUMMARY FOR THE IRIGARAY PROJECT

13.1 GENERAL

The general need for uranium is subsumed in the operation of nuclear power reactors. In reactor licensing evaluations the benefits of the energy produced are weighed against related environmental costs, including a prorated share of the environmental costs of the uranium fuel cycle. These incremental impacts in the fuel cycle are justified in terms of the benefits of energy generation. However, it is appropriate to review the specific site-related benefits and costs of an individual fuel-cycle facility such as the Irigaray project.

13.2 QUANTIFIABLE ECONOMIC IMPACTS

Monetary benefits accrue to the community from the presence of the project, such as local expenditures of operating funds and the state and local taxes paid by the project. Against these monetary benefits are monetary costs to the communities involved, such as those for new or expanded schools and other community services. It is not possible to arrive at an exact numerical balance between these benefits and costs for any one community unit, or for the project, because of the ability of the community and possibly the project to alter the benefits and costs. For example, the community can use various taxing powers to redress any perceived imbalance in favor of the project. The project, on the other hand, may create larger revenues through increased product price to redress any imbalance it suffers through direct or indirect taxation.

13.3 THE BENEFIT-COST SUMMARY

The benefit-cost summary for a fuel cycle facility such as the Irigaray project involves comparing the societal benefit of an assured U_3O_8 supply (ultimately providing energy) against local environmental costs for which there is no directly related compensation. For the project, these uncompensated environmental costs are basically three: groundwater impact, radiological impact, and disturbance of the land. The radiological impacts of the project are small, and eventually radioactive wastes will be disposed of offsite (Sect. 4.6.4). The disturbance of the land is also a small environmental impact. All of the disturbed land will be reclaimed after the project is decommissioned and will become available for other uses. Complete reclamation of an aquifer contaminated by a commercial-scale project has not yet been demonstrated although the staff considers that, in view of the applicant's pilot-scale demonstration, such reclamation is feasible. The benefit of the production up to 1.1×10^6 kg (2.5×10^6 lb) of U_3O_8 is considered to offset the risk that the groundwater quality underlying the 20-ha (50-acre) mining zone will not be completely restorable. Moreover, development and demonstration of an acceptable restoration technique is an integral part of the project (Sect. 5.1.4).

13.4 STAFF ASSESSMENT

The staff concludes that the adverse environmental impacts and costs are such that the use of the mitigative measures suggested by the applicant and the regulatory agencies involved would reduce the short- and long-term adverse impacts associated with the project to acceptable levels.

In considering the energy value of the U_3O_8 produced, minimal radiological impacts, minimal long-term disturbance of land, and mitigable nature of the societal impacts, the staff has concluded that the overall benefit-cost balance for the Irigaray project is favorable, and the indicated action is that of granting a source material license for this solution mining project with the conditions specified in the Summary and Conclusions.

Appendix A

RESERVED FOR COMMENTS ON THE

DRAFT ENVIRONMENTAL STATEMENT

Appendix B

WELL WATER QUALITY DATA

Table B.1. Water quality assays of WMC wells and private wells, 1974

In parts per million unless otherwise indicated.
The locations of the wells are shown in Fig. 2.8

Determination	W-1[a]	W-2[a]	W-3[a]	W-5	W-6	W-19	W-21	W-22	W-23
Alkalinity, total (as $CaCO_3$)	133	172	105	82	162	172	98	1.0	114
Alkalinity, phenolphthalein (as $CaCO_3$)	0	110	1.1	4.2	0	8.3	3.3	5.0	4.5
Aluminum	0.18	0.75	0.41	0.13	0.05	0.09	0.12	0.06	0.05
Ammonia (as N)	0.1	0.29	0.1	0.18	4.2	0.1	0.1	0.19	0.15
Arsenic	0.01	0.01	0.02	0.01	0.01	0.01	0.1	0.01	0.01
Barium	0.5	0.5	0.3	0.5	0.5	0.5	0.5	0.5	0.5
Bicarbonate (as $CaCO_3$)	133	0	103	74	162	158	92	100	105
Boron	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cadmium	0.008	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Calcium	375	29	19	6.9	18	5.3	3.2	4.3	4.3
Carbonate (as $CaCO_3$)	0	124	2	8	0	17	7	10	9
Chloride	123	10	12	11	11	10	9	9	10
Chromium, hexavalent	0.005	0.005	0.011	0.005	0.044	0.005	0.015	0.005	0.005
Copper	0.02	0.02	0.005	0.005	0.005	0.005	0.005	0.03	0.01
Cyanide	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fluoride	1.2	0.28	0.34	0.34	0.28	1.4	0.96	0.56	0.64
Hardness, total (as $CaCO_3$)	1,355	74.0	55.3	20.0	65.0	15.0	9.7	12.9	12.0
Lead	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Iron	0.04	0.02	0.02	0.06	0.94	0.06	0.42	0.03	0.03
Magnesium	140	0.01	1.9	0.05	2.7	0.98	0.38	0.52	0.49
Manganese	0.16	0.005	0.005	0.01	0.45	0.01	0.0001	0.0001	0.0001
Mercury	0.0001	0.0006	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Molybdenum	0.07	0.04	0.1	0.04	0.08	0.04	0.04	0.04	0.04
Nickel	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Nitrate (as N)	0.06	0.03	0.05	0.03	0.08	0.03	0.03	0.03	0.03
pH	7.0	10.9	8.5	8.9	7.4	8.8	8.7	8.8	8.8
Phosphorus, total (as P)	5.4	0.32	0.9	0.15	4.0	0.05	0.05	0.05	0.05
Potassium	52	3.9	2.8	2.0	9.7	1.8	1.4	1.3	1.3
Selenium	0.010	0.007	0.018	0.005	0.07	0.005	0.005	0.005	0.007
Silver	0.004	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Sodium	850	149	137	137	139	146	123	126	122
Sulfate	2,600	155	224	195	159	137	112	135	124
Total dissolved solids (180°C)	4,600	440	452	325	492	470	329	354	376
Uranium, as U (ppb)	41.0	2.2	215	1.5	1.9	1.5	1.5	1.5	1.5
Vanadium	0.009	0.009	0.042	0.014	0.024	0.001	0.001	0.001	0.001
Zinc	0.04	0.14	0.04	0.03	1.7	0.005	0.02	0.005	0.12
Gross alpha ± precision[b]	35 ± 7	660 ± 30	540 ± 30	1.9 ± 1.9	2.7 ± 1.8	0.0 ± 0.7	0.8 ± 1.1	0.4 ± 0.7	1.3 ± 1.3
Gross beta ± precision[b]	91 ± 36	450 ± 20	410 ± 30	18 ± 8	30 ± 11	3 ± 8	5 ± 7	5 ± 7	15 ± 8
Ra 226 ± precision[b]	4.1 ± 2.8	22 ± 5	141 ± 12	0.5 ± 1.2	0.0 ± 0.9	0.0 ± 0.9	0.0 ± 0.8	0.0 ± 0.8	0.1 ± 0.4
Th 230 ± precision[b]	0.0 ± 1.9	0.0 ± 2.6	45 ± 7	0.0 ± 0.6	0.0 ± 0.7	0.0 ± 0.7	0.0 ± 0.6	0.0 ± 0.6	0.0 ± 0.6

[a] Wyoming Mineral Corporation well.

[b] Variability of the radioactive disintegration process (counting error) at the 95% confidence level 1.960.

Table B.2. Baseline groundwater quality, Irigaray test site 517

See Fig. 2.8 for locations of wells

Determination	Baseline value[a]
As, ppm	<0.0025
Ba, ppm	0.12
B, ppm	0.16
Cd, ppm	<0.005
Cr, ppm	0.0135
Cu, ppm	0.019
Mn, ppm	0.12
Hg, ppm	0.0028
Ni, ppm	0.018
Se, ppm	0.013
Ag, ppm	<0.005
Zn, ppm	0.003
Total dissolved solids, mg/liter	798
Pb, ppm	0.0035
U_3O_8, ppm	0.098[b]
NH_3, ppm	<1.0[b]
HCO_3, mg/liter	139[b]
Cl, ppm	10.75[c]
Gross alpha, pCi/liter	168 ± 11
Gross beta, pCi/liter	164 ± 19
Ra-226, pCi/liter	26.8 ± 5.2

[a]Average baseline value (9 wells, 517-2 to -6, M1 to M4) taken as a once-only sample without variability.

[b]Well baseline value (5 wells, M1 to M5).

[c]Well baseline value (4 wells, W1 to W4).

Table B.3. Water quality data, Section 9 pilot-scale well field

Table represents mean values with estimate of standard deviation with N = 5. Samples taken from 11-9-76 to 2-24-77
< indicates all data below detectable limits. All data reported as parts per million or milligrams per liter unless otherwise indicated

	Trend well[a] zone (approximately 200 ft away from production well zone)					Production well[a] zone (mineralized zone)				Monitor well[a] zone (approximately 450–700 ft away from production well zone)				
	T1	T2	T3	T5	T6	P3	P4	P5	P10	M1	M2	M3	M4	M5
NH_4	<0.2	0.24 ± 0.07	<0.2	<0.2	<0.2	0.18 ± 0.05	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.24 ± 0.07
As	0.01 ± 001	0.01 ± 002	<01	01	<010	0.10 ± 0.01	09 ± 01	<01	<010	<010	010	01 ± 002	01 ± 01	01 ± .00
Ba	0.01 ± 0004	0.02 ± 003	<.01	02	01	0.01 ± 3.2	02 ± 01	0.03 ± 0.01	02 ± 004	02 ± 01	02 ± 01	02 ± 02	02 ± 01	04 ± 02
HCO_3	89.5 ± 10.0	9.1 ± 4.8	66.8 ± 5.5	67.4 ± 14.6	80.3 ± 5.4	80.70 ± 12.16	90.5 ± 18.6	38.9 ± 27.9	86.1 ± 11.0	42.[illegible] ± 57.2	68.2 ± 27.0	92.1 ± 3.9	44.3 ± 40.2	72.5 ± 21
B	0.05 ± 01	0.02 ± 0.01	0.05 ± 0.01	05 ± 01	05 ± 01	0.12 ± 0.07	10 ± 02	0.10 ± 0.03	10 ± 04	06 ± 02	07 ± 02	.06 ± 01	05 ± 02	05 ± 02
Cd	<002	<002	<002	<002	<002	<.002	<002	<002	<.002	<002	<002	<002	<002	<002
Ca	7.0 ± 0.8	1.9 ± 0.74	5.2 ± 0.9	5.1 ± 1.3	6.7 ± 3	7.88 ± 1.15	10.5 ± 2.4	2.8 ± 1.77	7.5 ± 1.0	3.4 ± 2.5	3.0 ± 1.7	4.5 ± 9	3.8 ± 3.0	6.5 ± 9
CO_3	4.1 ± 3.5	17.0 ± 15.8	9.5 ± 8.6	11.2 ± 5.9	6.9 ± 7.0	5.93 ± 6.90	5.3 ± 4.9	19.4 ± 8.29	4.2 ± 5.5	18.8 ± 5.7	4.0 ± 11.2	6.1 ± 6.8	14.0 ± 7.7	4.1 ± 6.0
Cl	11.4 ± 1.1	12.1 ± 1.5	12.2 ± 1.3	13.2 ± 1.9	12.7 ± 1.5	11.62 ± 1.84	9.7 ± 4.8	11.94 ± 1.83	12.5 ± 2.1	17.0 ± 7.2	12.6 ± 1.0	12.1 ± 1.3	12.4 ± 1.4	17.6 ± 9.
Cr	<002	<002	002 ± 001	<.002	<002	<002	<002	004	004	<002	<002	<002	<002	003 ± 0
Conductivity[b]	547 ± 45.6	647 ± 51	624 ± 68	595 ± 30.4	620 ± 60	613 ± 6.5	613 ± 56.7	618 ± 16.7	589 ± 10.3	685 ± 74	624 ± 28	571 ± 25	607 ± 41	610 ± 25
Cu	005 ± 001	006 ± 002	08 ± 0.14	<005	<005	<005	01 ± 002	006 ± 002	<005	006 ± 002	<005	<005	<005	01 ± 00
F	.25 ± 05	0.24 ± 03	28 ± 05	31 ± 04	25 ± 03	.38 ± 20	33 ± .02	0.28 ± 02	29 ± 03	0.23 ± 04	0.29 ± 01	28 ± 04	23 ± 01	22 ± 03
Gross alpha[c]	34.7 ± 39.0	1.7 ± 11.0	5.2 ± 4.3	4.3 ± 3.9	5.3 ± 7.4	1496 ± 462	6341 ± 3353	122.4 ± 139.2	389 ± 202	4.0 ± 4.3	2.9 ± 3.4	19.4 ± 14.2	3.5 ± 5.5	4.4 ± 6.5
Gross beta[c]	69.1 ± 101.3	107.3 ± 167.1	100.4 ± 137.3	81.2 ± 114.8	39.8 ± 85.1	493.3 ± 477.3	1644 ± 1621	117.8 ± 208.4	143.6 ± 186.8	65.9 ± 104.8	63.2 ± 123.8	66.6 ± 126.0	80.4 ± 160.0	102.0 ± 1
$CaCO_3$	90.3 ± 1.5	95.4 ± 5.4	81.3 ± 2.1	91.3 ± 2.2	93.1 ± 4.9	93.9 ± 2.8	102.2 ± 3.6	88.9 ± 4.9	93.9 ± 2.8	97.9 ± 5.4	107.9 ± 13.0	93.7 ± 6.4	87.1 ± 2.5	96.2 ± 12
Fe	0.15 ± 0.08	0.13 ± 07	0.21 ± 0.12	12 ± 10	10 ± 02	.30 ± 22	21 ± 25	0.18 ± 0.11	1.05 ± 73	0.19 ± 0.11	.12 ± 05	12 ± 06	.09 ± 08	38 ± 32
Pb	<002	.003 ± 003	<002	.004 ± 002	02 ± 04	006 ± 003	<002	<002	.004 ± 003	01 ± .02	003 ± 002	01 ± 004	003 ± 002	004 ± 0
Mg	1.01 ± 0.11	0.2 ± 08	0.39 ± 0.08	51 ± 16	72 ± 03	80 ± 0	1.0 ± 14	0.14 ± 0.08	1.00 ± 14	27 ± 23	38 ± 17	51 ± .12	.33 ± 27	.48 ± 26
Mn	<025	<025	<.025	<025	<025	<.025	<025	<.025	03 ± 01	<025	<025	<025	<025	<025
Hg	<.0002	<.0002	<.0002	<.0002	<.0002	<0002	<0002	<.0002	<0002	<.0002	<.0002	<0002	<0002	<0002
Mo	<02	<02	<.02	<02	<02	<02	02 ± 01	<02	<02	03 ± 01	<02	<02	<02	<02
Ni	<.2	<2	<2	<2	<.2	<2	<2	<2	<2	<2	<2	<2	<2	<.2
NO_3	0.54 ± 0.14	0.35 ± 0.10	0.32 ± 0.14	.91 ± 1.35	40 ± 07	40 ± .10	0.58 ± 0.10	0.32 ± 0.09	.38 ± 08	.55 ± 19	57 ± 25	53 ± .27	42 ± .14	.78 ± 65
NO_2	0.29 ± 0.24	<.02	0.13 ± 0.22	11 ± .18	.31 ± .21	.08 ± .12	<.02	<.02	08 ± 11	<02	03 ± 02	.13 ± 23	.04 ± .03	<.02
pH	8.71 ± 0.16	10.22 ± 0.97	9.04 ± 0.45	9.13 ± 0.45	8.78 ± 28	8.65 ± 0.27	8.79 ± 0.26	9.94 ± 0.43	8.59 ± 35	9.80 ± 1.00	9.31 ± 74	8.69 ± 31	9.51 ± 81	8.91 ± 1.
K	1.6 ± 0.2	5.6 ± 1.00	2.1 ± 0.3	1.9 ± 0.1	1.7 ± 0.1	2.3 ± 2	2.2 ± 3	4.3 ± 0.89	1.9 ± 0.3	3.9 ± 1.6	2.0 ± 40	2.0 ± 9	2.3 ± 6	2.5 ± 2.2
Ra-226[c]	12.1 ± 12.0	3.0 ± 1.8	.8 ± .8	2.61 ± 1.7	0.4 ± 0.2	57.8 ± 15.0	144.3 ± 56.	23.5 ± 3.0	28 ± 8.4	6.8 ± 7.4	.7 ± 7	1.4 ± .9	3 ± 3	1.6 ± 3.1
Se	<.010	<.010	<.01	<01	<.01	.060 ± .08	0.73 ± 0.84	.088 ± .090	.027 ± 03	.02 ± 01	02 ± 01	<010	<010	<.010
Si	2.74 ± 1.63	363 ± 0.43	3.70 ± 0.23	3.50 ± 0.21	3.54 ± 0.30	3.81 ± 06	4.38 ± 0.17	3.61 ± 0.38	3.54 ± 20	3.75 ± 06	3.86 ± 46	3.54 ± .41	3.73 ± 42	3.55 ± 0.
Ag	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<002	<.002	<002	<002	<002	<002	<.002
Na	12[illegible] ± 5.8	128 ± 5.3	126 ± 3.4	121 ± 6.5	129 ± 5.3	128.5 ± 3.9	131 ± 9.4	127.5 ± 2.1	126.0 ± 4.2	130 ± 2.2	127.8 ± 4.4	119.2 ± 4.5	123 ± 2.4	121.0 ± 2
SO_4	182 ± 8.2	209 ± 28.3	181.2 ± 3.3	169.5 ± 10.1	1[illegible]7.6 ± 6.7	193.3 ± 6.2	204.8 ± 4.1	207 ± 23.4	188.0 ± 6.2	173.3 ± 41.2	167.0 ± 6.7	160.1 ± 2.9	188 ± 14.5	178.3 ± 8
Total dissolved solids	355 ± 26.8	340 ± 32	356 ± 20.4	356 ± 36.3	362.4 ± 29.2	376 ± 15.1	399.5 ± 25.7	340 ± 23.8	382 ± 23.2	393 ± 8.8	361 ± 22.6	333 ± 24.3	330 ± 24.3	364 ± 26
Th-230[c]	0.2 ± .1	0.15 ± 0.17	0.3 ± 0.2	0.2 ± 0.1	.5 ± 4	1.0 ± 42	9.0 ± 14.7	0.2 ± 0.2	3.3 ± 3.3	0.9 ± 1.6	1 ± 08	23 ± 45	.1	.08 ± .05
Y	<.05	<.05	<.05	<.05	<.05	.06 ± 02	.34 ± 15	0.10 ± 0.01	06 ± .01	<.05	<.05	<.05	<.05	<05
U_3O_8	0.08 ± 05	0.02 ± 0.02	0.02 ± 0.01	.02 ± 01	.01 ± 01	3.85 ± 0.88	13.57 ± 3.79	0.39 ± 0.12	1.16 ± 0.33	05 ± 02	05 ± 04	10 ± 08	04 ± 04	.02 ± .004
Zn	<.02	<02	<.02	<02	<02	<.02	<.02	<02	<02	<02	02 ± 01	.02 ± 01	02 ± 01	02 ± 01

[a] Well locations are sho[illegible]n Fig. 4.4
[b] Micromhos per cen[illegible]
[c] Picocuries per liter.

Appendix C

BIOLOGIC STUDY CONDUCTED FOR
WYOMING MINERAL CORPORATION

May, 1975

To: Wyoming Mineral Corporation
From: Dr. Jack C. Turner, Environmental Consultant
Subject: Report of Vertebrate Fauna, N. E. Sussex Site

INTRODUCTION

This report is concerned with a survey of the terrestrial vertebrate animals living within the sphere of influence of the proposed Wyoming Mineral Corporation mining site. The area is located in southeast Johnson County, Wyoming, in T44N, R77W approximately 11 miles NE of Sussex and 5 miles E of the Powder River.

Field studies commenced late November and extended through the middle of April. A total of 13 field days (10-15 hrs/day) were spent at 3 different time intervals during the study period. Field investigations were conducted from two to four consecutive days each visit to the study area.

I wish to acknowledge the cooperation of the Wyoming Game and Fish for certain information provided.

Scientific nomenclature and other terminology is according to the following authorities:

Long, C. A., 1965. The Mammals of Wyoming. University of Kansas Publication, Museum of Natural History 14(18): 493-758.

American Ornithologist Union, 1957. Check-list of North American Birds. 5th Edition, and A.O.U. 1973. Thirty-second supplement to the American Ornithologist Union Check-list of North American Birds. Auk. 90:411-419.

Baxter, G. T., 1947. The Amphibians and Reptiles of Wyoming. Wyoming Wildlife, August and October.

Field Procedure

Transect trapping for rodents was done in the township. Transects were 300 meters long with two museum special traps set at 10 meter intervals. Each transect was trapped for two consecutive 24 hour periods for a total of 120 trap-nights per transect. Twelve transects consisting of 1440 trap-nights were trapped during the study period. Traps were baited with a mixture of peanut-butter, rolled oats, bacon grease and velveeta cheese. Transects were dispersed throughout the study area, most of which were placed into the specialized habitats of the study area. These areas included: ravine bottoms, rocky outcroppings, areas in which big sagebrush (*Artemisia tridentata*) predominated and areas of grass prairie.

General observations were made for all vertebrates on the study area. The study area was traversed on foot at least once each visit. Animal sign, feces, tracks, calls or songs, skeletal remains, burrows, etc., were taken as evidence of a species' presence as well as actual sightings of the animals.

RESULTS

Small Mammals

Twenty-two species of mammals belonging to ten families (five orders) were found to occur within the study area(Table C.1). Rodents comprised the most abundant group present, being represented by five families and eleven species. The deer mouse (*Peromyscus maniculatus*) was the most frequent rodent captured and was trapped in all habitat types, rocky areas being slightly preferred. A total of 197 *Peromyscus* sp. were captured in all transects, representing 91 percent of the total (217) rodents captured. *Peromyscus* sp. comprised a major fraction of the rodent biomass.

Table C.1. Taxonomic listing of mammals occurring within T44N, R77W (excluding bats).

Species	Common Name
Order: Insectivora	
Family: Soricidae	
Sorex vagrans vagrans	Vagrant Shrew
Order: Lagomorpha	
Family: Leporidae	
Sylvilagus audubonii baileyi	Desert Cottontail
Sylvilagus nuttalli grangeri	Nuttal's Cottontail
Lepus townsendii campanius	White-tailed Jackrabbit
Order: Rodentia	
Family: Sciuridae	
Spermophilus tridecemlineatus pallidus	Thirteen-lined Ground Squirrel
Family: Geomyidae	
Thomomys talpoides bullatus	Northern Pocket Gopher
Family: Heteromyidae	
Perognathus fasciatus olivaceogriseus	Olive-backed Pocket Mouse
Dipodomys ordii terrosus	Ord's Kangaroo Rat
Family: Cricetidae	
Reithrodontomys megalotis dychei	Plains Harvest Mouse
Peromyscus maniculatus nebrascensis	Deer Mouse
Onychomys leucogaster missouriensis	Northern Grasshopper Mouse
Neotoma cinerea orolestes	Bushy-tailed Wood Rat
Microtus ochrogaster haydeni	Prairie Vole
Family: Erethizontidae	
Erethizon dorsatum bruneri	Porcupine
Order: Carnivore	
Family: Canidae	
Canis latrans latrans	Coyote
Vulpes vulpes regalis	Red Fox
Family: Mustelidae	
Mustela frenata nevadensis	Long-tailed Weasel
Taxidea taxus taxus	Badger
Mephitis mephitis hudsonica	Striped Skunk
Family: Felidae	
Lynx rufus pallescens	Bobcat
Order: Artiodactyla	
Family: Cervidae	
Odocoileus hemionus hemionus	Mule Deer
Family: Antilocapridae	
Antilocapra americana americana	Pronghorn

Rabbits were abundant within the study area. The desert cottontail (*Sylvilagus audubony baileyi*) and Nuttal's cottontail (*Sylvilagus nuttalli grangeri*) were sympatric, however, the desert cottontail was more abundant preferring ravines. The Nuttal's cottontail was sparsely distributed in open flat lands and in the sagebrush plant community. Jackrabbits (*Lepus townsendi campanius*) occur primarily within sagebrush cover.

Pocket gophers (*Thomomys talpoides bulbatus*) were evidenced by their mound building activity. They are widely distributed over the grass land habitat of the study area.

The skeletal remains of a porcupine (*Erethizon dordatum bruneri*) was found on a dirt road within the study area. It is doubtful a viable population of these animals exists within the study area due to the lack of suitable habitat. Perhaps single individuals migrate into the area on a random basis.

Several mammalian predators have been observed. Coyotes (*Canis latrans latrans*) and badger (*Taxidea taxus taxus*) were frequently observed as was sign of their activity. The striped skunk (*Mephitis mephitis hudsonica*) was also abundant, especially in riparian habitats. Two long-tailed weasels (*Mustela frenata nevadensis*) were trapped in association with riparian habitat. Additionally, several active burrows were found with sign identified as red fox (*Vulpes vulpes regalis*). Tracks and feces of a medium sized felid, probably those of a bobcat (*Lynx rufus pallescens*) were observed around several rocky outcropings.

Large Mammals

Pronghorn (*Antilocapra americana americana*) were the most conspicuous component of the mammalian biota. They were distributed through the entire study area, being concentrated in areas of sagebrush habitat. Numbers of individuals observed ranged from 32 to 142 individuals per day with an average of 75 individuals per day. The average sex ratio was 6 females per male.

Mule deer (*Odocoileus hemionus hemionus*) populations were varied. Numbers of individuals observed ranged from 7 to 22 individuals per day with an average of 10 individuals per day. Most deer occurred in groups of 1 to 5 individuals. Deer were associated with riparian habitat and at the heads of draws in sagebrush habitat.

Birds

Twenty-seven species of birds representing 13 families were observed within the study area (Table C.2 Seven species of waterfowl (Anatidae) were observed, however, they were migratory. No resident waterfowl was observed. Similarly, seven species f hawks (Accipitridae) were observed, only one golden eagle (*Aquila chrysaetos*) appeared to be resident. Two great horned owls (*Bubo virginianus*) were observed in a small cluster of cottonwood trees (*Populus sargentii*) in a ravine bottom.

Although few sage grouse (*Centrocercus urophasianus*) were observed, their droppings occurred over much of the study area. No strutting grounds were found. Meadowlarks (*Sturnella neglecta*) and horned larks (*Eremophila alpestris*) were the most widespread and abundant birds on the study area.

Ectothermic Vertebrates

Owing to season and lateness of spring snows no observations were made of frogs, toads or reptiles as they had yet to emerge. Amphibians and reptiles which may occur in the study area according to Baxter (1947)

Table C.2. Birds observed within T44N, R77W from December to May.

Species	Common Name
Family: Anatidae	
Branta canadensis	Canada Goose
Anas platyrhynchos	Mallard
Anas acuta	Pintail
Anas strepera	Gadwall
Anas discors	Blue-winged Teal
Anas cyanoptera	Cinnamon Teal
Oxyura jamaicensis	Ruddy Duck
Family: Cathartidae	
Cathartes aura	Turkey Vulture
Family: Accipitridae	
Accipiter gentilis	Cooper's Hawk
Circus cyaneus	Marsh Hawk
Buteo lagopus	Rough-legged Hawk
Buteo regalis	Ferruginous Hawk
Buteo jamaicensis	Red-tailed Hawk
Aquila chrysaetos	Golden Eagle
Falco sparverius	Sparrow Hawk
Family: Strigidae	
Bubo virginianus	Great Horned Owl
Asio flammeus	Short-eared Owl
Family: Tetraonidae	
Centrocercus urophasianus	Sage Grouse
Family: Rallidae	
Fulica americana	American Coot
Family: Caprimulgidae	
Chordeiles minor	Common Night Hawk
Family: Picidae	
Colaptes auratus cafer	Red-shafted Flicker
Family: Alaudidae	
Eremophila alpestris	Horned Lark
Family: Corvidae	
Corvus brachyrhynchos	Crow
Family: Fringillidae	
Calamospiza melanocorys	Lark Bunting
Pooecetes gramineus	Vesper Sparrow
Family: Icteridae	
Sturnella neglecta	Meadowlark
Family: Mimidae	
Oreoscoptes montanus	Sage Thrasher

are included in Table C.3.

Vegetation

There is no commercially merchantable timber within the study area. Few trees are evident and are generally confined to ravine bottoms where at least semipermanent water is available. The plains cottonwood (*Populus sargentii*) is the dominant tree cover although sparsely distributed. Some stands of willow (*Salix* sp.) also exist in riparian situations which are minimal within the study area.

Vegetative cover of the entire study area consists of a series of interdigitating sagebrush and sagebrush-grass complexes. A compilation of the major plant species observed is found in Table C.4. Vegetation observed within the study area is consistent with that found on eastern short-grass prairies of Wyoming with the possible exception of big sagebrush (*Artemisia tridentata*) being more abundant than on most grassland areas.

Area of vegetative cover varied greatly over the study area. The average cover was 57 percent based three 10 ha. plots sampled by a stratified sampling technique. Cover ranged from 0 percent to a maximum of 78 percent.

Climate

A continental climate prevails over the study area. Few days during the year are without insolation. Wide fluctuations exist in the seasonal and diurnal temperatures (ambient). Summer extremes produce temperatures above 100°F; the winter produces minimums in excess of -25°F. Precipitation varies between 7 and 19 inches with a mean of 12 inches per year (10 year average.

Table C.3. Reptiles and amphibians which may occur within T44N, R77W (after Baxter, 1947).

Species	Common Name
Reptiles	
Phrynosoma douglassi	Eastern Short Horned Lizard
Sceloporus undulatus	Northern Prairie Lizard
Pituophis melanoleucus	Common Bull Snake
Crotalus viridis	Prairie Rattlesnake
Heterodon nasicus	Western Hognose Snake
Coluber constrictor	Blue Racer
Thamnophis ordinoides	Wandering Garter Snake
Thamnophis radix	Plains Garter Snake
Thamnophis sirtalis	Red-sided Garter Snake
Amphibians	
Pseudacris nigrita	Swamp Cricket Frog
Rana pipiens	Leopard Frog
Scaphiopus bombifrons	Central Plains Spadefoot Toad
Bufo woodhousii	Rocky Mountain Toad

Table C.4. Major plant species observed within T44N, R77W.

Species	Common Name
Agropyron smithii	Western Wheat Grass
Alopecurus carolinianus	Carolina Foxtail
Artemisia cana	Silver Sagebrush
Artemisia pedatifida	Birdfoot Sagewort
Artemisia tridentata	Big Sagebrush
Atriplex argentea	Tumbling Sagebrush
Bouteloua gracilis	Blue Grama Grass
Bromus tectorum	Cheatgrass Brome
Carex douglasii	Douglas Sedge
Carex filifolia	Threadleaf Sedge
Chrysothamnus viscidiflorus	Rabbitbrush
Distichlis spicata	Inland Saltgrass
Eleocharis acicularis	Slender Spikerush
Eriogonum annuum	Wild Buckwheat
Eriogonum ovalifolium	Cushion Buckwheat
Franseria discolor	Skeleton-leaf Bursage
Hordeum jubatum	Foxtail Barley
Koeleria cristata	Prairie Junegrass
Opuntia polyacantha	Plains Prickly Pear
Poa ampla	Big Bluegrass
Poa pratensis	Kentucky Bluegrass
Populus sargentii	Plains Poplar
Salix sp.	Willow
Salsola kali	Russian Thistle
Stipa comata	Needle and Thread Grass
Yucca glauca	Soapweed

DISCUSSION AND SUMMARY

The study area is within the Powder River faunal subdivision of the Great Plains Faunal Area. Much of the study area is of the Transitional Life Zone with an interdispersion of the Sonoran Life Zone. The fauna observed is consistent with that expected on the basis of the habitat and cover availability.

Vegetation is primarily that of a grassland prairie with a big sagebrush intrusion, the condition of which varies with season and the availability of moisture.

Bird populations probably increase as would diversity with the onset of spring. Passerine birds would probably be the majority of the breeding bird population with meadowlarks and horned larks being the most abundant. Due to the lack of suitable habitat, waterfowl and most raptors would not breed within the study area. However, the rodent and rabbit population would probably support several hawks, owls and/or eagles.

Sage grouse may also occupy the study area in greater numbers than observed. Sign (droppings) indicate sage grou[illegible] be dispersed over much of the study area.

There is an abundant rodent and small mammal population. The diversity of which is probably greater than measured due to prevailing winter conditions during this study.

Deer and pronghorn are abundant within the study area and contribute to both the aesthetic and recreation considerations of the available land resources. Although the use of the area by deer is perhaps seasonal, winter range is the most important aspect of deer habitat. Pronghorn use of the area is year-around, although pronghorn herds wander on and off the study area in their daily movements.

Relative to the type and magnitude of the proposed mining operation, the fauna will be effected to a greater or lesser degree. Any activity will serve to displace some component of the vertebrate fauna. Exploitation of the resources will alter the present environment by actual removal of vegetation and subsequent loss of animal populations from the construction(s) sites, through loss of habitat by construction of transportation systems and through the various impacts of mining personnel in their activities, both job related and personal.

Bird populations will be effected to the extent of surface disturbance. Since most birds require vegetation for nesting activity and minimal human encroachment, breeding populations will diminish with proximity to mining activities. Probably least effected will be ground nesting species, such as the meadowlark and horned lark, whose nesting specificity is less rigorous than most other passerine species as well as being more abundant. Again, however, man's activities can greatly (adversely) effect fledging success.

Sage grouse will be adversely effected by removal of sagebrush by the loss of cover and food. Without adequate cover for the precocicus chicks, survival will diminish within the sphere of influence of mining activity. The sage grouse will probably be eliminated.

Rodent populations will be altered with an increase in man's activities. The deer mouse and thirteen-lined ground squirrel will probably be least effected owing to their high reproductive rates and relative high abundance. Possibly, mining activities could serve to increase their populations. Other rodent populations will be displaced to the extent they are restricted to a particular habitat which is being altered. In some circumstances, components of the rodent fauna will be extirpated. This will negatively influence the raptor diversity and abundance.

Rabbits are a conspicuous component of the grassland-sagebrush habitat. Jackrabbits are intolerant of human encroachment. Additionally, hunting pressure (year-around) will increase with increased access to the area, potentially eliminating this species very quickly. Cottontail rabbits would be less adversely effected due to seasonal hunting pressure. Although sensitive to habitat changes, cottontails appear to be more adaptive and tolerant of man and his activities than do the hares.

Carnivores are effected by availability of food and, as such, tend to be wide ranging and opportunistic in feeding behavior. The effect of reduced prey items will diminish predator population, but such reductions should be less obvious with the over-all effect on carnivores being less. This assumes that predators would not be totally reduced from increased hunting and trapping pressure as a result of increased access and human population.

Big game species, pronghorn and mule deer, are intolerant of man and his activities. Such species will move away from disturbances into neighboring habitat until spacial limitations restrict such movements. With increased growth of mining operations, the subsequent influx of people and the continued removal of suitable big game habitat, pronghorn and mule deer populations could be greatly reduced. Additionally, the influx of people not only provide a harassment factor but also contribute to an increased demand for game species. The accumulative impact can serve to diminish game populations, possibly to extirpation. Such impact could be reduced through habitat rehabilitation and game management activities.

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Appendix D

DETAILED RADIOLOGICAL ASSESSMENT

When evaluated in conjunction with Sects. 4.6.5 and 6.7, the following information permits a detailed analysis of the radiological impact of the Irigaray project and permits complete review and verification by qualified radiological scientists. Calculations of radiation doses have been made for radionuclides and receptors around the site.

D.1 MODELS AND ASSUMPTIONS

AIRDOS-II, a FORTRAN computer code[1] was used to estimate individual and population doses resulting from the continuous atmospheric release of airborne radioactive materials from the normal project operations and from accidental releases. Pathways to man include (1) inhalation of radionuclides in air, (2) immersion in air containing radionuclides, (3) exposure to ground surfaces contaminated by deposited radionuclides, (4) ingestion of food produced in the area, and (5) immersion (swimming) in water subjected to surface deposition from plumes. Doses are estimated for the total body as well as for the following organs: gastrointestinal tract, bone, thyroid, lungs, muscles, kidneys, liver, spleen, testes, and ovaries. The dose to the bronchial epithelium from radon daughters is also estimated.

The area surrounding the project was divided into 16 sectors. Each sector is bounded by radial distances of 0.8, 1.6, 3.2, 4.8, 6.4, 8.0, 16, 32, 48, 64, and 80 km (0.5, 1.0, 2.0, 3.0, 4.0, 5.0, 10, 20, 30, 40, and 50 miles) from the point of release. Human population, numbers of beef and dairy cattle, and specifications as to whether each of the areas lying outside the plant boundary is used for producing vegetable crops or is a water area are required as input data.

The first part of AIRDOS-II is an atmospheric dispersion model (AIRMOD) that estimates concentrations of radionuclides in the air at ground level and their rates of deposition on ground surfaces as a function of distance and direction from the point of release. Annual average meteorological data for Casper, Wyoming, were supplied as input for AIRMOD.

AIRMOD is interfaced with environmental models within AIRDOS-II to estimate doses to man through the five pathways. One such model is a terrestrial model (TERMOD) developed by Booth, Kaye, and Rohwer[2] which estimates radionuclide intakes from ingestion of radionuclides deposited on crops, soil, and pastures. Such intakes result from drinking milk and eating beef and vegetable crops.

Population doses are summarized in the output tables of AIRDOS-II. Actual population distributions were summarized from 1970 Census Bureau tape records. The computer code PANS[3] provides sector summaries which correspond to the same sectors and annuli in the 16 compass directions for which χ/Q values are calculated. The population dose is calculated for each division and then summed over the entire 80-km (50-mile) radius.

The dose conversion factors for the radionuclides are based on two ICRP reports.[4,5] The method used in estimating radiation doses is given in a reference handbook.[6]

D.2 ATMOSPHERIC DISPERSION (METEOROLOGY)

The basic equation used to estimate atmospheric transport to the terrestrial environment is Pasquill's Equation[7] as modified by Gifford.[8] For particulate releases, the meteorological χ/Q values are used in conjunction with dry deposition velocities and scavenging coefficients to estimate air concentrations. Radioactive decay during plume travel is taken into account in AIRDOS-II.[1] Daughters produced during plume travel must be added to the AIRDOS-II source term. Concentrations of air for each sector are used to calculate the doses via inhalation and submersion in air. Ground-surface concentrations are used for external radiation exposure. The ground deposits are also assimilated into food which, when ingested, results in an additional dose via the food-chain pathway.

The meteorological data required for the calculations are joint frequency distributions of wind velocities and directions summarized by stability class. These data are shown in Tables D.1 and D.2 for the Casper, Wyoming, meteorology.

Table D.1. Frequencies of wind directions and true average wind speeds

Casper, Wyoming, meteorological data for 1967–1971 period

Wind direction (toward)	Frequency	Wind speeds for each stability class (m/sec)						
		A	B	C	D	E	F	G
N	0.023	1.80	3.09	4.29	6.19	3.98	2.54	0.0
NNW	0.011	2.63	2.95	3.99	4.48	3.99	2.64	0.0
NW	0.018	2.83	3.13	4.06	4.89	4.04	2.97	0.0
WNW	0.028	2.83	3.18	4.23	5.35	4.13	2.74	0.0
W	0.046	2.14	2.89	4.04	5.65	4.11	2.91	0.0
WSW	0.034	1.46	2.95	4.11	5.12	4.11	3.13	0.0
SW	0.043	2.83	3.36	4.12	5.50	4.06	2.97	0.0
SSW	0.061	2.42	3.30	4.19	5.80	4.05	3.15	0.0
S	0.057	2.83	3.21	4.19	5.74	4.04	2.78	0.0
SSE	0.037	2.83	3.22	4.78	5.13	4.04	2.99	0.0
SE	0.034	0.77	3.64	4.17	6.17	4.04	3.06	0.0
ESE	0.047	2.83	3.39	4.40	6.53	4.08	2.95	0.0
E	0.115	2.60	3.22	4.92	6.77	4.15	2.90	0.0
ENE	0.167	2.42	3.54	4.81	7.31	4.21	3.00	0.0
NE	0.183	1.46	3.34	5.21	8.27	4.19	2.81	0.0
NNE	0.095	2.32	3.40	4.73	8.50	4.19	2.74	0.0

Table D.2. Frequency of atmospheric stability classes for each direction

Casper, Wyoming, meteorological data for 1967–1971 period

Sector	Fraction of time in each stability class						
	A	B	C	D	E	F	G
N	0.0090	0.1613	0.1547	0.4835	0.0848	0.1267	0.0
NNW	0.0901	0.1832	0.1473	0.3179	0.1322	0.1292	0.0
NW	0.0112	0.1381	0.1498	0.4327	0.1468	0.1214	0.0
WNW	0.0108	0.0632	0.1199	0.5325	0.1641	0.1096	0.0
W	0.0066	0.0608	0.1043	0.5709	0.1439	0.1135	0.0
WSW	0.0091	0.0366	0.0884	0.5865	0.1416	0.1378	0.0
SW	0.0071	0.0402	0.0643	0.6417	0.1313	0.1153	0.0
SSW	0.0084	0.0387	0.0584	0.6702	0.1047	0.1197	0.0
S	0.0036	0.0384	0.0691	0.5698	0.1330	0.1861	0.0
SSE	0.0083	0.0695	0.0788	0.4326	0.1598	0.2510	0.0
SE	0.0060	0.0442	0.0916	0.4620	0.1685	0.2278	0.0
ESE	0.0110	0.0437	0.0937	0.4982	0.1642	0.1892	0.0
E	0.0080	0.0371	0.0842	0.4802	0.2303	0.1600	0.0
ENE	0.0031	0.0174	0.0636	0.6527	0.1985	0.0647	0.0
NE	0.0017	0.0165	0.0400	0.8456	0.0730	0.0233	0.0
NNE	0.0043	0.0223	0.0436	0.8425	0.0547	0.0327	0.0

The χ/Q values for the residences nearest the recovery plant and well field (Irigaray and Reculusa ranches) are shown in Table D.3.

Table D.3. χ/Q values at receptor points[a]

Casper, Wyoming, meteorology

Location	χ/Q value (sec/m^3)	
	Particulates	Rn 222
Irigaray Ranch		
Well field		1.26E–8
Recovery plant[a]	5.65E–9[b]	
Reculusa Ranch		
Well field		3.67E–8
Recovery plant[a]	2.31E–8	

[a] Stack height is 10.7 m (35 ft).
[b] Read as 5.65×10^{-9}.

D.3 CONTRIBUTION OF RADIONUCLIDES, PATHWAYS AND VARIOUS OPERATIONS TO DOSE

The amounts of radionuclides routinely released (source terms) during a year's operation of the recovery plant and well field on which annual dose calculations to the individual and the population are based are shown in Table D.4. The dose conversion factors used in the radiological assessments for the processes are shown in Table D.5.

D.4 OTHER PARAMETERS USED IN RADIOLOGICAL ASSESSMENT

Other principal parameters used in the radiological assessment of the Irigaray project are shown in Table D.6.

Table D.4. Release rates for radionuclides from well field and recovery plant[a]

Radionuclide	Release rate (Ci/year)
Recovery plant	
U-238	1.5E–1[b]
U-234	1.5E–1
U-235	7.0E–3
Th-230	2.6E–3
Ra-226	1.0E–4
Pb-210	1.0E–4
Bi-210	1.0E–4
Po-210	1.0E–4
Well field	
Rn-222	7.6E–1

[a] Estimated based on information contained in the ER, pp. 27 and 38 (5.0×10^5 lb of U_3O_8 processed per year; 1000 lb of U_3O_8 released per year from yellow cake stack).
[b] Read as 1.5×10^{-1}.

Table D.5. Dose conversion factors used in the radiological assessment for uranium mills

Radionuclide	Dose conversion factors				
	Total body	Bone	Lungs	Kidneys	Bronchial epithelium
	Yellow cake stack effluents (rems/μCi)				
U 234	3.0E-1[a]	4.9	5.8E2	1.2	
U 235	2.9E-1	4.7	5.6E2	1.0	
U 238	2.7E-1	4.5	5.1E2	1.0	
Th 230	3.1E1	1.0E3	5.7E2	3.1E2	
Ra 226	2.4E1	2.4E2	1.3E2	2.4E1	
Pb 210	9.7E-1	3.0E1	1.7E1	2.5E1	
Po 210	1.7E-1	7.1E-1	4.9E1	5.2	
	Releases from combined operations (millirem/year per picocurie per cubic meter of air)				
Ra 222 and daughters					0.625

[a]Read as 3.0×10^{-1}.

Table D.6. Some parameters and conditions used in the radiological assessment of the Irigaray project's uranium ore handling facilities

Parameters	Process circuit
Plant life expectancy	10 years
Plant operating time	365 days/year
Ore process rate	500,000 lb of U_3O_8 per year
Emission rate	1000 lb of U_3O_8 per year
Stack height (mill)	10.7 m (35 ft)

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Appendix E

BASIS FOR NRC EVALUATION OF THE PROPOSED IRIGARAY PROJECT

THE NUCLEAR FUEL CYCLE

The nuclear fuel cycle comprises all the processes involved in the utilization of uranium as a source of energy for the generation of electrical power.

The nuclear fuel cycle consists of several steps:

1. extraction – removing the ore (uranium) from the ground, separating uranium from the waste, and converting the uranium to a chemically stable oxide (nominally U_3O_8);
2. conversion – changing the U_3O_8 to a fluoride (UF_6), which is a solid at room temperature but becomes a gas at slightly elevated temperatures, prior to enrichment;
3. enrichment – concentrating the fissionable isotope (uranium-235) of uranium from the naturally occurring 0.7% to 2-4% for use in reactors for power generation;
4. fabrication – converting the enriched uranium fluoride to uranium dioxide (UO_2), forming it into pellets, and encasing the pellets in tubes (rods) that are assembled into fuel bundles for use in power generating reactors;
5. nuclear power generation – using the heat resulting from the fissioning of uranium and plutonium for generating steam for the turbines;
6. spent fuel reprocessing – chemical separation of fissionable and fertile values (uranium-235, uranium-238, plutonium) from fission products (waste), with concurrent separation of uranium from plutonium;
7. waste management – storage of fission products and low-level wastes resulting from reprocessing in a manner that is safe and of no threat to human health or the environment.

This cycle is portrayed in Fig. E.1.

Nuclear reactor operation converts about 75% of the fissionable isotope (uranium-235) into fission products, thereby liberating thermal energy and creating plutonium, another fissionable element, in the process. The remaining quantities of fissionable uranium (uranium-235) (about the same concentration as exists in natural uranium) and the plutonium are recoverable for reuse in the cycle.

The spent fuel removed from the reactor is stored at the reactor site and later at the reprocessing plant to "cool" the spent fuel. The radioactivity of the fuel is reduced by a factor of about ten after 150 days storage.

The reprocessing of spent fuel would produce fissionable material that could be used in combination with new (virgin) material obtained by mining and milling. In the absence of reprocessing, all replacement fuel must come from the mining and milling of uranium ore.

USE OF NUCLEAR FUEL IN REACTORS

Two types of reactors are currently used to generate essentially all of the nuclear energy sold in the United States: the boiling-water reactor (BWR) and the pressurized-water reactor (PWR). Each reactor type is operated with a fuel management scheme designed to meet the requirements of the utility operator. Different fuel management schemes result in different fuel burnup rates which, along with other design parameters, affect the quantity of residual fissionable materials and the type and amount of radioactive wastes in the spent fuel. These differences, in turn, require specific treatment processes at the reprocessing plant, thus, for maximum overall