AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 3

REMEDIAL ACTION PLAN AND SITE DESIGN FOR STABILIZATION OF THE INACTIVE URANIUM MILL TAILINGS SITE MAYBELL, COLORADO

**Remedial Action Selection Report
Attachment 2, Geology Report**

Final

June 1994

**RECEIVED
SEP 12 1994
OSTI**

**Appendix B of the
Cooperative Agreement
No. DE-FC04-81AL16257**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

INTENDED FOR PUBLIC RELEASE

This report has been reproduced from the best available copy. Available in paper copy and microfiche.

Number of pages in this report: 210

DOE and DOE contractors can obtain copies of this report from:

**Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831
(615) 576-8401**

This report is publicly available from:

**National Technical Information Service
Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650**

**REMEDIAL ACTION SELECTION REPORT
MAYBELL, COLORADO, SITE**

Final

June 1994

**Prepared for
U.S. Department of Energy
UMTRA Project Office
Albuquerque, New Mexico**

**Prepared by
Jacobs Engineering Group Inc.
Albuquerque, New Mexico**

EXECUTIVE SUMMARY

INTRODUCTION

The Maybell uranium mill tailings site is 25 miles (mi) (40 kilometers [km]) west of the town of Craig, Colorado, in Moffat County, in the northwestern part of the state. The unincorporated town of Maybell is 5 road mi (8 km) southwest of the site. The site is 2.5 mi (4 km) northeast of the Yampa River on relatively flat terrain broken by low, flat-topped mesas. U.S. Highway 40 runs east-west 2 mi (3.2 km) south of the site.

The designated site covers approximately 110 acres (ac) (45 hectares [ha]) and consists of a concave-shaped tailings pile and rubble from the demolition of the mill buildings buried in the former mill area. The site is situated between Johnson Wash to the east and Rob Pit Mine to the west. Numerous reclaimed and unreclaimed mines are in the immediate vicinity. Aerial photographs (included at the end of this executive summary) show evidence of mining activity around the Maybell site. Contaminated materials at the Maybell processing site include the tailings pile, which has an average depth of 20 feet (ft) (6 meters [m]) and contains 2.8 million cubic yards (yd³) (2.1 million cubic meters [m³]) of tailings. The former mill processing area is on the north side of the site and contains 20,000 yd³ (15,000 m³) of contaminated demolition debris. Off-pile contamination is present and includes areas adjacent to the tailings pile, as well as contamination dispersed by wind and surface water flow. The volume of off-pile contamination to be placed in the disposal cell is 550,000 yd³ (420,000 m³). The total volume of contaminated materials to be disposed of as part of the remedial action is estimated to be 3.37 million yd³ (2.58 million m³).

PREVIOUS DISPOSAL CELL DESIGN AND GROUND WATER COMPLIANCE STRATEGY

Information presented in this Final Remedial Action Plan (RAP) and referenced in supporting documents represents the current disposal cell design features and ground water compliance strategy proposed by the U.S. Department of Energy (DOE) for the Maybell, Colorado, tailings site. Both the disposal cell design and the ground water compliance strategy have changed from those proposed prior to the preliminary final RAP document as a result of prudent site-specific technical evaluations. These changes are summarized below. The DOE document *Remedial Action Plan and Site Design for Stabilization of the Inactive Uranium Mill Tailings Site at Maybell, Colorado*, draft, UMTRA-DOE/AL-050514.0000, September 1990, presents detailed information regarding the earlier ground water compliance strategy.

The Preliminary Design for Review issued in August 1990 included a vegetative cover topslope for erosion protection that conformed to the draft RAP. Subsequent to the issue of the initial preliminary design, an evaluation of various cover types indicated that a riprap-protected topslope would meet the performance criteria and would provide better protection against erosion and reduce gullyng potential. Thus, the cover design was revised.

The DOE draft RAP submitted in September 1990 proposed meeting a concentration limit for each identified hazardous constituent to protect ground water at the Maybell site. Concentration limits were proposed as the U.S. Environmental Protection Agency (EPA) maximum concentration limits (MCL) or the statistical maximum of background ground water quality at the tailings site (whichever was higher) for those hazardous constituents without MCLs. In addition, the DOE established a point of compliance (POC) and recommended a ground water monitoring program to demonstrate compliance with the proposed ground water protection strategy. This strategy subsequently was changed to the ground water protection strategy presented in this document, based on a reevaluation of site background ground water quality and usage and the changes in disposal cell cover design.

REMEDIAL ACTION

Pursuant to the requirements of the Uranium Mill Tailings Radiation Control Act (UMTRCA) (42 USC §7901 *et seq.*), the proposed RAP will satisfy the EPA standards 40 CFR Part 192, Subparts A through C (40 CFR Part 192 (1993) and 52 FR 36000 (1987)), for cleanup, stabilization, and control of the residual radioactive materials (tailings and other contaminated materials) at the disposal site. The construction of an engineered disposal cell will satisfy the tailings control requirements of 40 CFR §192.02(a)(1) (40 CFR Part 192 and 52 FR 36000).

The remedial action is to stabilize the existing tailings pile in place. Demolition debris from the former mill processing yard, windblown areas containing contaminated soils, waterborne contamination from surface water runoff from the area around the tailings pile and from releases of tailings effluents, and vicinity property contamination will be placed with the tailings on the existing pile. Stabilization in place was selected as the remedial action because it presents the fewest potential negative impacts to the environment and is the least costly option.

The completed disposal cell will contain the estimated 3.37 million yd³ (2.58 million m³) of contaminated materials on approximately 66 ac (27 ha). The disposal cell will rise an average of 40 ft (12 m) above the surrounding topography. A rock apron 20 ft (6 m) wide will be placed along the south and east sides of the pile to prevent headward erosion of gullies into the pile. Permanent ditches also will be constructed on the north and west sides of the stabilized pile to divert flow away from the pile. The disposal cell will contain a multicomponent cover 6.7 ft (2 m) thick. The cover will include a radon/infiltration barrier (sandy clay/sandy silt amended with 10 percent Redmond bentonite), a layer to protect the radon/infiltration barrier against frost penetration and prevent moisture buildup, a sand and gravel bedding/drainage layer, and a rock erosion protection layer at the cell surface.

Upon issuance of the preliminary final RAP, a study was initiated to evaluate the potential for eliminating the frost protection layer, based on the performance of the amended bentonite layer undergoing multiple freeze-thaw cycles. Previous studies performed by Wong and Haug (1991) and others showed a reduction in the permeabilities of sands amended with bentonite with an increasing number of freeze-thaw cycles. The DOE arranged similar freeze-thaw testing with the site-specific barrier material at Maybell

amended with a range of percentages of Redmond bentonite, to assess if it too will demonstrate improved performance under freeze-thaw cycles in terms of reduced permeabilities. Should these tests be conclusive in demonstrating improved performance of the amended Redmond bentonite material, this final RAP may be amended to eliminate or reduce the thickness of a frost protection layer.

The DOE will follow Subpart C of 40 CFR §192.21(b) (40 CFR Part 192 (1993)) regarding the use of supplemental surface cleanup standards for portions of Johnson Wash and Lay Creek. Contaminated materials (except the localized "hot spots") in Johnson Wash and in Lay Creek will not be excavated.

DESIGN ANALYSES

Detailed investigations of geologic, geomorphic, and seismic conditions at the Maybell site were conducted and incorporated in the remedial action design. The disposal site will be stable geomorphically, i.e., against gully erosion in the cell vicinity or slope failure. Tributary gullies between Johnson Wash and the disposal embankment also will be stabilized by slope control and protected by riprap material. Seismic design parameters were developed for the geotechnical analyses of the disposal cell. The geotechnical stability of the disposal cell was analyzed to ensure long-term performance in meeting the design standards. Geotechnical analyses included slope stability, settlement, cover cracking, and liquefaction potential.

The disposal cell cover and erosion protection features were analyzed and designed to protect the contaminated materials against surface water and wind erosion. A rock apron 20 ft (6 m) wide will be placed along the south and east sides of the pile to prevent headward erosion of gullies into the pile. Permanent ditches also will be constructed on the north and west sides to divert flow away from the pile. Rock to be used on the disposal cell top, sideslopes, apron, and ditches was sized to withstand probable maximum precipitation/flood events.

The disposal cell's 1.5-ft (0.5-m)-thick, fine-grained radon barrier will meet the radon emissions requirements of 40 CFR §192.02(a)(2), Subpart A, (40 Part CFR 192 (1993)). The compacted overburden materials from the Rob Pit overburden pile will be amended with 10 percent Redmond bentonite by weight to form a low-permeability layer that will reduce radon release to below performance standards and limit infiltration of precipitation through the tailings.

Upon issuance of the preliminary final RAP, a study was initiated to evaluate the potential of reducing the 10 percent bentonite requirement in the barrier material. The current 10 percent bentonite design is based primarily on the cover infiltration flux of 1×10^{-7} centimeters per second (2.8×10^{-4} feet per day). Only 8.7 inches (22 centimeters) of cover are required to meet the radon emanation requirement (Calculation MAY-326-02-00, Attachment 1, Volume III). Radon emanation can be shown to be within the standard required in 40 CFR §192.02(a)(2) (40 CFR Part 192) by using a significantly lower percentage of bentonite.

Design parameters of the proposed disposal cell have been evaluated in conjunction with the hydrologic and geochemical characteristics of the Maybell site. Although not necessary to the ground water protection strategy presented in the RAP, naturally occurring geochemical conditions within the Browns Park Formation aquifer (uppermost aquifer) tend to decrease ground water contamination downgradient within the influence of the Maybell tailings pile. Based on the site evaluations conducted to date, the proposed disposal cell design will comply with the proposed EPA ground water protection standards (52 FR 36000 (1987)).

GROUND WATER COMPLIANCE

The DOE has characterized the hydrogeologic units, hydraulic and transport properties, water quality, ground water use, and geochemical conditions at the Maybell site. The existing tailings pile is underlain by the Browns Park Formation. The principal aquifer system (uppermost aquifer) is the upper sandstone unit of the Browns Park Formation. The top of the unconfined ground water table occurs within this formation at depths from 35 to greater than 300 ft (11 to 90 m) beneath the ground surface. Ground water flows southwesterly, away from the existing tailings pile. The nearest downgradient domestic well is 3 mi (5 km) south of the tailings site.

To achieve compliance with the proposed EPA ground water protection standards, the DOE proposes a narrative supplemental standard based on the criterion that the ground water in the uppermost aquifer is Class III (40 CFR §192.21(g)) (52 FR 36000). Ground water in the Browns Park Formation is not an historic or current drinking water source and meets the definition of Class III based on widespread ambient contamination due to naturally occurring uranium mineralization and to mining activities not related to on-site uranium milling operations (40 CFR §192.11(e)(2)) (52 FR 36000). The following aerial photographs show the extent of mining activity around the site. The narrative supplemental ground water standard considered evaluation of long-term seepage, transient drainage, and geochemical conditions.

No POC ground water monitoring or numerical concentration limits are proposed for the Browns Park Formation at the Maybell site. POC ground water monitoring would not serve any purpose because of two site-specific conditions. First, background ground water quality in the Browns Park Formation is highly variable. Second, the Browns Park Formation aquifer is not an historic or current drinking water source downgradient of the proposed disposal cell. In lieu of POC ground water monitoring, the DOE proposes a conceptual cell performance monitoring plan to satisfy 40 CFR Part 192, Subparts A and B (40 CFR Part 192 (1993) and 52 FR 36000 (1987)), during the post-closure period. A detailed cell performance monitoring plan will be provided in the Maybell long-term surveillance plan.

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
EXECUTIVE SUMMARY	ES-1
1.0 GENERAL INFORMATION	1-1
1.1 Site geography and demography	1-1
1.1.1 History	1-1
1.1.2 Description	1-2
1.1.3 Mineral resources	1-2
1.1.4 Land use	1-2
1.1.5 Socioeconomics	1-4
1.2 Proposed action summary	1-5
1.2.1 Contaminated material	1-5
1.2.2 Proposed action overview	1-9
1.2.3 U.S. Environmental Protection Agency standards and proposed action compliance	1-13
1.3 Scope and content	1-17
1.4 Collateral documents	1-17
1.5 Remedial action selection report organization	1-18
2.0 GEOLOGIC STABILITY	2-1
2.1 Scope of work	2-1
2.2 Regional geology	2-2
2.2.1 Regional physiography	2-2
2.2.2 Stratigraphic setting	2-3
2.2.3 Structural setting	2-3
2.2.4 Seismotectonics	2-4
2.2.5 Resource development	2-5
2.3 Site geology	2-6
2.3.1 Bedrock geology	2-6
2.3.2 Surficial geology	2-6
2.3.3 Geomorphology	2-7
2.4 Geologic stability	2-8
2.4.1 Geomorphic stability	2-8
2.4.2 Seismotectonic stability	2-10
2.5 Geologic suitability	2-11
3.0 GEOTECHNICAL STABILITY	3-1
3.1 Site and material characterization	3-1
3.1.1 Geotechnical investigations	3-1
3.1.2 Testing program	3-3
3.1.3 Ground water conditions	3-4
3.1.4 Stratigraphy	3-4
3.2 Geotechnical engineering evaluation	3-5
3.2.1 Slope stability	3-5
3.2.2 Settlement	3-7

TABLE OF CONTENTS (Continued)

<u>Section</u>		<u>Page</u>
	3.2.3 Liquefaction potential	3-9
	3.2.4 Cover design	3-10
3.3	Construction details	3-11
	3.3.1 Construction methods and features	3-11
	3.3.2 Testing and inspection	3-12
	3.3.3 Construction activities and construction sequence	3-12
3.4	Summary	3-15
4.0	SURFACE WATER HYDROLOGY AND EROSION PROTECTION	4-1
4.1	Hydrologic description and conceptual design	4-1
4.2	Flooding determinations	4-1
	4.2.1 Probable maximum precipitation	4-4
	4.2.2 Infiltration losses	4-4
	4.2.3 Time of concentration	4-4
	4.2.4 Probable maximum precipitation rainfall distributions	4-4
	4.2.5 Probable maximum flood computation	4-4
4.3	Water surface profiles and channel velocities	4-5
	4.3.1 Adjacent waterways	4-5
	4.3.2 Drainage ditches	4-5
	4.3.3 Embankment top and sides	4-6
4.4	Erosion protection design	4-6
	4.4.1 Adjacent waterways	4-6
	4.4.2 Drainage ditches	4-7
	4.4.3 Disposal cell top and sides	4-7
	4.4.4 Toe apron	4-7
4.5	Rock durability	4-8
4.6	Quality control (testing and inspection) for erosion protection	4-8
4.7	Upstream dam failures	4-8
4.8	Summary	4-8
5.0	WATER RESOURCE PROTECTION	5-1
5.1	Hydrogeologic site characterization	5-1
	5.1.1 Hydrogeologic units identification	5-1
	5.1.2 Hydraulic and transport properties	5-1
	5.1.3 Geochemical conditions	5-1
	5.1.4 Characterization methods	5-2
	5.1.5 Water use	5-2
	5.1.6 Background ground water quality	5-2
	5.1.7 Tailings characterization	5-2

TABLE OF CONTENTS (Continued)

<u>Section</u>		<u>Page</u>
	5.1.8 Extent of existing contamination	5-3
5.2	Conceptual design features for water resources protection	5-3
5.3	Disposal	5-3
	5.3.1 Ground water protection standard for disposal	5-3
	5.3.2 Supplemental standards	5-5
	5.3.3 Performance assessment	5-6
	5.3.4 Closure performance demonstration	5-7
	5.3.5 Ground water monitoring and corrective action plan	5-9
5.4	Ground water cleanup	5-9
5.5	Summary	5-10
6.0	RADON ATTENUATION AND SITE CLEANUP	6-1
6.1	Radon attenuation	6-1
	6.1.1 Parameter selection	6-1
	6.1.2 Calculational methodology and design results	6-4
6.2	Processing site cleanup	6-5
	6.2.1 Radiological site characterization	6-5
	6.2.2 Cleanup standards	6-10
	6.2.3 Cleanup verification	6-11
6.3	Summary	6-12
7.0	LIST OF CONTRIBUTORS	7-1
8.0	REFERENCES	8-1

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1.1	Location map of the Maybell tailings site near Maybell, Colorado	1-3
1.2	Present conditions at the Maybell tailings site near Maybell, Colorado	1-6
1.3	Approximate boundaries of radium-226 soil contamination and cleanup at the Maybell tailings site near Maybell, Colorado	1-8
1.4	Final conditions at the Maybell disposal site near Maybell, Colorado	1-10
1.5	Typical cross section of the Maybell tailings site near Maybell, Colorado	1-11
3.1	Construction schedule, Maybell, Colorado, tailings site	3-16
4.1	Surface water features at the Maybell tailings site near Maybell, Colorado	4-2
4.2	Disposal cell erosion protection requirements at the Maybell tailings site near Maybell, Colorado	4-3

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1.1	Areas and estimated volumes of contaminated materials at the Maybell, Colorado, tailings site	1-5
1.2	Relationship between design details/criteria and supporting calculations and reports	1-19
3.1	Results of slope stability analyses	3-5
3.2	Material properties used in stability analyses	3-6
6.1	RAECOM input parameter values	6-2
6.2	Background and on-site radiation measurements for the Maybell site near Maybell, Colorado	6-6
6.3	Average radionuclide concentrations in sediments from Johnson Wash as a function of depth	6-8
6.4	Average radionuclide concentrations in sediments from Lay Creek as a function of depth	6-9

LIST OF ACRONYMS AND ABBREVIATIONS

<u>Acronym</u>	<u>Definition</u>
ac	acre
ASTM	American Society for Testing and Materials
BLM	Bureau of Land Management
Bq/m ² s	becquerels per square meter per second
Bq/m ³	becquerels per cubic meter
cm	centimeter
cm/s	centimeters per second
cm ² /s	square centimeter per second
DOE	U.S. Department of Energy
EA	environmental assessment
EPA	U.S. Environmental Protection Agency
ft	foot
ft ²	square foot
ft/s	feet per second
ft ³ /s	cubic feet per second
g/cm ³	grams per cubic centimeter
ha	hectare
HMR	hydrometeorological report
in ² /s	square inches per second
km	kilometer
km ²	square kilometer
L/s	liters per second
lb/ft ³	pounds per cubic foot
LTSP	long-term surveillance plan
M	magnitude
m	meter
m ²	square meter
m ³	cubic meter
M _b	body-wave magnitude
mBq/g	millibecquerels per gram
mBq/m ² s	millibecquerels per square meter per second
MCL	maximum concentration limit
ME	maximum earthquake
mi	mile
mi ²	square mile
m/s	meters per second
NRC	U.S. Nuclear Regulatory Commission
O.D.	outside diameter
pCi/g	picocuries per gram
pCi/L	picocurie per liter
pCi/m ² s	picocuries per square meter per second
PMF	probable maximum flood
PMP	probable maximum precipitation

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

<u>Acronym</u>	<u>Definition</u>
POC	point of compliance
Ra	radium
RAC	Remedial Action Contractor
RAP	remedial action plan
RAS	remedial action selection
RRM	residual radioactive materials
SF&C	standard format and content
SRP	standard review plan
TAC	Technical Assistance Contractor
TAD	Technical Approach Document
t_c	time of concentration
TER	technical evaluation report
U_3O_8	uranium oxide
UMTRA	Uranium Mill Tailings Remedial Action
UMTRCA	Uranium Mill Tailings Radiation Control Act
yd ³	cubic yard

1.0 GENERAL INFORMATION

The inactive uranium mill tailings site near Maybell, Colorado, is one of 24 abandoned uranium mill sites designated to be remediated by the U.S. Department of Energy (DOE) under the Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978 (42 USC §7901 *et seq.*). Part of the UMTRCA requires the U.S. Nuclear Regulatory Commission (NRC) to concur with the DOE's remedial action plan (RAP) and certify compliance of site remedial action with the standards promulgated by the U.S. Environmental Protection Agency (EPA).

Included in the RAP is this remedial action selection (RAS) report, whose purpose is twofold. First, it describes the activities proposed by the DOE to accomplish remediation and long-term stabilization and control of the radioactive materials at the inactive uranium mill processing site near Maybell, Colorado. Second, upon concurrence and execution by the DOE, the state of Colorado, and the NRC, it becomes Appendix B of the Cooperative Agreement between the DOE and the state of Colorado.

It is the DOE's intent, as required by UMTRCA, to comply with EPA regulations in Subparts A through C of 40 CFR Part 192 (1993) and 52 FR 36000 (1987) in the preparation of this RAP. All remedial action planning and design considerations contained herein reflect the incorporation of this regulatory guidance. Therefore, by performing all remedial action activities in accordance with the design presented in this RAP, the DOE will meet the standards of 40 CFR Part 192 and 52 FR 36000. Section 1.2.3 summarizes these regulations and proposed action compliance by the DOE.

1.1 SITE GEOGRAPHY AND DEMOGRAPHY

1.1.1 History

The Trace Elements Corporation established the Maybell, Colorado, mill site in 1955 and 1956. The Union Carbide Corporation assumed control of the site and began operating the mill in 1957. Umetco Minerals Corporation, a wholly owned subsidiary of the Union Carbide Corporation, holds the radioactive materials license for the tailings site and continues as the operational controller. Uranium ore was obtained from nearby open pit mines. Under Umetco's 7 years of operation, the mill processed approximately 2.6 million tons (2.4 million tonnes) of ore, having a grade of 0.098 percent uranium oxide (U_3O_8). All concentrate produced was sold to the U.S. Atomic Energy Commission. An upgrader circuit at the processing plant treated low-grade ore prior to leaching. After the mill shut down in November 1964, Umetco dismantled it and, in 1971, started stabilizing the tailings in accordance with state of Colorado regulations. Remaining features include the tailings pile, foundation materials at the former mill processing site area, open pit mines, and overburden piles.

1.1.2 Description

The Maybell site is 25 miles (mi) (40 kilometers [km]) west of the city of Craig, Colorado, in Moffat County, in the northwestern portion of Colorado (Figure 1.1). The site is 2.5 mi (4 km) northeast of the Yampa River on relatively flat terrain broken by low, flat-topped mesas. U.S. Highway 40 runs east-west 2 mi (3.2 km) south of the site. The small, unincorporated town of Maybell is 5 road mi (8 km) southwest of the site. The nearest residence is 2.9 mi (4.7 km) southwest of the site.

The Maybell tailings pile is in Section 19, Township 7 North, Range 94 West, Sixth Principal Meridian, and at 40 degrees 32 minutes 40 seconds north latitude and 107 degrees 59 minutes 30 seconds west longitude. The former processing mill site is adjacent to the northern boundary of the tailings pile. The former mill site is in parts of Sections 18 and 19, Township 7 North, Range 94 West, Sixth Principal Meridian (FBDU, 1981).

The Maybell tailings site is drained by Johnson Wash, a dry arroyo (with gullies up to 40 feet [ft] deep) (12 meters [m]) that is a tributary to Lay Creek. Johnson Wash remains dry except during major runoff events. Lay Creek is a tributary to the Yampa River; its confluence with the river is about 5 mi (8 km) southwest of the Maybell tailings pile. The only permanent body of water near the tailings site is in the bottom of Rob Pit, located 2000 ft (600 m) west of the tailings pile. The Maybell tailings site is approximately 200 ft (60 m) higher in elevation than the Lay Creek floodplain at its confluence with Johnson Wash. Therefore, flooding in either Lay Creek or the Yampa River will not impact the Maybell tailings site.

1.1.3 Mineral resources

Known economically important mineral resources in the region are limited to uranium ores, coal, and oil and gas deposits. The Maybell site area has been extensively mined for uranium, and ore bodies are still present. Uranium mining has not occurred in this area in recent years. Coal-bearing formations do not occur in the site area. The site is within two active Bureau of Land Management (BLM) oil and gas leases, and numerous unpatented mining claims are at and around the site (Perez, 1992). No ongoing oil and gas or mineral development activities are occurring at or around the site. The Maybell environmental assessment (EA) (DOE, 1994) presents additional information on mineral resources.

1.1.4 Land use

The majority of the land around the site is under federal ownership and is administered by the BLM. However, private land is south, east, and west of the site. The northern portion of the designated site is on land administered by the BLM; the southern portion is on private land. Umetco holds the radioactive materials license for the designated site and continues as the operational

LEGEND

- PERENNIAL STREAM
- - - EPHEMERAL STREAM
- = = = = DIRT ROAD
- U.S. HIGHWAY
- STATE HIGHWAY

FIGURE 1.1
LOCATION MAP OF THE MAYBELL TAILINGS SITE
NEAR MAYBELL, COLORADO

controller. Umetco is not a landowner of the designated site. The state of Colorado is authorized to perform land appraisals of the privately held properties associated with the proposed remedial action. Upon acquisition of the privately held properties, title shall transfer from the state of Colorado to the DOE. Prior to initiation of the remedial action, the final disposal site area administered by the BLM also would transfer to the United States of America under the DOE's administration.

Virtually all of the land around the site is used for low-density livestock grazing. The tailings site is within three BLM grazing leases totaling 9369 acres (ac) (3792 hectares [ha]) and having a combined grazing capacity of 954 animal unit-months (Hillberry, 1986). Open pit mining and related activities have disturbed areas northeast, north-northwest, and south of the site. Four inactive open pit mines are within 1 mi (1.6 km) of the site. The EA (DOE, 1994) presents additional land use information for the Maybell area.

1.1.5 Socioeconomics

The Maybell tailings site is in a remote area in northwestern Colorado. The closest service center, county seat, and only town of size in Moffat County is Craig, approximately 25 mi (40 km) east of Maybell. Between 1970 and 1980, Moffat County's population approximately doubled due to increases in oil and gas exploration, coal mining, and the construction of a large coal-fired, electric-generating plant. Virtually all of the population increase occurred in Craig (Economic Development Commission, n.d.; Gibbons, 1986). The Colorado-Ute Power Plant just south of Craig was completed in the early 1980s. The 1980s also saw a general decline in the energy industry and subsequent decline in population in Moffat County. The 1990 census reported a population of 11,357 in Moffat County and 8091 in Craig (DOC, 1991). The population of Maybell (unincorporated), which also includes area ranches, has remained relatively stable at approximately 100 residents (Johnson, 1986; Moch, 1992).

Historically, agriculture and mining have been the primary employment activities in Moffat County. However, by the early 1980s, employment data indicated changes in the historical employment activities. Agriculture had been replaced by retail trade and government employment activities. Retail trade, government, and mining are the current primary sources of employment in the county. In Craig, long-term coal mining leases within and adjacent to Moffat County were the basis for a major source of employment. The Colorado-Ute Power Plant is another significant employer in Craig. No projects currently proposed for Moffat County or the city of Craig would affect existing employment patterns (Moch, 1990).

1.2 PROPOSED ACTION SUMMARY

1.2.1 Contaminated material

Table 1.1 summarizes the estimated volumes of contaminated materials distributed at the Maybell site. The estimated volume of contaminated material is 3.37 million cubic yards (yd³) (2.58 million cubic meters [m³]).

Table 1.1 Areas and estimated volumes of contaminated materials at the Maybell, Colorado, tailings site

Area	Approximate contaminated volumes	
	(yd ³)	(m ³)
Tailings pile	2,800,000	2,140,000
Demolition debris	20,000	15,000
Off-pile contaminated material (including north, west, and south sides of tailings pile; windblown; and waterborne)	550,000	420,000
Total site	3,370,000	2,580,000

The site (Figure 1.2) consists of a concave tailings pile and rubble from the demolition of the mill buildings buried in the former mill processing area. The tailings pile is nearly rectangular, with an average thickness of 20 ft (6 m). A fence restricts access to the tailings pile.

Numerous abandoned uranium mines exist in the Maybell tailings pile area. Rob Pit, 2000 ft (600 m) west of the Maybell tailings pile, contains standing water in the pit bottom. Johnson Pit, 1000 ft (300 m) south of the tailings pile, has been partially backfilled with mine overburden. Several reclaimed and unreclaimed overburden piles are also in the immediate area (Figure 1.2).

The tailings pile at the Maybell site contains approximately 2.8 million yd³ (2.1 million m³) of tailings. Figure 1.2 shows the tailings area within the designated site boundary. Union Carbide, the former mill operators, covered the tailings pile with 6 inches (15 centimeters [cm]) of soil, in accordance with state of Colorado regulations. The soil cover was revegetated with crested wheatgrass (DOE, 1983). However, surface water flow (FBDU, 1981) has eroded the cover soil and approximately 20 percent of the pile has exposed tailings.

The former mill processing area is on the north side of the site (Figure 1.2). Within this area is an estimated 20,000 yd³ (15,000 m³) of contaminated demolition debris located directly north of the tailings pile. Calculation

MAY-340-01-01 in Attachment 1, Volume III, presents quantity estimates and descriptions for the various types of demolition debris.

In addition to the tailings pile area of contamination shown in Figure 1.2, off-pile contamination also exists. The volume of off-pile contaminated material is approximately 550,000 yd³ (420,000 m³) and is composed of contamination adjacent to the tailings pile (244,000 yd³ [187,000 m³]), as well as windblown (240,000 yd³ [184,000 m³]) and waterborne (61,000 yd³ [47,000 m³]) contamination. Figure 1.3 presents the areal extent of contamination exceeding 5 picocuries per gram (pCi/g) (185 millibecquerels per gram [mBq/g]) radium (Ra)-226 in the area surrounding the tailings pile and outside the designated site.

Areas on the north, west, and south sides of the tailings pile contain approximately 244,000 yd³ (187,000 m³) of contaminated material. The material consists of contaminated soils and a raffinate pond adjacent to the southwest end of the tailings pile. These areas are divided into sections as described on Sheets 8 and 9 of Calculation MAY-377-01-00, Attachment 1, Volume III. Sheet 44 of Calculation MAY-377-01-00 shows the locations of these sections.

Wind has dispersed contamination to areas surrounding the tailings pile. Approximately 240,000 yd³ (184,000 m³) of soils are contaminated, with the largest areas located north and east of the tailings pile. These areas are divided into subareas, as described on Sheets 6 and 7 of Calculation MAY-377-01-00, Attachment 1, Volume III. Sheet 44 of Calculation MAY-377-01-00 shows the locations of these subareas.

Surface water flow has dispersed contamination to drainage areas near the tailings pile. Approximately 61,000 yd³ (47,000 m³) of soils are contaminated. Areas of contamination are divided into subareas as described on Sheets 6 and 7 of Calculation MAY-377-01-00, Attachment 1, Volume III. Sheets 39, 40, and 42 of Calculation MAY-377-01-00 show the locations of these subareas.

Two areas of elevated contamination ("hot spots") in the drainage systems are the result of waterborne contaminant transport (Figure 1.3). One hot spot is approximately 3000 ft (900 m) east of the tailings pile in Johnson Wash as it crosses under a county road. It is designated Subarea "Z" and consists of three separate locations covering approximately 2.7 ac (1.1 ha) (see Sheet 42 of Calculation MAY-377-01-00, Attachment 1, Volume III). Approximately 8800 yd³ (6700 m³) of soil will be excavated to an average depth of 2 ft (0.6 m) in these three areas and placed in the disposal cell.

The other hot spot, also in Johnson Wash, is south of the tailings pile near the confluence of Johnson Wash and Lay Creek. This hot spot consists of two areas within Johnson Wash, one on either side of U.S. Highway 40, designated Subarea "Z-1" and Subarea "Z-2." These two subareas cover approximately 7.5 ac (3.0 ha) (see Sheet 39 of Calculation MAY-377-01-00, Attachment 1,

Volume III). Approximately 24,100 yd³ (18,400 m³) of soil will be excavated to an average depth of 2 ft (0.6 m) in these two areas and placed in the disposal cell.

Cleanup of contaminated materials will not include the entire area depicted in Figure 1.3. The tailings pile, adjacent contaminated areas, and windblown contamination will be consolidated in the disposal cell, which will be constructed at the location of the existing tailings pile. Waterborne contamination in the two hot spots along Johnson Wash and Lay Creek also will be placed in the disposal cell. Drawings MAY-PS-10-0209 and MAY-PS-10-0210 of Attachment 1, Subcontract Documents, show the locations of all contaminated areas to be excavated as part of the remedial action.

With the exception of a few localized hot spots, the areas in Johnson Wash and Lay Creek only slightly exceed EPA standards (40 CFR Part 192) for Ra-226. Additional radiological characterization of Johnson Wash and Lay Creek will be performed prior to the start of remedial action. If additional localized hot spots are encountered, they will be excavated and placed in the tailings pile during remediation. The DOE will apply supplemental surface cleanup standards to the remaining contaminated areas of Johnson Wash and Lay Creek.

1.2.2 Proposed action overview

The proposed remedial action for the tailings pile and nearby areas of contaminated materials will be stabilization at the present location of the tailings pile. Contaminated materials (with the exception of localized hot spots) in Johnson Wash south of the windblown contaminated area and materials in Lay Creek will not be excavated. Part of the proposed action is to apply supplemental surface cleanup standards to the Johnson Wash and Lay Creek areas and not clean them up.

The completed disposal cell will cover approximately 66 ac (27 ha) and will be somewhat triangular, with a maximum length of 2650 ft (810 m) and a maximum width of 1750 ft (530 m) (Figure 1.4). A gently sloping rock erosion protection apron will extend out 20 ft (6 m) from the above grade sideslopes of the pile along the south and east toes. The apron will prevent headward erosion of gullies into the pile. The rock will be sized to resist erosion by flow from the probable maximum precipitation (PMP) on the pile or flow from the probable maximum flood (PMF) around the pile. In addition, areas around the pile will be graded to control surface drainage away from the disposal cell.

Contaminated materials stabilized in place at the present tailings pile location will be consolidated and contoured to form a disposal cell with maximum sideslopes of 20 percent (five horizontal to one vertical) and topslopes of 3 percent. The top of the cell will average 40 ft (12 m) above the surrounding terrain. Figure 1.5 shows a typical cross section of the disposal cell, including topslope and sideslope design parameters. The topslope of the cell will be covered with a fine-grained radon barrier 1.5 ft (0.5 m) thick. The radon barrier will consist of compacted overburden materials from the Rob Pit Overburden Pile, which have

NOT TO SCALE

NOTE: ELEVATIONS ARE GIVEN IN FEET.
TO CONVERT FROM FEET TO METERS,
MULTIPLY FEET BY 0.3048.

FIGURE 1.5
TYPICAL CROSS SECTION OF
THE MAYBELL TAILINGS SITE NEAR MAYBELL, COLORADO

been amended with 10 percent Redmond bentonite by weight to form a low-permeability layer that will reduce radon release to below performance standards and limit infiltration of precipitation through the tailings. A frost protection layer 4 ft (1.2 m) thick will overlie the radon barrier to prevent frost penetration from reaching the radon barrier and increasing its permeability. The uppermost cover of the cell will consist of a 6-inch (15-cm) gravel bedding layer overlain by an 8-inch (20-cm)-thick layer of riprap to prevent wind and water erosion and gully development. The riprap protection was designed to resist erosion by flow from the PMP on the pile.

Sideslopes of the disposal cell will be covered with a 1.5-ft (0.5-m)-thick, fine-grained radon barrier. The radon barrier will consist of compacted overburden materials from the Rob Pit Overburden Pile. The Rob Pit overburden materials will be amended with 10 percent Redmond bentonite by weight to form a low-permeability layer that will reduce radon release to below performance standards and limit infiltration of precipitation through the tailings. A 4-ft (1.2-m)-thick frost protection layer will overlie the radon barrier to prevent frost penetration from reaching the radon barrier and affecting its permeability. The outermost sideslope cover will consist of a 6-inch (15-cm)-thick gravel bedding layer overlain by a 1-ft (0.3-m)-thick riprap layer. The bedding layer and riprap were designed to resist PMP peak discharges in accordance with standard design procedures described in the Uranium Mill Tailings Remedial Action (UMTRA) *Technical Approach Document* (TAD) (DOE, 1989).

On the north, west, and south sides of the stabilized pile, permanent ditches will be constructed to divert flow away from the pile. Figure 1.4 presents the location and extent of two permanent ditches (Nos. 1 and 2). The rock designed for the erosion protection layer for the two ditches will be sized to resist erosion by flow from the PMP or PMF.

Key trenches designed to be collapsible and provide a stable slope against scours are provided at the outlet for permanent ditch No. 1 and the gullies along Johnson Wash and at the inlet for permanent ditch No. 2 and the apron along the eastern and southern embankment toe. Additional erosion protection (Figure 1.4) for the stabilized pile will be implemented in the area between the pile and Johnson Wash. This area will be regraded and the gullies protected with rock riprap.

The final restricted area will cover approximately 265 ac (107 ha). Warning signs, boundary markers, and survey monuments will mark the perimeter of the area. The areas surrounding the disposal cell that were disturbed by the remedial action will be backfilled as required, graded to control surface drainage, and revegetated.

To achieve compliance with the proposed EPA ground water protection standards (52 FR 36000), the DOE proposes a narrative supplemental standard to ensure protection of human health and the environment. Design parameters of the proposed disposal cell have been evaluated in conjunction with the

hydrogeologic and geochemical characteristics of the Maybell site. Although not necessary to the ground water protection strategy presented in the RAP, naturally occurring geochemical conditions within the Browns Park Formation aquifer (uppermost aquifer) tend to decrease contamination of ground water downgradient within the influence of the existing tailings pile. Because the disposal cell design will restrict water infiltration, steady-state seepage from the disposal cell following construction will be less than the seepage that is currently occurring. Therefore, contamination of ground water downgradient of the affected area should be less than that currently present over the long term. Based on the site evaluations conducted to date, the DOE has demonstrated that the proposed disposal cell design will comply with the proposed EPA ground water protection standards (52 FR 36000 (1987)).

1.2.3 U.S. Environmental Protection Agency standards and proposed action compliance

On November 8, 1978, Congress passed the UMTRCA 42 USC §7901 *et seq.* Title I of the UMTRCA authorized the Secretary of Energy to enter into cooperative agreements with affected states or Indian tribes to clean up those inactive sites contaminated with uranium mill tailings. Title I required the EPA to promulgate standards for these sites and defined the role of the NRC.

In developing these standards, the EPA determined that the primary objective for control of residual radioactive materials (RRM) is isolation and stabilization to prevent their misuse by people and dispersion by natural forces. Other objectives are to reduce radon emissions and eliminate significant public exposure to gamma radiation.

On September 3, 1985, the U.S. Court of Appeals for the Tenth Circuit remanded the portion of the standards relating to ground water. Proposed standards were issued for comment by the EPA on September 24, 1987 (52 FR 36000). Subpart A of the proposed standards sets forth the requirements for control of the contaminant releases to ground water at the disposal sites.

As required by the UMTRCA, remedial action at the Maybell site must comply with the regulations established by the EPA in Subparts A through C of 40 CFR Part 192 (1993) and 52 FR 36000 (1987). The regulations and proposed action compliance with the EPA standards can be summarized as follows:

Disposal site longevity

The disposal site will be designed to stabilize and control the tailings and other RRM's for 1000 years to the extent reasonably achievable and, in any case, for at least 200 years (40 CFR §192.02(a)(1)) (40 CFR Part 192 (1993) and 52 FR 36000 (1987)).

The proposed remedial action, stabilization in place at a repository cell, has been designed to meet 40 CFR Part 192, Subpart A, and 52 FR 36000. Design

parameters for the proposed repository follow the latest UMTRA Project guidance (DOE, 1989) developed to ensure compliance with 40 CFR Part 192 performance criteria. Repository design components were chosen to meet the minimum of 200-year effectiveness and the desired 1000-year effectiveness requirements.

The construction of an engineered disposal cell will satisfy the requirements for long-term tailings control. Detailed investigations of geologic, geomorphic, and seismic conditions at the Maybell site were conducted and incorporated in the remedial action design.

Seismic design parameters were developed for the geotechnical analyses of the disposal cell. The geotechnical stability of the disposal cell was analyzed to ensure long-term performance in meeting the design standards. Geotechnical analyses included slope stability, settlement, and liquefaction potential.

The top cover and sideslope design will minimize water infiltration through the pile and pile erosion. The disposal cell cover and erosion protection features were analyzed and designed to isolate the contaminated materials from surface water and wind erosion. The disposal site will be stable geomorphically, i.e., against gully erosion in the vicinity of the cell or slope failure. Tributary gullies between Johnson Wash and the disposal embankment also will be stabilized by slope control and protected by riprap material.

Radon emission barrier

The disposal site design will prevent radon-222 emission from the RRM to the atmosphere such that the flux rate does not exceed 20 picocuries per square meter per second (pCi/m²s) (0.74 becquerels per square meter per second [Bq/m²s]) or increase the annual average concentration of radon-222 in air at or above any location outside the disposal site by more than 0.5 picocurie per liter (pCi/L) (18.5 becquerels per cubic meter [Bq/m³]) (40 CFR §192.02(a)(2)) (40 CFR Part 192 and 52 FR 36000).

The disposal cell's 1.5-ft (0.5-m)-thick fine-grained radon barrier will meet the radon emissions requirements of 40 CFR §192.02(a)(2), Subpart A (40 CFR Part 192 and 52 FR 36000). The compacted overburden materials from the Rob Pit Overburden Pile will be amended with 10 percent Redmond bentonite by weight to form a low-permeability layer that will reduce radon release to below performance standards and limit infiltration of precipitation through the tailings.

Surface cleanup standards

Surface remedial action will be conducted to provide reasonable assurance that the Ra-226 concentration in land not part of the disposal site averaged over any area of 100 square meters (m²) (1076 square ft [ft²]) does not exceed the background level by more than 5 pCi/g (185 mBq/g) averaged over the first 6 inches (15 cm) of soil below the surface and 15 pCi/g (555 mBq/g) averaged

over 6-inch (15-cm) layers of soil more than 6 inches (15 cm) below the surface, as a result of any RRM's at the designated processing site (40 CFR §192.12(a)), Subpart B (40 CFR Part 192).

Detailed investigations on the extent of contamination at the Maybell site have determined that, in addition to the contaminated material in the existing tailings pile and the demolition debris from the former processing mill, off-site contamination also exists. Wind dispersion and storm water runoff have contaminated areas adjacent to the tailings pile. Waterborne contamination is present in Johnson Wash and a portion of Lay Creek near its confluence with Johnson Wash.

The requirements of 40 CFR §192.12(a), Subpart B (40 CFR Part 192), will be followed as cleanup standards. Cleanup of the contaminated areas with subsequent disposal within the engineered cell will ensure the protection of human health and the environment. Contaminated materials from the former mill processing yard, windblown areas, vicinity properties, and the localized hot spots in Johnson Wash and Lay Creek will be placed with the tailings on the existing pile.

The DOE will follow Subpart C of 40 CFR 192.21(b) (40 CFR 192) regarding the proposed use of supplemental surface cleanup standards for portions of Johnson Wash and Lay Creek. Contaminated materials (except the localized hot spots) in Johnson Wash south of the windblown contaminated area and materials in Lay Creek will not be excavated and placed in the tailings pile. Justification for DOE's proposed use of supplemental surface cleanup standards to most of Johnson Wash and Lay Creek is based on the following criteria:

- Environmental harm to riparian and wetland areas.
- Costly excavation and diversion of Lay Creek.
- Detrimental effects on geomorphic stability in Johnson Wash.
- Low radon flux from existing contaminants.
- Low predicted effects from human consumption of cattle that graze in Johnson Wash.

Ground water protection compliance

The DOE must demonstrate compliance with the proposed EPA ground water protection standards (52 FR 36000).

The DOE has characterized the hydrogeologic units, hydraulic properties, water quality, ground water use, and geochemical conditions at the Maybell site. The Browns Park Formation underlies the existing tailings pile. The principal aquifer system (uppermost aquifer) is the upper sandstone unit of the Browns Park

Formation. The top of the unconfined ground water table occurs within this formation at depths from 35 to greater than 300 ft (11 to 90 m) beneath the ground surface. Ground water flows southwesterly, away from the existing tailings pile. The nearest downgradient domestic well is 3 mi (5 km) south of the tailings site.

The disposal option proposed for the Maybell tailings site involves stabilizing the existing tailings and associated contaminated materials in place. An above-ground disposal cell has been designed to reduce radon emanation, minimize infiltration of water, withstand differential settlement, resist degradation, and meet the proposed EPA ground water protection standards (52 FR 36000).

To achieve compliance, the DOE proposes a narrative supplemental standard to ensure protection of human health and the environment. The supplemental ground water standard applies to the Browns Park Formation. The consideration of a supplemental ground water standard has included long-term seepage and transient drainage from the completed disposal cell. Favorable geochemical conditions at the site enhance the disposal cell performance but are not necessary to the supplemental standard ground water protection strategy.

The DOE is not proposing numerical concentration limits or a designated point of compliance (POC) for hazardous constituents identified in the ground water at the Maybell site. Background ground water quality in the Browns Park Formation aquifer is highly variable and generally poor. Concentrations of the EPA proposed hazardous constituents vary from below laboratory method reporting limits to one order of magnitude above the proposed EPA standards. In addition, the ground water in the Browns Park Formation downgradient of the affected area is not an historic or current drinking water source. Establishing numerical concentration limits for the identified hazardous constituents at a specified POC will not further protect human health and the environment.

Ground water cleanup criteria

Cleanup of contaminated ground water must be addressed under conditions of 40 CFR Part 192, Subpart B, of the EPA proposed ground water standards (52 FR 36000). Additional investigations will be conducted to identify an appropriate remediation strategy. The final decision of how EPA ground water cleanup standards will be met at the Maybell site will be part of the UMTRA Ground Water Project.

A performance assessment indicates that the proposed remedial action will comply with the proposed EPA ground water standards (52 FR 36000) because 1) most downgradient monitor wells within the influence area of the tailings pile have not provided evidence of ground water contamination resulting from mill operations at the designated site; 2) the disposal cell design will minimize infiltration of water; 3) temporary increased seepage rates will occur immediately following disposal cell closure but will return to steady-state conditions after 1.5 years (the effects of this temporary increased seepage rate

will be no worse than that which occurred during the period of mill operations); and 4) favorable geochemical conditions rapidly decrease contamination of ground water downgradient within the influence of the tailings pile.

1.3 SCOPE AND CONTENT

This RAS report is structured to provide a brief but comprehensive description of the proposed remedial action for the Maybell site. An extensive amount of data and supporting information generated and evaluated for this remedial action are not incorporated into this single document, but are included or referenced in the supporting documents. Pertinent information and data are included in this RAP with reference to the supporting documents. The RAP will consist of this RAS and the following supporting documents:

- Attachment 1: Subcontract documents, calculations, specifications, design drawings, and information for bidders contain detailed information on the remedial action design. Attachment 1 includes the following documents:
- "Subcontract Documents, Final Design for Construction."
 - "Calculations, Final Design for Construction," Volumes I-V.
 - "Information for Bidders, Final Design for Construction," Volumes I-V.
- Attachment 2: Geology Report; describes the details of geologic, geomorphic, and seismic conditions at the site.
- Attachment 3: Ground Water Hydrology Report; describes the hydrology, water quality, and water resources at the site, includes the Hydrological Services Calculations as Appendix A and Ground Water Quality by Location as Appendix B.
- Attachment 4: Water Resources Protection Strategy; describes how the remedial action will comply with the proposed EPA ground water standards.

These reports provide data, analyses, and a more detailed description of the various aspects of the RAP.

1.4 COLLATERAL DOCUMENTS

The Maybell EA (DOE, 1994) describes existing conditions at the site and the potential impacts of the remedial action. The EA describes the proposed remedial action, the alternatives, and the associated environmental impacts of the alternatives. The EA presents environmental information describing the site in greater detail than in the RAP. The EA provides additional site information on

threatened and endangered species and presents the floodplain assessment for the Johnson Wash and Lay Creek areas.

The TAD (DOE, 1989) describes the technical approaches and procedures used on the UMTRA Project. The TAD contains discussions on major technical areas; design considerations; surface water hydrology and erosion control; geotechnical aspects of disposal cell design; radiological issues, in particular, as they pertain to the radon barrier; and the protection of ground water resources.

Copies of these collateral documents, as well as supporting data and calculations for the Maybell project, are on file in the UMTRA Project Office in Albuquerque, New Mexico.

1.5 REMEDIAL ACTION SELECTION REPORT ORGANIZATION

Sections 2.0 through 6.0 of this RAS report have been organized by technical discipline. The compilation and presentation of information in this RAS have been modeled after the approach taken in the NRC site technical evaluation report (TER). The RAS report has been formatted in accordance with the requirements of the NRC's standard format and content (SF&C) (NRC, 1989) guide for documentation as applicable to the UMTRA Project site. This document has been generated to facilitate the NRC's preparation of a TER for the proposed remedial action at the Maybell site. The design details of the proposed remedial action and relevant criteria are available in supporting documents, reports, drawings, specifications, and calculations, as described in Section 1.3 and summarized in Table 1.2.

Table 1.2 Relationship between design details/criteria and supporting calculations and reports

Design detail or criteria	Calculation number	Title ^a
Geomorphology	MAY-330-03-00	Embankment Design—Bedrock and Top of Original Ground Contours (Calculations; Attachment 1, Volume I)
Seismicity	MAY-337-01-01	Maybell Processing (Uranium Tailings) Site—Evaluation of Site Seismicity and Design Earthquake Parameters (Calculations; Attachment 1, Volume I)
Surface water	MAY-323-02-01	Site Hydrology—Probable Maximum Precipitation (Calculations; Attachment 1, Volume IV)
	MAY-323-11-01	Site Hydrology—Rainfall Depth, Intensity, Duration, and Frequency Relations (Calculations; Attachment 1, Volume IV)
	MAY-336-15-00	Permanent Site Drainage—Sediment Properties (Calculations; Attachment 1, Volume IV)
	MAY-354-01-00	Permanent Site Drainage—Permanent Drainage Ditches (Calculations; Attachment 1, Volume IV)
	MAY-354-02-00	Permanent Site Drainage—Drainage Swale 2 (Calculations; Attachment 1, Volume IV)
Geotechnical	MAY-354-03-00	Permanent Site Drainage—Drainage Swale 1 (Calculations; Attachment 1, Volume IV)
	MAY-330-01-01	Embankment Design—Contaminated Material Properties (Calculations; Attachment 1, Volume I)
	MAY-335-02-01	Embankment Design—Slope Stability Analysis (Calculations; Attachment 1, Volume II)
	MAY-338-01-01	Liquefaction Potential (Calculations; Attachment 1, Volume I)
	MAY-338-02-00	Earthquake Induced Settlement (Calculations; Attachment 1, Volume II)
	MAY-355-03-01	Embankment Design—Physical Properties of Radon Barrier Material (Calculations; Attachment 1, Volume III)
	MAY-392-01-00	Embankment Design—Settlement Analysis (Calculations; Attachment 1, Volume II)
	MAY-394-01-00	Embankment Design—Cover Cracking Analysis (Calculations; Attachment 1, Volume II)
	MAY-396-01-00	Rob Pit Overburden Pile—Slope Stability Analysis (Calculations; Attachment 1, Volume II)

Table 1.2 Relationship between design details/criteria and supporting calculations and reports (Continued)

Design detail or criteria	Calculation number	Title*
Radon barrier	MAY-326-01-00	Radon Barrier Design—RAECOM Input Data (Calculations; Attachment 1, Volume III)
	MAY-327-02-01	Radon Barrier Design—Statistical Analysis of Ra-226 Concentration Data (Calculations; Attachment 1, Volume III)
	MAY-326-02-00	Radon Barrier Design—Thickness Design (Calculations; Attachment 1, Volume III)
	MAY-358-01-00	Radiological Characterization—Rob Pit Overburden Pile (Calculations; Attachment 1, Volume III)
	MAY-398-03-00	Cover Design—Frost Penetration (Calculations; Attachment 1, Volume III)
Erosion protection	MAY-336-05-01	Erosion Protection—Johnson Wash Flooding Potential (Calculations; Attachment 1, Volume II)
	MAY-336-06-00	Erosion Protection—Rock Quality Evaluation (Calculations; Attachment 1, Volume I)
	MAY-336-07-02	Erosion Protection—Gradation Requirements (Calculations; Attachment 1, Volume I)
	MAY-336-11-01	Erosion Protection—Embankment Top and Sideslopes (Calculations; Attachment 1, Volume IV)
	MAY-336-12-01	Erosion Protection—Embankment Toe Apron (Calculations; Attachment 1, Volume IV)
	MAY-336-13-02	Erosion Control—Rob Pit Overburden Pile (Calculations; Attachment 1, Volume IV)
	MAY-350-01-00	Erosion Protection—Johnson Wash Tributary Gullies 1 to 4 (Calculations; Attachment 1, Volume II)
Construction	MAY-320-01-01	Borrow Site Evaluation (Calculations; Attachment 1, Volume V)
	MAY-325-01-01	Site Hydrology/Temporary Facilities—Temporary Drainage and Retention Basins (Calculations; Attachment 1, Volume V)
	MAY-340-01-01	Demolition Debris—Quantity Estimate (Calculations; Attachment 1, Volume III)
	MAY-347-03-03	Bid Schedule Quantities and Material Balance—Quantity Estimates (Calculations; Attachment 1, Volume V)

Table 1.2 Relationship between design details/criteria and supporting calculations and reports (Continued)

Design detail or criteria	Calculation number	Title*
Construction (continued)	MAY-350-01-00	Water Consumptions—Construction Water Requirements (Calculations; Attachment 1, Volume V)
	MAY-356-01-01	Embankment Quantities—Cover and Erosion Protection (Calculations; Attachment 1, Volume V)
	MAY-356-02-01	Final Site Grading—Earthwork Quantities (Calculations; Attachment 1, Volume V)
	MAY-356-03-00	Drainage Swale 1—Earthwork Quantities (Calculations; Attachment 1, Volume V)
	MAY-377-01-00	Contaminated Material—Excavation Limits and Quantities (Calculations; Attachment 1, Volume III)
Ground water hydrology	MAY-11-93-14-07-00	Calculation of Regional Hydraulic Gradient and Average Linear Ground Water Velocity in the Browns Park Formation (Hydrological Services Calculations; Attachment 3, Appendix A)
	MAY-09-90-14-11-00	Source Concentration Calculation of Mean Source Concentration (Averaged Concentrations from Lysimeters 081, 083, 085) (Hydrological Services Calculations; Attachment 3, Appendix A)
	MAY-03-90-14-03-00	Calculation of Transmissivity, Storativity, and Hydraulic Conductivity in Tertiary Browns Park Formation (Hydrological Services Calculations; Attachment 3, Appendix A)
	MAY-03-94-14-03-00	Volumetric Mixing Calculations. Revised to reflect correct hydraulic gradient and revised cover flux for the disposal cell. Estimates resultant concentrations of constituents in ground water at the downgradient edge of tailings pile (Hydrological Services Calculations; Attachment 3, Appendix A)
	MAY-09-90-14-02-00	Analysis of Slug Test Data Using the Bouwer-Rice Method (Hydrological Services Calculations; Attachment 3, Appendix A)
	MAY-03-94-12-04-00	Simulation of Cover Flux Using the HELP Model (Hydrological Services Calculations; Attachment 3, Appendix A)
	MAY-03-94-12-05-00	Transient Drainage From Consolidation of Slimes (Hydrological Services Calculations; Attachment 3, Appendix A)

Table 1.2 Relationship between design details/criteria and supporting calculations and reports (Concluded)

Design detail or criteria	Calculation number	Title*
Ground water hydrology (continued)	MAY-03-94-12-06-00	Contaminant Transport of Transient Drainage (Hydrological Services Calculations; Attachment 3, Appendix A)

*The reference source for calculation number is provided in parentheses at the end of the title.

2.0 GEOLOGIC STABILITY

This section presents data and analyses showing that the DOE has adequately characterized the Maybell site regarding the impact of geologic conditions on long-term performance objectives of the remedial action as defined by 40 CFR §192.02(a)(1) (40 Part CFR 192 (1993) and 52 FR 36000 (1987)).

The EPA standards listed in 40 CFR Part 192 and 52 FR 36000 do not include generic or site-specific requirements for the characterization of geologic conditions at UMTRA Project sites. Rather, 40 CFR §192.02(a)(1) and 52 FR 36000 require tailings control to be effective for 1000 years to the extent reasonably achievable and, in any case, for at least 200 years. To achieve this long-term stability, certain geologic performance objectives must be met. For example, as noted in the NRC draft Standard Review Plan (SRP) (NRC, 1985), basic regional and site geology and site stratigraphy information is required. This information is the basis for the geotechnical and ground water aspects of the disposal cell performance evaluation described in Sections 3.0 and 5.0, respectively, of this document. An evaluation of the potential for geomorphic hazards is required, and the DOE must show that potential geomorphic change will not affect the disposal cell's integrity over its design life. The site geological characterization provides estimates of earthquake-induced ground accelerations that could occur at the site, as well as the potential for other types of tectonic hazards that could affect the disposal cell performance. The site geological characterization also demonstrates that future resource development will not adversely affect the disposal cell stability over the design life. The TAD (DOE, 1989) describes additional criteria used in the site evaluation.

2.1 SCOPE OF WORK

Detailed investigations of geologic, geomorphic, and seismic conditions at the site were conducted in accordance with the procedures and approaches described in the TAD (DOE, 1989) to gather the data specified in the NRC's SF&C guide (NRC, 1989). These investigations include a compilation and analysis of previously published and unpublished geologic maps and literature; review of historical and instrumental seismic data; review of site-specific subsurface geologic data, including logs of exploratory boreholes and test pits in the site area; photogeologic interpretation of LANDSAT and conventional aerial photographs; low-sun-angle aerial reconnaissance of the site region; and ground reconnaissance and mapping of the site region and detailed mapping of the site area. The documents referenced in this section provide details of the data gathering and interpretation procedures.

The most significant geologic features affecting the disposal cell's long-term stability are the gullies eroding into the existing tailings pile and the high concentration of faults identified on the site. This RAP gives special attention to analysis and discussion of these features.

2.2 REGIONAL GEOLOGY

A regional geology description provides the background for the detailed site geology. As noted in the NRC SRP (NRC, 1985), the regional geology must be defined in sufficient detail to provide a clear perspective and orientation to the site-specific subsurface information.

Attachment 2, Geology Report, characterizes the regional geologic conditions. Most information in this RAS report was derived from published studies referenced therein. The site region is defined as the area within a 40-mi (65-km) radius of the disposal site.

2.2.1 Regional physiography

The Maybell site region is in the Sand Wash Basin subprovince of the Wyoming Basin physiographic province. The basin is a depression bounded on the west by the Middle Rocky Mountains and on the south by the Southern Rocky Mountains and is contiguous with the Great Plains to the northeast. Minor folding and faulting have divided the region into subbasins.

As called for in the NRC SF&C guide (NRC, 1989), the following is a description of the main physiographic features of the region:

- Type of geomorphic surface surrounding the site: Fluvial erosional and depositional surfaces occur in the basin. At higher elevations, moraines and terraces associated with mountain glaciation are present.
- General relief and topography of the region: The depth of the Yampa River canyon in the site region is about 500 ft (150 m). The slopes in the region are generally less than 15 percent, except in some canyons of the Yampa River.
- Regional drainage systems: Superimposed meandering rivers and streams and tributary perennial and ephemeral streams characterize the basin. The lack of relationship between the drainage pattern in the region and any pre-Miocene structures suggests that the stream system was established on top of a formerly continuous cover of the Browns Park Formation. As the Browns Park Formation was steadily eroded, the drainage system was "let down" and superimposed onto the underlying rocks and structures.
- Major regional geomorphic processes: The dominant regional geomorphic cycles of stream aggradation and degradation control landscape development. Major rivers and their tributaries have dissected the basin by headward erosion and nickpoint migration.

Section 2.1, Physiographic Setting, Attachment 2, provides further details of the regional physiographic setting and the basis for the above brief description. It

describes the geomorphic landforms, the regional relief and topography, the drainage systems, and the types and rates of the major geomorphic processes.

2.2.2 Stratigraphic setting

Bedrock in the site region consists mainly of Oligocene to Miocene Browns Park Formation. This formation comprises eolian sand deposits that unconformably overlie rocks of mostly Early Tertiary and Mesozoic age throughout the basin. Tertiary volcanic rocks are in the eastern part of the region, and a granitic Precambrian basement complex underlies Precambrian sedimentary rocks in the western part.

Section 2.2, Stratigraphic Setting, Attachment 2, provides further details of the technical approach to and the results of the characterization of the regional and site stratigraphy. The report gives further details of the age, name, thickness, lithology, induration, relationship to adjacent units, and geographic distribution of stratigraphic units.

2.2.3 Structural setting

The structural portion of the Sand Wash Basin that underlies the site, defined by Hansen (1986) as the Axial Basin Arch, trends northwest in the site and is the dominant structural feature in the site region. This arch is a collapsed anticlinal structure tectonically related to the Uinta Uplift to the northwest and the White River Uplift to the southeast. On a larger scale, the Axial Basin Arch is a transition between the Colorado Plateau to the south and the Wyoming Basin to the north.

The Axial Basin Arch experienced several compressional and extensional events that developed during the Proterozoic (pre and syn-Uinta Mountain Group) and were reactivated and enhanced during Cambrian, Pennsylvanian-Permian, and the Late Cretaceous-Early Tertiary Laramide orogeny. The Axial Basin Arch collapsed in mid-Tertiary before deposition of the Browns Park Formation and was reactivated after Browns Park time (Miocene—5 to 20 million years ago). Quaternary displacements of the Axial Basin Arch have not been documented in the site region.

Section 2.3, Structural Setting, Attachment 2, provides greater details of the site region's structural setting. The regional structural elements show the relationship of the site region to adjoining structural provinces. The section discusses the nature and formation of the structures and the current stress regime of the province within which the site lies relative to adjoining elements, as well as the bedrock structure of the disposal site foundation.

2.2.4 Seismotectonics

The DOE has characterized the potential for tectonic activity in local and regional structures that may contribute to earthquake generation and affect the suitability of the site and design as follows.

Seismicity

Section 4.2, Seismotectonic Stability, Attachment 2, discusses the historical seismicity record in detail. This historical record is derived from the seismic data within a 125-mi (200-km) site radius. Tables 4.2 through 4.4 in Section 4.2 of Attachment 2 present the historical seismicity of all earthquakes within a 40-mi (65-km) radius of the Maybell site. These tables include the date and time of each event, the epicenter, the distance from the Maybell site, the depth of focus, the magnitude, and the intensity. Table 4.2 presents the maximum earthquake seismotectonic provinces recommended by previous studies. Table 4.3 presents earthquakes of magnitude 4.0 or greater located instrumentally since 1963. Table 4.4 presents the data for earthquakes of Intensity III or greater before 1963.

Section 2.4, Seismotectonic Setting, Attachment 2, discusses the seismic setting in detail, referencing all sources of information. The section describes seismic activity possibly related to known or suspected fault systems (discussed below) and details the expected acceleration resulting from the largest regional earthquakes. A summary of the main points follows.

No areas of recurring seismicity are within a 40-mi (65-km) site radius; however, within a 125-mi (200-km) radius are several locations with clusters of epicenters, especially along the margins of the Colorado Plateau, the Western Mountain Province, and the Rio Grande Rift. Steamboat Springs, Colorado, is the nearest active location. The maximum instrumentally recorded earthquake within the 125-mi (200-km) radius was a 1973, body-wave magnitude (M_b) = 5.4, event located 51 mi (82 km) from the site. The largest historical earthquake in the 125-mi (200-km) radius was an 1882 event of Intensity VIII (M = approximately 6.4) outside the 40-mi (65-km) site region.

Local areas in the site region may respond to regional earthquakes with anomalously high intensity. Thus, an earthquake with an epicenter 130 mi (210 km) away could have a much higher intensity response in the Maybell vicinity than earthquakes at intervening distances. The site-specific response of saturated alluvium in these nearby sites probably causes such anomalies, which apparently do not represent bedrock site response. The town of Maybell, 5 mi (8 km) southwest of the site, is situated on saturated floodplain deposits that amplify seismic waves. The fact that the site area is on bedrock and not saturated alluvium suggests that regional seismic events will differ significantly from those of the town of Maybell.

The parameters used to design pile stability against earthquake-induced forces are based on the information discussed herein.

Tectonics

Section 2.4, Seismotectonic Setting, Attachment 2, describes in detail the seismotectonic setting related to the structural geology of the region. Figure 2.9 of Attachment 2 shows the tectonic provinces, which are based on previously referenced studies of the region that correlate structural features with seismic activity. Evidence of tectonic activity within the provinces, such as uplift or subsidence rates, active fault traces, volcanism, and heat flow, is cited as characteristic of each province. The section discusses areas of earthquake activity that cannot be correlated to known structures. Plate 1 of Attachment 2 shows epicentral locations within a 40-mi (65-km) site radius relative to the known fault systems in the site region. A brief summary of important aspects of the regional tectonics follows.

The Maybell site lies within the central part of the Uinta-Elkhead seismotectonic province, whose dominant structure is the complex fault system associated with the east-west axis of the Uinta Anticline and Axial Basin Arch. The axial structure is bounded on the north by the Uinta-Sparks Fault system and on the south by the Willow Creek Fault system.

Geomorphic evidence was collected to determine the age of the last fault movement in the Maybell site region and to estimate the minimum time since displacement. Based on the appearance of stability of the regional and local drainages, the evidence suggests that the last movements did not occur before the Late Pleistocene. The analysis of all known fault groups within the 40-mi (65-km) radius concluded that all the faults are noncapable.

The above information on the site region tectonics provides the basis for estimating the site-specific seismic design parameters.

2.2.5 Resource development

To ensure that no future resource development jeopardizes the disposal cell, the occurrence of recoverable earth resources in the site area was characterized. Resources of concern are those that, if exploited, could result in inadvertent intrusion into the disposal site.

Economic resources in the site region consist of energy and mineral resources including uranium and vanadium ores, coal, oil and gas, oil shale, and other metallic and nonmetallic minerals including gold, silver, copper, gypsum, and potash. Only uranium has been exploited in the immediate site area.

Section 2.5, Mineral Deposits and Other Resources, Attachment 2, presents further details of the site and regional resources. Figure 2.10 of Attachment 2 shows the locations of regional mineral resources.

The DOE has identified resources occurring near the site, such as fossil fuels, metallic and nonmetallic mineral deposits, and geothermal energy sources. No resources are likely to be developed at the site to the extent that they affect the disposal cell.

2.3 SITE GEOLOGY

Site bedrock geological conditions have been characterized to provide the basic information required for the geotechnical stability evaluations (Section 3.0 of this report) and for water resources protection at the site (Section 5.0 of this report). Surficial geologic conditions characterized to establish the geomorphic history and processes at the site will determine if the long-term stability standards will be met.

The procedures to characterize site geology and the details of that characterization are in Section 3.0, Site Geology and Geomorphology, Attachment 2. The following briefly describes the site's geologic features.

2.3.1 Bedrock geology

The Browns Park Formation immediately underlies the site and consists of approximately 800 to 900 ft (240 to 275 m) of thinly bedded to massive, crossbedded, light gray and white, silty, fine-grained sandstone. The sandstone is slightly to moderately cemented in outcrops and in the unsaturated zone but is only weakly cemented below the water table. Unconformably beneath the Browns Park Formation at the site are the Mancos Shale and older Mesozoic, Paleozoic, and Precambrian sediments. Pre-Browns Park Formation erosion has removed upper Cretaceous through Eocene formations found below the Mancos Shale at other localities in the Sand Wash Basin.

Figures 3.1, 3.2, 3.3, and 3.4 of Attachment 2 show bedrock at the site area.

2.3.2 Surficial geology

All contaminated materials from the Maybell tailings site will be consolidated onto the existing tailings pile. The existing tailings pile overlies colluvium-mantled slopes and narrow alluvial deposits in gullies that feed Johnson Wash. These colluvial and alluvial deposits are up to 25 ft (7 m) thick.

Soils on the surficial deposits either lack B horizons or have thin B horizons that are siltier and redder than the underlying sandy alluvium and probably formed in sporadic eolian deposits. The presence of multiple soil horizons suggests that changes in precipitation and vegetation have caused alternating periods of landscape stability and erosion during Holocene time.

The surficial soils of the site are shown in Figure 3.1 and described in Section 3.2, Surficial Geology, Attachment 2.

2.3.3 Geomorphology

Site geomorphology has been characterized to confirm the current landscape stability and provide reasonable assurance of continued stability for the performance period required by the standards (40 CFR §192.02(a)(1)) (40 CFR Part 192 (1993) and 52 FR 36000 (1987)). The DOE has characterized the regional and site geomorphology by reference to published literature, topographic maps, site inspections, and the procedures described in the TAD (DOE, 1989). Section 2.1.2, Regional Geomorphology, Attachment 2, details the regional geomorphology; Section 4.1, Geomorphic Stability, Attachment 2, details the site-specific geomorphology. The following summarizes the main aspects of the geomorphology directly relevant to site remedial action.

The dominant geomorphic feature at the site area is the drainage basin of Johnson Wash, a minor southward-flowing tributary of Lay Creek. This drainage basin has three distinct parts—an upper basin, a central basin, and a lower basin. The upper basin headwaters include the dissected flank of a broad ridge. The central basin is underlain by a sloping, bowl-like area where main gullies join to form the main channel of Johnson Wash. The lower basin cuts through a high ridge, forming a narrow, steep-sided valley 200 to 250 ft (60 to 75 m) deep before intersecting Lay Creek. Overall, the basin is 5 mi (8 km) long and has an approximate 4.3-square mi (mi²) (11.1 square km [km²]) drainage basin area above the Lay Creek confluence. Total relief of the basin from Lay Creek to the drainage divide is 760 ft (230 m), with the present tailings pile about 230 ft (70 m) higher than Lay Creek.

The disposal cell area is in the central basin of Johnson Wash. The central basin probably acquired its bowl-like shape because of large sediment yields from the surrounding, steeper hillside. The central basin has experienced several cycles of Quaternary erosion and stability. Open pit mine walls expose paleo-gullies now filled with surficial deposits, and modern gullies are incised into alluvium. The lower basin contains terraces along its outlet valley, further attesting to at least two periods of channel incision followed by deposition.

The DOE has described the geomorphic processes that determined the site's landforms, examined the geomorphic processes that could affect site stability, and assessed the future geomorphic processes likely to occur. Section 4.1, Geomorphic Stability, Attachment 2, presents a detailed discussion of the Maybell site geomorphology. This characterization is considered sufficient to undertake an assessment of the site geomorphic stability, as described in Section 2.4.1 of this report.

2.4 GEOLOGIC STABILITY

This section describes the local geologic and seismic conditions likely to affect the geotechnical stability of the disposal cell and the long-term stability of the surrounding landscape. The analysis considers the characteristics of unconsolidated deposits and geomorphic processes at the site that may affect long-term stability. This section establishes the suitability of the site lithology, stratigraphy, and structural conditions as a disposal cell foundation. Information provided supports a performance assessment of the interaction of tailings leachate on the ground water (Section 5.0 of this report). This section demonstrates that geomorphic processes are not likely to affect the long-term stability of the disposal cell. Potential geologic events, including seismic shaking, liquefaction, on-site rupture, ground collapse, and volcanism, are eliminated as potential disturbing forces on the cell, because either they will not occur or the geotechnical design of the cell is formulated to resist such forces.

2.4.1 Geomorphic stability

The DOE provides evidence of the long-term site stability and the expected stability for the performance period of the disposal cell in Section 4.0 of this report and in Section 4.1, Geomorphic Stability, Attachment 2. The main geomorphic stability concerns at the site are discussed below.

Fluvial processes of most concern to long-term cell stability are gully formation and migration, stream channel erosion, sheetwash erosion, and the effects of base-level changes. The large-scale processes controlling the geomorphology of the Lay Creek basin are temporary sediment storage and flushing in the central basin and continuing incision due to base-level changes. The central basin of Johnson Wash is in a period of erosion, as expressed by headward extension, branching, and incising of gullies and by slumping along gully sides.

The greatest geomorphic hazard at the disposal site is the potential headward erosion and gully incision of tributary channels to Johnson Wash. Several incised gullies extend westward from the main trunk of Johnson Wash to the edge of the existing tailings pile. One of these gullies, buried by tailings, extends approximately halfway through the tailings pile. This gully cuts into the Browns Park Formation and the overlying tailings. Actively eroding nickpoints occur in this and other gullies near their junction with the main trunk of Johnson Wash and may be eroding headward as fast as 3 or 4 ft (1 to 1.2 m) per year.

The most important geomorphic issues concern future gully growth and methods for restricted growth near the proposed disposal cell embankment. Any modifications to the outlet valley of Johnson Wash would significantly affect erosion processes upstream near the proposed disposal cell. Unless a stable base level is provided at the upstream end of the reach from which the alluvium is removed, the central basin could experience significant headcut migration and gully growth.

Because of the concerns for gully growth, as well as wetland areas in Johnson Wash wherein contamination occurs, the DOE proposes using supplemental standards for surface cleanup of specific areas. Only localized hot spots of contaminated materials in Johnson Wash and Lay Creek between the existing tailings pile and U.S. Highway 40 will be cleaned up and placed in the disposal cell. Section 6.2.2 of this report further discusses the proposed application of supplemental surface cleanup standards to these areas.

Gullyng on the site will be prevented by implementing engineering designs for the slopes, providing stable base levels for channels, covering the ground with coarser material, and reseeding disturbed areas. The following proposed design features will protect the disposal cell and ensure its long-term performance:

- A perimeter ditch will be constructed between the cell and the adjacent overburden pile on the west and southwest sides of the cell. The ditch will divert runoff through rechanneled Tributary T9 at a point 1000 ft (300 m) from the cell toe. The ditch shall be armored with erosion protection rock suitable for design flow where it lies within 200 ft (60 m) of the cell.
- Four existing tributaries at the southwest side of the cell, designated on Figure 4.1 of Attachment 2, as T5 through T8, will be armored for design flow from a point at the 1 percent apron slope for a distance of at least 100 ft (30 m) in the bottom and 200 ft (60 m) on the sideslopes. The armored section of the tributaries will be set back at least 50 ft (15 m) from Johnson Wash to avoid damage from the greater design flow in that channel.
- The apron on the east side of the cell, in lieu of rock erosion protection, will be graded for sheet flow conditions on a slope not to exceed 5 percent to a minimum distance of 500 ft (150 m) from the toe of the cell.
- The runoff upland of the graded east side apron will be diverted from the northeast side of the cell through a reconstructed upper reach of Tributary T4 angling southeasterly away from the east apron to meet the Johnson Wash channel. Erosion protection is not necessary because there is no potential for headcutting toward the cell.

Section 4.1, Geomorphic Stability, Attachment 2, discusses the age of the geomorphic surfaces. Section 4.2, Seismotectonic Stability, Attachment 2, concludes with a discussion of fault age related to geomorphic processes. The DOE has identified and quantified the short- and long-term geomorphic processes that could influence the tailings stabilization. Specific projections relating to recommendations and engineering designs for site stability are presented regarding the potential for headward erosion of gullies, nickpoint migration of stream channels, sheetwash erosion, and base-level changes. On the basis of these evaluations, the DOE concludes that the site can be designed to be geomorphically stable for the performance period of the disposal cell.

2.4.2 Seismotectonic stability

The DOE has determined that the disposal site and designs will provide long-term stability during a seismic event. Having catalogued the seismic activity, identified the significant geologic structures, and delineated the tectonic provinces, the DOE analyzed the seismic sources most likely to affect site stability. Section 4.2, Seismotectonic Stability, Attachment 2, describes this analysis and technical approach. Tables 4.2 through 4.4 of Section 4.2, Attachment 2, list each potentially active fault and the remote seismotectonic sources, along with the calculated maximum earthquake (ME) and the estimated ME determined in previous studies. Using appropriate attenuation relationships for the site region, the peak horizontal acceleration for these sources is presented.

The determination of parameters for the design earthquake, presented at the conclusion of the referenced section, is summarized below.

Specific seismic parameters to be used for the design are presented in the following paragraph. The design criteria, appropriate soil strength parameters, pile geometry, and ground water information were used to assess slope stability and liquefaction potential. Section 4.2, Seismotectonic Stability, Attachment 2, presents seismic design parameters derived using procedures set forth in the TAD (DOE, 1989).

The design earthquake for this site was determined to be a magnitude (M) = 6.5 event at a radial distance of 9 mi (15 km) from the site as a floating earthquake. The peak horizontal acceleration of bedrock at the site is estimated to be 0.27 g. The duration of motion assuming deep soil on the site, based on a motion of 0.05 g, is 10 seconds.

The design criteria are as follows:

- Long-term slope stability seismic coefficient: $K = 0.18$ (two-thirds of peak horizontal acceleration).
- Short-term slope stability seismic coefficient: $K = 0.14$ (one-half of peak horizontal acceleration).
- Liquefaction analysis: ground surface horizontal acceleration $a_{\max} = 0.27$ g.

The DOE discusses the potential for other hazards at the Maybell site in Section 5.0, Geologic Suitability, Attachment 2. Specific concerns include liquefaction potential, induced seismic hazards, volcanic hazards, and induced landslides and subsidence. The conclusions expressed therein complete the analysis of the geologic suitability and demonstrate compliance of the conditions with the EPA requirements for long-term suitability in 40 CFR §192.02(a)(1) (40 CFR Part 192 (1993) and 52 FR 36000 (1987)).

2.5 GEOLOGIC SUITABILITY

Detailed investigations of geologic, geomorphic, and seismic conditions at the Maybell site have been conducted. Section 5.0, Geologic Suitability, Attachment 2, describes those processes most likely to affect long-term stability of the disposal site. Information from site and regional investigations used in subsequent engineering analyses and disposal cell design features is presented elsewhere in this RAS and in other documents supporting this RAP. On the basis of the geologic evaluations and the stability provisions in the engineering design of the disposal cell, the DOE concludes that there is a reasonable assurance that the regional and site geologic conditions have been characterized adequately to meet 40 CFR §192.02(a)(1) (40 CFR Part 192 and 52 FR 36000).

Conditions potentially affecting long-term stability have been identified and either avoided by design layout or mitigated by the details of the proposed remedial action design. These conditions are as follows:

- The erosion potential of tributary gullies in the central basin of Johnson Wash has the greatest potential to affect disposal cell stability. Engineering designs for the disposal cell, including riprap at the head of these gullies, will mitigate this concern. Also, stabilization of the base level of Johnson Wash, especially in the outlet valley in the lower basin, will further lessen incision of the gullies.
- The numerous faults in the site area and region would seem to pose a threat to the seismic stability of the disposal cell. However, the geomorphic details presented in Section 2.4, Seismotectonic Setting; Section 3.1.1, Structural Faults in the Site Area; and Section 4.2, Seismotectonic Stability of Attachment 2 show no evidence of Quaternary displacement on these faults.
- Local areas near the site, such as the towns of Maybell and Meeker, Colorado, may respond to regional earthquakes with anomalously high intensity (see Section 4.2.7, Anomalous Response to Regional Seismicity, Attachment 2). However, this anomalous enhancement depends on the nature of the surficial geology and is most likely a site-specific response of saturated alluvium in those areas. Both Maybell and Meeker are located on saturated floodplain deposits, but the disposal cell is on a very thin layer of alluvium above bedrock, which will prevent these enhanced effects.

The DOE concludes that the positive geologic conditions described in this section will allow compliance of the disposal cell with the longevity standard of 40 CFR §192.02(a)(1) (40 CFR Part 192 and 52 FR 36000). Features incorporated into the disposal cell design will mitigate potential problems caused by adverse geologic conditions.

3.0 GEOTECHNICAL STABILITY

This section and associated references describe the geotechnical engineering aspects of the remedial action at the Maybell site. The following aspects of the remedial action are described: the geotechnical information related to the processing site, tailings pile, and the borrow sites; the design details related to the disposal cell and cover; and the materials associated with the remedial action, including the tailings and other contaminated materials.

3.1 SITE AND MATERIAL CHARACTERIZATION

3.1.1 Geotechnical investigations

Subsurface geotechnical investigations and site characterization programs were performed at the processing site, disposal cell area, and borrow sites. The scope of the geotechnical field investigations included boreholes, piezocones, and test pits. Drawings MAY-PS-10-0224, MAY-PS-10-0225, and MAY-PS-10-0226 in Attachment 1, Subcontract Documents, present the locations of the geotechnical field investigations. Attachment 1, Information for Bidders, Volumes II, III, and IV, provides the data obtained during these characterization programs.

Processing site

The scope of the subsurface geotechnical investigations of the contaminated area included boreholes and piezocones. Drawings MAY-PS-10-0224 and MAY-PS-10-0225 in Attachment 1, Subcontract Documents, show the locations investigated. Attachment 1, Information for Bidders, Volumes II and III, Tailings Pile and Off-Pile information, presents data compiled from the boreholes and piezocones.

Disposal cell area

The scope of the subsurface geotechnical investigations included boreholes and test pits. Drawings MAY-PS-10-0224 and MAY-PS-10-0225 in Attachment 1, Subcontract Documents, show the locations investigated. Logs of the boreholes and test pits at the proposed disposal cell location were compiled and are included in Attachment 1, Information for Bidders, Volumes II and III, Tailings Pile and Off-Pile information.

Test pits were excavated with a tracked backhoe. Individual borehole logs provide specific information about the drilling methods used. Generally, 6.5-inch (16.5-cm) hollow stem augers were used until refusal; thereafter, a 4.0-inch (10-cm) rotary bit and casing were used to bedrock. Three samplers used during the soils investigation were a 2.0-inch O.D. (outside diameter) (5.1-cm) standard split spoon sampler for the American Society for Testing and Materials (ASTM) standard penetration test (ASTM Standard D 1586-84) (ASTM, 1988a),

a 3.0-inch O.D. (7.6-cm) ring-lined split barrel sampler, and a 3.0-in (7.6-cm) thin-walled Shelby tube sampler. Soil samples were obtained from the test pits and the boreholes, and selected samples were tested in the laboratory. Relatively undisturbed Shelby tube samples were used in laboratory triaxial and consolidation tests.

Piezometers were also installed in the majority of the boreholes (see drawings MAY-PS-10-0224 and MAY-PS-10-0225 in Attachment 1, Subcontract Documents, for locations). Generally, the piezometers consist of a 2.0-inch (5.1-cm) diameter slotted polyvinyl chloride pipe with soil backfill.

Data from the logs and the laboratory tests were used to construct stratigraphic sections (see Section 3.1.4), augment the site geological characterization (see Section 2.0), define the engineering properties of the site soils and rocks (see Section 3.1.2), and characterize the manner in which these soils would affect or be affected by the disposal cell.

Borrow areas

The scope of the geotechnical investigations for the borrow areas included boreholes, test pits, samples collected by hand, and laboratory analyses of the field samples.

Investigations were conducted at both on-site and off-site locations. On-site investigations were conducted at the Rob Pit Overburden Pile, which is located adjacent to the western edge of the existing tailings pile and which will be used during construction of the radon barrier. Drawing MAY-PS-10-0225 in Attachment 1, Subcontract Documents, shows the locations of the geotechnical field investigations at the Rob Pit Overburden Pile. Attachment 1, Information for Bidders, Volume III, Borrow Sites, presents the laboratory results of the samples.

Off-site geotechnical field investigations were conducted at numerous locations to evaluate their potential use for borrow materials for various components of the remedial action. The field logs and laboratory results were compiled and are included in Attachment 1, Information for Bidders, Volumes III and IV, Borrow Sites. The off-site borrow sites evaluated included the following locations:

- Yampa River Gauging Station
- Juniper Hot Springs Source
- Craig Basalt Quarry (Don Steele Basalt Quarry)
- River Gravel Source
- Umetco's Quarry
- Cedar Mountain Source
- Maybell Gravel Source
- Darryl Steele's Gravel Pit
- Juniper Mountain Limestone Quarry (Don Steele Limestone Quarry)
- Lone Mountain Limestone Quarry

- Breeze Mountain Basalt Quarry
- Little Snake River

3.1.2 Testing program

Geotechnical testing programs were conducted for materials at the Maybell site and at the borrow sites. Samples collected from boreholes, from test pits, and by hand were sent to laboratories for analyses.

On-site materials

Geotechnical testing was performed on samples from on-site locations. Testing included gradation, Atterberg limits, specific gravity, moisture density determinations, compaction tests, consolidation tests, saturated hydraulic conductivity, capillary moisture, and triaxial strength tests. Attachment 1, Information for Bidders, Volumes II and III, Tailings Pile and Off-Pile information, contains the results of individual tests.

Borrow materials

Geotechnical testing programs were conducted on each of the borrow sites proposed for the Maybell remedial action. These borrow sites included the Maybell Gravel Source, Rob Pit Overburden Pile, Juniper Mountain Limestone Quarry (Don Steele Limestone Quarry), and Craig Basalt Quarry (Don Steele Basalt Quarry).

Durability tests and petrographic analyses were performed on the rock samples from the Maybell Gravel Source, Juniper Mountain Limestone Quarry, and Craig Basalt Quarry. The durability tests included Los Angeles abrasion, sulfate soundness, absorption, specific gravity, Schmidt hammer, and Brazilian disk tensile tests. Petrographic analyses also were conducted. Attachment 1, Information for Bidders, Volumes III and IV, Borrow Sites, contains the results of the individual tests.

Testing of the radon/infiltration barrier materials from the Rob Pit Overburden Pile, which will be amended with approximately 10 percent Redmond bentonite for construction, included soil classification and geotechnical properties. These tests include gradation, Atterberg limits, saturated hydraulic conductivity, capillary moisture, triaxial strength, and specific gravity. Attachment 1, Information for Bidders, Volume III, Borrow Sites, contains the results of the individual tests. Attachment 1, Information for Bidders, Volume V, presents freeze-thaw permeability data for soil-bentonite radon/infiltration barrier covers.

Conclusion

All of the laboratory and field testing procedures followed the standards published by the ASTM or the U.S. Army Corps of Engineers, Manual EM 1110-2-1906 (USACE, 1970). The testing program employed a sufficient

number of samples and tests to define all of the critical soil or rock parameters appropriate in support of the engineering analyses. In addition, the scope of the testing program and the use of the resulting data to define material properties conform with applicable provisions of the NRC draft SRP (NRC, 1985). Quality assurance and quality control were performed in accordance with UMTRA standard operating procedures (DOE, 1992a).

3.1.3 Ground water conditions

The upper sandstone unit of the Browns Park Formation is the principal (uppermost) aquifer in the Maybell tailings pile vicinity. Unconfined ground water occurs within this formation at depths from 35 to 300 ft (11 to 90 m) beneath the ground surface. The average hydraulic conductivity of this aquifer is 1.7 ft/day (6×10^{-4} centimeters per second [cm/s]) and the average linear ground water velocity is 0.17 ft/day (62 ft per year) (5.2 cm/day) (19 m per year).

Recharge of the Browns Park Formation uppermost aquifer is principally from the infiltration of precipitation in the form of rain or snow, although the upslope catchment basin is of limited extent. Potentiometric surface variations probably result from local differences in the amount of recharge available. Ground water elevations fluctuated less than 2 ft (0.6 m) over 3 years. The potentiometric surface indicates that the ground water flows southwestwardly away from the tailings site.

A PMF occurrence may result in a minimal variation of ground water elevation in the uppermost aquifer, but is not considered significant due to the short duration of such a design event and the limited extent of the catchment basin upgradient of the tailings pile vicinity.

No perched ground water zones were observed in the immediate tailings site vicinity.

3.1.4 Stratigraphy

Subsurface investigations were conducted at the tailings pile which is the proposed disposal cell location. These investigations included boreholes and test pits that provided information on the geotechnical properties of the tailings pile and its stratigraphy. Drawings MAY-PS-10-0224 and MAY-PS-10-0225 in Attachment 1, Subcontract Documents, show the locations of the boreholes and test pits. Logs of the boreholes and test pits were compiled and are included in Attachment 1, Information for Bidders, Volumes II and III, Tailings Pile and Off-Pile information. Attachment 2 contains a detailed description of the stratigraphic setting of the Maybell site.

The Maybell site existing tailings pile consists of interlayered sands and slimes overlying alluvial soils. The thickest slime layers (up to 24 ft [7.3 m]) are in the south-central portion of the pile, with thinner zones along the pile's western

edge. The slimes generally grade to sand-slimes and then sands in the northern portion of the pile. Starter dikes used in the construction of the pile on the south and east sides consist of silty sands. Approximately 6 inches (15 cm) of rooting medium cover the pile surface, although surface water flow has eroded approximately 20 percent (FBDU, 1981).

Materials in the pile range from coarse to fine-grained tailings. The coarse materials are medium to fine sands and silty sands. The fine-grained materials are low-plasticity slimes. The cover soils are clayey sands. The subgrade soils are light-brown to reddish-brown alluvial, silty sands.

Bedrock below the site area is the Browns Park Formation, a light gray and white, silty, fine-grained sandstone, which is 800 to 900 ft (240 to 275 m) thick. Only drainage channels incised into the alluvial soil cover break the bedrock surface. The alluvial soil, 30 ft (9 m) thick in the center of the basin of Johnson Wash, thins to 3 ft (1 m) at the basin edges.

3.2 GEOTECHNICAL ENGINEERING EVALUATION

This section and referenced supporting documents present the engineering evaluation of the data collected and analyses conducted to demonstrate compliance of the proposed remedial action design with the relevant EPA standards in 40 CFR §192.02(a)(1) (40 CFR Part 192 (1993) and 52 FR 36000 (1987)) for long-term stability, including slope stability, settlement, liquefaction, and cover cracking.

This section identifies the analysis methods, which are described in the relevant supporting and referenced calculations.

3.2.1 Slope stability

Calculation MAY-335-02-01 in Attachment 1, Volume II, presents the slope stability analyses, the results of which are shown in Table 3.1. These analyses show that for both static and seismic conditions, the slopes of the disposal cell and the cell foundation meet the minimum acceptable factors of safety against failure for the design life criteria. The following paragraphs summarize the design approaches, parameters, methods, and results of the analyses.

Table 3.1 Results of slope stability analyses

Condition analyzed	Calculated safety factor		Minimum safety factor required
	(A-A')	(B-B')	
End of construction, static	2.2	2.2	1.3
End of construction, seismic	1.1	1.3	1.0
Long-term, static	2.7	2.5	1.5
Long-term, seismic	1.3	1.3	1.0

Selected analysis locations

Two disposal cell cross sections were selected for stability analysis. One section (A-A', Sheet 14A, Calculation MAY-335-02-01 in Attachment 1, Volume II), on the southeast side of the cell, was selected because this location's embankment is at its maximum height, it is along the axis of a previous drainage gully, and it is representative of the conditions in and beneath the disposal cell. The other section (B-B', Sheet 14A of Calculation MAY-335-02-01, Attachment 1, Volume II), on the west side of the disposal cell was selected because layers of tailings slimes, up to 17 ft (5.2 m) thick, were encountered in boreholes along the cell's edge. The slimes were found to have the lowest shear strengths, which would be critical to slope stability.

Adopted design properties

Included in Calculation MAY-335-02-01 in Attachment 1, Volume II, is an assessment of the geotechnical properties of the materials comprising the disposal cell and foundation used in the stability analyses. Table 3.2 lists these material properties. Assignment of strength and density values to material types (whether based on field, laboratory, or literature data) followed conventional geotechnical engineering practice and was in accordance with SRP (NRC, 1985) and TAD (DOE, 1989) provisions.

Table 3.2 Material properties used in stability analyses

Material	Short term			Long term		
	C (psf)	ϕ (degree)	γ_t (pcf)	C (psf)	ϕ (degree)	γ_t^* (pcf)
Cover layer	500	22	123	0	30	125
Compacted tailings	0	28	115	0	28	115
<i>In situ</i> non-slime tailings	0	25	105	0	28	110
<i>In situ</i> slime tailings	550	0	90	0	25	100
Native soils	0	33	118*	0	35	120

* Assumed.

Analysis methods

As described in Calculation MAY-335-02-01 in Attachment 1, Volume II, the Modified Janbu slope stability method, as incorporated into the computer code STABL5 (Carpenter, 1986), was used. Both circular and sliding block failure surfaces were analyzed; shallow failure conditions were assessed using infinite slope stability methods. These are appropriate methods widely accepted and

used in engineering practice. Seismic conditions were analyzed using pseudostatic methods. The horizontal seismic coefficients were based on the site and regional geological evaluation performed in accordance with the TAD (DOE, 1989), as discussed in Section 2.0. Using the pseudostatic method is acceptable in view of the low seismic loading coefficients and the relatively flat slopes.

Analysis results

The calculated factors of safety against failure of the slopes of the disposal cell and the foundation exceed the minimum acceptable values established in the TAD (DOE, 1989) for the end of construction and long-term periods under static and seismic conditions.

3.2.2 Settlement

Calculations were performed to estimate the post-construction settlement of the disposal cell at the Maybell site. The evaluation of total settlement that may produce unacceptable surface depressions or affect the radon barrier included only primary consolidation and secondary compression.

Selected analysis locations

Embankment settlement at the proposed Maybell disposal cell was evaluated at 51 locations where piezocone sounding tests were performed. Forty locations within the disposal cell boundaries were selected for settlement calculations. These 40 locations represent a mixture of conditions across the cell and include areas with the thickest zones of slimes (which will consolidate the most). Sheet 7 of Calculation MAY-392-01-00, Attachment 1, Volume II, provides the locations of the piezocone sounding tests.

Engineering properties

Fifty-one locations, 40 of which were within the boundaries of the disposal cell, were evaluated using piezocone soundings to estimate post-construction settlement of the disposal cell. Continuous stratigraphic data obtained from piezocone soundings were used to construct the geotechnical profiles for the tailings pile. The consolidation properties of the particular tailings type in each profile were used to evaluate settlement. Because the settlement of concern is the post-construction settlement, the loading sequence was also taken into account.

Sheet 8 of Calculation MAY-392-01-00, Attachment 1, Volume II, presents bar code classification information for the piezocone data and was used to classify *in situ* sand-slime and slime tailings. Sheet 20 of Calculation MAY-392-01-00, Attachment 1, Volume II, summarizes the geotechnical properties used for settlement analysis.

Attachment 1, Information for Bidders, Volumes II and III, Tailings Pile and Off-Pile information, provides borehole logs and piezocone sounding test results. Sheets 9 through 18 of Calculation MAY-392-01-00, Attachment 1, Volume II, present geotechnical profiles for the piezocone locations.

Settlement estimating methods

Settlement calculations were performed for primary consolidation and secondary compression. Calculations MAY-392-01-00 and MAY-394-01-00 in Attachment 1, Volume II, provide the settlement and the cover cracking methodologies, calculations, and results, respectively.

Primary consolidation calculations performed using the computer program CONSOL (Wang and Duncan, 1984) evaluated the total and time rate of consolidation in slime and sand-slime layers.

Secondary compression is that part of settlement occurring under constant effective stress and starting at the end of primary consolidation. Secondary compression calculations were performed according to accepted practice (Calculation MAY-392-01-00 in Attachment 1, Volume II).

Settlement estimate results

The total embankment settlement expected to occur after the cover is placed ranges from approximately 1 to 15 inches (2.5 to 38 cm). The time from the beginning of placement of contaminated materials to completion of primary consolidation settlement ranges from approximately 10 months to 9 years. Sheet 7 of Calculation MAY-392-01-00, Attachment 1, Volume II, provides the locations where settlements were analyzed.

Sheet 5 of Calculation MAY-394-01-00, Attachment 1, Volume II, indicates two sections analyzed for differential settlement. Sheets 6 and 7 of Calculation MAY-394-01-00, Attachment 1, Volume II, provide vertical and horizontal strain profiles. Differential settlement would be highest in the south-central portion of the disposal cell, particularly in the area around piezocone 504B (Section A-A', Sheet 6 of Calculation MAY-394-01-00, Attachment 1, Volume II). This section has a peak horizontal tensile strain of 0.04 percent. Differential settlement is not expected to cause any flow concentration or adversely affect the stability of the riprap placed on 3 percent topslope or 20 percent sideslopes of the disposal cell.

The estimated failure tensile strain of the radon barrier is at a lower bound of 0.05 percent, with increasing allowable strain for any barrier material having a plasticity index greater than zero. The barrier material will be amended with approximately 10 percent Redmond bentonite, giving it a cracking strain greater than 0.05 percent. Therefore, no tensile cracking occurs due to differential settlement.

Construction of the Maybell disposal cell will include the installation of settlement plates, as required for disposal cells where the RRM is stabilized in place (DOE, 1992b). The location, spacing, and emplacement depth of the settlement plates are determined based on the extent and depth of the thickest consolidating layers. The Remedial Action Contractor (RAC) will install the settlement plates, which will be monitored during the remedial action.

The UMTRA long-term surveillance program manual (DOE, 1992b) will guide post-stabilization settlement monitoring, if required. The long-term surveillance plan (LTSP) prepared for the Maybell site will specify the schedule for evaluation of disposal cell settlement.

3.2.3 Liquefaction potential

To evaluate the long-term stability of the Maybell disposal cell, the liquefaction potential of the stabilized pile and foundation soils under design earthquake conditions were assessed.

Analysis method

The analysis method described in the TAD (DOE, 1989) was used to assess the liquefaction potential. Attachment 2 presents additional seismotectonic stability information regarding the Maybell site.

Appropriateness of soil parameters analyzed

The liquefaction potential analysis considered materials within the existing tailings pile and nearby contaminated areas. All available borehole logs and piezocone data were examined to determine the presence of loose saturated sands. Drawings MAY-PS-10-0224 and MAY-PS-10-0225 in Attachment 1, Subcontract Documents, show borehole and piezocone locations within and near the existing tailings pile. Attachment 1, Information for Bidders, Volumes II and III, Tailings Pile and Off-Pile information, presents data from the borehole logs and piezocones. Calculation MAY-338-01-01 in Attachment 1, Volume I, presents the analyses to determine liquefaction potential.

Analysis results

Four areas of the disposal cell in the south-central and west-central areas of the tailings pile were identified as having strata of loose sands. Sheet 15 of Calculation MAY-338-01-01, Attachment 1, Volume I, shows the locations of the four areas. Only Area 1 was considered to be liquefiable under the design seismic acceleration of 0.27 gravity. Tailings materials in the existing pile at depths of 12 to 15 ft (3.7 to 4.6 m) and 27 to 33 ft (8.2 to 10 m) in the vicinity of borings D10 and D12, respectively, would be potentially liquefiable. However, these zones were determined to be localized in extent. Settlement and stability analyses (Calculations MAY-338-02-00 and MAY-335-02-01 in

Attachment 1, Volume II) of this area indicate that neither the stability of the pile nor the cover would be adversely affected.

The three remaining areas (Areas 2, 3, and 4) containing loose sands in the disposal cell location were determined not to have potential liquefaction. This determination was based on the layers' depths being greater than 50 ft (15 m), the confinement of which was evaluated under nonliquefiable soils.

3.2.4 Cover design

The proposed remedial action is designed to control the tailings and other RRM to meet the standards in 40 CFR §192.02(a)(2) (40 CFR Part 192 (1993) and 52 FR 36000 (1987)). The Maybell disposal cell cover is designed to resist degradation and erosion, meet geotechnical stability requirements, minimize infiltration, and meet radon protection standards throughout its design life. Sections 3.2.1 through 3.2.3 address geotechnical engineering concerns, Section 4.4 describes erosion resistance, and Section 4.5 describes rock durability. Section 5.0 discusses ground water protection concerns as they relate to the cover design, and Section 6.0 describes radon protection.

The proposed design for the disposal cell cover consists of the following, in ascending order above the contaminated materials:

Topslope

- One and one-half-ft (0.5-m)-thick radon/infiltration barrier consisting of clayey sands amended with 10 percent Redmond bentonite. (See Attachment 1, Information for Bidders, Volume III, and Calculation MAY-355-03-01 in Attachment 1, Volume III, for a list and detailed descriptions of the geotechnical properties of this material.)
- Four-ft (1.2-m)-thick frost protection layer comprised of sandy soils. (See Attachment 1, Information for Bidders, Volume III, and Calculation MAY-398-03-00 in Attachment 1, Volume III, for descriptions of the properties of this material).
- One-half-ft (15-cm)-thick bedding layer.
- Eight-inch (20-cm)-thick erosion protection layer. (See Attachment 1, Information for Bidders, Volumes III and IV and Calculation MAY-336-11-01 in Attachment 1, Volume IV, and Calculations MAY-336-06-00 and MAY-336-07-02 in Attachment 1, Volume I, for a list and descriptions of the properties of the riprap material).

The topslope of the cover will have a 3 percent slope to the west and runoff will be to a ditch adjacent to the cell (Figure 1.4). The radon/infiltration barrier materials, clayey sands amended with 10 percent Redmond bentonite, will have a saturated hydraulic conductivity of 1×10^{-7} cm/s (2.8×10^{-4} ft/day) or less

based on laboratory testing (see Calculation MAY-355-03-01 in Attachment 1, Volume III). This layer will minimize infiltration into the contaminated materials and thereby minimize leachate from the bottom of the cell.

Sideslopes

- One and one-half-ft (0.5-m)-thick radon/infiltration barrier (see above).
- Four-ft (1.2-m)-thick frost protection layer (see above).
- One-half-ft (15-cm)-thick bedding layer.
- One-ft (0.3-m)-thick erosion protection layer. (See Attachment 1, Information for Bidders, Volumes III and IV, and Calculation MAY-336-11-01 in Attachment 1, Volume IV, and Calculations MAY-336-06-00 and MAY-336-07-02 in Attachment 1, Volume I, for a list and descriptions of the properties of the riprap material).

The sideslopes of the disposal cell (five horizontal to one vertical) are protected by a riprap apron on the south and east sides. On the north and west sides of the cell, the sideslopes are part of the main ditch that will carry surface runoff from the cell and adjacent off-cell areas. All upland runoff will be intercepted and routed around the disposal cell. The relatively high slopes and the high permeability bedding layer will enhance immediate surface runoff and minimize precipitation infiltration. The bedding material is sized to resist erosion of the frost protection materials while maintaining the highest possible hydraulic conductivity.

3.3 CONSTRUCTION DETAILS

3.3.1 Construction methods and features

Attachment 1 provides detailed descriptions of the remedial action. The attachment contains site plans and engineering drawings that clearly convey the remedial action design features and construction specifications that provide a more detailed explanation of the construction methods to be employed.

The following general criteria have been established for the remedial action construction:

- The percentage of organics contained within the reshaped disposal cell will not exceed 5 percent by volume, and the material will be distributed to avoid pockets or layers of organic matter.
- All uncontaminated vegetation and organic material in areas subject to excavation and placement will be removed and disposed of off the site.

- Contaminated demolition debris will be reduced to manageable pieces and placed carefully in the embankment to ensure that no voids or nesting exists around the debris and that the adjacent contaminated materials are compacted to at least 90 percent of the Standard Proctor density (ASTM D698-78, Method A) (ASTM, 1988b).
- Excavation of all contaminated materials will be monitored carefully to prevent inclusion of unnecessary, uncontaminated materials in the cell.
- The relocated tailings and contaminated materials will be compacted to a minimum of 90 percent of the Standard Proctor density (ASTM D698-78, Method A) (ASTM, 1988b) and will be moisture-conditioned or dried to a moisture content to achieve specified density. Vibratory type compaction will be employed for granular materials to prevent bulking.
- The radon barrier cover will be placed at a minimum of 100 percent of the Standard Proctor density (ASTM D698-78, Method A) (ASTM, 1988b), at a moisture content ranging from optimum to 3 percent above optimum, and compacted by a kneading method.

3.3.2 Testing and inspection

The Maybell site remedial action inspection plan will provide the details of the methods, procedures, and frequencies by which construction materials and activities are to be tested and inspected to verify compliance with the design specifications.

Quality assurance will be controlled in accordance with the DOE/UMTRA quality assurance plan (DOE, 1992a).

DOE and the Technical Assistance Contractor (TAC) will conduct quality assurance audits and in-process surveillances to verify and ensure performance of remedial action activities in accordance with approved requirements.

3.3.3 Construction activities and construction sequence

Construction activities will occur at the existing site areas, areas contaminated by windblown and waterborne tailings, and borrow sites.

During remedial action construction, all contaminated runoff at the site will be diverted to retention basins. Contaminated disturbed areas will be graded so that runoff drains to the wastewater retention basins. Uncontaminated disturbed areas will be graded to divert runoff from contaminated areas.

Ditches will be sized to carry the peak runoff flows from a 25-year storm event, thus preventing uncontaminated runoff from entering contaminated areas.

The wastewater retention basins will receive water from the following:

- Runoff from contaminated areas.
- Decontamination activities, including equipment and truck washdown.
- Laundry, shower, and washbasin facilities.

The retention basins can retain the accumulated runoff volume from the contributing drainage areas for the combination of a 10-year, 24-hour storm, the accumulated runoff volume due to ordinary average precipitation over a 1-month period, the wastewaters generated from the remedial action activities, and all sediment inflow during the project construction period. Under these conditions, no wastewater discharge will be necessary during the construction period. At the end of construction, any water remaining in the retention basins will be assessed for treatment needs and discharged according to applicable effluent limitations. If a storm event greater than the 10-year, 24-hour event occurs, the associated discharge is anticipated to fall under the storm exemption specified in 40 CFR §440.131 (40 CFR Part 440 (1993)).

The emergency spillways from the basins can discharge the peak 25-year, 24-hour storm runoff while 1 ft (0.3 m) of freeboard is maintained between the top of the embankment and the water surface, with the emergency spillway flowing at design depth.

Wastewater treatment

Wastewater will be directed to the wastewater retention basins, which will provide primary settling as well as flow and contaminant equalization. The untreated water from the basin may be recycled for dust control and compaction moisture for contaminated materials.

Equipment decontamination pad

To prevent contaminated materials from exiting the construction area, a decontamination pad with a holding pond and pump will be provided at the site to wash contaminated equipment, as required.

Dust control

Water and water-based surfactants sprayed from hoses or trucks will control and minimize dust generated by excavation, earth movement, vehicle use, temporary materials stockpiling, and similar activities. Special care will be taken to control dust created by the demolition of the former building foundations and the temporary stockpiling or mixing of contaminated materials.

The dust suppression water may include untreated water from the wastewater retention basins. Only uncontaminated water will be used to control dust in all uncontaminated areas.

Construction sequence

Stabilization of the contaminated material in place will require the following major construction activities.

- Site preparation activities.
 - Establishing a site security system.
 - Clearing and grubbing.
 - Demolishing the concrete foundations of the former milling operations.
 - Upgrading the haul roads to the borrow sites.
 - Constructing two, lined wastewater retention ponds.
 - Constructing drainage control features to direct wastewater and storm water runoff from the contaminated areas to the retention ponds.
 - Installing erosion control measures for all disturbed areas.
- Consolidation of contaminated materials.
 - Excavating the relatively shallow tailings along the north, west, and south periphery of the tailings pile and placement on the thicker portions of the pile.
 - Moving all contaminated materials from the mill yard, waterborne, and windblown contaminated areas onto the existing tailings pile.
- Construction of permanent drainage features.
- Construction of the erosion protection cover.

Top and sideslopes

- Excavating, hauling, and placing a 1.5-ft (0.5-m)-thick compacted layer over the contaminated materials to serve as the radon/infiltration barrier. Materials would come from the Rob Pit Overburden Pile and would be amended with 10 percent Redmond bentonite.
- Excavating, hauling, and placing 4.0 ft (1.2 m) of frost protection materials that would come from the Rob Pit Overburden Pile.

- Placing a 6-inch (15-cm)-thick bedding/filter layer over the frost protection layer.
- Excavating, hauling, and placing rock over the bedding/filter layer.
- Quarrying (including blasting), hauling, and placing a rock apron around the base of the stabilized tailings pile, in the gullies leading to Johnson Wash, and in the diversion ditches.
- Site restoration activities.
 - Backfilling, recontouring, and revegetating areas excavated during remedial action as required by the appropriate permits and approvals.
 - Installing warning signs, monuments, and benchmarks around the disposal cell.

Schedule

Figure 3.1 shows a possible construction schedule.

3.4 SUMMARY

The geotechnical engineering and construction evaluations used techniques agreed upon between the DOE and the NRC, with levels of detail in general conformance with the applicable provisions of the SRP (NRC, 1985). Evaluation of the previously presented results has shown that the proposed remedial action design will comply with the EPA standards in 40 CFR Part 192, Subpart A (40 CFR Part 192 and 52 FR 36000) for the geotechnical engineering and construction aspects.

FIGURE 3.1
CONSTRUCTION SCHEDULE
MAYBELL, COLORADO, TAILINGS SITE

4.0 SURFACE WATER HYDROLOGY AND EROSION PROTECTION

4.1 HYDROLOGIC DESCRIPTION AND CONCEPTUAL DESIGN

Johnson Wash, an ephemeral stream, drains the tailings site. Johnson Wash is a tributary to Lay Creek; its confluence with the creek is 1.5 mi (2.4 km) south of and 230 ft (70 m) lower in elevation than the tailings pile (Figure 4.1). Johnson Wash is deeply incised, with branching gullies up to 40 ft (12 m) deep. It appears to be eroding downward into the sandstone bedrock, which lies within a few feet of the surface near the pile. Stretches of wetlands exist along the wash. The drainage area contributing to Johnson Wash above the Maybell tailings site is approximately 2.5 mi² (6.5 km²).

The tailings pile is at the lower end of three upland subdrainages totaling about 465 ac (188 ha). The subdrainages have a maximum reach of about 7000 ft (2100 m) and an average slope of 4 percent. A swale and diversion ditch to Johnson Wash diverts drainage from one area of approximately 177 ac (72 ha) away from the cell on the north. Two permanent ditches divert drainage from two upland basins of approximately 288 ac (117 ha) around the disposal cell on the west.

The only surface body of water near the tailings site is in the bottom of Rob Pit, approximately one-quarter mi (0.4 km) west of the pile. Rob Pit acts as a sink for runoff in the immediate vicinity. The water surface elevation is about 50 ft (15 m) below natural grade, approximately corresponding to the water table elevation in the area.

The design basis event for disposal cell protection is the PMP and the PMF. Attachment 1, Volume IV, presents all hydrologic design parameters, permanent site drainage features, and erosion protection measures in detail. The erosion protection riprap on the top and sideslopes of the disposal cell will be sized to withstand the on-cell PMP storm runoff. A 5-ft (1.5-m)-thick rock erosion protection apron will protect the cell. The apron will extend out 20 ft (6 m) at a 5 percent grade along the south and east toes of the disposal cell. Riprap will stabilize four gullies into Johnson Wash below the southeast toe of the cell (Figure 4.2). Areas surrounding the disposal cell that are disturbed by the remedial action will be backfilled as required, graded to control surface drainage, and seeded.

4.2 FLOODING DETERMINATIONS

To determine site impacts from flooding, the PMF over the drainage areas was used to calculate peak flows and velocities. Erosion protection features were designed to withstand this design event. The PMF design event meets the criteria outlined in the SRP (NRC, 1985).

FIGURE 4.2
DISPOSAL CELL EROSION PROTECTION REQUIREMENTS
AT THE MAYBELL TAILINGS SITE NEAR MAYBELL, COLORADO

4.2.1 Probable maximum precipitation

The PMP for the Maybell site is 7.3 inches (18.5 cm) of rain in 1 hour with a maximum intensity (at 2.5 minutes time of concentration [t_c]) of 48 inches (122 cm) per hour (see Calculation MAY-323-02-01 in Attachment 1, Volume IV). This rainfall estimate was developed using standard procedures described in Hydrometeorological Report (HMR) No. 49 (NOAA, 1977).

4.2.2 Infiltration losses

To size the erosion protection riprap, peak flow was calculated using the conservative assumption of full saturation of the soils and zero infiltration within the drainage basins (see Calculations MAY-354-01-00, MAY-354-02-00, MAY-354-03-00, MAY-336-11-01, MAY-336-12-01, and MAY-336-13-02 in Attachment 1, Volume IV).

4.2.3 Time of concentration

The t_c is the time for runoff to reach the outlet of a drainage basin from the most remote point in the basin. The peak runoff for a given drainage basin is inversely proportional to the t_c for that basin. If the t_c is conservatively computed to be small, the peak discharge will be conservatively large.

Various conservative t_c for the permanent drainage ditches, the drainage swales, and the aprons and disposal cell were estimated using the Kirpich Method (see Calculations MAY-323-02-01, MAY-354-01-00, MAY-354-02-00, MAY-354-03-00, MAY-336-11-01, MAY-336-12-01, and MAY-336-13-02 in Attachment 1, Volume IV).

4.2.4 Probable maximum precipitation rainfall distributions

The PMP rainfall intensities for durations beginning at 2.5 minutes (UMTRA Project minimum t_c) to durations of less than 1 hour were derived according to procedures recommended in HMR No. 49 (see Calculation MAY-323-02-01 in Attachment 1, Volume IV). The peak rainfall intensities, for durations corresponding to the respective t_c , were used to compute peak flow rates on the top, sideslopes, and toe apron of the disposal cell, as well as the permanent drainage ditches, swales, and outfall gullies. The 6-hour local storm PMP totaling 8.9 inches (22.6 cm) also was distributed in 5-minute intervals according to HMR No. 49 for the flood hydrograph computation on Johnson Wash.

4.2.5 Probable maximum flood computation

The design flood event (PMF) is developed for the various surfaces and areas by application of the PMP over the particular surfaces or areas. Hydrologic models determine the runoff response as described below.

Adjacent waterways

Because the disposal cell is 230 ft (70 m) higher than Lay Creek at its confluence with Johnson Wash, flooding in Lay Creek (and the Yampa River) cannot inundate the cell and thus was not considered.

The HEC-1 (USACE, 1981) model estimated the runoff response and peak discharge rate in Johnson Wash just below the disposal site due to a local PMP storm on the watershed area above the site. It was assumed that the soils are initially fully saturated; thus, no losses through infiltration occur during the design storm. The estimated peak discharge of Johnson Wash from the watershed above the site is about 14,210 cubic feet per second (ft³/s) (402,000 liters per second [L/s]) (see Calculation MAY-336-05-01 in Attachment 1, Volume II).

On-site drainage

The PMF design flood event on the cell utilizing the rational formula and PMP intensities to compute peak sheet flow rates was used to size erosion protection riprap on the top, sideslopes, and toe apron of the cell (see Calculations MAY-336-11-01 and MAY-336-12-01 in Attachment 1, Volume IV). The PMF flowing in the permanent ditches and in the gullies was used to size the erosion protection in these features (see Calculations MAY-354-01-00 in Attachment 1, Volume IV, and MAY-350-01-00 in Attachment 1, Volume II).

4.3 WATER SURFACE PROFILES AND CHANNEL VELOCITIES

4.3.1 Adjacent waterways

Water surface profiles using the HEC-2 hydraulic model (USACE, 1982) were developed for Johnson Wash for the PMP peak discharge of 14,210 ft³/s (402,000 L/s) (see Calculation MAY-336-05-01 in Attachment 1, Volume II). No other waterways are close enough to flood the pile.

Cross sections were constructed for input into the HEC-2 hydraulic model (USACE, 1982) at the locations shown in Sheets 10, 10a, and 11 of Calculation MAY-336-05-01, Attachment 1, Volume II. The distance between the first and last cross sections is approximately 1450 ft (440 m). The approximate PMF boundary is 400 ft (120 m) from the cell toe, where the water surface elevation is 20 ft (6 m) lower. Cell flooding is not likely for PMF conditions. The calculated flow velocity at the PMF boundary point nearest the pile is approximately 16 feet per second (ft/s) (5 meters per second [m/s]).

4.3.2 Drainage ditches

The two proposed permanent ditches were designed using the PMF flows from the upland and on-cell areas using the design rainfall intensities developed from the specific t_c and the PMP event, application of the rational formula, and

Manning's Formula (Calculation MAY-354-01-00 in Attachment 1, Volume IV). Ditches 1 and 2 will have 5:1 sideslopes and will be 4350 ft (1325 m) and 350 ft (107 m) long, respectively (Figure 4.2). Ditch No. 1 will have maximum flow depth of 6 ft (1.8 m), with a minimum freeboard of 4 ft (1.2 m). The peak flow velocity is 12.4 ft/s (3.8 m/s). Ditch No. 2 will have maximum flow depth of 5 ft (1.5 m), with a minimum freeboard of 2 ft (0.6 m). The peak flow velocity is 15.7 ft/s (4.8 m/s). Sheets 10 and 11 of Calculation MAY-354-01-00, Attachment 1, Volume IV, summarize the ditch flow information.

Ditches 1 and 2 can carry away sediment inflows from the upland area due to combined overland flows and potential gully flows. Calculation MAY-336-15-00, Attachment 1, Volume IV, summarizes the sediment properties, specific gravity, and gradation limits from soil samples collected in the upland watershed areas. These sediment properties are used in the sedimentation analysis for the permanent drainage ditches.

Erosion protection added to the Rob Pit Overburden Pile will minimize gully development and sediment inflow to Ditch No. 1. The pile will be set back 50 ft (15 m) with a bench at a 2-percent slope, and the pile slope facing Ditch No. 1 will be reduced to 3.5:1. The bench and pile slope riprap was designed for the PMP event (see Calculation MAY-336-13-02 in Attachment 1, Volume IV).

4.3.3 Embankment top and sides

The design flows and velocities for the cell top and sideslopes were developed from the PMP event and sheet flow condition using the Manning Formula (see Calculation MAY-336-11-01 in Attachment 1, Volume IV). The topslope has a 3-percent slope, a peak velocity of approximately 3.9 ft/s (1.2 m/s), and a peak flow rate of approximately 0.9 ft³/s/ft (80 L/s/m). The 5:1 sideslope has a peak flow rate of 0.97 ft³/s/ft (90 L/s/m) and a peak velocity of 5.1 ft/s (1.6 m/s).

4.4 EROSION PROTECTION DESIGN

4.4.1 Adjacent waterways

Four tributary gullies are between the disposal cell and Johnson Wash (Figure 4.2). Riprap sized for the PMF by the Safety Factors Method (Calculation MAY-350-01-00, Attachment 1, Volume II) will line each gully to prevent headcutting erosion of the gullies into the cell.

All of the gullies will be lined with 24-inch (61-cm)-thick, 10-inch (25-cm) D₅₀ diameter riprap. This riprap will be placed on an intermediate layer of 6-inch (15-cm)-thick, 1.7-inch (4.3-cm) D₅₀-diameter riprap and a 6-inch (15-cm) bedding layer. The toe of each gully outlet will have 8-ft (2.4-m)-thick, 24-inch (61-cm) D₅₀-diameter riprap on 9-inch (23-cm)-thick, 3.7-inch (9.4-cm) D₅₀-diameter riprap and a 6-inch (15-cm) bedding layer. Sheet 32 of Calculation MAY-350-01-00, Attachment 1, Volume II, shows the typical gully riprap protection.

4.4.2 Drainage ditches

Ditch No. 1 will outfall to a gully that is tributary to Johnson Wash. Similar to the gullies, the ditch will be lined with 24-inch (61-cm)-thick, 10-inch (25-cm) D_{50} -diameter riprap. This riprap will be placed on an intermediate layer of 6-inch (15-cm)-thick, 1.7-inch (4.3-cm) D_{50} -diameter riprap and a 6-inch (15-cm) bedding layer. The Ditch No. 1 gully outlet will have 17-ft (5.2-m)-thick, 24-inch (61-cm) D_{50} -diameter riprap on 9-inch (23-cm)-thick, 3.7-inch (9.4-cm) D_{50} -diameter riprap and a 6-inch (15-cm) bedding layer. Calculation MAY-354-01-00 in Attachment 1, Volume IV, summarizes the gully riprap depth protection and shows the typical section of the Ditch No. 1 outlet.

Erosion protection for the Rob Pit Overburden Pile was designed using the Safety Factors Method for the bench and Stephenson's Method for the east slope facing Ditch No. 1 (see Calculation MAY-336-13-02 in Attachment 1, Volume IV). The slope and bench conservatively will have 12-inch (30-cm)-thick, 4.7-inch (12-cm) D_{50} -diameter riprap on a 6-inch (15-cm) bedding layer.

4.4.3 Disposal cell top and sides

The cell top and sides will be covered by riprap erosion protection designed to withstand the sheet flow velocities occurring from an on-cell PMP (Calculation MAY-336-11-01, Attachment 1, Volume IV).

Using the Safety Factors Method, the riprap requirement on the 3-percent topslope of the cell is 8 inches (20 cm) thick, 1.7 inches (4.3 cm) D_{50} diameter, on a 6-inch (15-cm) bedding layer.

Using Stephenson's Method, the riprap requirement on the 20 percent west sideslope of the cell is 1 ft (30 cm) thick, 4.7 inches (12 cm) D_{50} diameter, on a 6-inch (15-cm) bedding layer. On the 20 percent east sideslope, the requirement is 1 ft (30 cm) thick, 3.7 inches (9.4 cm) D_{50} diameter, on a 6-inch (15-cm) bedding layer.

4.4.4 Toe apron

A 20-ft (6-m)-wide toe apron with a minimum D_{50} of 10 inches (25 cm) will be provided on the toe of the east and south sideslopes of the embankment, where no drainage ditch is connected. The toe apron is 5 ft (1.5 m) deep. The lower 10 ft (3 m) of the sideslope above the toe apron also will be protected by the 10-inch (25-cm) D_{50} rock with a layer thickness of 24 inches (61 cm). Several methods, including the Safety Factors Method, the Corps of Engineers Stilling Basin Method, and the Stephenson's Method were used to size the rock. The 5-ft (1.5-m) toe apron depth was designed to prevent potential scour due to PMP storm runoff away from the apron.

4.5 ROCK DURABILITY

Rock from the three proposed borrow sources (Craig Basalt Quarry, Maybell Gravel Source, and Juniper Mountain Limestone Quarry) was tested for quality and durability. Calculation MAY-336-06-00 in Attachment 1, Volume I, lists the data and results. The rock meets all the standard UMTRA Project durability requirements.

4.6 QUALITY CONTROL (TESTING AND INSPECTION) FOR EROSION PROTECTION

Section 3.3 of this report details the construction, construction control quality assurance, and testing and inspection procedures.

4.7 UPSTREAM DAM FAILURES

No impoundments exist in the site area or upstream of the site whose failure could potentially affect the site.

4.8 SUMMARY

The DOE concludes that the Maybell site design will meet EPA requirements as stated or referenced in 40 CFR Part 192 with regard to flood design measures and erosion protection. An adequate hydraulic design has been provided to ensure stability of the contaminated material at the Maybell site for up to 1000 years.

5.0 WATER RESOURCE PROTECTION

5.1 HYDROGEOLOGIC SITE CHARACTERIZATION

The DOE has characterized the hydrogeologic units, hydraulic and transport properties, water quality, ground water use, and geochemical conditions at the Maybell site. Major points of this characterization are summarized below. Attachment 3, Ground Water Hydrology Report, the Hydrological Services Calculations (Appendix A), and Ground Water Quality by Location, (Appendix B) detail the hydrologic site characterization.

5.1.1 Hydrogeologic units identification

The existing tailings pile overlies the Browns Park Formation of Miocene age, which unconformably overlies truncated rocks of the Cretaceous Mancos Shale. In the site area, the Browns Park Formation consists of poorly cemented fluvio-lacustrine and eolian sandstones. Within these sandstones are small lenses of shale and well-cemented intervals of calcite. The underlying Cretaceous Mancos Shale consists of low-permeability dark gray marine shale, with lenticular sandstone beds near the top and base. Section 3.3, Hydrostratigraphy, Attachment 3, presents a more complete discussion of the hydrostratigraphy.

5.1.2 Hydraulic and transport properties

The principal aquifer system is the upper sandstone unit of the Browns Park Formation. Unconfined ground water occurs within this formation at depths from 35 to greater than 300 ft (11 to 90 m) beneath the ground surface. The arithmetic mean for transmissivity and storativity determined from pumping tests were 92 ft²/day (8.5 m²/day) and 4.0×10^{-3} , respectively. The average hydraulic conductivity of this aquifer was 1.7 ft/day (6×10^{-4} cm/s) and the average linear ground water velocity was 0.17 ft/day (5.2 cm/day) (62 ft/year) (19 m/year).

The Maybell site is in a recharge area with a limited upslope catchment basin. Ground water recharge to the Browns Park Formation is principally from the infiltration of precipitation in the form of rain or snow. The ground water in the Browns Park Formation discharges to the Yampa River alluvial aquifer system. The potentiometric surface indicates that the ground water is flowing southwesterly, away from the existing tailings site. Section 3.4, Hydraulic Characteristics, Attachment 3, presents a more detailed discussion of hydraulic characteristics.

5.1.3 Geochemical conditions

Section 3.9, Attachment 3 presents a discussion of the Maybell tailings site and the geochemical mechanisms that attenuate ground water contamination at the site.

5.1.4 Characterization methods

The DOE has characterized the Maybell site hydrology with field investigations, including corehole drilling, monitor well completion, water level measurement, suction lysimeter installation, open corehole packer testing, and monitor well slug testing. Long-term pumping tests also were conducted to measure aquifer parameters. Ground water geochemical and microbiological analyses included collecting and analyzing ground water and surface water for the constituents listed in Table 8.1 of the TAD (DOE, 1989), Table A of 40 CFR §192.02(a)(3)(ii) (52 FR 36000), and Table 1 of 40 CFR §264.94 (40 CFR Part 264). Sections 3.1, Previous Investigations, and 3.2, Current Investigations, Attachment 3, give additional details regarding the characterization methods.

5.1.5 Water use

The nearest downgradient domestic well is 3 mi (5 km) south of the existing Maybell tailings site. The well is completed in the Yampa River Valley alluvium, which is recharged by the Browns Park Formation. The cost for annual water use in the Maybell area was estimated to be \$17,400. Section 4.0, Ground Water Use, Value, and Alternative Supplies, Attachment 3, provides additional information on ground water use, value, and alternative supplies.

5.1.6 Background ground water quality

Upgradient background ground water quality in the Browns Park Formation has maximum observed concentrations of arsenic, cadmium, lead, molybdenum, selenium, uranium, and the combined activities of Ra-226 and Ra-228 that exceed the proposed EPA maximum concentration limits (MCL) (52 FR 36000). Downgradient background ground water quality in the Browns Park Formation has maximum observed concentrations of arsenic, cadmium, lead, molybdenum, nitrate, selenium, and uranium that exceed the proposed EPA MCLs (52 FR 36000). The integration of data from upgradient and uncontaminated downgradient monitor wells yields a more complete picture of the variable (and often poor) water quality in the Browns Park Formation. Browns Park domestic well 650 in particular shows elevated levels of hazardous constituents (e.g., nitrate), yet it is located near Maybell several miles downgradient of the tailings pile. This well is far beyond the possible influence of contamination from the tailings pile. Section 3.5, Background Ground Water Quality, Attachment 3, provides additional information on the background ground water quality at the site.

5.1.7 Tailings characterization

Existing concentrations of hazardous constituents in the tailings pile were estimated by chemical analyses of tailings pore water samples obtained from suction lysimeters installed in the tailings pile. Hazardous constituents were those listed in Table A of 40 CFR §192.02(a)(3)(ii) (52 FR 36000) and Table 1 of 40 CFR §264.94 (40 CFR Part 264). Concentrations of hazardous

constituents were compared with the proposed EPA MCLs (52 FR 36000). Mean concentrations of hazardous constituents from the lysimeter samples that exceed the proposed EPA MCLs are arsenic, cadmium, molybdenum, nitrate, selenium, uranium, and the combined activities of Ra-226 and Ra-228. See Sections 3.6, Tailings Characterization, and 3.7, Tailings Subsoil Characterization, Attachment 3, for further discussion of the tailings characterization.

5.1.8 Extent of existing contamination

Geochemical conditions affect contaminant migration in the aquifer at the existing tailings site. There is evidence of neutral pH and reducing conditions in the Browns Park Formation, which would cause precipitation of many of the hazardous constituents of concern. Section 3.8, Extent of Existing Ground Water Contamination, Attachment 3, provides additional discussion on the extent of existing contamination in the Browns Park Formation.

5.2 CONCEPTUAL DESIGN FEATURES FOR WATER RESOURCES PROTECTION

The disposal option proposed for the Maybell tailings site involves stabilization in place of the contaminated materials. Windblown tailings and waterborne contamination will be added to the existing tailings pile. All contaminated materials will be consolidated and compacted to form a completed disposal cell covering approximately 66 ac (27 ha). Natural materials will cover the contaminated materials to achieve a multicomponent cover. The cover has been designed to stabilize the contaminated materials, meet the radiation protection standard, reduce the amount of precipitation infiltration, protect the radon barrier from frost and biointrusion, and protect ground water resources. Section 3.2.4, Cover Design, of this RAS report and Section 2.2, Design Features, Attachment 4, Water Resources Protection Strategy, present a detailed discussion of the cover design.

5.3 DISPOSAL

5.3.1 Ground water protection standard for disposal

To achieve compliance with the proposed EPA ground water protection standards (52 FR 36000), the DOE proposes a narrative supplemental standard that ensures protection of human health and the environment. Section 3.2, Narrative Supplemental Standard, in Attachment 4 details the DOE-proposed narrative supplemental standard.

Hazardous constituents

Identified hazardous constituents are likely to be in, or derived from, RRM at the Maybell tailings site. Pore fluids obtained from suction lysimeters installed in the tailings were analyzed for the hazardous constituents listed in Table A of 40 CFR §192.02(a)(3)(ii) (52 FR 36000) and Table 1 of 40 CFR §264.94

(40 CFR Part 264). Mean concentrations of hazardous constituents were compared with the proposed EPA MCLs (52 FR 36000). Mean concentrations of hazardous constituents from the tailings pore water that exceed the proposed EPA MCLs are arsenic, cadmium, molybdenum, nitrate, selenium, uranium, and the combined activities of Ra-226 and Ra-228.

A scan for the presence of organic hazardous constituents was conducted in October 1989. Ground water samples collected from monitor wells 643, 645, and 648 were analyzed for organic hazardous constituents listed in Appendix IX of 40 CFR Part 264. No Appendix IX organic hazardous constituents were detected. Monitor wells 643, 645, and 648 are located within the tailings pile footprint, and ground water samples analyzed from these wells would be the best indicator for the presence of organic hazardous constituents due to proximity to tailings seepage. Sections 3.6 (Tailings Characterization), 3.7 (Tailings Subsoil Characterization), and 3.8 (Extent of Ground Water Contamination), in Attachment 3 and Section 3.1.1, Hazardous Constituents, in Attachment 4 provide further discussion of tailings characterization.

Concentration limits

The DOE is not proposing numerical concentration limits for hazardous constituents identified in the ground water at the Maybell site, because upgradient and downgradient background ground water quality in the Browns Park Formation is highly variable. Concentrations of the proposed EPA hazardous constituents vary from below laboratory method reporting limits to 1 order of magnitude above the proposed EPA MCLs (see Section 3.5, Background Ground Water Quality, Attachment 3).

The ground water in the Browns Park Formation is not an historic or current drinking water source downgradient of the affected area. Therefore, establishing numerical concentration limits for the identified hazardous constituents at a specified POC will not further protect human health and the environment.

Point of compliance

No POC ground water monitoring is proposed for the Browns Park Formation at the Maybell site. POC ground water monitoring would not serve any purpose because of several site-specific conditions. First, upgradient and downgradient background ground water quality in the uppermost aquifer is highly variable and generally poor. Second, the Browns Park Formation aquifer is not an historic or current drinking water source downgradient of the proposed disposal cell. Third, the proposed remedial action comes as close to meeting the otherwise applicable standards as is reasonable under the circumstances.

In lieu of POC ground water monitoring, the DOE proposes a conceptual cell performance monitoring plan to satisfy 40 CFR Part 192, Subparts A and B

(40 CFR Part 192 and 52 FR 36000) during the post-closure period. A detailed cell performance monitoring plan will be provided in the Maybell LTSP.

5.3.2 Supplemental standards

To achieve compliance with the proposed EPA ground water standards, the DOE proposes the application of a narrative supplemental ground water standard at the Maybell site. The basis for this application is that ground water in the aquifer (Browns Park Formation) meets the Class III criterion (40 CFR §192.21(g)) (52 FR 36000) due to widespread ambient contamination. Section 3.2, Narrative Supplemental Standard, Attachment 4, presents a detailed discussion of the DOE-proposed supplemental standard for the Maybell site. The following sections summarize that discussion.

Applicability demonstration

The widespread, ambient contamination of background ground water quality in the Browns Park Formation in the Maybell site vicinity is not related to milling activities at the designated site. The upgradient and downgradient background ground water quality is contaminated by both naturally occurring uranium mineralization and mining activities not related to uranium milling operations on the site.

The nearest drinking water well is more than 3 mi (5 km) southwest of the existing tailings pile. This well is obtaining water from the Yampa River Valley alluvium, not the Browns Park Formation. Future use of ground water in the affected area will be minimal because of the remote location of the Maybell tailings site to existing and future potential water users and the generally poor quality of ground water in the mineralized Browns Park Formation aquifer.

Supplemental standards description

The DOE is not proposing numerical concentration limits for the hazardous constituents identified in the contaminated materials at the Maybell site. In addition, no POC has been established. The Browns Park Formation is not an historic or current drinking water source downgradient of the tailings disposal site. Establishing numerical concentration limits for the identified hazardous constituents at a specified POC will not further protect human health and the environment.

Demonstration of remedial action compliance with supplemental standards

The proposed disposal cell design for the Maybell site meets the NRC's "as low as reasonable under the circumstances" criterion for supplemental standard application (NRC, 1989). The DOE's consideration of a supplemental standard included evaluating long-term seepage, transient drainage, and geochemical

conditions at the site. Results of these evaluations indicate that the proposed design of the disposal cell and its anticipated longevity performance will ensure protection of human health and the environment.

Demonstration of remedial action adherence with applicable standards

To demonstrate compliance of the proposed disposal cell design with the proposed EPA ground water standards (applicable standards), design parameters were evaluated in conjunction with the hydrogeologic and geochemical characteristics of the Maybell site. These investigations were conducted to determine the distribution of hazardous constituents in ground water under steady state conditions and the potential for contaminant migration after stabilization. From these investigations, the DOE has concluded that by incorporating design features that are as close to meeting the otherwise applicable standard as is reasonable under the circumstances, the remedial action will protect the Browns Park Formation aquifer.

5.3.3 Performance assessment

Design parameters of the proposed disposal cell were evaluated in conjunction with the hydrogeologic and geochemical characteristics of the Maybell site. Important aspects of this evaluation were to determine the distribution of hazardous constituents in ground water under current conditions and to determine the potential for contaminant migration after stabilization. Based on the evaluation, the DOE has demonstrated compliance of the proposed disposal cell design with the proposed EPA ground water protection standards (52 FR 36000).

There is evidence that naturally occurring alkaline and reducing geochemical conditions exist within the Browns Park Formation in the Maybell tailings site vicinity. These conditions have decreased the extent of contamination of ground water downgradient of the site within the influence of the existing tailings pile. These same conditions, though not necessary to the supplemental standard ground water protection strategy, provide conservatism for the proposed disposal cell performance compliance with the proposed EPA ground water protection standards (52 FR 36000).

Geochemical and biological characteristics of the soils and sediments underlying the existing tailings pile are conducive to precipitation and/or adsorption of uranium, arsenic, molybdenum, Ra-226 and Ra-228, and selenium and to denitrification of nitrate. Water quality data, mineralogical characterization, and microbiological studies support the hypotheses that precipitation, adsorption, and microbiological processes remove contaminants in the tailings leachate from solution. Although slightly oxidizing conditions exist in ground water directly beneath the existing tailings pile, relatively alkaline and reducing conditions are generally present in ground water downgradient from the pile. Under these relatively alkaline and reducing conditions, uranium, selenium, Ra-226 and Ra-228, arsenic, and molybdenum will precipitate or be adsorbed, thereby

resulting in lower concentrations in ground water. Nitrate is removed by denitrification under these reducing conditions.

Section 3.9 of Attachment 3 provides a more detailed discussion of the geochemical conditions and mechanisms. Further discussion of the performance assessment is provided in Section 3.4, Performance Assessment, Attachment 4.

5.3.4 Closure performance demonstration

The DOE has assessed the performance of the proposed disposal cell design at the Maybell site in conjunction with the hydrological system. The proposed disposal cell design was shown to minimize and control releases of hazardous constituents to ground water and surface water, and control radon emissions to the atmosphere to the extent needed to protect human health and the environment (40 CFR §192.02(a)(4)) (40 CFR Part 192 and 52 FR 36000).

Natural, stable materials have been evaluated and are recommended for use in construction of the proposed Maybell disposal cell to ensure the longevity standard of 40 CFR §192.02(a)(1) (40 CFR Part 192 and 52 FR 36000). The Maybell LTSP will include a detailed cell performance monitoring plan in order to verify the expected performance of the completed disposal cell. However, the cell performance monitoring plan will be discussed conceptually to demonstrate the DOE's commitment to comply with 40 CFR Part 192, Subparts A and B and 52 FR 36000 during the specified post-closure period.

A number of scenarios may compromise cell performance. Some scenarios involve intrusion into the protective cover or tailings material through surface erosion, unwanted plant growth, or burrowing animals. The annual site inspection protocol of the LTSP will ensure that these potential risks to the cell integrity do not occur. Visual inspection may also be used in the event of imminent slope failure through subsidence of the topslope or bulging of the sideslopes. The LTSP will address detailed corrective actions in the unlikely event that any of these conditions are observed. Scenarios compromising cell integrity that cannot be observed visually will be monitored through indirect measurements and are addressed in the following conceptual cell performance monitoring plan.

The conceptual cell performance monitoring plan will indirectly monitor for any unlikely failure condition within the cell, such as cover cracking from unusual differential settlement, or other unlikely event, such as seismic activity. The cover can restrict infiltration by promoting lateral drainage of precipitation on the cell, protecting the radon/infiltration barrier from frost damage, and providing a low-permeability barrier to infiltration by amending the infiltration barrier with 10 percent Redmond bentonite. Failure of any one of these design features could increase infiltration through the cover over that projected to occur based on laboratory permeability tests. Increased infiltration may be evidenced through eventual adverse changes in contaminant levels in ground water within the Browns Park Formation aquifer.

This aspect of cell performance may be monitored by establishing a baseline of constituent levels within the aquifer downgradient of the cell prior to remediation. The baseline will be established by sampling from two designated cell performance monitor wells downgradient of the cell that are separated by some distance. The two designated wells may involve installing new monitor wells in order to provide wells as close as possible to the cell, but outside of the construction zone of the surface remediation.

As a result of remediation, levels of constituents within the downgradient aquifer may be elevated temporarily. This would result primarily from drainage of pore water from the fully saturated tailings slimes due to the increased loading from the relocated contaminated and uncontaminated cover materials on top of the existing pile. In addition, transient drainage from normal compaction and dust control water during construction will combine with the slime tailings pore water. The water from these sources will drain from the cell to the aquifer. Depending on the volume of drainage from the cell, constituent levels at the cell performance wells may change relative to the baseline values. During this transitory phase, the travel time of transient drainage vertically from the cell to the aquifer and horizontally within the aquifer to the cell performance wells should be considered before elevated levels of contaminants in the performance wells are construed as indicators of cell failure.

An "upper bound" predictive model will be developed to quantify the potential influence from the transient drainage. The upper-bound model will incorporate pore water production caused by consolidation of the slimes and release of construction control water to provide a time-dependent flux from the cell to the ground water. This time-dependent flux will be entered into a contaminant transport model of the aquifer to produce an upper-bound response at the location of the cell performance wells. The upper-bound curves will indicate the approximate transient pulse duration and pulse maximum contaminant levels that could occur in the ground water due to the source term mass loading.

The model will be based on only a few key indicator parameters, one being nitrate. Constituent concentrations from the cell performance wells may then be compared to the upper-bound model results during the transitory phase. Constituent concentrations in the cell performance wells after steady state conditions return should give concentration levels of the indicator parameters at or below the baseline levels established prior to remediation. This will provide an assessment of cell performance through both the transitory period and the final steady-state conditions. The detailed cell closure performance plan also will entail a second approach in order to verify proper performance of the completed cell. Settlement plates will be installed over locations where the slimes are known to be the thickest. Since the contamination is primarily related to the pore water within the slimes, comparing measurements of actual and predicted post-cell closure settlements will provide an assessment of the expected cell performance.

5.3.5 Ground water monitoring and corrective action plan

Section 3.8, Extent of Existing Ground Water Contamination, Attachment 3, presents the results of the existing on-site ground water monitoring program.

Following construction of the disposal cell, the DOE will institute a LTSP for the post-disposal period, pursuant to 40 CFR § 192.02(a)(4)(b) (40 CFR Part 192 and 52 FR 36000). Development of the LTSP will follow the criteria described in the DOE's *Guidance for Implementing the UMTRA Project Long-term Surveillance Program* (DOE, 1992b).

The Maybell disposal cell has been designed and will be constructed to perform for the mandated design life of 1000 years. The disposal cell design has incorporated standard safety factors and should therefore perform for a period of greater than 1000 years with minimal maintenance. Failure of the proposed designed disposal cell at the Maybell site is not anticipated because natural materials will be used.

5.4 GROUND WATER CLEANUP

Cleanup of contaminated ground water must be addressed under the conditions of 40 CFR Part 192, Subpart B, of the EPA proposed ground water standards (52 FR 36000) for the UMTRA Project. The need for and extent of ground water cleanup at the Maybell site is based on the extent of existing contamination, the potential for current or future use of the aquifer, and the technical practicability of restoring the aquifer from an engineering perspective. In the meantime, studies are under way to develop plans, guidance materials, and procedures for aquifer restoration activities. Additional investigations will identify the appropriate remediation strategy. The final decision of how to meet EPA ground water cleanup standards at the Maybell site will be part of the UMTRA Ground Water Project.

Hazardous constituents

Hazardous constituents were identified that are likely to be in, or derived from, RRM at the Maybell tailings site. Section 5.3.1 of this report describes the hazardous constituents identified in tailings pore water at the site.

Concentration limits

The DOE is not proposing numerical concentration limits for hazardous constituents identified in the ground water at the Maybell site. Section 5.3.1 of this report discusses the rationale for this position.

5.5 SUMMARY

The DOE must demonstrate compliance with the proposed EPA ground water protection standards pursuant to 40 CFR Part 192 (1993) (52 FR 36000 (1987)). To achieve compliance, the DOE proposes a narrative supplemental standard that ensures protection of human health and the environment. The supplemental standard applies to the Browns Park Formation and will not include numerical concentration limits for the hazardous constituents identified in the contaminated materials at the Maybell site. In addition, no POC has been proposed.

The disposal option proposed for the Maybell tailings site involves stabilizing in place the existing tailings and associated contaminated materials. An above-ground disposal cell has been designed to reduce radon emanation, minimize infiltration of water, withstand differential settlement, resist degradation, and meet the proposed EPA ground water protection standards (52 FR 36000).

The DOE has characterized the Browns Park Formation aquifer at the Maybell site. Ground water is not an historic or current source of drinking water and is designated as Class III (limited use), based on naturally occurring widespread ambient contamination. Background ground water quality upgradient and downgradient of the tailings pile is highly variable and generally poor. Extensive low-grade uranium mineralization found in the Browns Park Formation has affected water quality naturally, as have open pit mining operations upgradient from the site.

Because of the remote location of the tailings site to existing and future potential drinking water users and the generally poor ground water quality in the Browns Park Formation, expected future use of ground water as a drinking water source in the site area is minimal. The historical lack of ground water use as a drinking water source near the Maybell tailings site supports this conclusion.

The performance assessment indicates that the remedial action will allow for compliance with the proposed EPA ground water protection standards (52 FR 36000) because 1) most downgradient monitor wells within the influence of the tailings pile have not provided evidence of ground water contamination resulting from mill operations at the Maybell site; 2) the disposal cell design will minimize infiltration of water; 3) temporary increased seepage rates will occur immediately following disposal cell closure but will return to steady-state conditions after 1.5 years (the effects of this temporary increased seepage rate will be no worse than that which occurred during the period of mill operation); and 4) favorable geochemical conditions rapidly decrease contamination of ground water downgradient within the influence of the tailings pile.

Remedial action will not preclude any future evaluation of ground water at the Maybell site. The DOE is not leaving a threat to human health or the environment in the Browns Park Formation because no drinking water wells

currently exist within the affected environment adjacent to the mill site that withdraw water from the Browns Park Formation aquifer.

Following construction of the disposal cell, the DOE will institute a LTSP for the post-disposal period, pursuant to 40 CFR §192.02(a)(4)(b) (40 CFR Part 192 and 52 FR 36000). In order to verify the expected performance of the completed disposal cell, the Maybell site-specific LTSP will provide a detailed cell performance monitoring plan. The plan will include the installation and sampling of cell performance monitor wells immediately downgradient of the tailings pile. Development of the LTSP will follow the criteria described in the DOE's *Guidance for Implementing the UMTRA Project Long-term Surveillance Program* (DOE, 1992b).

6.0 RADON ATTENUATION AND SITE CLEANUP

This section summarizes the disposal cell design and relevant parameters selected in evaluating the radon barrier. The radiation survey plan is discussed with respect to providing reasonable assurance of compliance with EPA standards at the Maybell site.

6.1 RADON ATTENUATION

Contaminated materials will be covered with 1.5 ft (0.5 m) of compacted earthen radon barrier materials amended with approximately 10 percent Redmond bentonite. Four ft (1.2 m) of frost protection material will be placed over the radon barrier. Erosion protection materials will consist of 1 ft (0.3 m) of rock on the sideslopes and 8 inches (20 cm) of rock on the topslope, both placed on a 6-inch (15-cm)-thick bedding layer. Erosion and frost protection materials were not considered in the radon attenuation calculations. The sequence of contaminated materials will place windblown materials with relatively low average Ra-226 concentrations over mill yard/ore storage materials, which will be placed over existing tailings with relatively high Ra-226 concentrations.

6.1.1 Parameter selection

The radon barrier design parameters and supporting calculations were utilized in conjunction with the RAECOM model (NRC, 1984) to determine the cover thickness needed to control radon flux to meet EPA standards of 20 pCi/m²s (740 mBq/m²s) (40 CFR §192.02(a)(2)(i)) (40 CFR Part 192 (1993) and 52 FR 36000 (1987)). An ambient radon concentration in air of 2.0 pCi/L (74 Bq/m³) was used for the RAECOM computer code, based on air samples collected north of the tailings pile boundary. The radon barrier thickness was determined based on procedures specified in the TAD (DOE, 1989).

Specific design parameters discussed include 1) long-term moisture content, 2) radon diffusion coefficient, 3) Ra-226 content, 4) radon emanation coefficient, 5) material thickness, and 6) bulk density, specific gravity, and porosity. Calculation MAY-326-01-00 in Attachment 1, Volume III, presents the RAECOM input parameters for Maybell materials. Table 6.1 summarizes these RAECOM input parameters.

As of January 16, 1994 (the date of Calculation MAY-326-01-00), analytical test data for some material properties were incomplete. All available test data to date have been used in the calculation. The radon barrier design parameters will be verified and/or revised upon completion of additional analytical testing.

Long-term moisture content

Average long-term moisture contents for contaminated materials and the radon barrier materials were determined using an analysis of optimum moisture

Table 6.1 RAECOM input parameter values

Layer description	Thickness cm (in) ^a	Bulk density g/cm ^{3b} (lb/ft ³) ^c	Porosity (fraction)	Assumed moisture content (%)	Specific gravity	Emanating fraction	Ra-226 concentration pCi/g (mBq/g)	Radon diffusion coefficient cm ² /s ^d (in ² /s) ^e
Tailings pile (bottom)	1981 (780)	1.2 (75)	0.57	10	2.76	0.30	156 (5770)	0.05 (0.008)
Mill yard/ore storage	160 ^f (63)	1.60 ^f (100)	0.39 ^f	6	2.64	0.35	168 (6220)	0.031 (0.005)
Windblown	92 (36)	1.60 ^f (100)	0.39 ^f	6	2.64	0.35	36 (1330)	0.031 (0.005)
Cover (top)	46 (18)	(1.78) ^g (111)	0.33 ^g	13.7	2.66	0.35	1.7 (63)	0.0006 (0.00009)

^ain = inches.

^bg/cm³ = grams per cubic centimeter.

^clb/ft³ = pounds per cubic foot.

^dcm²/s = square centimeters per second.

^ein²/s = square inches per second.

^fDesign compaction of 90 percent.

^gDesign compaction of 100 percent.

contents, 15-bar capillary moisture tests, and computer modeling results. Modeling results were selected because they were the lowest and therefore most conservative results. A conservative long-term moisture content of 13.5 percent was assumed for the radon barrier materials, which had average 15-bar test results of 14.1 percent. Six percent was determined for the off-pile windblown and mill yard/ore storage materials. The tailings materials were assumed to have a long-term moisture content of 10 percent.

Radon diffusion coefficient

Radon diffusion was measured in the laboratory as a function of moisture saturation for samples of radon barrier, tailings, and windblown materials. The derived data were plotted and least-square curves were obtained for each sample. Diffusion coefficients then were calculated for each sample using specific moisture saturations derived from densities, porosities, and long-term moisture content values. An average diffusion coefficient of 0.0006 square centimeters per second (cm^2/s) (0.00009 square inches per second [in^2/s]) was obtained for the radon barrier materials. Tailings materials had an average of 0.05 cm^2/s (0.008 in^2/s) for diffusion. A diffusion coefficient of 0.031 cm^2/s (0.005 in^2/s) was obtained for windblown material and was assumed for mill yard/ore storage materials.

Radium-226 content

Ra-226 concentrations in samples from boreholes and surface/subsurface soils were determined primarily by gamma spectroscopy. Average Ra-226 concentrations then were calculated for each layer (see material thickness below) by volume-weighting individual layers of contamination within the tailings pile and subareas within the windblown and mill yard/ore storage areas. Average Ra-226 concentrations for the tailings pile, mill yard/ore storage, and windblown layers were 156, 168, and 36 pCi/g (5770, 6220, and 1330 mBq/g), respectively. Ra-226 concentration data can be found in Calculations MAY-327-02-01 and MAY-326-01-00 in Attachment 1, Volume III.

Radon emanation coefficient

Radon emanation coefficients for tailings materials were determined from a series of standard laboratory measurements over a range of moistures and Ra-226 concentrations. Radon emanation was determined to be statistically independent of both moisture and Ra-226 concentrations using standard regression and statistical analyses.

Emanation coefficients ranged from 0.26 to 0.46 for tailings materials. The average radon emanation was 0.30 for tailings. Windblown, mill yard/ore storage, and radon barrier materials were assigned average emanations of 0.35 by default to the NRC-recommended values.

Material thickness

Specific thicknesses of three discrete layers were calculated for 1) the tailings pile, 2) mill yard/ore storage, and 3) windblown materials. Thicknesses were calculated based on volumes of materials and their ultimate geometric placement in the disposal cell. Volumes were determined from analyses of borings from the tailings pile and soil samples from off-pile locations. Information on layer thicknesses can be found in Calculation MAY-326-01-00 in Attachment 1, Volume III.

Bulk density, specific gravity, and porosity

Bulk densities, specific gravities, and porosities of contaminated and radon barrier materials were determined using standard tests and procedures, assuming design compactions of 90 percent for contaminated materials and 100 percent of Standard Proctor maximum density for barrier materials. Radon barrier materials had an average dry bulk density of 1.78 grams per cubic centimeter (g/cm^3) (111 pounds per cubic foot [lb/ft^3]) at 100 percent of Standard Proctor maximum density. The porosity was 0.33 at 100 percent compaction and the specific gravity was 2.66. Radon barrier materials samples were amended with 10 percent Redmond bentonite and compaction tests were based on the ASTM D698-78, Method A (ASTM, 1988b) procedure. Information on radon barrier materials physical properties can be found in Calculation MAY-355-03-01 in Attachment 1, Volume III.

Tailings materials had an average density of 1.2 g/cm^3 (75 lb/ft^3), porosity of 0.57, and specific gravity of 2.76, assuming a long-term moisture content of 10 percent. The mill yard/ore storage and windblown materials had an average density of 1.60 g/cm^3 (100 lb/ft^3) and porosity of 0.39 at 90 percent of Standard Proctor maximum density, and the specific gravity was 2.64. Information on contaminated materials physical properties can be found in Calculation MAY-326-01-00 in Attachment 1, Volume III.

6.1.2 Calculational methodology and design results

The radon barrier design was evaluated with respect to compliance with the EPA radon flux standard of $20 \text{ pCi/m}^2\text{s}$ ($740 \text{ mBq/m}^2\text{s}$) (40 CFR §192.02(a)(2)(i)) (40 CFR Part 192 and 52 FR 36000) using the RAECOM computer code (NRC, 1984). The current design assumes the relocated tailings and contaminated materials will be compacted to 90 percent of Standard Proctor maximum density and the radon barrier materials will be amended with 10 percent Redmond bentonite and compacted to 100 percent of Standard Proctor maximum density.

A maximum cover thickness of 2 inches (5 cm) was required to achieve the $20 \text{ pCi/m}^2\text{s}$ ($740 \text{ mBq/m}^2\text{s}$) (40 CFR §192.02(a)(2)(i)) (40 CFR Part 192 and 52 FR 36000) radon flux standard using mean values for all parameters. Two inches (5 cm) of cover materials also would be required if contaminated

materials from the windblown or mill yard/ore storage areas were not relocated under the sideslopes of the disposal cell. A sensitivity analysis calculation is not required unless at least 5.9 inches (15 cm) is required from calculations with average values. The 18-inch (46-cm) minimum "constructable" thickness cover, as required by the TAD (DOE, 1989), is adequate to reduce radon fluxes to below the 20 pCi/m²s (740 mBq/m²s) (40 CFR §192.02(a)(2)(i)) (40 CFR Part 192 and 52 FR 36000) standard. Information on the evaluation of the radon barrier can be found in Calculation MAY-326-02-00 in Attachment 1, Volume III. Figure 1.5 of this report shows a typical cross section of the designed disposal cell.

The radon barrier has been designed to control the tailings and other RRM to meet the EPA standards in 40 CFR §192.02(a)(2) (40 CFR Part 192 and 52 FR 36000). The Maybell disposal cell cover also can resist degradation and other geotechnical concerns, minimize infiltration, and meet radon protection standards throughout its design life. Section 3.2.4 of this report provides detailed information regarding the infiltration barrier of the disposal cell cover.

6.2 PROCESSING SITE CLEANUP

A number of investigators conducted extensive field sampling and radiological surveys to determine the extent and degree of contamination at the Maybell site. Distribution of contaminated materials are shown in Calculation MAY-326-01-00 in Attachment 1, Volume III. As discussed in the Executive Summary and Section 1.2.3 of this report, supplemental surface cleanup standards will be applied to most of Johnson Wash and Lay Creek. Justification is based on environmental harm to riparian and wetland areas, costly excavation and diversion of Lay Creek, detrimental effects on geomorphic stability in Johnson Wash, low radon flux from existing contaminants, and low predicted effects from human consumption of cattle that graze in Johnson Wash.

6.2.1 Radiological site characterization

Table 6.2 summarizes measurements of background and existing radiological site conditions. Calculation MAY-327-02-01 of Attachment 1, Volume III, presents additional information.

Approximately 3.37 million yd³ (2.58 million m³) of contaminated materials exist at the Maybell site. The existing tailings pile 2.8 million yd³ (2.1 million m³) has an average Ra-226 concentration of 201 pCi/g (7440 mBq/g). The mill yard/ore storage area north of the tailings pile has an average Ra-226 concentration of 44 pCi/g (1630 mBq/g). The DOE will investigate to determine the amount of this contamination that may have been incorrectly identified as RRM, but in reality is naturally occurring uranium deposits. The fact that several uranium pits are nearby and the site was an open pit mine supports this possibility.

Johnson Wash and a section of Lay Creek are contaminated from past accidental and routine releases of liquid effluents. Tables 6.3 and 6.4

Table 6.2 Background and on-site radiation measurements for the Maybell site near Maybell, Colorado

Measurement	Average	Range	Source
Gamma exposure rate ($\mu\text{R/hr}$)			
Background	14	7 - 15	EG&G, 1982
Tailings pile	120	30 - 300	BFEC, 1985
Mill yard/ore storage	73	29 - 248	BFEC, 1985
Windblown	30	17 - 70	BFEC, 1985
Radon in air $\text{pCi/L (mBq/m}^3\text{)}$			
Background	0.7 (2.6×10^4)	0.3 - 2.8 (1.1×10^4 - 1.0×10^5)	DOE, 1990
Tailings site	3.4 (1.3×10^5)	1.1 - 5.0 (4.1×10^4 - 1.9×10^5)	DOE, 1990
Radon surface flux $\text{pCi/m}^2\text{s (mBq/m}^2\text{s)}$			
Background	10^a (370) ^a	10^a (370) ^a	FBDU, 1981
Tailings site (1976)	87 (3219)	75 - 99 (2775 - 3663)	FBDU, 1981
(1980)	125 (4625)	73 - 191 (2701 - 7067)	FBDU, 1981
Soil concentrations pCi/g (mBq/g)			
Background			
Uranium	3.1 (115)	1.4 - 5.6 (52 - 207)	BFEC, 1985
Th-230	1.3 (48)	1.0 - 1.7 (37.0 - 63)	BFEC, 1985
Ra-226	1.4 (52)	0.5 - 2.2 (19 - 81)	BFEC, 1985
Tailings site			
Uranium	34 (1258)	1 - 505 (37 - 1.9×10^4)	MSRD, 1982
Th-230	230 (8510)	3 - 575 (111 - 2.1×10^4)	BFEC, 1985
Ra-226	201 (7437)	3 - 1107 (111 - 4.1×10^4)	BFEC, 1985
Mill yard/ore storage			
Th-230	103 (3811)	7 - 329 (259 - 1.2×10^4)	BFEC, 1985
Ra-226	44 (1628)	1 - 924 (37 - 3.4×10^4)	BFEC, 1985

Table 6.2 Background and on-site radiation measurements for the Maybell site near Maybell, Colorado (Concluded)

Measurement	Average	Range	Source
Groundwater pCi/L (mBq/m ³)			
Background			
Gross alpha	10 (3.7x10 ⁵)	0 - 45 (0 - 1.7x10 ⁸)	TAC, 1986
Uranium	7.3 (2.7x10 ⁵)	0.2 - 37 (7.4x10 ³ - 1.4x10 ⁶)	TAC, 1986
Ra-226	0.6 (2.2x10 ⁴)	0.1 - 0.8 (3.7x10 ³ - 3.0x10 ⁴)	TAC, 1986
Tailings site			
Gross alpha	1300 (4.8x10 ⁷)	22 - 3500 (8.1x10 ⁵ - 1.3x10 ⁸)	TAC, 1986
Uranium	1100 (4.1x10 ⁷)	14 - 3750 (5.2x10 ⁵ - 1.4x10 ⁸)	TAC, 1986
Ra-226	1.2 (4.4x10 ⁴)	0.1 - 2.1 (3.7x10 ³ - 7.8x10 ⁴)	TAC, 1986

*Value reported based on one measurement.

μR/hr = microrentgens per hour.

mBq/m³ = millibecquerels per cubic meter.

Table 6.3 Average radionuclide concentrations in sediments from Johnson Wash as a function of depth

Sediment ^b depth	Average concentration $\pm$ standard error in pCi/g dry (mBq/g dry) ^a			
	Johnson Wash			
inches (cm)	Ra-226	No. of samples	Th-230	No. of samples
0-6	5.7 $\pm$ 1.1	16	27.9 $\pm$ 9.4	16
(0-15)	(211 $\pm$ 41)		(1032 $\pm$ 348)	
6-12	10.2 $\pm$ 2.8	16	38.1 $\pm$ 13.2	15
(15-30)	(377 $\pm$ 104)		(1410 $\pm$ 488)	
12-18	12.1 $\pm$ 4.9	16	65.9 $\pm$ 17.8	13
(30-46)	(448 $\pm$ 181)		(2438 $\pm$ 659)	
18-24	40.4 $\pm$ 16.6	11	NS ^c	
(46-61)	(1495 $\pm$ 614)			

^aConcentrations in picocuries per gram; converted to millibecquerels per gram.

^bDepth in inches; converted to centimeters in parentheses.

^cSamples not collected for analysis.

Table 6.4 Average radionuclide concentrations in sediments from Lay Creek as a function of depth

Sediment ^b depth	Average concentration $\pm$ standard error in pCi/g dry (mBq/g dry) ^a			
	Lay Creek			
in (cm)	Ra-226	No. of samples	Th-230	No. of samples
0-6	19.2 $\pm$ 10.8	54	24.1 $\pm$ 10.5	54
(0-15)	(710 $\pm$ 400)		(892 $\pm$ 389)	
6-12	15.4 $\pm$ 5.4	51	23.5 $\pm$ 6.3	54
(15-30)	(570 $\pm$ 200)		(870 $\pm$ 233)	
12-18	11.5 $\pm$ 2.8	52	19.4 $\pm$ 4.9	30
(30-46)	(426 $\pm$ 104)		(718 $\pm$ 181)	
18-24	10.1 $\pm$ 1.5	32	NS ^c	
(46-61)	(374 $\pm$ 56)			

^aConcentrations in picocuries per gram; converted to millibecquerels per gram.

^bDepth in inches; converted to centimeters in parentheses.

^cSamples not collected for analysis.

summarize average Ra-226 and Th-230 concentrations in sediments as a function of depth in Johnson Wash and Lay Creek, respectively. Ra-226 and Th-230 concentrations in Johnson Wash increase with depth (Table 6.3), but deeper samples from nearby test pits indicate Ra-226 concentrations of less than 5.0 pCi/g (185 mBq/g) below 24 inches (61 cm). Th-230 concentrations in excess of 35 pCi/g (1300 mBq/g) extend to 4 ft (1.2 m) in one test pit near the tailings pile.

Radionuclide concentrations decrease with depth for Ra-226 and Th-230 in sediments from Lay Creek. Sediments in Lay Creek are contaminated to a mean depth of 1.5 ft (0.5 m). Average Ra-226 and Th-230 surface concentrations shown in Table 6.4 are expected to drop to 5 and 11 pCi/g (185 and 407 mBq/g), respectively, following remediation of the Lay Creek hot spot. Thorium-230 and Ra-226 concentrations in the hot spot range up to 531 and 552 pCi/g (19,600 and 20,400 mBq/g), respectively, but are confined to a narrow depth of 1 ft (0.3 m) or less.

6.2.2 Cleanup standards

The DOE is committed to removing surface and near-surface contaminated materials and placing them in an engineered disposal cell to meet the requirements of 40 CFR §192.12(a), Subpart B (40 CFR Part 192). All disturbed areas will be restored to grade for adequate control of surface drainage.

The DOE will follow Subpart C (40 CFR §192.21 (b)) (40 CFR Part 192 and 52 FR 36000) regarding the proposed use of supplemental surface cleanup standards for portions of Johnson Wash and Lay Creek. The DOE will perform additional characterization of the Johnson Wash and Lay Creek areas prior to construction activities. Any additional hot spots will be addressed appropriately in excavation design. Contaminated materials (except the localized hot spots) in Johnson Wash and in Lay Creek will not be excavated. Justification for DOE's proposed use of supplemental surface cleanup standards for most of Johnson Wash and Lay Creek is based on several criteria:

- Environmental harm to riparian and wetland areas.
- Costly excavation and diversion of Lay Creek.
- Detrimental effects on geomorphic stability in Johnson Wash.
- Low radon flux from existing contaminants.
- Low predicted effects from human consumption of cattle that graze in Johnson Wash.

The DOE has no plans to release for unrestricted use any contaminated materials from the former processing site or equipment or structures from the former processing mill. Union Carbide dismantled the former processing mill and its

associated equipment and structures after the mill ceased operations in November 1964.

During the construction phase of the proposed remedial action, various types of equipment will become contaminated. Any required decontamination will be performed to levels that meet EPA standards; requirements for the *UMTRA Project Environmental, Safety, and Health Plan* (DOE, 1992c) and guidelines of the *UMTRA Project Office Quality Assurance Program Plan* (DOE, 1992a).

6.2.3 Cleanup verification

Excavation control monitoring will be conducted during remedial action to ensure meeting the 5.0 pCi/g (185 mBq/g) and 15 pCi/g (555 mBq/g) above background Ra-226 design standards for surface and subsurface soils, respectively. Verification sampling will prevent both underexcavation and costly overexcavation. The verification survey's intent is to provide reasonable assurance of compliance with the standards. In addition, if Th-230 is encountered in significant concentrations in soils following removal of Ra-226 to EPA standards, supplemental surface cleanup standards under criterion (h) of 40 CFR §192.21, Subpart C, and criterion (b) of 40 CFR §192.22, Subpart C (40 CFR Part 192 and 52 FR 36000) will be imposed in accordance with the current "Generic Protocol for Th-230 Cleanup/Verification at UMTRA Project Sites" position paper (DOE, 1993). No further site Th-230 characterization is planned prior to construction activities.

The DOE and the TAC will conduct independent radiological surveillances and health/safety audits of RAC efforts during remedial action to ensure that all activities meet federal, state, and local standards and guidelines. Quality control and quality assurance requirements and procedures are in place to ensure that adequate cleanup and subsequent verification are properly implemented and documented (DOE, 1992a).

Final verification surveys will document average Ra-226 concentrations on all 100 m² (1076 ft²) areas remediated. Nine-plug composite surface soil samples will be collected for each 100-m² (1076-ft²) area and analyzed by gamma spectroscopy to verify compliance with EPA standards. Average surface Ra-226 concentrations must be below 5.0 pCi/g (185 mBq/g) plus background and measured to within plus or minus 30 percent of the mean at the 95-percent confidence level. Verification samples also will be collected in accordance with the current version of the "Generic Protocol for Th-230 Cleanup/Verification at UMTRA Project Sites" position paper (DOE, 1993) to document that average Th-230 soil concentrations are below established supplemental standards.

In addition, a nine-point composite gamma measurement technique may be used in windblown contamination areas. This hand-held verification protocol will be site-specific and must be approved by the DOE UMTRA Project Office. The radiation tracking system mobile detection unit may be used to verify contaminated areas that are too large to sample by hand.

6.3 SUMMARY

The disposal cell and radon barrier as designed will reduce radon flux to levels below EPA standards in 40 CFR §192.02(a)(2)(i), Subpart A (40 CFR Part 192 and 52 FR 36000). The DOE is committed to clean up the Maybell site in accordance with EPA standards and UMTRA Project safety and health requirements. Data (e.g., layer thickness, densities, Ra-226 concentrations, emanation fractions, and residual radionuclide concentrations) will be collected, verified, and analyzed during remediation to ensure fulfillment of this commitment.

7.0 LIST OF CONTRIBUTORS

The following individuals contributed to the preparation of this remedial action plan.

Name	Contribution
M. Hansen	Author, document coordination
Technical contributors/authors	
G. Ruskauff, E. Storms	Site hydrologists
B. Meyers	Site engineer
J. Blount	Site geochemist
W. James	Radiological specialist
J. Blount, J. Crain, R. Heydenburg, J. Lommler, B. Meyers, J. McBee, G. Ruskauff, L. Ulland	Document review
D. Thalley, K. Walston	Technical editing, document production coordination
E. Bond, S. Suniga, E. Wagner	Graphics
L. Keith	Text processing

8.0 REFERENCES

- ASTM (American Society for Testing and Materials), 1988a. *1988 Annual Book of ASTM Standards*, Volume 04.08 Soil and Rock, Building Stones; Geotextiles, Standard D 1586-84, "Standard Method for Penetration Test and Split-Barrel Sampling of Soils," ASTM, Philadelphia, Pennsylvania.
- ASTM (American Society for Testing and Materials), 1988b. *1988 Annual Book of ASTM Standards*, Volume 04.08 Soil and Rock, Building Stones; Geotextiles, Standard D 698-78, Method A, "Standard Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 4.4-lb (2.49-kg) Rammer and 12-in (305-mm) Drop," ASTM, Philadelphia, Pennsylvania.
- BFEC (Bendix Field Engineering Corporation), 1985. *Radiologic Characterization of the Maybell, Colorado, Uranium Mill Tailings Remedial Action Site*, GJ-39, prepared by BFEC, Grand Junction, Colorado, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- Carpenter, James R., 1986. *PC STABLE5 User Manual*, Joint Highway Research Project, JHRP-86.14, Indiana Department of Highways.
- DOC (U.S. Department of Commerce), 1991. *Population and Housing, Summary of Population and Housing Characteristics, Colorado*, July 1991, Bureau of the Census, U.S. Government Printing Office, Washington D.C.
- DOE (U.S. Department of Energy), 1994. *Environmental Assessment of Remedial Action at the Maybell Uranium Mill Tailings Site near Maybell, Colorado*, UMTRA-DOE/AL-0347, Revision 1, April 1994, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- DOE (U.S. Department of Energy), 1993. "Generic Protocol for Th-230 Cleanup/ Verification at UMTRA Project Sites," unpublished working paper, May 3, 1993 revision, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- DOE (U.S. Department of Energy), 1992a. *UMTRA Project Office Quality Assurance Program Plan*, UMTRA-DOE/AL 40324.0185, Revision 4, Final, June 1992, Uranium Mill Tailings Remedial Action Project Office, Albuquerque Field Office, U.S. Department of Energy, Albuquerque, New Mexico.
- DOE (U.S. Department of Energy), 1992b. *Guidance for implementing the UMTRA Project Long-term Surveillance Program*, UMTRA-DOE/AL 350125.0000, Revision 1, final, September 1992, U.S. DOE, Uranium Mill Tailings Remedial Action Project, Albuquerque, New Mexico.

AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

2 of 3

- DOE (U.S. Department of Energy), 1992c. *UMTRA Project Environmental, Safety, and Health Plan*, UMTRA-DOE/AL-150224.0006, revised November 1992, Uranium Mill Tailings Remedial Action Project Office, Albuquerque Field Office, Department of Energy, Albuquerque, New Mexico.
- DOE (U.S. Department of Energy), 1990. *Maybell Radon Monitoring: Pre-Remedial-Action Summary*, monitoring period: April 27, 1989, through June 6, 1990, file location number 14.17.3.5, August 1990, U.S. Department of Energy, Uranium Mill Tailings Remedial Action Project, Albuquerque, New Mexico.
- DOE (U.S. Department of Energy), 1989. *Technical Approach Document*, UMTRA-DOE/AL 050425.0002, Revision II, December 1989, Uranium Mill Tailings Remedial Action Project, Albuquerque, New Mexico.
- DOE (U.S. Department of Energy), 1983. *Environmental Assessment of Remedial Actions on the Uranium Mill Tailings at the Maybell Site, Moffat County, Colorado*, DOE UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- Economic Development Commission, n.d. *City of Craig Economic Profile*, City of Craig Economic Commission, Craig, Colorado.
- EG&G (Edgerton, Germershausen, and Grier; Energy Measurements Group), 1982. *An Aerial Radiological Survey of the Area Surrounding the Maybell Site, Maybell, Colorado*, EG&G Survey Report EP-U-017, prepared by EG&G, Las Vegas, Nevada.
- FBDU (Ford, Bacon & Davis Utah Inc.), 1981. *Engineering Assessment of Inactive Uranium Mill Tailings, Maybell Site, Maybell, Colorado*, DOE/UMT-0116, FBDU 360-11, UC 70, September 1981, prepared by FBDU, Salt Lake City, Utah, Contract No. DE-AC04-76GJ01658, for the U.S. Department of Energy, Albuquerque Operations Office, Uranium Mill Tailings Remedial Actions Project Office, Albuquerque, New Mexico.
- Gibbons, R., 1986. County Planner, Moffat County Sheriff's Department, Craig, Colorado, personal communication to Sandra Beranich, Environmental Services, Jacobs Engineering Group Inc., Albuquerque, New Mexico, dated September 23, 1986.
- Hansen, W. R., 1986. "Neogene Tectonics and Geomorphology of the Eastern Uinta Mountains in Utah, Colorado and Wyoming," U.S. Geological Survey, Professional Paper 1356.
- Hillberry, D., 1986. U.S. Bureau of Land Management, Little Snake Resource Area, Craig, Colorado, personal communication to Dale Jones, Environmental Services, Jacobs Engineering Group Inc., Albuquerque, New Mexico, dated October 22, 1986.

- Johnson, B., 1986. Resident deputy, Moffat County Sheriff's Department, Maybell, Colorado, personal communication to Sandra Beranich, Environmental Services, Jacobs Engineering Group Inc., Albuquerque, New Mexico, dated September 25, 1986.
- Moch, J., 1992. Community Development Secretary, City Hall, Craig, Colorado, personal communication to Sandra Beranich, Environmental Services, Jacobs Engineering Group Inc., Albuquerque, New Mexico, dated September 21, 1992.
- Moch, J., 1990. Community Development Secretary, City Hall, Craig, Colorado, personal communication to Sandra Beranich, Environmental Services, Jacobs Engineering Group Inc., Albuquerque, New Mexico, dated February 14, 1990.
- MSRD (Mountain States Research and Development), 1982. *Economic Evaluation of Inactive Uranium Mill Tailings, Maybell Site, Maybell, Colorado*, UMTRA-DOE/ALO-177, prepared by MSRD, Tucson, Arizona, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.
- NOAA (National Oceanic and Atmospheric Administration), 1977. *Hydrometeorological Report No. 49, Probable Maximum Precipitation Estimates—Colorado River and Great Basin Drainages*, Silver Spring, Maryland.
- NRC (U.S. Nuclear Regulatory Commission), 1989. "Standard Format and Content for Documentation of Remedial Action Selection at Title I Uranium Mill Tailings Sites," February 24, 1989, Staff Technical Position, Division of Low-Level Waste Management and Decommissioning, Office of Nuclear Material Safety and Safeguards, Washington, D.C.
- NRC (U.S. Nuclear Regulatory Commission), 1985. "Draft Standard Review Plan for UMTRCA Title I Mill Tailings Remedial Action Plans," unpublished report, NRC, Division of Waste Management, Washington, D.C.
- NRC (U.S. Nuclear Regulatory Commission), 1984. *Radon Attenuation Handbook for Uranium Mill Tailings Cover Design*, NUREG/CR-3533, prepared by Rogers and Associates Engineering, Salt Lake City, Utah, for the U.S. Nuclear Regulatory Commission, Washington, D.C.
- Perez, R. N., 1992. U.S. Bureau of Land Management, Little Snake Resource Area, Craig, Colorado, personal communication to Sandra Beranich, Environmental Services, Jacobs Engineering Group Inc., Albuquerque, New Mexico, dated September 3, 1992.
- TAC (Technical Assistance Contractor), 1986. "Maybell Groundwater and Surface Water Sampling," unpublished data, prepared by the Technical Assistance Contractor (Jacobs-Weston Team), Albuquerque, New Mexico, for the U.S. Department of Energy, UMTRA Project Office, Albuquerque Operations Office, Albuquerque, New Mexico.

- USACE (U.S. Army Corps of Engineers), 1982. *HEC-2 Water Surface Profiles, User's Manual*, Computer Program 723-X6-L202A, Water Resources Support Center, The Hydrologic Engineering Center, Davis, California.
- USACE (U.S. Army Corps of Engineers), 1981. *HEC-1 Flood Hydrograph Package, User's Manual*, Computer Program 723-X6-L2010, Water Resources Support Center, The Hydrologic Engineering Center, Davis, California.
- USACE (U.S. Army Corps of Engineers), 1970. *Laboratory Soils Testing*, Manual EM 1110-2-1906, November 30, 1970, Change 1, and August 20, 1986, Change 2.
- Wang, K. S., and J. M. Duncan, 1984. "CONSOL: A Computer Program for One-Dimensional Consolidation Analysis of Layered Soil Masses," Report No. UCB/GT184-06, April 1984, microcomputer version, Department of Civil Engineering, Berkeley, California.
- Wong, L. C., and M. D. Haug, 1991. "Cyclical Closed System Freeze—Thaw Permeability Testing of Soil Liner and Cover Materials," *Canadian Geotechnical Journal*, Volume 28, Number 6, pp. 784-793.

CODE OF FEDERAL REGULATIONS

- 40 CFR Part 192, *Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings*, U.S. Environmental Protection Agency, 1993.
- 40 CFR Part 264, *Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities*, U.S. Environmental Protection Agency, 1993.
- 40 CFR Part 440, *Ore Mining and Dressing Point Source Category*, U.S. Environmental Protection Agency, 1993.

FEDERAL REGISTER

- 52 FR 36000, "Standards for Remedial Actions at Inactive Uranium Processing Sites; Proposed Rule," September 24, 1987.

UNITED STATES CODE

- 42 USC §7901, *et seq. Uranium Mill Tailings Radiation Control Act*, November 8, 1978.

ATTACHMENT 2
GEOLOGY REPORT

TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
1.0 INTRODUCTION	1-1
1.1 Content and organization of section	1-2
1.2 Criteria and definitions	1-2
1.3 Geomorphic evaluation	1-4
1.4 Data collection	1-4
1.4.1 Compilation and analysis of previous work	1-4
1.4.2 Earthquake data compilations	1-5
1.4.3 Subsurface geologic data	1-5
1.4.4 Photogeologic interpretation of LANDSAT and conventional aerial photography	1-5
1.4.5 Low-sun-angle aerial reconnaissance	1-5
1.4.6 Ground reconnaissance	1-6
2.0 REGIONAL GEOLOGY	2-1
2.1 Physiographic setting	2-1
2.1.1 Major physiographic subdivisions of the site region	2-1
2.1.2 Regional geomorphology	2-1
2.1.3 Older erosion surfaces	2-3
2.1.4 Landform development	2-3
2.1.5 Drainage system development	2-5
2.1.6 Yampa River drainage	2-5
2.1.7 Lay Creek drainage	2-7
2.1.8 Surficial deposits	2-9
2.1.9 Regional erosion rates	2-9
2.1.10 Post-glacial climate	2-10
2.1.11 Pollen studies	2-11
2.1.12 Tree-ring studies	2-12
2.1.13 Wind, precipitation, and temperature	2-12
2.2 Stratigraphic setting	2-13
2.3 Structural setting	2-18
2.3.1 Structural history of the Axial Basin Arch	2-22
2.3.2 Major structural features of the site region	2-22
2.3.3 Uinta Mountains Province	2-24
2.3.4 Colorado Plateau Province	2-24
2.3.5 Wyoming Basin province	2-24
2.3.6 White River Uplift	2-25
2.3.7 Elkhead Mountains	2-25
2.4 Seismotectonic setting	2-25
2.4.1 Seismotectonic provinces	2-27
2.4.2 Uinta-Elkhead province	2-27
2.4.3 Wyoming Basin province	2-28
2.4.4 Colorado Plateau	2-28
2.4.5 Western Mountains	2-29
2.4.6 Fault compilation and analysis	2-29

TABLE OF CONTENTS (Continued)

<u>Section</u>	<u>Page</u>
2.5 Mineral deposits and other resources	2-44
2.5.1 Uranium	2-44
2.5.2 Coal	2-44
2.5.3 Oil and gas	2-46
2.5.4 Oil shale	2-46
2.5.5 Gold and other metallic minerals	2-47
2.5.6 Geothermal resources	2-47
2.5.7 Potash	2-47
3.0 SITE GEOLOGY AND GEOMORPHOLOGY	3-1
3.1 Bedrock geology	3-1
3.1.1 Structural faults in the site area	3-6
3.2 Surficial geology	3-7
4.0 GEOLOGIC STABILITY	4-1
4.1 Geomorphic stability	4-1
4.2 Seismotectonic stability	4-5
4.2.1 Technical approach	4-5
4.2.2 Order of presentation of seismic analysis	4-5
4.2.3 Previous studies	4-7
4.2.4 Epicentral compilation	4-8
4.2.5 Determination of floating earthquake magnitude	4-14
4.2.6 Effects of ME of other seismotectonic provinces in the region	4-14
4.2.7 Anomalous response to regional seismicity	4-15
4.2.8 Fault age assessment for Maybell site area	4-15
4.2.9 Assessment of fault age by previous workers	4-15
4.2.10 Determination of design earthquake	4-16
5.0 GEOLOGIC SUITABILITY	5-1
5.1 Geomorphic suitability	5-1
5.2 Other geologic processes	5-3
5.3 Seismic suitability	5-4
5.4 Earthquake-induced landslide or subsidence hazard	5-5
6.0 LIST OF CONTRIBUTORS	6-1
7.0 REFERENCES	7-1

LIST OF FIGURES

Figure	Page
2.1 Physiographic provinces of the Maybell site region	2-2
2.2 Generalized distribution of the Browns Park Formation, Bishop Conglomerate, and bare-rock Gilbert Peak erosion surface in the Eastern Uinta Mountains and adjacent areas	2-4
2.3 Regional and areal drainage system	2-8
2.4 Stratigraphic column, Maybell tailings site near Maybell, Colorado	2-17
2.5 Structural setting of the Maybell site region	2-19
2.6 Structural contour map of the Sand Wash basin, Maybell site region	2-20
2.7 Structural map and cross section of axial basin fault system, Maybell site region	2-21
2.8 Cross sections showing structures of Wyoming Basin and Uinta Arch, Maybell site region	2-23
2.9 Seismotectonic provinces of Maybell site region	2-26
2.10 Principal locations of energy and mineral resources, Maybell site region	2-45
3.1 Maybell site geology map	3-2
3.2 Structural cross section through Maybell site area	3-3
3.3 Generalized geologic map of Maybell site region	3-4
3.4 Generalized cross section showing Uinta-Sparks fault system in Maybell site area	3-5
4.1 Channel fill deposits and major tributaries of Johnson Wash, Maybell site near Maybell, Colorado	4-3

LIST OF TABLES

<u>Table</u>	<u>Page</u>
2.1 Description of stratigraphic units in the Maybell, Colorado, site area	2-14
2.2 Summary analysis of mapped faults and lineaments within a 40-mi (65-km) radius of the Maybell, Colorado, site	2-31
4.1 Probabilistic estimates of maximum acceleration, velocity, and intensity in the site region	4-7
4.2 Summary of maximum earthquakes recommended by previous studies	4-9
4.3 Earthquakes of $M \geq 4.0$ since 1963 in Maybell site region	4-10
4.4 Historic earthquakes of $MMI = III$ or greater in Maybell site region	4-12

PLATE

- 1 Seismicity and fault map of Maybell site region

LIST OF ACRONYMS AND ABBREVIATIONS

<u>Acronym</u>	<u>Definition</u>
AAF	ancestral axial fault
AEC	U.S. Atomic Energy Commission
BLM	Bureau of Land Management
°C	degrees Celsius
cm	centimeter
EPA	U.S. Environmental Protection Agency
°F	degrees Fahrenheit
FE	floating earthquake
ft	foot
ISB	Intermountain Seismic Belt
km	kilometer
LSA	low sun angle
m	meter
M _b	body-wave magnitude
ME	maximum earthquake
mi	mile
M	magnitude
MMI	Modified Mercalli Intensity
M _s	surface-wave magnitude
NGDC	National Geophysical Data Center
NOAA	National Oceanic and Atmospheric Administration
NRC	U.S. Nuclear Regulatory Commission
PHA	peak horizontal acceleration
TAC	Technical Assistance Contractor
UMTRA	Uranium Mill Tailings Remedial Action
WGS	Wyoming Geologic Survey

1.0 INTRODUCTION

Detailed investigations of geologic, geomorphic, and seismic conditions at the Maybell site in northwestern Colorado were conducted by the Uranium Mill Tailings Remedial Action (UMTRA) Technical Assistance Contractor (TAC). The purpose of these investigations was basic site characterization and the identification of potential geologic hazards that could affect long-term site stability. Subsequent engineering studies (e.g., analyses of the hydrologic regime and liquefaction potential) use this data. The geomorphic analysis is employed in the design of effective erosion protection. Studies of the regional and local seismotectonic setting, which included a detailed search for possible capable faults within a 40-mile (mi) (65-kilometer [km]) radius of the site, provided the basis for estimating seismic design parameters.

A broad basis of technical data was assessed, including the following:

- Compilation and analysis of previously published and unpublished geologic literature and maps.
- Review of historical and instrumental seismic data.
- Review of site-specific subsurface geologic data, including logs of exploratory boreholes and test pits in the site area.
- Photogeologic interpretation of LANDSAT and conventional aerial photography.
- Low-sun-angle (LSA) aerial reconnaissance of the site region.
- Ground reconnaissance and mapping of the site region.
- Detailed mapping of the site area.

The site and the surrounding area, out to a radius of about 1 mi (1.6 km), are referred to in this section as the site area. The area out to a radius of 40 mi (65 km), encompassing northwestern Colorado and a small adjoining area in southern Wyoming, is referred to as the site region.

The following topics relevant to the stabilization of mill tailings at the Maybell site are discussed:

- Characterization of the regional geologic setting and its correlation to site geology.
- Identification of geomorphic hazards and requirements for mitigating potential impacts.
- Seismotectonic evaluation to provide earthquake design parameters. (Subsequent engineering analyses fully assess the liquefaction potential and slope stability.)
- On-site fault rupture potential.

- Potential impact of subsidence due to geothermal, volcanic activity, tectonic causes, reservoir-induced seismicity, and the like.
- Analysis of mineral resource potential and the possible impact of past and future mineral resource development on site stability.

1.1 CONTENT AND ORGANIZATION OF SECTION

This attachment is divided into five sections (1.0 through 5.0) plus a folded plate presenting a seismicity and fault map of the Maybell site region.

This first section contains the introduction. Sections 2.0 through 4.0 present the basic information on the regional setting and natural processes acting on the site region, as well as a detailed discussion of on-site conditions. The analyses of geologic hazards presented in Section 5.0 result from the integration of the regional and local studies discussed above.

1.2 CRITERIA AND DEFINITIONS

The following is a discussion of the standards and definitions that were applied in the evaluation of geologic hazards at the Maybell site.

- **Design life.** As specified by the U.S. Environmental Protection Agency (EPA) standards for control of residual radioactive materials from inactive uranium processing sites (40 CFR §192.02(a)(1)) (40 CFR Part 192 (1993); 52 FR 36000 (1987)), the controls implemented at the UMTRA Project sites are to be effective for up to 1000 years, to the extent reasonably achievable, and, in any case, for at least 200 years. In the case of seismic hazards, the criteria established and the methodologies applied seek to ensure that the reclaimed wastes will not be damaged by earthquake ground motions or related ground rupture for up to 1000 years.
- **Design earthquake.** For UMTRA Project sites, the earthquake that produces the largest on-site impact will be the design earthquake. Typically this will be the earthquake that produces the largest on-site peak horizontal acceleration. This design earthquake could be the floating earthquake (FE) or an earthquake whose magnitude is derived from a relationship between fault rupture or fault length and maximum magnitude for a verified, capable fault of known rupture length.
- **Floating earthquake.** An FE is an earthquake within a specific seismotectonic province that is not associated with a known tectonic structure. Before assigning the maximum FE magnitude, the earthquake history and tectonic character of the province are analyzed.
- **Capable fault.** A capable fault has exhibited one or more of the following characteristics:

- Movement at or near the ground surface at least once within the past 35,000 years, or movement of a recurring nature within the past 500,000 years.
- Macroseismicity (magnitude 3.5 or greater) instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault.
- A structural relationship to a capable fault such that movement on one fault could be reasonably expected to cause movement on the other.

This definition is essentially the one adopted by the U.S. Nuclear Regulatory Commission (NRC) for the siting of nuclear power plants (10 CFR Part 100 (1993), Appendix A, III, Definitions (g)(1)).

- **Acceleration.** Within the context of the UMTRA Project studies, acceleration is defined as the mean of the peaks of the two horizontal components of an accelerogram record. The exact term used is "peak horizontal acceleration." The design accelerations are determined from the constrained attenuation relationship based on distance and magnitude developed by Campbell (1981). The mean-plus-one standard deviation (84th percentile) value will be adopted. The design value is considered a nonamplified peak horizontal acceleration.
- **Duration of strong earthquake ground motion.** For the purposes of UMTRA Project studies, duration is defined, after Krinitzsky and Chang (1977), as the bracketed time interval in which the acceleration is greater than 0.05 gravity. The methodology of Krinitzsky and Chang is applied in estimating the duration of strong ground motion at a particular site.
- **Magnitude and intensity.** Magnitude (M) was originally defined by C. F. Richter as the base-10 logarithm of the amplitude of the largest deflection observed on a torsion seismograph located 62 mi (100 km) from the epicenter. This value may not be the same as the body-wave (M_b) and surface-wave (M_s) magnitudes derived from measurements at teleseismic distances. Unless specified otherwise, M values will be used.

Intensity is the index of the effects of an earthquake on the human population and man-made structures. The most commonly applied scale is the 1931 Modified Mercalli Intensity (MMI) scale. Because pre-instrumental earthquakes are reported in intensity and instrumental records are in magnitude, there may be a need to relate these values. Several equations have been proposed. Unless otherwise specified, the relationship developed by Gutenberg and Richter (1956) is applied. This equation is as follows:

$$M = 1 + 2/3 I$$

where,

M = magnitude on the Richter scale.

I = Modified Mercalli intensity in the epicentral area.

- **Maximum earthquake (or maximum-magnitude earthquake).** The term "maximum earthquake" (ME) was defined by Krinitzsky and Chang (1977) as "the largest earthquake that is reasonably expected" on a given structure or within a given area. No recurrence interval is specified for such an event.

1.3 GEOMORPHIC EVALUATION

The purpose of the evaluation is to characterize the current geomorphic conditions and to assess the impact of geomorphic processes on the long-term stability of the uranium mill tailings pile. These evaluations are restricted to the assessment of natural processes and the effects of past land-use activities, but do not address the effects of future human activities.

Schumm and Chorley (1983) discuss, in detail, the processes that may affect a tailings site. Nelson et al. (1983) present a handbook approach to specific methods for site assessment, engineering procedures for mitigation, and confidence levels for hazard predictions over periods of 200, 500, and 1000 years. Wells and Gardner (1985) have established geomorphic criteria for selecting stable tailings disposal sites and have presented a means of determining the potential for gully development. The methodologies and criteria presented in the above publications were used as guides for the geomorphic investigations.

1.4 DATA COLLECTION

1.4.1 **Compilation and analysis of previous work**

A review of all pertinent stratigraphic, lithologic, tectonic, seismologic, geophysical, geomorphic, mineral resource, and soils literature and maps of the site region was performed. A GeoRef data search was employed to ensure complete coverage of all published information. References used during this study are listed at the back of this report.

Copies of published geologic maps and open-file reports covering a 40-mi (65-km) radius of the site were obtained and employed in the fault compilation. All faults identified during the survey were compiled onto a single base map with a 1:250,000 scale. A search was also made for other unpublished seismic evaluations for large engineered structures (dams, power plants, waste disposal areas, and the like).

Personal communications with experts on seismic evaluation and geologic researchers active in the study region supplement the literature.

1.4.2 Earthquake data compilations

Historical earthquake data for the area within a 125-mi (200-km) radius of Maybell were obtained from the National Geophysical Data Center (NGDC), National Oceanic and Atmospheric Administration (NOAA) and analyzed (NGDC/NOAA, 1986).

Published probabilistic seismic hazard studies for the United States (Algermissen et al., 1982; Coffman et al., 1982; Liu and DeCapua, 1975) were also reviewed for comparison with the results of the earthquake data compilations.

The ME values for remote seismotectonic provinces (e.g., the Colorado Plateau, the Western Mountain Province, and the Northern Rio Grande Rift) were taken from published studies. In addition, a regional epicentral compilation was obtained from the NGDC/NOAA (NGDC/NOAA, 1986) for use in calculating the ME value and recurrence interval for the Uinta-Elkhead Province.

1.4.3 Subsurface geologic data

Subsurface geologic data obtained in the site area for this study consist of the logs of 14 boreholes advanced on the site (off the pile) during September and October of 1986. The boreholes were drilled to depths ranging from 100 to 450 feet (ft) (30 to 150 meters [m]) to assess ground water conditions and subsurface stratigraphy. An assessment of the tailings pile and foundation was performed using piezocone soundings and auger borings. Logs of all boreholes were compiled by TAC representatives and are discussed in other sections of this document. In addition to the boring logs, inspections of site geologic conditions were made directly by examining the walls of the nearby open pit mines, some of which have depths of 100 ft (30 m).

1.4.4 Photogeologic interpretation of LANDSAT and conventional aerial photography

A photogeologic study of the site region included examination of existing black and white LANDSAT photography and stereo-pair black and white and natural color conventional aerial photography obtained from the U.S. Bureau of Land Management (BLM).

The LANDSAT image of the Maybell site region is at a scale of 1:250,000 and was taken on September 8, 1984. It is indexed as NOAA LANDSAT flight line 035-032, scene 05727-095, photo identification number E-50191-17194-4. Aerial photo coverage of the site area taken during 1977 and 1982 was purchased from the BLM.

1.4.5 Low-sun-angle aerial reconnaissance

Two LSA aerial reconnaissance flights were conducted by the TAC on May 19 (evening) and 20 (morning), 1986. Both flights used a Cessna 210

turbo-charged high-wing aircraft with four TAC geologists/observers on board. Good LSA conditions existed for both flights. Regional geologic structures were inspected under both morning and evening illumination. All mapped faults and lineaments within 40-mi (65-km) of the site were inspected at least once. The purposes of the LSA reconnaissance include examination of mapped faults for evidence of Quaternary fault activity and a search of the site region for previously unidentified Quaternary faulting. Particular attention was paid to a detailed examination of the immediate site area. The LSA aerial reconnaissance mission also provided an opportunity to examine the overall geomorphic setting and critical geomorphic features.

Glass and Slemmons (1978) indicate that the most definitive indication of active faulting is oversteepened land surfaces (fault scarps). They further indicate that the single most effective method of detecting and delineating fault scarps in regions having climatic and vegetative settings such as that surrounding Maybell is to conduct aerial reconnaissance and remote sensing to produce shadows and highlights on scarps. Slemmons (1978) indicates that the use of LSA methods can greatly aid in delineating very subtle geomorphic features associated with fault displacement. The degradation of fault scarps has been shown by Wallace (1982) and Bucknam and Anderson (1979) to occur as a result of mass wasting and erosional processes over a period of several hundred thousand to a few million years in the climate of the Basin and Range of the western United States. Although, in general, erosional processes may work somewhat faster in the Wyoming Basin than in the arid Basin and Range, the climate of the site region is semiarid, so it is reasonable to assume that any faulting of Holocene age (about the last 10,000 years) would still exhibit scarps detectable using LSA methods of observation.

LSA methodology has been discussed by Slemmons (1978, 1969); Glass and Slemmons (1978); Cluff and Slemmons (1972); and Clark (1971). They indicate that LSA reconnaissance in areas of moderate terrain is best accomplished when the sun is from 10° to 25° in elevation above the horizon. Glass and Slemmons (1978) recommend a "multi" approach (i.e., using multiple observers, multiple times of the day, and multiseason flights). The project missions used all but multi-seasonal flights; multi-season observations are not necessary in the project area, as seasonal vegetation differences are negligible. The missions were flown between 1000 and 3000 ft (300 and 900 m) above mean terrain altitudes for easy observation of small features.

1.4.6 Ground reconnaissance

Ground reconnaissance and field verification of geologic and geomorphic features were performed by TAC geologists concurrently with the other phases of this study from December 8 through 12, 1986; January 12 and 13, 1987; and February 11 through 13, 1987. Additional field investigation of potential geologic hazards was performed from April 14 through 17, 1987.

Mapped faults and linear features delineated by LSA aerial reconnaissance and inspection of aerial photography were examined in the field. All major structures within the 40-mi (65-km) radius of the site were inspected. Particular attention was given to faults found to underlie the tailings pile in the adjoining open pit mines and to potential geomorphic hazards at the site, including gully erosion, floods, landslides, and other phenomena.

2.0 REGIONAL GEOLOGY

2.1 PHYSIOGRAPHIC SETTING

The site region is in the Sand Wash Basin subprovince of the Wyoming Basin physiographic province (Figure 2.1) (Hunt, 1967). The Wyoming Basin is characterized by subbasins containing thick deposits of Tertiary-aged sediments with low to moderate topographic relief. The basin is an elevated depression separating the Middle and Southern Rocky Mountains and is continuous with the Great Plains to the northeast. Minor folding and faulting have separated the region into subbasins. Some buried and partially exhumed mountain structures are present, indicating that the Rocky Mountain structure is continuous in the subsurface.

The Sand Wash Basin contains some Tertiary volcanic mountains and ridges and is rimmed by faulted Tertiary deposits. Topography of the site area is typical of the basin region; however, the area is underlain by eroded, folded, and faulted structures that are more typical of the Uinta Basin, which lies to the west. The meandering streams of the region are characteristic of the basin as a whole. The Green and Yampa Rivers have been superimposed upon the uplifted structures of the bordering provinces. The site region is drained by the Yampa River system. Elevations of the site area vary from 6280 to 6340 ft (1910 to 1930 m) above mean sea level.

2.1.1 Major physiographic subdivisions of the site region

Physiographic subdivisions are defined by regional structural features. Major physiographic provinces include the Colorado Plateau to the south, the Middle Rocky Mountain Province to the west and the Southern Rocky Mountain Province to the east.

2.1.2 Regional geomorphology

The present regional geomorphic setting of the Maybell site area reflects the influences of tectonic activity, drainage adjustments, and widespread erosion since the mid-Tertiary period. Tectonic events and changes in the drainage patterns of the area's major rivers during the Quaternary have exerted the major influence on the geomorphic processes of regional erosion and drainage system expansion.

The following summary of regional geomorphology is extracted mainly from the tectonic and geomorphic studies of the Uinta Mountains area by Hansen (1986a, 1984) and geologic studies by Madole (1982).

REFERENCE : HUNT, 1967

FIGURE 2.1
PHYSIOGRAPHIC PROVINCES OF THE MAYBELL SITE REGION

2.1.3 Older erosion surfaces

Extensive flat to gently rolling pediment surfaces are prominent topographic features of the eastern Uinta Mountains. Areal erosion surfaces developed during the Eocene, Oligocene, and Miocene ages. The high elevation Wild Mountain erosion surface developed while alluvial and lacustrine sediments were being deposited during the Eocene age in the Green River, Uinta, and Sand Wash Basins (Hansen, 1986a). Remnants of this surface are present about 600 ft (200 m) above the Oligocene pediment surface.

The Oligocene-age Gilbert Peak erosion surface (Figure 2.2) began to develop in the eastern Uinta Mountains after the end of the Laramide Orogeny (Hansen, 1984). This surface now forms high mesas and sloping plains around the flanks of the Uinta Mountains. Current elevations of this pediment range from about 13,000 ft (4000 m) at Gilbert Peak in the central Uinta Mountains to about 7000 ft (2100 m) near Green River, Wyoming (Hansen, 1986a). High mountain areas of the Gilbert Peak surface exist as dissected bare rock surfaces, whereas the lower elevation pediments are capped by the Bishop Conglomerate (Hansen, 1984). The Gilbert Peak pediments apparently once extended to the floors of the Uinta, Green River, Sand Wash, and Washakie basins (Hansen, 1986a).

Erosion surfaces, which probably correlate with the Gilbert Peak surface, occur south of Maybell on the Citadel Plateau, to the southwest on Pinyon Ridge near Elk Springs, and on Cathedral Bluff near Rangely (Hansen, 1986a). Old dendritic valleys formed at the headway parts of the Gilbert Peak erosion surface occur near the crests of the Uinta Mountains. The correlation of the Citadel Plateau south of Maybell with the Gilbert Peak erosional surface indicates that the Yampa River did not exist at its present location prior to the Late Oligocene period (Hansen, 1986a).

2.1.4 Landform development

The structural portion of the Sand Wash Basin that underlies the site, defined by Hansen (1986a) as the Axial Basin Arch, trends to the northwest in the site area and developed during extensional tectonics and subsidence in the early Miocene period. This basin currently is filled with Browns Park Formation sandstones and tuffs deposited from 8 to 25 million years ago (Figure 2.2). The present drainage system of the site area is developed mainly on sediments of this formation.

Development of the present landforms in the Maybell area has been influenced most strongly by tectonic activity prior to and during deposition of the Browns Park Formation and by changes in the locations of the Green River and Yampa River drainage systems. By the late Miocene age, the Browns Park Formation had filled the depositional valley and covered the adjacent uplands, except for the highest peaks (Hansen, 1986a).

The present distribution of the Browns Park Formation reflects the greater thickness of sediment accumulated in the Maybell area because of the development of a depositional syncline within the Axial Basin Arch. Browns Park Formation sediments have subsequently been removed by erosion from most areas outside of the northwestward-trending syncline.

2.1.5 Drainage system development

Both the Green River and Yampa River drainages have changed significantly since the deposition of the Browns Park Formation. The Green River formerly flowed southeastward around the end of the Uinta Mountains. Its current path southward through the Uintas at Ladore Canyon reflects superposition through the thickened Browns Park Formation (Hansen, 1986a). Rejuvenation of the drainage systems in the eastern Uinta Mountains resulted in capture of the upper Green River at Green River, Wyoming, about 600,000 years ago (Hansen, 1985). Subsequent incision rates along the Green River system probably have greatly increased since the capture of the upper Green River and runoff of the entire Green River basin.

The present course of the Yampa River is superimposed across the eastern end of the Uinta Mountains from its position on the Browns Park Formation. Rejuvenation of the Yampa River drainage system followed the change in position of the Green River (Hansen, 1986a). Capture of the ancestral upper Yampa River flowing on the Browns Park Formation has greatly affected erosion and incision rates in the Maybell area since Pliocene time. Headward extension of the Yampa River tributaries, following its superposition across the entire Axial Basin Arch, probably allowed the ancestral Lay Creek to grow eastward. Capture of the headward reaches of the northern tributaries of the Yampa River by Lay Creek resulted in the present deeply entrenched tributaries on the north side of Lay Creek, such as Johnson Wash, which flows south out of the Maybell site area. Landscape equilibrium in the Maybell area may be affected by the fairly recent drainage adjustments due to extension of the Lay Creek drainage system.

2.1.6 Yampa River drainage

The Quaternary history of the Yampa River is important because it affects erosion rates near the Maybell site. Also, the Yampa River terraces may serve as datums for identifying regional warping of the middle to late Quaternary age. The history of the Yampa River is summarized here in relative detail because recent work is not readily available.

After deposition of the Browns Park Formation, drainages in the region have incised more or less continuously without significant aggradation. The Yampa River was superimposed across Cross Mountain, Juniper Mountain, and the anticlines west of Craig from the depositional surface of the Browns Park Formation (Hancock, 1925). The depth of the Yampa River canyon through Juniper Mountain is about 500 ft (150 m) (Hansen, 1986b). Dividing this depth

by the average incision rate of 0.36 ft (0.11 m) per 1000 years (Madole, unpublished) gives an age for superposition of about 1,400,000 years. This age must be regarded as a rough estimate because the incision rate was calculated for the last 600,000 years and may be too high for the hard rock in Juniper Mountain.

Subsequently, the drainage has continued to incise, but terraces have formed intermittently along the Yampa River and some of its tributaries in the Park Range in response to glacial and climatic cycles. Along Elk River and Fish Creek, the Pinedale terrace is about 13 ft (4 m) above the present channel. The Bull Lake terrace is at most 10 to 13 ft (3 to 4 m) higher and is represented by very few remnants. Along the Yampa River terraces of the last two glaciations (Bull Lake and Pinedale) extend only a few miles downstream from correlative moraines. Madole (unpublished) believes that the Pinedale and Bull Lake terraces are restricted in area because the volume of associated outwash gravel was small; furthermore, the Bull Lake glaciation (> 150,000 years) may have been relatively weak in the Park Range (only one moraine has been found instead of the usual two), and the Bull Lake terrace may have been largely eroded during the Pinedale glaciation (30,000 to 10,000 years ago). In any case, terraces of Pinedale and Bull Lake age are absent along the Yampa River by the time it reaches Steamboat Springs.

Madole (Madole, unpublished) considers the lowest extensive terrace, about 65 ft (20 m) above the river, to be pre-Bull Lake in age for several reasons. Along the Elk River, this terrace projects above till that Madole (Madole, unpublished) correlates with the Bull Lake till in the Front Range, on the basis of geomorphic expression, weathering, and soil development. Further downstream, near Clark, the terrace gravel contains many highly weathered and decomposed clasts typical of pre-Bull Lake deposits. Finally, the terrace is overlain by reddish-brown loess. Along Fish Creek, similar loess must have accumulated before the Bull Lake glaciation because it overlies pre-Bull Lake till and is buried by Bull Lake till. Other relatively extensive terraces occur at heights of 115 and 210 ft (35 and 65 m) above the creek. A few terrace remnants are also found at heights of 140, 420, 490, 530, and 600 ft (45, 130, 150, 160, and 200 m).

At Craig, Madole (Madole, unpublished) describes two terraces representing the 115-ft (35-m) and 210-ft (65-m) levels described above. Downstream from Craig, the terraces become less distinct because the gravel deposits, which are important for terrace preservation, are thinner; furthermore, preservation is less likely within the narrow canyon (Madole, unpublished). These terraces are mapped discontinuously from Craig to Juniper Mountain. Madole's (Madole, unpublished) mapping ends at Juniper Mountain, but terrace remnants have also been mapped in the Maybell-Sunbeam area by Carrara (1980) and Izett et al. (1985).

2.1.7 Lay Creek drainage

Lay Creek joins the Yampa River just downstream from Juniper Mountain. The west-southwest trending reaches of Lay Creek and its major tributary, Big Gulch, now form a trunk stream that follows the outcrop belt of the Browns Park Formation and part of Lay Syncline (Figure 2.3).

This trunk stream probably grew toward the east by headward erosion and capture after the Yampa River became superimposed on Juniper Mountain and Axial Basin Arch. South of the Yampa River, numerous subparallel tributaries cross fold axes and outcrop belts of several Cretaceous formations without deflection. The absence of any relationship between drainage pattern and structure suggests that the tributaries were established on top of a formerly continuous cover of Browns Park Formation, and then later were superimposed onto the underlying rocks. Isolated remnants of the Browns Park Formation support this interpretation. A similar drainage pattern probably existed north of the Yampa River, although in this area the earlier pattern has been more disrupted by subsequent changes. The northern tributaries of the Lay Creek-Big Gulch trunk stream appear superimposed because they cross underlying Tertiary and Cretaceous rocks without regard to varying erosional resistance. Superposition is most obvious for the branches of Big Gulch, which otherwise could not cross the relatively resistant, sandstone-bearing formations between outcrops of the Browns Park Formation. Furthermore, major northern tributaries of the Lay Creek-Big Gulch trunk stream are aligned with northern tributaries of the Yampa River. Although short, these Yampa River tributaries have large, seemingly old valleys in comparison with the southern tributaries of Lay Creek, which seem to be much younger. Reconstructed stream lengths north and south of the Yampa River are also comparable in age to the Yampa River tributaries. Therefore, it appears that the northern Yampa River tributaries once flowed south across the present location of the Lay Creek-Big Gulch trunk stream.

The formation of the Lay Creek-Big Gulch trunk stream may be explained by changes in the incision rate following superposition of the Yampa River onto pre-Browns Park Formation rocks. It is unclear whether the incising Yampa River first encountered the hard Paleozoic rocks of Juniper Mountain or the Cretaceous rocks of the Axial Basin Arch. However, once superposition had occurred, Yampa River incision would have slowed in relation to that of Lay Creek, which, although much smaller in discharge, was flowing on the softer Browns Park Formation. When the northern tributaries of the Yampa also became superimposed on the Axial Basin Arch, their incision rates upstream from the arch would have decreased, facilitating capture of their headwaters by Lay Creek. Erosion-rate calculations suggest that the Yampa River was superimposed and the Lay Creek-Big Gulch drainage began to form in early Pleistocene time.

LEGEND

- LOCATION WHERE INCISION RATES FOR DRAINAGE HAVE BEEN ESTIMATED

25 0 25 75 MILES

40 0 40 80 120 KILOMETERS

LEGEND

- ▨ DISTRIBUTION OF BROWNS PARK FORMATION
- PALEOZOIC AND PRECAMBRIAN ROCKS EXPOSED IN CORE OF JUNIPER MOUNTAIN
- DOWN THROWN SIDE
- SYNCLINE FOLD
- ANTICLINE FOLD

5 0 5 10 MILES

10 0 10 20 KILOMETERS

FIGURE 2.3
REGIONAL AND AREAL DRAINAGE SYSTEM

2.1.8 Surficial deposits

The landscape of the Maybell area has been influenced by few significant geomorphic processes other than the fluvial processes of erosion and deposition. Moraines and terraces associated with mountain glaciation are present along the Yampa River only near the limit of glaciation in the Park Range and disappear near Steamboat Springs. Yampa River terraces associated with periods of increased flow during climatic cycles occur discontinuously from Steamboat Springs to the Maybell area.

Within the area of the Browns Park Formation, surficial deposits consist of residuum, colluvium, alluvium, and eolian sediment. Undisturbed residuum or ridgetops reflect the continuing weathering of bedrock exposures. Colluvial and sheetwash deposits are the result of surface runoff on slopes and soil creep accentuated by local freeze-thaw processes within the unconsolidated soil. Eolian deposits range from 1 to 15 ft (0.3 to 4.5 m) thick within the Maybell area. These generally have weakly developed soils indicative of a time of deposition no more than about 10,000 years ago.

Processes of slope modification, such as landslides, slumps, and debris flows, are generally absent in the low elevation site area. Small, localized talus deposits are present along some vertical bedrock outcrops. Minor, shallow soil failures occur along oversteepened slopes next to stream channels. No landslide or debris flows are known to exist in the site area.

As previously discussed, fluvial processes constitute the main geomorphic controls on the landscape. Both stream aggradation and erosion are occurring in major drainage systems. The alluvial fill within stream channels reflects cycles of deposition and incision during the Quaternary period. The dominant regional geomorphic cycles of stream aggradation-degradation will continue to be the main control on future landscape development in the Maybell area.

2.1.9 Regional erosion rates

Yampa River

Incision rates for the Yampa River basin may be estimated from rates for other rivers nearby, from the height of the Lava Creek B ash, and from the apparent lack of post-Bull Lake incision throughout most of the basin. Late Cenozoic incision rates for the Roaring Fork River have been estimated from the heights of several dated volcanic flows (Larson et al., 1975); these indicate roughly 2000 ft (600 m) of downcutting from 8 to 10 million years ago (1 ft/1000 years) (0.3 m/1000 years), very little downcutting from 1.5 to 8 million years ago (nearly 0 ft/1000 years) (0 m/1000 years), and 1000 ft (300 m) of downcutting from 1.5 million years ago to the present (0.7 ft/1000 years) (0.2 m/1000 years). Madole (Madole, unpublished) speculates that similar changes in relative incision rates may have occurred along the Yampa River.

Hansen (1986a,b; 1985) also suggests that the incision rate of the Green River may have increased in middle Pleistocene time after a period of slower incision.

Incision rates for later intervals may be estimated as follows. The Lava Creek B ash occurs in the sandy alluvium of a terrace 210 ft (65 m) above the river near Clark (locality 32 of Izett and Wilcox, 1982). This ash has been dated elsewhere at approximately 620,000 years (Izett and Wilcox, 1982). If terrace incision began about 600,000 years ago, the long-term average incision rate has been about 0.36 ft/1000 yrs (0.11 m/1000 years) (Madole, unpublished). However, the general absence of Pinedale (10,000 to 30,000 years old) and Bull Lake (> 130,000 years old) terraces, except within a few miles downstream from the moraines, suggests that the average incision rate has been very low throughout most of the basin during the last 150,000 years. If so, the average incision rate from 150,000 to 600,000 years may have been as high as 0.5 ft/1000 years (0.2 m/1000 years) (Madole, unpublished), while from 150,000 years to the present the rate may have been much lower.

Lay Creek

A period of Pleistocene-age changes in incision rates near the Maybell site is suggested by the current topography of the Lay Creek Valley. Near the Maybell site the valley has a compound cross-profile, with a rolling upland surface at elevations of 6300 to 6400 ft (1900 to 1950 m), into which the present, steep-walled inner valley has been cut to a depth of about 200 ft (60 m). The cause and time of this change from relative landscape stability to more rapid incision are unknown. The change may be associated with superposition of the Yampa River on Juniper Mountain. Changes in landscape stability along Lay Creek appear closely related to incision and base level conditions in the Yampa River drainage. Erosion rates along Lay Creek are estimated to be within the same range as those of the Yampa River.

2.1.10 Post-glacial climate

Climatic changes during the next 1000 years in the site region will probably be smaller in magnitude than the major climatic shift that followed the last full glacial period.

For the next few hundred to 1000 years, the average temperature and precipitation probably will fluctuate within the same ranges as during the recent past. However, extreme events exceeding the range of historic variability probably have occurred and may recur within the lifetime of a tailings site. The geomorphic stability of surfaces at a site can be affected either by extreme events or by brief shifts in average conditions, especially if the landscape is sensitive to change.

Broad changes in the post-glacial climate have been documented for the western United States. Following a period of transitional climate, changes in average temperature for periods on the order of hundreds of thousands of years probably

were about $\pm 4^{\circ}$ Fahrenheit ($^{\circ}$ F) ($\pm 2^{\circ}$ Celsius [$^{\circ}$ C]) (Knox, 1983). However, few of the paleoenvironmental data available have been used to derive quantitative estimates of climate change.

The time following the last glaciation has been divided into three climatic intervals:

- A transitional period from 14,000 or 12,000 to 8000 or 7000 years ago.
- A slightly warmer period ending around 4000 years ago.
- A slightly cooler period continuing to the present.

Evidence for the Mid-Holocene warm period is abundant in surrounding areas but is poor in Colorado, perhaps because the sites studied are insensitive to small climatic changes (Baker, 1983).

2.1.11 Pollen studies

No data on Holocene climates are available for the Maybell site region, but inferences may be drawn from pollen studies in surrounding areas (Baker, 1983). Pollen-containing sites surrounding the site area in high alpine locations (elevations 8100 to 12,500 ft, or 2500 to 3800 m) were all glaciated. Sites in the San Juan Mountains include Molas Lake (Maher, 1961), Hurricane Basin (Andrews et al., 1975), and Lake Emma (Carrara et al., 1984); in the La Plata Mountains, Twin Lakes (Peterson and Mehringer, 1976); in the Front Range, Bedrock Lake (Maher, 1972); and in the Wasatch Mountains, Snowbird Bog (Madsen and Curry, 1979). In general, these sites display the trend of Early Holocene warming, Mid-Holocene warmth, and slight Late Holocene cooling. However, the timing of the changes and the number and direction of briefer climatic fluctuations varies. The Swan Lake site (Bright, 1966) at an elevation of 4750 ft (1450 m) in southeast Idaho was not glaciated and shows a Mid-Holocene warm period. Another unglaciated site at Alkali Basin in northwest Colorado (elevation 9000 ft or 2800 m) does not reflect this warm period (Markgraf and Scott, 1981). The period from about 10,000 to 4000 years ago is interpreted to be about 1.8° F (1° C) cooler than and 50 percent moister than the period from about 4000 years ago to the present. The highest postglacial temperatures probably exceeded present temperatures by about 2° F (1.1° C) at Molas Lake (Maher, 1961), at least 0.7° F (0.4° C) at Lake Emma (Carrara et al., 1984), and 1.3° F (0.7° C) at Hurricane Basin (Andrews et al., 1975). Temperature changes probably differed slightly at lower elevations.

Pollen sites on the Snake River Plain of southern Idaho reflect times of maximum Holocene aridity that vary with site elevation (Davis et al., 1986). Low sites (elevations of less than 4900 ft [1500 m]) show maximum summer temperatures during July for the period of about 8000 to 10,000 years ago. Higher sites (6900 to 8200 ft) (2100 to 2500 m) reflect a maximum

temperature during September at about 6000 years ago. Sites in both elevation ranges indicate very cold winter temperatures from 8000 to 10,000 years ago and maximum Holocene summer temperatures of about 4°F (2°C) higher than today (Davis et al., 1986).

2.1.12 Tree-ring studies

Tree-ring studies of the last few centuries (Fritts, 1971) have shown significant variability in climate during periods ranging from a few years to a few decades and longer. Historic records (Bradley, 1976), although for a shorter period of time, corroborate these variations in climate. Relative changes in effective moisture during the last several centuries in the Colorado Plateau have been interpreted from tree-ring data by Stockton and Jacoby (1976); this study included data from several sites in western Colorado.

Annual mean precipitation varied from 13.5 to 23 inches (34 to 58 centimeters [cm]). Variations also occurred in the seasonal distribution of temperature and precipitation and in the amount of rainfall events in particular size classes.

2.1.13 Wind, precipitation, and temperature

General trends in temperature indicate regional cooling from the late 1860s until about 1930, followed by regional warming. General trends in precipitation are roughly inverse to those in temperature, but are much less consistent. Poor early records suggest that precipitation may have been very low in the 1860s, and thereafter increased until the 1890s. A major low around 1900 was followed by a rapid increase to a major peak about 1908. The following period was characterized by frequent fluctuations, with another major low in 1929 to 1932. Increased precipitation in the Maybell area from about 1880 to 1950 is suggested by a period of net channel degradation for this period (Andrews, 1978). Aggradation in the Yampa River drainage system since about 1950 (Andrews, 1978) reflects a period of regional warming and less moisture.

An increase in the rate and magnitude of gully erosion began in the mid- to late-19th century throughout the southwest. The initiation of erosion is thought to be a result of either livestock overgrazing or short-term climatic change. Previous work on the causes of increased gullying is summarized by Wells and Gardner (1985). Most investigators agree that a brief period of decreased moisture preceded gully erosion and that overgrazing initiated gully formation. Gullying may have developed later in response to drought without overgrazing.

Mean annual precipitation at the Maybell site is approximately 11 to 14 inches (28 to 36 cm) and is distributed relatively uniformly throughout the year. The snowfall accumulation is approximately 65 inches (165 cm) per year and generally does not result in rapid runoff. Based on conditions at the Craig, Colorado, airport the prevailing winds are from the west-southwest, and to a lesser degree from the east-northeast. The prevailing wind at the tailings pile is

toward the east and to a lesser degree north and south along Johnson Gulch (URS Company, 1976).

The average maximum temperature in July is only 86°F (30°C); the average minimum temperature in January is 1°F (-17°C). Extreme temperatures recorded at Lay, Colorado, range from 101°F to -47°F (38°C to -44°C) (URS Company, 1976). Average annual lake evaporation for the site area is 32 inches (81 cm) (Dames & Moore, 1975).

In the immediate site area, the vegetation consists of sagebrush and sparse low grasses. The growth covers all soil areas including the slopes and bottoms of the Johnson Wash drainage system. The native vegetation cover has been self-restored on unused trails and other manmade disturbances in the surficial soils. In the ridges bordering the basin where there is moderate relief and the soil is thin, the vegetation includes sparse to moderate growth of juniper. This pattern of vegetation is prevalent throughout the southern Wyoming Basin. Riparian vegetation is very sparse. There are few phreatophytes in the region.

2.2 STRATIGRAPHIC SETTING

Stratigraphic units in the site region are described in Table 2.1 and Figure 2.4. Bedrock underlying the site area and a large portion of the site region consists of the Browns Park Formation of Oligocene and Miocene age, the youngest widespread formation in northwestern Colorado. A few miles north of the site in the Sand Wash Basin, bedrock consists of the lower Tertiary Green River, Wasatch, and Fort Union Formations, the Upper Cretaceous Lance and Lewis Shale Formations, and the Mesaverde Group, consisting of the Williams Fork and Iles Formations. These rocks in turn overlie the Mancos Shale. At the site, and for several miles to the south, bedrock consists of the Browns Park Formation underlain unconformably by the Cretaceous-aged Mancos Shale. Following uplifts along the Axial Basin Arch, the rocks in the interval overlying the Mancos Shale were removed by erosion. These missing formations, which are present a few miles north of the site, have a total thickness of up to 12,000 ft (3700 m) (Steele et al., 1979) elsewhere in the Sand Wash Basin.

Sedimentary units of Jurassic, Triassic, Permian, and Pennsylvanian ages are exposed around the cores of uplifted structures. Lower Paleozoic rocks are thin or missing from the region. The oldest sedimentary rocks, the Uinta Mountain Group of Precambrian age, are exposed only in the cores of uplifted structures, such as at Juniper and Cross Mountains. The granitic basement complex underlies the Uinta Group at an average depth of 9000 ft (2700 m) in the site region (Stone, 1986; Hansen, 1984).

Tertiary volcanic rocks are found in the eastern area of the region, in the Elkhead and Flathead Mountains, as vents and flows with associated dikes.

Within the site region, the Browns Park Formation occurs primarily along the axis of the Lay Syncline within the Axial Basin Arch. The deepest part of the

Table 2.1 Description of stratigraphic units in the Maybell, Colorado, site area^a

System	Series	Geologic unit	Occurrence	Thickness ft (m)	Physical characteristics
Quaternary	<u>Holocene</u> Pleistocene	Alluvium	River-channel deposits of the Yampa and Little Snake rivers and their major tributaries. Lesser windblown, glacial, landslide, and lacustrine deposits.	Generally less than 30 ft (9 m).	Unconsolidated surficial deposits consisting of clay, silt, sand, gravel, and boulders. Includes river-channel, landslide, glacial, and windblown deposits.
Tertiary	<u>Miocene</u> Oligocene	Browns Park Formation (North Park Fm. and Bishop Conglomerate)	Occurs on the northern flank of the Uinta Mountains, along the west of the Axial Basin Arch, in the southern part of the Sand Wash Basin, and west of the Park Range and Sierra Madre Uplifts.	Approximately 800 to 900 ft (240 to 275 m) thick at the site.	Comprised of loosely consolidated fluvial clays, silts, and light gray to chalky white, fine- to medium-grained sandstones. Persistent basal conglomerate (Bishop Member), consists of subangular pebbles less than 1 inch in diameter of felsic and mafic igneous and metamorphic rocks. Locally contains volcanic ash.
Tertiary	Eocene	Green River and Wasatch Formations	Missing in site vicinity due to erosional unconformity. Green River Formation mostly overlies the Wasatch and is exposed primarily in the Washakie Basin in Wyoming. The Wasatch Formation is exposed primarily in the Sand Wash Basin in Colorado.	Green River is as much as 3000 ft (900 m) thick. Wasatch is about 1000 to 5000 ft (300 to 1500 m) thick.	Green River Formation: consists of variegated and interbedded marlstone shale, oil shale, and sandstone of lacustrine origin. Wasatch Formation: interbedded fluvial sandy mudstone, calcareous sandstone, carbonaceous shale, and conglomerate. Where exposed, weathering has resulted in a badlands-type topography.
Tertiary	Paleocene	Fort Union Formation	Missing at site vicinity due to erosional unconformity. Exposed primarily north of Craig along the Yampa River, along the west edge of the Park Range, and in the Rock Springs Uplift. Also occurs with the Lewis Shale and Lance Formations at depth in the Sand Wash and Washakie Basins.	1500 ft (450 m).	Consists of interbedded gray carbonaceous shale, gray and brown massive cross-bedded sandstone and conglomerate, and coal beds.
Cretaceous	Upper Cretaceous	Lance Formation	Missing at site vicinity. Generally exposed in same areas as the Fort Union and Lewis Shale. Occurs at depth in the Sand Wash and Washakie Basins.	1000 to 1500 ft (300 to 450 m).	Consists of a series of nonmarine light-gray and yellowish-brown massive resistant sandstones, separated by soft, thin beds of muddy sandstone, siltstone, gray shale, and coal.
Cretaceous	Upper Cretaceous	Lewis Shale	Missing at site vicinity. Exposed in same areas as the Lance and Fort Union Formations. Exposed at surface in the Maybell area.	1500 to 2000 ft (450 to 600 m).	A homogenous dark-gray limey marine shale with thin and discontinuous soft limey sandstone lenses in the upper part.

Table 2.1 Description of stratigraphic units in the Maybell, Colorado, site area^a (Continued)

System	Series	Geologic unit	Occurrence	Thickness ft (m)	Physical characteristics
Cretaceous	Upper Cretaceous	Williams Fork and Iles Formations (Mesaverde Group)	Missing at site vicinity. Primarily exposed in the Williams Fork Mountains in Colorado, the Rock Springs Uplift in Wyoming, and adjacent to the Sierra Madre Uplift along the east margin of the study area. Crops out on upturned limb of the Maybell Monocline with Lewis Shale, Lance, and Fort union Formations.	Williams Fork is 1100 to 2000 ft (335 to 600 m) thick; Iles Formation is 1500 ft (450 m) thick.	Included in the Mesaverde Group in Colorado, and consists of an upper unit (the Williams Fork Formation) that is comprised of interbedded buff sandstone, gray shale, and coal beds as much as 10 feet thick. Contains much poorly exposed shale in the middle part. The lower unit (the Iles Formation) consists of interbedded buff fine-grained sandstone, gray shale, brown carbonaceous shale, and a few thin beds of coal.
Cretaceous	Upper Cretaceous	Mancos Shale	Reportedly underlies the Browns Park Formation in the site vicinity. Exposed extensively in Colorado along the southern margin of the Yampa River Basin, in the Rawlins Uplift in Wyoming, and found at depth in the Sand Wash and Washakie Basins.	1500 ft (450 m).	A homogenous marine shale. The upper 1000 ft (300 m) contain a discontinuous series of sandstone layers that are transitional with the overlying Mesaverde Group. The lower part contains some sandstone and limestone beds.
Cretaceous	Lower Cretaceous	Dakota Sandstone	Exposed in small areas near Danforth Hills and near the Utah Border. Found at depth in the Sand Wash and Washakie Basins.	30 to 260 ft (9 to 80 m).	Resistant, yellow to light gray; cross- bedded, mostly fluvial sandstone and subordinate pebble conglomerate; minor shale and coal.
Jurassic	Upper Jurassic	Morrison Formation	Reportedly 486 ft (150 m) thick at Juniper Mountain near the site. Exposed in small outcrops with Dakota Sandstone. Found at depths in regional basins.	500 to 1500 ft (150 to 450 m).	Soft, variegated light gray, red- and light-purple shale; claystone; siltstone and cross-bedded sandstone; includes Brushy Basin Member and Salt Wash Member.
Jurassic	Lower Jurassic	Entrada Sandstone	Rare exposure at Cross Mountain. Found at depth in regional basins. Thinning west to east.	100 to 250 ft (30 to 75 m).	Resistant, light gray, buff, or pink; prominently cross-bedded sandstone; mainly eolian in origin.
Triassic	Upper Triassic	Chinle Formation	Rare exposure at Cross mountain, generally thinning from west to east.	200 to 450 ft (60 to 140 m).	Siltstone, sandstone, and shale; soft to moderately resistant; red to light gray, purple, and light green; mainly of fluvial and lacustrine origin. Basal Conglomerate Member.

Table 2.1 Description of stratigraphic units in the Maybell, Colorado site area^a (Concluded)

System	Series	Geologic unit	Occurrence	Thickness ft (m)	Physical characteristics
Triassic	Lower Triassic	Moenkepi Formation	Exposed in small outcrops within Entrada and Chinle Formations, generally thinning west to east.	500 to 1100 ft (150 to 335 m).	Moderately resistant, medium-red to green, ripple-laminated siltstone and shale. Marine and continental. Locally sandy and gypsiferous.
Permian	Lower Permian	Phosphoria Formation (Park City Formation)	Exposed in Dinosaur National Monument and Cross Mountain area. Thinning east and south.	0 to 425 ft (0 to 130 m).	Contains the peak Phosphatic Shale Member with phosphatic rocks as much as 50 ft (15 m) thick.
Pennsylvanian	Lower Permian Upper Pennsylvanian	Weber Sandstone	Exposed with Phosphoria Formation. Thinning away from Uinta Mountains.	650 to 1150 ft (200 to 350 m).	Resistant light gray and buff, prominently cross-bedded. Eolian and marine in origin.
Pennsylvanian	Middle Pennsylvanian	Morgan Formation	Thinning away from Uinta Mountains.	30 to 1150 ft (9 to 350 m).	Locally cross-bedded; sandstone and interbedded limestone with minor soft-red shale. Marine in origin. Limestone contains chert concretions. Fossiliferous.
Mississippian	Lower Mississippian	Madison Limestone	Exposed on Cross Mountain and north of Douglas Mountain.	425 to 1000 ft (130 to 300 m).	Resistant, tan to gray, cherty limestone. Locally fossiliferous and locally dolomitic.
Devonian	Upper Devonian	Dyer Formation (Chaffee Group)	Recognized in deep wells in site vicinity.	<500 ft (150 m).	Inter-bedded red, pink, and yellow sandstone and bluish limestone. Well cemented.
Cambrian	Upper Cambrian	Sawatch or Ladore Group	Exposed in Ladore Canyon west of Maybell near the Utah-Colorado border.	50 to 500 ft (15 to 150 m).	Resistant, light gray and pale green glauconitic fine-to coarse-grained, thinly to thickly bedded conglomeratic sandstone and quartzite; contains a few beds of red and green shale and siltstone.
Pre-Cambrian	Protozoic	Uinta Mountains Group	Thinning away from Uinta Mountains	4000 to 15,000 ft (1200 to 4500 m).	Red, massive, cross-bedded sandstone. Some micaceous shale and quartzite with minor dolomite.

^aRef. Stone, 1986; Rowles et al., 1985; Steele et al., 1979; Tweto, 1976; and McKay and Bergin, 1974.

NOTE: MISSING FROM SITE AREA WITHIN EROSIONAL UNCONFORMITY ABOVE MANCOS SHALE ARE: GREEN RIVER AND WASATCH Fm.; FT. UNION Fm.; LANCER Fm.; LEWIS SHALE Fm.; MESAVERDE GROUP (WILLIAMS FORK AND ILES Fm.) ADOPTED FROM STONE, 1986

FIGURE 2.4
STRATIGRAPHIC COLUMN MAYBELL TAILINGS SITE
NEAR MAYBELL, COLORADO

Axial Basin Arch, in which most of the deposition occurred, lies just east of Maybell (Luft, 1985). The formation may be as thick as 1400 ft (430 m) in the Lay Syncline (Chenoweth, 1986a). At the site, the formation depth is estimated to be between 800 and 900 ft (240 and 275 m) (FBDU, 1981). The formation contains tuff beds, which are the primary source of the uranium ore mined at the site. Luft (1985) has reported that tuffaceous beds are widespread throughout the Browns Park Formation. Along the Axial Basin Arch, the width of the formation varies from 5 mi (8 km) (at a point just west of Craig, Colorado) to 15 mi (24 km) (just west of the Utah state boundary, a distance of about 90 mi [145 km]).

Formation remnants are found in the Sand Wash Basin, in the White River Uplift, and in the Western Rocky Mountains extending north well into Wyoming, indicating that the formation has been greatly reduced in size by erosion (Luft, 1985). Grutt and Whalen (1955) indicate that the Browns Park Formation may formerly have extended across the Colorado Plateau. In the Axial Basin region, the topography, at the time of deposition, was similar to modern topography (Hansen, 1984). Deposition began about 25 million years ago in Oligocene time and continued until about nine million years ago in the Miocene. By Quaternary time, the formation had been cut by faults and eroded from many areas (Hansen, 1984).

2.3 STRUCTURAL SETTING

The site is on the Axial Basin Arch, a collapsed anticlinal structure (Figures 2.5 through 2.7). This is a narrow, northwestward-trending structural province that lies along the axial trace of the Uinta Mountains uplift and separates it from the White River uplift. It occupies the region of transition between the Colorado Plateau to the south and the Wyoming Basin to the north. The Yampa River and its major tributary, Williams Fork, occupy the middle part of this structure. The anticlinal structure is revealed in Juniper and Cross Mountains, which represent the cores of two anticlinal segments along the axial trend of the uplift. Both mountains are dissected by the Yampa River as a result of superposition of the stream on the basin fill sediment of the Browns Park Formation. Until recently, the dissection of Cross Mountain at the northwest end of the province was thought to be a consequence of uplift rather than of superposition (Hansen, 1986b). Quartzite of the Precambrian-aged Uinta Mountains Group is exposed in the dissected cores.

The Axial Basin Arch extends northeastward to the Uinta Mountains, and southeastward to the White River Uplift. These structures were contained within a single ancestral axial fault system until mid-Tertiary time (Hansen, 1986b; 1984; Stone, 1986). An understanding of this pre-Tertiary structural relationship is essential to understanding the present seismotectonic setting as well as the present structural setting.

The Axial Basin Arch is bordered on the north by subbasins of the Wyoming Basin physiographic and structural province. Bordering the southern side is the

AFTER:
 HEYMAN O.G., PW GUNTOON AND MD WHITE-HEYMAN 1986
 TWETO, 1980
 HUNT, 1967
 KIRKHAM AND ROGERS, 1981
 FROM: STEELE et al, 1979

LEGEND

----- 200 KM
 (125 Mi)

FIGURE 2.5
STRUCTURAL SETTING OF THE MAYBELL SITE REGION

FROM: STEELE et al, 1979

FIGURE 2.6
STRUCTURAL CONTOUR MAP OF THE SAND WASH BASIN
MAYBELL SITE REGION

Note : Location of Cross Section A-A'

FROM : DONALD S. STONE, 1986

FIGURE 2.7
STRUCTURAL MAP AND CROSS SECTION OF
AXIAL BASIN FAULT SYSTEM MAYBELL SITE REGION

Piceance Basin, a subprovince of the Colorado Plateau. Northwestward-trending thrust faults of Laramide age form the northerly and southerly boundaries. The boundaries with the Uinta Mountains on the northwest and the White River Uplift on the southeast are formed by faults that have dissected the ancestral Axial Fault system (Stone, 1986). These faults and their geologic history are discussed in more detail in Section 2.4.

Another structural element within the Axial Basin Arch, in addition to Juniper and Cross Mountains, is the Danforth Hills anticline, which lies along the south margin of the Axial Basin Arch. The northwestward trends of this structure and several less-prominent folds parallel the axial anticline extending to the southeast from Juniper Mountain.

2.3.1 Structural history of the Axial Basin Arch

The present structure of the Axial Basin Arch had its origin in Proterozoic time when a westward-trending structural trough was formed in which the Uinta Mountain group sediments were deposited. The system along this structural trough experienced major structural movement in Cambrian time and again in Pennsylvanian-Permian time (Stone, 1986). During the Late Cretaceous-Early Tertiary Laramide Orogeny, the earlier folds and faults were reactivated and many new thrust-fold structures formed (Stone, 1986; Hansen, 1984).

The collapse of the Axial Basin section of the arch, which now distinguishes it from the Uinta Mountain and White River uplifts, occurred in mid-Tertiary (Oligocene and Miocene) time (Hansen, 1984). Subsequent erosion along the axis resulted in an erosional trough referred to as the Lay Syncline, or Browns Park Syncline, in which the Browns Park Formation was deposited.

The region was relatively stable in early Oligocene time as evidenced by the Gilbert Peak erosional period, which resulted in deposition of a widespread basal conglomerate, the Bishop Conglomerate, preceding the Browns Park deposition (Hansen, 1984). The present local relief is due in part to recurring movements on faults that formed both during and after deposition of the Browns Park Formation, which ended during the Miocene epoch 5 to 20 million years ago (Hansen, 1986a, 1984).

Quaternary displacement of the Browns Park Formation has been observed in the Uinta Mountain in Utah but has not been reported in the site region in the Axial Basin Arch province.

2.3.2 Major structural features of the site region

The relationship between major structural features is shown in Figures 2.5 and 2.8.

A. NORTH-SOUTH THROUGH SUBBASIN OF WYOMING BASIN.
APPROXIMATELY 20 MILES EAST OF THE SITE

FROM: STEELE et al, 1979

NORTH-SOUTH SECTION THROUGH
EAST END OF UINTA MOUNTAIN ARCH
APPROXIMATELY 50 MILES WEST OF
SITE

FROM : HANSEN, 1984

FIGURE 2.8
CROSS SECTIONS SHOWING STRUCTURES OF
WYOMING BASIN AND UINTA ARCH, MAYBELL SITE REGION

EXPLANATION

T Tertiary rocks

Kmv Mesaverde Group

Km Mancos Shale

Mz Mesozoic undifferentiated

Pz Paleozoic undifferentiated

Pu Uinta Mountain Group

2.3.3 Uinta Mountains Province

The Uinta Mountains consist of a large, eastward-trending compound anticline whose axis extends westward to the Wasatch Range and southeastward through the Axial Basin to the White River Uplift (Hansen, 1984; Hintz, 1979; Tweto, 1979). The total axial length is 200 mi (320 km) (Hansen, 1984). Near the east end of the Wasatch Range, the anticlinal axis plunges beneath the Browns Park Formation and re-emerges further to the southeast as the Axial Basin Arch.

2.3.4 Colorado Plateau Province

The site is about 16 mi (26 km) north of the boundary of the Colorado Plateau. The plateau is a stable intracontinental subplate characterized by a thick cover of relatively flat-lying Phanerozoic sedimentary rock overlying a complex Precambrian igneous and metamorphic core. The central stable portion of the Colorado Plateau exhibits characteristics of cratonic areas, while margins of the subplate exhibit crustal structure similar to more highly active bordering provinces (Tweto, 1980). The plateau is surrounded on the east by the Rio Grande Rift.

The portion of the Colorado Plateau within the site region includes the broad northwestward-trending Piceance Basin on the north edge of the plateau. The Piceance Basin is an intermountain basin of Laramide age bounded by the Douglas Creek Arch on the west (separating it from the Uinta Basin) and by the Uncompahgre Uplift on the south.

The present basin structure was preceded by a northwest-southeast-trending graben system that developed parallel to the Uinta Mountains Uplift in Pennsylvanian time (Waechter and Johnson, 1986). These earlier faults were reactivated during the Late Cretaceous-Early Tertiary Laramide Orogeny to form the present Piceance Basin structure.

The modern Piceance Basin has been uplifted to a broad plateau by post-Laramide, probably Pliocene, movement of the bounding structures (Ochs and Cole, 1981).

2.3.5 Wyoming Basin province

The Sand Wash Basin, the southern portion of the Wyoming Basin province, is separated from the Washakie Basin subprovince of the Wyoming Basin by the Cherokee Ridge anticline, which trends east-west along the Wyoming-Colorado border. The Washakie Basin was continuous with the Piceance and Axial Basin Arch in Cretaceous time (Irwin, 1986; Osmond, 1986; Steele et al., 1979; McKay and Bergin, 1974). About 6000 ft (1800 m) of Paleozoic sediments are overlain by roughly 12,000 ft (3700 m) of Cretaceous deposits. Following the Laramide Orogeny and separation of the basins, about 12,000 ft (3700 m) of Tertiary deposits were emplaced over the older units.

2.3.6 White River Uplift

The White River Uplift is considered to be the southeastward extension of the Axial Basin Arch and connects with the Uinta Mountains Uplift (Hansen, 1986b). The northwest-southeast structural trend follows that of the Axial Basin Arch, which forms the northern boundary of the uplift. The uplift, also referred to as the White River Plateau, rose in Eocene time and was the last of the major Laramide Mountain units to form (Tweto, 1973). Presently, the uplift forms the northern extent of the Western Mountains seismotectonic province of Kirkham and Rogers (1981), and is structurally separated from the Uinta Mountains Uplift by the intervening Axial Basin.

2.3.7 Elkhead Mountains

The Elkhead Mountains form a belt of highlands within the Sand Wash Basin. The mountains are an erosional remnant of a Tertiary volcanic field that formerly included Cedar Mountain at Craig, Colorado, and extended into Wyoming north of Steamboat Springs. Fortification Dike, between Craig, Colorado, and Baggs, Wyoming, is the westernmost extension. These volcanics merge with the volcanic rocks associated with the White River Uplift south of the Elkhead Mountains.

Lava flows in the Mount Welba and Mount Elephant areas are found to overlie the Browns Park Formation. Carey (1955) has concluded that these mountains formed as a result of volcanic and intrusive activity with associated uplift during the Pliocene, Miocene, and Oligocene ages. The predominant rock types are intermediate volcanics, which appear to be of similar age but of different sources than the basaltic flows in the White River Uplift (Carey, 1955).

2.4 SEISMOTECTONIC SETTING

The area of significance for seismic investigations was determined to have a radius of 40 mi (65 km) around the Maybell site based on attenuation-distance relationships (Campbell, 1981). This site region is an area of complex structural elements; however, under the present seismotectonic regime it is relatively stable. Most of the structures are Laramide uplifts and basins. Some late Tertiary activity resulted in volcanism and movement along old fault systems. Due to the elevated seismicity of the Intermountain Seismic Belt (Smith and Sbar, 1974) and the Rio Grande Rift Province (Algermissen et al., 1982), these remote provinces were also considered in the seismic study even though they lie beyond the 40 mi (65 km) radius (Figure 2.9).

No areas of recurring seismicity exist within the 40-mi (65-km) site radius; within a 125-mi (200-km) site radius there are several locations with clusters of epicenters as indicated by the NGDC/NOAA earthquake data (NGDC/NOAA, 1986). The epicenters are plotted on Plate 1. Most of these are on the margins of the Colorado Plateau, the Western Mountain Province, and the Rio Grande Rift. Steamboat Springs is the nearest active location. The recurrent activity

FIGURE 2.9
SEISMOTECTONIC PROVINCES OF MAYBELL SITE REGION

at Rangely, Colorado, is attributed to artificially induced seismicity in the Rangely oil fields (Kirkham and Rogers, 1981).

The maximum instrumentally recorded earthquake within the 125-mi (200-km) radius was a 1973 $M_b = 5.4$ event located 51 mi (82 km) from the site in the Piceance Basin of the Colorado Plateau. The largest historical earthquake in the 125-mi (200-km) radius is an 1882 event of Intensity VIII ($M \sim 6.4$), which was initially thought to be near the site. After recent study, it has been relocated outside the site region (Kirkham and Rogers, 1986; 1981). NGDC/NOAA had also located an 1891 event of Intensity VI near the site (NGDC/NOAA, 1986).

No known faults are associated with seismic activity within a 40-mi (65-km) site radius. The nearest confirmed Quaternary faults are located in the Uinta Basin of the Colorado Plateau near Vernal, Utah (Hansen, 1986b), and near Glenwood Springs, Colorado (Nakata et al., 1982).

The Maybell site lies within the Uinta-Elkhead seismotectonic province as defined by Kirkham and Rogers (1981). This province is bounded by the Colorado Plateau on the south and by the Western Mountains, northern Rio Grande Rift, and Eastern Mountains on the southeast and east (Figure 2.9). The north side is bounded by the Wyoming Basin at Cherokee Ridge, which lies along the Wyoming-Colorado border separating the Washakie Basin on the north from the Sand Wash Basin. These features are shown on the cross section of the Wyoming Basin structure (Figure 2.8).

2.4.1 Seismotectonic provinces

Beyond the immediate boundary provinces lie the Rio Grande Rift and the Intermountain Seismic Belt. Both were considered as potential sources of on-site accelerations, but were not found to affect the site significantly and are therefore not further discussed.

2.4.2 Uinta-Elkhead province

The west- to northwest-trending faults of the Uinta-Elkhead Province terminate the northerly section of the Northern Rio Grande Rift Province (Kirkham and Rogers, 1981). Seismotectonic elements within the Uinta-Elkhead Province listed by Kirkham and Rogers (1981) consist of the collapsed Uinta Arch of the Axial Basin Arch; faults that bound Cross Mountain; a series of en echelon faults near Craig; a number of faults that cut through Elkhead Mountain; and the Spring Creek and associated faults in North Park. Tweto (1979) has suggested that the North Park Fault may join in the east with a system in the Front Range.

The Uinta-Elkhead Province is characterized by high westward-trending magnetic and gravity anomalies. The province is substantially thinner in crustal section than the Colorado Plateau to the south, which ranges from 25 to 28 mi (40 to 45 km) thick, while the provinces to the north and east have a crustal thickness of 19 to 22 mi (30 to 35 km) as well as a higher heat flow and a different

orientation of stress fields (Keller et al., 1979; Thompson and Zoback, 1979). Tweto (1979) has shown that Precambrian basement rocks, which underlie the approximate area of the Uinta-Elkhead Province, are younger than the basement rocks in Wyoming.

The dominant structure in the central part of this seismotectonic province is the complex fault system associated with the axis of the Uinta Anticline and Axial Basin Arch that extends 200 miles (320 km) (Hansen, 1984). This axial structure is generally bounded on the north by the Uinta-Sparks Fault system and on the south by the Willow Creek Fault system.

The southeastern segment of the Axial Basin Arch structure is located by Kirkham and Rogers (1981) in the Western Mountain Seismotectonic Province. This distinction appears to be made because the west-northwest trend of the axial faulting in the Uinta-Elkhead Province takes a more north-south trend as it approaches the White River Uplift to the south. Kirkham and Rogers (1981) have also identified several faults in the Uinta-Elkhead Province that appear, on the basis of aerial photographs, to warrant consideration as Quaternary faults. These features are discussed later in this section.

2.4.3 Wyoming Basin province

This province consists of a series of broad basins and uplifts that are structurally and tectonically similar to the Colorado Plateau. It is north of the Wyoming-Colorado border, approximately 31 mi (50 km) north of the site at its closest approach. Structural elements include the Washakie Basin, bounded by the east-west trending Cherokee Ridge Anticline along the province boundary; the Rock Springs Anticline, a north-south trending uplift; the Wamsutter Arch; the Great Divide Basin; Saratoga Basin; the Sierra Madres; and the Rawlins Uplift. The east boundary of this province, as with the Uinta-Elkhead Province, is the Medicine Bow Mountains of the Eastern Mountain Province. Folded structures associated with the Laramide Orogeny are the dominant structures (Stone and Webster, 1986).

2.4.4 Colorado Plateau

The modern Colorado Plateau is composed of a stable interior portion bounded on the west, south, and east by more active border zones. For this study, the interior and border zones are defined as separate subprovinces, and the boundary is drawn at the 25 mi (40 km) crustal thickness contour. The border zones lie within the physiographic boundary of the Colorado Plateau but are characterized by elevated seismicity, thinner crust, higher heat flow, more common normal faulting, and elevated levels of Tertiary and Quaternary volcanism relative to the interior. Nearly all of the larger historical earthquakes of the Plateau have occurred in these border zones. At its closest approach to the site, the Colorado Plateau is approximately 15 mi (25 km) away.

The plateau is transected by the Colorado Lineament, trending to the northeast, and by the Olympic-Wichita Lineament, which trends to the northwest and intersects the Northeast Lineament in east central Utah (Baars and Stevenson, 1981; Warner, 1980). The Olympic-Wichita Lineament, which underlies the Piceance Basin, the Uncompahgre Uplift, and the Western Mountain Province, is associated with seismic trends. The seismicity trends in the western Colorado portion of the Colorado Plateau appear to be associated with the northwestward-trending Colorado and Olympic-Wichita Lineaments (Baars and Stevenson, 1981).

The suspected Quaternary faults in the Piceance Basin are approximately 50 mi (80 km) south of the site. Evidence of Quaternary activity on northwest-trending faults in the Uncompahgre Uplift and the Piceance Basin is described by Kirkham and Rogers (1981).

2.4.5 Western Mountains

As defined by Kirkham and Rogers (1981), the Western Mountain Seismotectonic Province is 11 mi (18 km) south of the site at its closest approach. It includes the southeast half of the Axial Basin Arch structure, the White River Uplift, the Grand Hogback, Elk and West Elk Mountains, and the west flank of the Sawatch Range. This province, and the Colorado Plateau Seismotectonic Province that borders it on the west, has a common northern boundary with the Uinta-Elkhead Province at a point just south of Juniper Mountain along the projected east-west alignment of the Axial Basin Thrust Fault (see Figure 2.9).

The province is characterized by north-south trending, Precambrian-cored, anticlinal mountain ranges that are fault bounded (Kirkham and Rogers, 1981). Relatively few Neogene faults (Miocene and Pliocene) are known in this province. None are major tectonic faults that have experienced Quaternary activity (Kirkham and Rogers, 1981).

2.4.6 Fault compilation and analysis

All known and suspected faults and lineaments within a 40-mi (65-km) radius of the site are shown in Plate 1. Additionally, all epicenters of historically or instrumentally located earthquakes are also plotted on this plate.

During the LSA aerial reconnaissance, all faults and lineaments within 40 mi (65 km) were observed. Features that appeared to warrant additional attention were noted on the base map for further inspection during the field reconnaissance. All features within 9 mi (15 km) of the site and faults within the 40-mi (65-km) radius that were marked for additional study from the LSA aerial reconnaissance (including "fresh" features noted by the Kirkham and Rogers [1981] study) were examined critically in the field.

The field reconnaissance performed for this study indicates that there are many faults in this region that are not mapped, primarily because they have little or no topographic expression. Quaternary alluvial channel filling and soil mantles have masked the exposures of bedrock in all drainage systems. Only the occasional cut bank or open pit mine reveals faults that are otherwise obscured.

The following subsections contain discussions of the results of field and aerial observations and published information about the faults and lineaments within 40 mi (65 km) of the site. Faults that appear to be related to the same structure or system are discussed as a group. The names assigned to the faults or fault groups are arbitrarily taken from names of the nearest geographic features for purposes of discussion. The fault groups are discussed in order of their distance from the site beginning with on-site faults, and are numbered in Plate 1. A summary of the fault assessment is shown in Table 2.2.

Marge-Johnson Pit faults (Group 1)—Uinta-Sparks system

This group of faults includes those found within the open pit mines. They trend generally to the north-northwest and occur between segments of the more westerly system of the Uinta-Sparks Fault system that bounds the site basin. These faults appear to be secondary faults of short extent and appear to be localized within the basin. They have no surficial expression and were located during mining operations as a consequence of the localization of uranium ore that tended to occur along the strike of the faults. None of the faults cut surficial deposits that unevenly overlay the eroded surface of the Browns Park Formation. The western most fault in this group is thought to be the Marge Fault, mapped by M. J. Bergin in 1959 (Bergin, 1959) and shown on the Vernal 1° x 2° Quadrangle geology map (Rowles et al., 1985). However, the trend of the Marge Fault, as revealed in the Marge Pit, is more northwestward than the map indicates. Other faults mapped by Bergin (Bergin, 1959) are discussed in the following paragraphs.

Several faults found in the pits north and south of the tailings pile appear to extend below the tailings pile. The faults are generally near-vertical, show offsets of about 1 to 10 ft (0.3 to 3 m), and appear to be straight. It is apparent that these faults are related to movement on the Uinta-Sparks system and occurred prior to or in conjunction with the uranium mineralization.

The Marge Fault, one of the first faults encountered in the mining operation, was mapped by Bergin (Bergin, 1959) in a preliminary report. This fault was shown as one of several parallel faults in a closely spaced system that trended to the southeast for several miles across Lay Creek. An extension of this group was shown to occur in the Cedar and Section 16 mines about 5 mi (8 km) southeast of the site. However, no evidence of the southward extension of these faults was found as they are mapped. The extension of these faults is counter to the grain of prominent scarps, particularly the Cedar Knobs Fault, which was discovered and mapped during this study along the southern boundary of the Sugarloaf Basin. It is concluded that these faults do not exist

Table 2.2 Summary analysis of mapped faults and lineaments within a 40-mi (65-km) radius of the Maybell, Colorado, site

Fault group no.	Fault/lineament	Source	Length		Distance from site		Capable (C) or noncapable (NC) fault
			(mi)	(km)	(mi)	(km)	
1	Marge/Johnson Pit	This study	1.2	2.0	0.1	0.1	NC
2	Uinta-Sparks	Rowles et al. (1979) Stone (1986)	40 max	65 max	0.6	0.9	NC
3	Wolf Creek/ Juniper Mountain	Rowles et al. (1979) Stone (1986)	50 max	80 max	6.0	9.6	NC
2a	Cedar Knobs	This study	1.4	2.3	0.6	0.9	NC
2b	Lay Peak	Tweto (1976) Kirkham and Rogers (1981)	3.6	5.8	4.4	7.1	NC
4	Little Juniper Mountain	Tweto (1976) Hancock (1925)	1.6	2.5	4.0	6.4	NC
5	Juniper Mountain	Rowles et al. (1985)	2.2	3.5	5.6	9.0	NC
2c	East of Lay	Tweto (1976) Kirkham and Rogers (1981)	5.5	8.8	8.5	13.7	NC
6	Temple Canyon	Rowles et al. (1985) Izett et al. (1985)	4.5	7.2	10.5	16.9	NC
2d	Craig Southwest	Tweto (1976) Kirkham and Rogers (1981)	9.0	14.5	14.0	22.5	NC
7	Cedar Mountain	Tweto (1976) Kirkham and Rogers (1981) This study	9.5	15.3	15.5	24.9	NC
8	Monument Butte	Hancock (1925) Tweto (1976)	7.0	11.3	21.0	33.8	NC
9	Citadel Plateau	Izett et al. (1985) Rowles et al. (1985)	6.0	9.6	21.0	33.8	NC

Table 2.2 Summary analysis of mapped faults and lineaments within a 40-mi (65-km) radius of the Maybell, Colorado, site (Concluded)

Fault group no.	Fault/lineament	Source	Length		Distance from site		Capable (C) or noncapable (NC) fault
			(mi)	(km)	(mi)	(km)	
10	Cross Mountain	Rowles et al. (1985) Dyni (1968)	12.0	19.3	22.0	35.4	NC
11	Big Hole Gulch	Rowles et al. (1985) Dyni (1968)	5.0	8.0	23.0	37.0	NC
11a	Scandinavian Gulch	Rowles et al. (1985) Dyni (1968)	6.0	9.6	24.0	38.6	NC
12	Fortification Fault	Rowles et al. (1985) Dyni (1968)	3.6	5.8	27.0	43.4	NC
13	Williams Fork	Rowles et al. (1985) Dyni (1968)	5.0	8.0	28.0	45.0	NC
14	Meeker	Rowles et al. (1985) Dyni (1968)	5.0	8.0	29.5	47.5	NC
15	White River	Rowles et al. (1985) Dyni (1968)	10.0	16.1	33.0	53.1	NC
16	Douglas Mountain	Rowles et al. (1985) Dyni (1968)	9.5	15.3	30.0	48.3	NC
17	Cherokee Ridge (Wyoming Group)	Rowles et al. (1985) Dyni (1968)	9.3	14.9	34.0	54.7	NC
18	Yampa Fault	Rowles et al. (1985) Dyni (1968)	9.4 max	15.2 max	32.0	51.5	NC

ME = $6.02 + 0.729 \log l$ (Bonilla et al., 1984).
PHA (Campbell, 1981); Table 3 at 84th percentile x 1.47.

as mapped. Rather, it is believed that such secondary faults in the graben-like valley are more random in their direction, are of short extent, and are bounded by east-west fault segments of the Uinta-Sparks fault system that exhibit substantial displacement and recurrent movement.

The 3 faults in Johnson Pit trend at widely varying directions (N5°E, N55°E, and approximately N60°W). The Marge Fault was mapped as trending N10°W. A fault found in the pit northwest of the tailings trends N45°W, with similar trends found for 3 faults in the pits due north of the tailings pile. Displacements on these secondary faults typically are less than 10 ft (3 m). This contrasts with the east-west trend of the faults assigned to the Uinta-Sparks system (fault group 2), which also are distinguished by topographic position as bounding the valley, the apparent large displacements, and the multiple parallel faults. Since these faults are considered secondary displacements of the Uinta-Sparks fault system, they are by association considered noncapable (see Uinta-Sparks fault system, below).

Uinta-Sparks fault system (Group 2)

This fault system extends through the cedar-covered hills immediately north of the site and is exposed in two of the open pit mines that border the Sugarloaf Basin. The faults show a local east-west trend with multiple parallel faults as evidence of recurrent movement. The faults appear within a zone 4 to 5 mi (6 to 8 km) wide, and extend 40 mi (65 km) northwest to the north flank of the Uinta Mountains and well beyond the 40-mi (65-km) site radius. Movement first occurred during the Laramide Orogeny and continued through deposition of the Browns Park Formation in the Miocene. There is no known Quaternary displacement along this system in Colorado or anywhere within the site region. As the north boundary of the Uinta Axial Arch the displacement during uplift was very great. Some of this movement was reversed during collapse of the structure.

The previous nearest-mapped easterly extension of this system was at Spring Creek about 3 mi (5 km) west of the site. However, based on faults observed on both sides of this creek, the exposures in pits, and by aerial-photo lineations, the fault system has been extended to within 0.75 mi (1.2 km) north of the tailings site and eastward through the mines northeast of the site. The great width and trend of the system may also include those faults named herein as Cedar Knobs, Lay Peak, East of Lay, and Craig Southwest. Because of the variations in distance from the site, the appearances of the scarps, and the references in published literature (Kirkham and Rogers, 1981), these faults are discussed separately but are numbered as part of Group 2.

The lineations of the faults in the site area are manifest as subtle topographic changes with frequent gaps in surface expression. The lineations trend on strike and parallel to the sharply dipping beds that mark the outcrop of the north limb of the Maybell monocline. The relationship of the faulting to the dipping beds is seen in Section 15, Range 95, along the Spring Creek Channel, where a fault gouge zone 50 ft (15 m) wide cuts the north dipping beds at a reverse direction of dip.

Since the offset beds do not constitute any significant change in lithology or pose a barrier to ground water, the fault trace is not manifest by color or vegetation changes. All topographic expressions appear to be thoroughly dissected by numerous, well-developed drainages. Based on faults found in the pit in the southeast quarter of Section 18, the face of the scarp has been eroded substantially from the fault trace.

Hansen (1986b) has cited possible Quaternary movement on a segment of the Uinta-Sparks fault based on a course change in Vermillion Creek, possibly near the 1983 epicenter of an $M=4.1$ event 45 mi (72 km) northwest of the site in Cold Springs Mountain. Also at nearby Diamond Mountain Peak, 54 mi (87 km) from the site, Quaternary movement had possibly occurred on very old west-northwest faults. These locations are beyond the 40-mile (65-km) radius of the site region and do not demonstrate activity of the system within the site region structure. These are the only known suspected fault displacements in the province that may have occurred in the last 2,000,000 years.

Because of the evidence cited herein and also in a discussion in Section 4.2 (Seismotectonic Stability) the Uinta-Sparks fault system is considered to be noncapable within the site region in the present tectonic stress regime.

Cedar Knobs (Group 2a)—Uinta-Sparks fault system

This fault bounds the south side of the valley in which the site is located. It appears to be a spur from the main Uinta-Sparks fault on the north side of the valley. The fault was identified by field inspection of lineations identified on stereo-pair aerial photos. Prominent rounded knobs mark the trace of parallel faults and form the elevated cedar-juniper covered ridge bordering the south side of the site basin. The extent of erosion with no single defined scarp indicates pre-Quaternary age and suggests that the fault movement was at least as old as the Uinta-Sparks fault on the opposing side of the graben-like valley.

The strong, closely-spaced, northwestward-trending joint system paralleling the faults was the only jointing observed and it appears to preclude the northward trend of several faults transecting this area as mapped by Bergin (Bergin, 1959). The jointing and differential cementation from mineralization are thought to account for the erosional landform.

The trend of the fault westward appears to be intercepted or offset by Johnson Wash, which has incised a fairly deep valley diagonally to the trend. West of the wash, the alignment follows at the base of a ridge that is much less eroded and younger in contrast to the weathered, knobby terrain east of the wash. No field evidence was found to indicate that Johnson Wash follows the trend of a fault. Based on the geomorphic expression of this fault group and from review of published literature, it is concluded that the faults are older than Quaternary and are not capable under this stress regime.

Lay Peak fault (Group 2b) – Uinta-Sparks fault system

This fault may be a continuation of the trend of the Uinta-Sparks fault system and also appears related to two similar faults formed en echelon that continue the trend towards Craig, Colorado. This fault has a prominent scarp that exhibits a younger profile than any other within the site region. The trend of this fault is west-northwest on an alignment that would extend into the south margins of Sugarloaf Basin, perhaps in alignment with the Cedar Knobs fault. The gullies that dissect the scarp near Lay, Colorado, have exposed closely-spaced faults that provide some evidence for recurrent movement.

A shorter second fault, which crosses Lay Peak, has no associated scarp. The fault is inferred by alignment of topographic erosional features.

The crest of the longer scarp is composed of moderately cemented sandstone, which appears to account in many places for the steepness of the scarp. At one point, the scarp face slope was measured at 33 degrees.

Special consideration was given to the Lay Peak fault scarp because of its comparatively young appearance. The field reconnaissance indicates that the scarp geomorphology may be a result of exhumation by erosion of the overlying Browns Park Formation to expose an older scarp rather than from fault movement in Quaternary time (or at least within the last 500,000 years). The fault is judged to be noncapable.

The study, discussed in detail in a preceding section, and a fault age assessment at the end of this section have concluded that the assessment of the age of this fault (and by implication the Uinta-Sparks fault) is best determined by areal geomorphic studies. The study suggests an overall stability of the region at least during the last 500,000 years and indicates that the faults are noncapable.

East of Lay, Colorado (Group 2c) – Uinta-Sparks system

This fault appears to be a part of the disconnected en echelon group of normal faults with north-side-down relative movement that extends eastward from the site area and includes the Lay Peak, East of Lay, and Craig-Southwest Groups. This particular fault is parallel and offset about 1.5 mi (2.4 km) from the adjoining faults.

The fault is 3 mi (5 km) east of the community of Lay, Colorado, and appears to terminate at the edge of the regional drainage (Lay Creek-Big Gulch) as does the Lay Peak Fault. Its up-thrown side appears to represent the south boundary of the Lay Syncline trough in which the greatest depth of the Browns Park Formation was deposited. The Browns Park Formation is in apparent depositional as well as faulted contact with the Iles Formation of Cretaceous age.

The trend of this fault parallels anticlinal and synclinal axes that partly align with the Craig Southwest faults. The subdued geomorphic features of the scarp, together with its well-developed dissection by local drainage and relationship to the areal study of the Lay Peak Fault, indicate it is older than Quaternary age and is not considered a capable fault.

Craig Southwest Faults (Group 2d)

This group consists of three parallel faults with northside-down relative movement. The longest of the group has a length of 9 mi (15 km). Tweto (1976) has mapped the axes of two anticlinal folds as apparent extensions of these faults. Kirkham and Rogers (1981) have assigned a Tertiary/Holocene age to these faults. They assigned this age on the basis of extremely fresh-looking, 7- to 10-ft (2- to 3-m) high scarps.

The descriptions were based on aerial photographic study and the faults were not examined in the field (Kirkham, 1987a). This fault and others with suspected fresh scarps were also examined by Chen and Associates, who concluded that no evidence was found to support Quaternary movement (Spitzer, 1987).

During this field investigation, no north-facing scarps were observed along the mapped traces of these faults. The trace of the faults is difficult to observe in flat areas; however, the trace can be observed by the differential bedrock erosion of embankments along the deeply incised drainage near its transection of the Yampa River.

Based on visual examination from the ground and the study of stereo-pair aerial photographs that cover the full length of the Craig Southwest faults and the East of Lay fault, this investigation has found no evidence of scarps that indicate Quaternary fault movement.

Wolf Creek-Juniper fault segment (Group 3)

This fault is a segment of the east-west trending ancestral axial fault (AAF) that has been truncated by a northeast-southeast spur at the east side of Juniper Mountain as shown in Figure 2.7. The presence of the AAF and the Juniper truncation fault is largely known by seismic reflection data; however, the surface expression is revealed on an aerial photograph at the edge of the domal uplift of the Juniper Mountain Arch. The ancestral east-west portion of this segment has a vertical offset of the basement rock of 15,000 ft (4600 m) (Stone, 1986).

It is this axial fault that has controlled the Uinta Mountain and White River Uplifts along the Axial Basin Arch province. Three periods of important displacement occurred beginning in Middle Proterozoic, then during Late Pennsylvanian with the Ancestral Rockies Orogeny, and finally during the Laramide Orogeny.

The Wolf Creek thrust fault segment is near the middle of the AAF and extends westward to where it merges with the Uinta Basin thrust fault (Hansen, 1986b). It extends eastward merging with the Axial Basin Arch segment and then the Indian Run segment where it merges with the Rio Grande Rift system. The AAF segment has a fault dip of 30° steepening upward, but the Juniper segment is more steep and more complex.

The faults that truncate the AAF are observed in seismic reflection data to die out before reaching the surface. Structures near Juniper Mountain and at Elk Springs may indicate surface expression of the fault. Except for the Wolf Creek fault in the Blue Mountain area, the fault is mapped as "inferred" location. Stone (1986) has shown that the system is merged or junctions with the Uinta-Sparks fault near Lay, Colorado, and also intersects with the Cross Mountain segment. Axial Basin Arch systems are considered to be connected at depth as illustrated by Hansen (1986b).

The nearest earthquake epicenter to the fault within the site region is a single microseismic $M=2.9$, 1968 event south of the zone estimated at a distance of 39 mi (63 km) from the site.

Hansen (1986b and 1984) has indicated that there are no Quaternary or suspected Quaternary displacements along this system. Based on a review of the literature and the lack of significant related seismicity this study concludes that the system is noncapable under the present stress regime. As the master fault system within the Axial Basin Arch, together with the Uinta-Sparks Fault system, the very low level of seismic activity on these faults is significant to the consideration of the capability of faults within this structural province.

Little Juniper Mountain faults (Group 4)

Two mapped faults pass on either side of Little Juniper Mountain at a point where the Yampa River dissects the uplifted arch of the mountain. The Little Juniper Mountain faults are manifest in aerial photographs as an abrupt change in the topographic grain with the ridge crest trending sharply north-south. Erosion along the Yampa River has exposed the traces of the faults.

These faults were observed and reported by Hancock (1925), from photographs showing the thrust fault features in the slope of the north side of the Yampa River.

The mapped traces of these faults nearly coincide with the epicenter location of the December 1891 earthquake, which had an estimated intensity of $MMI = VI$ as reported by the NGDC (NGDC/NOAA, 1986). The epicenter is at 40.5 degrees latitude and 108 degrees longitude. (This event is discussed previously in the section on epicentral compilation.) The margin of error for location of this historical event is sufficiently large so that the actual epicenter could be remote from this region.

No indication of faulting in alluvial deposits was noted at this location during this study, nor were any reported in previous studies. The field evidence obtained during this investigation suggests that the faults are of Laramide age and are not capable under the present seismotectonic regime.

Juniper Mountain (Group 5)

This fault is observed in the eroded core of Juniper Mountain and is mapped on the basis of visible faulted bedrock. Aerial photographs of the fault show only minor topographic expression along its trend as a result of differential erosion of the bedrock.

The fault is considered to be of Laramide age, formed during the uplift of the Juniper Arch. There is no evidence of dissected alluvium or fault scarps along the trend. It is not considered to be a capable fault.

Temple Canyon Fault (Group 6)

This fault group lies parallel to the strike of the northern most extension of the Grand Hogback on the west flank of the Danforth Hills anticlinal structure. A portion of the fault group merges with the axis of the Danforth Hills anticline. Several small faults have been mapped along the axis of the Danforth anticline and near the Grand Hogback.

This fault is just beyond the 9-mi (15-km) site radius and was studied from aerial photographs and the literature. No known occurrences of dissected alluvial deposits or escarpments exist that would indicate Quaternary movements. Detailed mapping by Izett et al. (1985) indicates that Quaternary deposits are not dissected by the fault. The fault is not considered capable.

Cedar Mountain faults (Group 7)

This group consists of four parallel, northwest-trending mapped faults (Tweto, 1976). The longest fault in the group has a mapped length of 9 mi (15 km). The only fault of the group that is easily confirmed in the field and by analysis of stereo pair color aerial photography is one that dissects the lava-capped Cedar Mountain and plug and extends south of the mountain.

There is field evidence and photographic evidence for a transecting northeast-trending fault system that truncates the south end of the mountain. The mountain appears entirely bounded by faults. A study of the photographs indicates this northeast-southwest system offset the northwest-trending set. The fault trend and geomorphic expression since faulting indicate that the fault movement is related to the Elkhead Mountain volcanic activity, which occurred from Mid-Tertiary to Paleocene. There are no Quaternary features associated with the fault movement and the faults are not considered capable. Other fault groups possibly related to this system are the Fortification Fault and Dike and the Scandinavian Gulch.

Monument Butte faults (Group 8)

The two parallel, east-west trending faults in this group form a graben structure. The faults were reported by Hancock (1925), who estimated that the faults may have formed at the same time folds were produced (in Laramide time) but probably formed later. The displacement is about 200 ft (60 m) on the northern fault and about 800 ft (240 m) on the southern fault (Monument Butte fault). These normal faults are likely the result of tensional forces that led to the collapse of the Axial Arch described by Hansen (1984).

The faults are in the Axial Basin Arch and situated parallel to the Axial Basin Anticline. The Mancos Shale underlies the area and has been severely eroded since fault movement occurred. Two streams, the Marapos Creek and Deer Creek, both cross the alignment. Monument Butte, on the upthrown side of the south fault, reflects the amount of displacement in the exposed stratigraphy. The apparent age of land forms around the butte suggests that faulting is not Quaternary. The faults are considered to be pre-Quaternary in age and are not capable in the present tectonic stress regime.

Citadel Plateau faults (Group 9)

This group consists of two parallel faults with the middle block downthrown as a graben block. The fault is just west of the Danforth Hills structure in a transition area between northeast-trending folds and an area of east-west trending folds. Much of the length of the north fault is inferred by Izett et al. (1985) and shows that the fault had not dissected Quaternary alluvial deposits.

The relationship of the fault to the folding suggests, as established in the Monument Butte fault group that the age is probably post Laramide when tension forces resulted in the Axial Arch in middle Tertiary. Based on evidence of geomorphic expression of the fault and from review of literature, the fault is not considered capable in the present tectonic stress regime.

Cross Mountain faults (Group 10)

The faults on Cross Mountain are mapped as thrust faults bounding the west and east sides of Cross Mountain (Rowles et al., 1985; Dyni, 1968). At the southwest corner of the mountain are a series of parallel normal faults that cut the Miocene-aged Browns Park Formation. Dyni (1968) has mapped the western group of these faults near U.S. Highway 40 as inferred faults.

These normal faults were discussed by Kirkham and Rogers (1981) (fault group 12 of their report). They concluded that the faults did not show any definite evidence of Quaternary activity but noted the occurrence of sharp, steep, linear scarps that suggested possibly Early Quaternary movement. These descriptions were based on aerial photographic study; the faults were not examined in the field (Kirkham, 1987a). Spitzer (1987) also inspected these faults in the field and concluded that they were not Quaternary in age.

Field examination of these faults indicates that higher elevations consist of a conglomerate formation, which may explain the scarp relief seen on aerial photographs. The fault traces are poorly defined when observed in the field.

Stone (1986) has shown that the Wolf Creek-Juniper fault segment of the AAF follows the east-west alignment of Elk Springs Ridge, which is the southern limit of the series of normal faults (see Figure 2.7). This relationship suggests that the normal faulting was related to stress on the buried south boundary fault of the Uinta Mountain Arch.

The nearest epicenter of seismic activity to the Cross Mountain region is a 1942 historical microseismic event of MMI=III. The location accuracy is typically to the nearest 15 minutes latitude and longitude (about 12 mi [20 km]). The faults are not capable within the current tectonic stress regime.

Big Hole Gulch faults (Group 11)

Rowles et al. (1985) mapped three closely spaced, parallel faults trending southwest-northeast through Quaternary/Tertiary gravel deposits. The gravel may be composed of the basal conglomerate unit of the Miocene age Browns Park Formation, which is otherwise missing in this region. The faults may be related to the large group of faults that are just north of the Wyoming border (refer to the Wyoming fault, Group 22). LSA aerial reconnaissance indicated no obvious offset of Quaternary deposits or evidence that the differential erosion across the faults may enhance the scarp relief.

The nearest earthquake epicenter to the fault reported by NGDC/NOAA (1986) produced an isolated microseismic event of $M=3.3$ in 1979, about 10 mi (16 km) southeast. This is due south of the Scandinavian Gulch fault about 5 mi (8 km) away. Stone and Webster (1986) have indicated that the Big Hole Gulch faults had their last movement in the Late Cenozoic (last 25 million years) and no recent seismicity has been associated with this group. Based on the geomorphic expression of the fault and review of literature, it is concluded that the faults are not capable.

Scandinavian Gulch faults (Group 11a)

Like the nearby Big Hole Gulch fault 3 mi (5 km) west, the Scandinavian Gulch fault appears to be a part of the swarm of faults that lie along the Wyoming border. The location and trend of this fault indicate a transition zone between the Wyoming Group and Elkhead Mountain to the southeast. The trend is the same as the trend of the Fortification Dike in the Elkhead Mountain. The trend of the well established drainage appears to be influenced by the fault structure. Differential erosion has locally exposed the fault trace.

This normal fault juxtaposes the Green River Formation and a younger member of the Wasatch Formation (Tweto, 1976). No Quaternary units are known to be offset by the fault.

A 1979 earthquake epicenter is located about 5 mi (8 km) south of this fault. No other events are recorded for this region. Stone and Webster (1986) have characterized the faults in the Wyoming Group as Late Cenozoic (last 25 million years) with no associated historical seismicity. Based on the lack of geomorphic expression in Quaternary deposits, it is concluded the fault is not capable.

Fortification fault (Group 12)

Fortification fault, 19 mi (30 km) north of Craig, Colorado, near the Baggs Highway, is associated with the intrusive Fortification Dike, which is related to the Elkhead Mountain volcanics and dike system (Carey, 1955). Based on this association, the age of the fault is likely contemporaneous with the Miocene collapse of the Uinta Arch and the deposition of the Browns Park Formation.

Carey (1955) states that "the volcanism is either Late Browns Park or North Park in age." He concluded the age is between Middle Miocene and Lower Pliocene. The fault is considered to be a noncapable system in the present tectonic regime.

Williams Fork Mountain faults (Group 13)

This fault is on the southwest flank of the Williams Fork Mountains anticline and has the characteristic northwest-southeast trend of the Axial Basin Arch-Uinta Mountain structure. The fault lies at the boundary of the Axial Basin Arch and Sand Wash Basin physiographic provinces and at the boundary between the Elkhead Mountains volcanic region and the Flat Tops volcanic region at the north edge of the White River uplift.

The fault is exposed by differential erosion where it is dissected by several transecting drainages, on the flank of the anticlinal structure (Tweto, 1976). From the geomorphic expression of the dissecting drainage, the fault is older than the Quaternary. The age appears to be similar to the Monument Butte faults (Group 12). The faults appear to be related to the folding that occurred in the Laramide Orogeny because of the similar trends with the fold axis.

It is concluded that the fault is noncapable in the present tectonic framework.

Meeker faults (Group 14)

The two normal faults of this group form a graben located just north of Meeker that offsets the Grand Hogback. These faults are likely related to the folding of the Danforth Hills Arch and the White River Uplift of Laramide age. The larger fault is exposed along Sulphur Creek, which follows the trace of the fault as a water gap through the Grand Hogback.

The fault trace is visible in the bedrock where contrasting lithologic types are juxtaposed by the offset. Alluvial deposits are not dissected. There is no evidence that the fault system is capable under the present seismotectonic regime.

White River faults (Group 15)

This group consists of several normal faults that trend parallel to the White River Valley west of Meeker. The faults occur as disconnected segments through a span of 25 mi (40 km). Most are downthrown toward the valley, indicating a graben valley.

The faults are locally parallel and lie immediately south of a major fold system that extends from Meeker to the Utah border, where the fold system merges with several parallel systems on the south flank of the Uinta Mountains. This system separates basins within the Colorado Plateau.

The relationship of the White River fault group to the structure of the Uinta-Axial Basin Arch system indicates that it is part of the Laramide Orogeny and experienced subsequent movement during collapse of the Axial Basin Arch. No seismic activity is assigned to faults in this region.

All scarps are well dissected by drainages with no evidence of movement since development of the much-elevated river terraces that border the valley.

It is concluded that the faults are noncapable under the present tectonic stress regime.

Douglas Mountain faults (Group 16)

This group comprises several faults on the crest of the Uinta Arch that trend diagonally to the axis of arch. Douglas Mountain forms the easternmost arch of the Uinta Mountains and lies east of the Green River Valley in Colorado.

The faults on the east end of Douglas Mountain are normal faults and are similar to another group adjacent to Ladore Canyon that shows the type of faulting (Hansen, 1986b) attributed to the collapse of the Axial Basin Arch in Mid-Tertiary time. The faults in this group are indicated by Hansen (1986b) as older than Quaternary and consequently are determined to be noncapable faults in the present tectonic regime. The youngest fault with possible Quaternary movement is more than 62 mi (100 km) from the site and 12 mi (20 km) east of Douglas Mountain (Hansen, 1986b). No seismicity is associated with that fault or with the Uinta Arch region.

Cherokee Ridge, Wyoming, faults (Group 17)

This group consists of a swarm of faults that trend northwest-southeast with an occasional set that trends east-west. With few exceptions, the east-west set is

offset by the northwest-southeast set. The main swarm contains about 35 faults in a width of about 12 mi (20 km). The fault traces appear to start at the Colorado border, which also marks the alignment of Cherokee Ridge. Roehler (1985) mapped only one fault extending about 0.6 mi (1 km) south of the Wyoming border.

The longest fault shown in this group within the 40 mi (65 km) site radius is about 9 mi (15 km) long. The only mapped Quaternary deposits are sand dunes of Holocene or Pleistocene age; these are not cut by faulting. The study for Sandstone Dam (Stone and Webster, 1986) characterizes these faults as typically normal with the north side downthrown. "Washakie Basin faults are estimated to have had last movement in the Late Cenozoic (last 25 million years) and a low susceptibility to earthquakes The faults displace Tertiary (Miocene) deposits, but not Quaternary deposits" (Stone and Webster, 1986). The report states that no historic seismicity was associated with this group.

Roehler (1987) believes that faulting in this area is related to the Cherokee Ridge and believes that the last movement of faults in this area and in the region around Maybell where the Browns Park Formation was faulted was during the Paleocene. No evidence exists for Quaternary fault movement. Seismicity in the region is not due to any significant stress regime but rather minor adjustments such as stress relief from erosion removal of overburden (Roehler, 1985).

Jim Case of the Geologic Hazards Section of the Wyoming Geologic Survey (WGS) reported that some faults in this area were erroneously included in the WGS map of suspected Quaternary faults (Case, 1986). It is concluded that faults in this group, which may be extended to cover the Big Hole Gulch and the Scandinavian Gulch fault, are not capable faults within the current tectonic stress regime.

Yampa fault (Group 18)

This fault lies just north of and parallels the Wolf Creek fault (Group 3). Hansen (1986b) describes this as one of the major structural features of the eastern Uinta Mountains. It formed in the ruptured synclinal bend of the Yampa monocline as a south-dipping thrust fault. Other investigators have called the system the south boundary of the Uinta Mountains uplift on the mistaken belief that this was a north-dipping thrust (Hansen, 1986b). A single microseismic event of $M = 2.9$ in 1968 was located on the alignment of this fault just beyond the 40-mi (65-km) site radius.

Some deformation of the Browns Park Formation has occurred in the Elk Springs area south of Cross Mountain on the alignment of the Yampa Monocline. No evidence exists for Quaternary faulting within this region (Hansen, 1986b).

It is concluded that this fault is not capable within the site region in the present tectonic region.

2.5 MINERAL DEPOSITS AND OTHER RESOURCES

Economic mineral resources in the Maybell site region include uranium and vanadium ores, coal, oil and gas, oil shale, and other metallic and nonmetallic minerals including gold, silver, copper, gypsum, and potash (Steele et al., 1979). Figure 2.10 shows the principal areas of energy and other mineral resources in the area.

2.5.1 Uranium

Of all the region's economic mineral resources, only uranium has been exploited in the immediate site area. Uranium deposits across the site are generally confined to the upper portion of the Browns Park Formation. Faulting and favorable geochemical conditions appear to have been the controlling factors in localizing the deposition of uranium. Uranium is concentrated on numerous steeply dipping normal faults as interstitial fillings on sand grains. It is believed that the uranium was carried in oxidizing ground water until conditions were favorable for precipitation (Chenoweth, 1986a). Hydrocarbons, both liquid and gaseous, migrating along the underlying Tertiary-Cretaceous nonconformity provided the reductant necessary to precipitate the uranium.

Early production history reported by the U.S. Atomic Energy Commission (AEC) (AEC, 1974) indicated that after construction of the Maybell mill, which began operation in November 1957, annual production of uranium reached its peak in 1963 when 355,041 tons (322,000 tonnes) of ore containing 720,384 pounds (326,800 kilograms) of yellow cake (U_3O_8) were produced. The mill was closed and dismantled in 1964 when Union Carbide elected to fill its contract with the AEC with uranium produced from its mill in Uravan, Colorado. Union Carbide resumed operations at the Maybell site in the mid-1970s when the price of uranium rose rapidly. This activity, however, was limited to heap leaching of material that had been left from previous milling operations. Falling uranium prices finally forced the closure of the Maybell mill in 1981 (Chenoweth, 1986a). The grade of ore processed over the life of the Maybell mill averaged 0.098 percent U_3O_8 , one of the lowest in the industry (FBDU, 1981). Analyses of ore samples taken by the AEC in 1977 indicated that the samples contained 0.012 percent U_3O_8 with no other metals in significant concentrations present.

2.5.2 Coal

The value of mined and extracted minerals in the region is quite small compared to fossil fuels, which constitute the most important mineral resources in the area. The Maybell site lies within the largest coal-bearing region in Colorado, accounting for 52.8 percent of Colorado's 1980 production (Boreck et al., 1981). This region, known as the Green River Coal Region, covers a vast area in northwestern Colorado and southwestern Wyoming. The coal beds of economic interest are present only in strata of Late Cretaceous and Tertiary age. The principal coal-bearing formations within the region are the upper Cretaceous

FIGURE 2.10
PRINCIPAL LOCATIONS OF ENERGY AND MINERAL RESOURCES MAYBELL SITE REGION

Iles and Williams Fork of the Mesaverde Group, the upper Cretaceous Lance, the Cretaceous-Paleocene Fort Union, and the Paleocene-Eocene Wasatch. Coal deposits in the Iles and Williams Fork Formations contain approximately 75 percent of the estimated reserves in Moffat County (Robinson and Associates, 1975).

Most coal mining has taken place in Routt County, east of Craig, Colorado. Coal produced from these mines has accounted for 98 percent of all production in the Yampa River Basin (Steele et al., 1979).

No coal-bearing strata of economic value lies beneath the Maybell site area as a result of the erosion of several thousand feet of Tertiary and Upper Cretaceous coal-bearing formations in the Juniper Mountain area.

2.5.3 Oil and gas

Oil and gas fields of the Sand Wash Basin, including the Axial Basin Anticline, have produced large amounts of hydrocarbons in the past. Most of the oil and gas production in the region has occurred in Moffat County with lesser amounts produced in Routt and Sweetwater Counties, Wyoming (Steele et al., 1979). The hydrocarbons occur in structural traps such as anticlinal closures or faults or in stratigraphic traps such as lenticular sands.

The major gas-producing formations in the area are the Wasatch, Fort Union, and Lewis Formations of Late Cretaceous and Early Tertiary ages. One of the largest gas-producing fields in the region is the Powder Wash Basin near the Wyoming-Colorado border. Total gas production in this field through 1976 was about 461,366,465 thousand cubic feet (13,066,000 thousand cubic meters) (Steele et al., 1979).

The Axial Basin Arch has not specifically been identified as a potential oil and gas resource area. Although the site area is underlain by the oil and gas-bearing strata of Cretaceous age, no production has been reported. Practically all of the known obvious structural traps in the region, including thrust faults at great depths, have been explored; however, exploration activity is continuing. This activity has declined due to the latest fall in oil prices but continues in the areas of greatest economic potential such as the Powder Wash Basin and the currently producing fields south and east of Craig, Colorado.

2.5.4 Oil shale

Oil shale occurs in the Tertiary Wasatch Formation in the northern part of the Sand Wash Basin in Sweetwater County, Wyoming, and in the Piceance Basin to the south of the Maybell site between Rifle and Grand Junction, Colorado. Development, which began by Exxon in Parachute, Colorado, was discontinued in 1982. No economic potential for oil shale exists at the Maybell site as a result of the removal of thousands of feet of Tertiary rocks prior to the deposition of the Browns Park Formation.

2.5.5 Gold and other metallic minerals

Gold, occurring in placer deposits, has been produced from gravel benches and stream terraces along the Yampa River, in Lay Creek south of the Iron Springs divide, in the Four Mile Creek area, and in the Hahns Peak area of the Elkhead Mountains (Figure 2.10). Although production histories are limited, records of the Colorado Bureau of Mines indicate some gold production in Moffat County from 1892 to 1960 (Robinson and Associates, 1975).

The Hahns Peak district has been producing a limited amount of gold, silver, copper, and lead since 1866. Placer gold has been mined on a limited scale from the acidic intrusives and adjacent sedimentary and Precambrian rocks (Carey, 1955).

Records indicate the nearest gold mine to be near the town of Lay, approximately 8 mi (13 km) from the Maybell site; however, present activity is unknown and no production history has been available since 1972 (Robinson and Associates, 1975). No known occurrences of gold or other metallic minerals have been reported in the Maybell site area. The Tertiary Browns Park Formation is not considered to be a very good prospect compositionally for these minerals and no historical development of these minerals has been reported.

2.5.6 Geothermal resources

The largest potential geothermal resource area in the region is near Steamboat Springs, east of the site region. Hot springs north of Steamboat Springs are associated with Tertiary age basaltic rocks (Steele et al., 1979). The springs have a total discharge of about 2000 gallons/minute (125 liters/second) and range in temperature from 75°F to 147°F (24°C to 64°C).

The only area of geothermal activity in the Maybell area is 6 mi (10 km) southeast of the Maybell site next to Juniper Mountain. The U.S. Geological Survey Water Resources Division is currently investigating the area's geothermal energy potential. It is unlikely that any geothermal potential exists at the Maybell site. No anomalies are indicated on the heat flow map of Zoback and Zoback (1980) within the site region. The nearest anomaly lies in the Western Mountain Province and in the Northern Rio Grande Rift Province.

2.5.7 Potash

Potash, also known as trona, occurs in the Green River Formation in southwestern Wyoming (Figure 2.10). Deposits here are easily recovered and supply the majority of the world's soda-ash industry (Steele et al., 1979). No economic potential for potash exists at the Maybell site. The Green River Formation, which contains vast potash reserves, was removed by erosion prior to the deposition of the Browns Park Formation.

3.0 SITE GEOLOGY AND GEOMORPHOLOGY

3.1 BEDROCK GEOLOGY

The site is near the northern boundary of the Axial Basin Arch defined by the Uinta-Sparks Fault (Figure 3.1). The axis of the east-west trending Maybell Monocline underlies the site. The northern limb of the monocline also coincides with the alignment of the Uinta-Spark Fault system. This is illustrated in the structural cross section through the site (Figure 3.2), that shows the relationship of the Maybell Monocline and the Lay Syncline erosional trough, which is filled by the Browns Park Formation. The site lies in an east-west trending, graben-like valley bordered by juniper-covered ridges. The small, bowl-shaped drainage basin, in which the tailings rest, drains to the south across the valley boundary. Figures 3.1 through 3.4 show that the area around the tailings pile and the surrounding strip-mined area are underlain by the Browns Park Formation of Miocene age. This formation has a thickness of 800 to 900 ft (240 to 275 m) in the site area (FBDU, 1981).

Bedrock crops out in the higher elevations around the site and exhibits substantial local relief near faulted slopes. At the site, bedrock has a gentle slope broken only by drainage channels incised into the soil cover. The soil cover in the center of the bowl-shaped basin appears to taper evenly to the edges of the drainage divide. Light-brown to red-brown soil rests on a slightly undulating erosional bedrock surface.

The Browns Park Formation consists of light gray and white, silty, fine-grained sandstone. The bedding thickness ranges from thinly bedded to massive cross-bedded strata and interbedded siltstone lenses. The sandstone, where exposed in the surrounding hills, shows a light to moderate cementation, but below the water table is only weakly cemented; minor cementing materials are calcite and clay (Chenoweth, 1986a). The Browns Park Formation can be observed in the open pit mines in the surrounding area to depths of 180 ft (55 m). At the site, the Browns Park Formation shows very little variation of grain size, with the exception of discontinuous lenses of cemented siltstone. The Browns Park Formation is of continental origin and consists of eolian and low energy fluvial deposits of silty fine- to medium-grained sand.

The vertical walls of the open pit mines show no evidence of massive slope failure. Only minor sloughing of sand particles and occasional cobble-sized fragments has occurred. There is no noticeable weeping of perched moisture from the walls and no obviously impervious strata on which perching might occur. Typically, the strata show such homogeneity that it is difficult to determine actual displacements on minor faults. Individual beds are more easily distinguished where mineralization has occurred especially near faults with large displacement. Ground water is found in the deepest pit mines within this formation.

FIGURE 3.1
MAYBELL SITE GEOLOGY MAP

REF: SITE FEATURES FROM AERIAL PHOTO BLM, 1977

ELEVATION CONTOUR FROM MOFFAT COUNTY
MAP, 1975; USGS LAY QUAD. 7.5 MIN., 1969;
AND USGS MAYBELL QUAD. 7.5 MIN., 1976

FIGURE 3.2
STRUCTURAL CROSS SECTION THROUGH THE MAYBELL SITE AREA NEAR MAYBELL, COLORADO

FIGURE 3.3
GENERALIZED GEOLOGIC MAP OF MAYBELL SITE REGION

Bedrock in the basin is naturally exposed only in the areas of moderate to high relief as shown in Figure 3.1. The tailings site and the immediate surroundings have soil depths ranging from 2 to 15 ft (0.6 to 4.5 m). The vegetation change from grass to juniper typically marks the approximate alluvium/bedrock contact. Bedrock is also exposed in a few of the lateral drainages of Johnson Wash.

The Browns Park Formation generally has a horizontal attitude with gentle undulations of 1 to 3 degrees dip (visible in the open pit mines) occurring over short distances. Regional dip of the Browns Park Formation at the site is toward the axis of the Lay Syncline at less than 10 degrees (Chenoweth, 1986b).

3.1.1 Structural faults in the site area

Because the faults in the site are significant to the site geologic conditions, the following is a brief discussion of these features. The faults are also discussed in Section 4.2, Seismotectonic Stability. The east-west trending faults that border the site area to the north and south appear to form a graben-like structure. These faults are separate segments of the broad Uinta-Sparks Fault system. Other segments of this system occur north of the site area. A generalized cross section shows the relationship of the fault system to the site area (see Figures 3.1 and 3.4). The faults bounding the north and south side of the valley occur along resistant ridges. The cementation of the Browns Park Formation in these ridges may be the result of partial mineralization along these east-west faults. Chenoweth (1986a) considered that the cementation of these ridges may also be due to case hardening. It is concluded that the relief of the site valley relative to these ridges is primarily a result of differential resistance to erosion as a consequence of fault-controlled cementation along the major fault system and not the result of fault displacement.

The north side of the Johnson Wash Basin valley is the trace of the Uinta-Sparks Fault system. One of several parallel faults in a band 5 to 8 mi (8 to 13 km) wide lies at the toe of the juniper-covered north ridge. This system was originally mapped only as far eastward as Spring Creek, 3 mi (5 km) west of the site. Aerial photo lineation and field reconnaissance substantiate their continuity through the site area. Hansen (1984) suggests that the en echelon normal faults between the site and Craig (Lay Peak Fault, Craig Fault) are a part of this fault system.

Secondary faults with moderate offsets of 1 to 6 ft (0.3 to 2 m) are observed in the pits in the interior of the valley. Johnson Pit shows three secondary faults with northwest-southeast, north-south, and northeast-southwest trends. However, the predominant trend is northwest-southeast in the vicinity of the tailings pile. In the walls of the strip mines north of the tailings pile secondary faults are typically nearly vertical, and trend about 40°N to 50°W.

One such fault, exposed for 0.25 mi (0.4 km) in a pit northwest of the tailings site (Marge Pit), trends in a direction that would cross the western third of the

tailings pile. Brief exposures in an adjacent pit due north of the pile indicate that two or three other parallel faults will also trend through the tailings pile between 200 and 600 ft (60 and 180 m) apart. These secondary faults appear to be intercepted by major fault segments of the east-west-trending Uinta-Sparks Fault system that bounds the basin. The secondary faults have no discernible topographic expression or lineations that may be observed in stereo-pair aerial photographs. Chenoweth (1986b) concurred that the basin faults, such as the Marge Fault reported by Bergin (1959), are secondary to the faults found in the Uinta-Sparks system that pass on the north side of the basin. The Marge Fault is visible in the open pit mine immediately north of the tailings pile and is one of several faults that appear to extend below the disposal site. The faults that are exposed in the walls of strip-mined areas are believed to have been associated with ore deposition.

Other unexposed faults may underlie the soil in the valley. Two northward-trending faults and one westward-trending fault are exposed in a gully at the south edge of the basin. Another fault found in lower Johnson Wash trends to the northwest at a slight angle to the ridge bounding the south side of the valley (see Figure 3.1).

The eastward-trending valley boundary faults are observed along juniper-crested ridges and exhibit substantial displacement as evidenced in the exposures in the walls of the strip mines and in the topographic relief. The fault bounding the north side of the site valley is exposed in the pit in the southeast quarter of Section 18, trending due west along the axis of the Lay Syncline (Figure 3.1). Chenoweth (1986a) reports that vertical displacement of as much as 30 ft (9 m) has been observed on these boundary faults. Since the major east-west trending faults may be made up of a system of up to four or five parallel faults, each showing displacements, the total displacement may be even greater.

3.2 SURFICIAL GEOLOGY

Central to the determination of the age of the most recent local faulting is the undissected soil that overlies the secondary faults and the site valley boundary faults. The best example of this is at the north end of Johnson Pit, located immediately south of the tailings pile, where about 15 ft (5 m) of buff to light brown silty sand with thin bedding planes and 4 ft (1.2 m) of soil with weakly developed B and C horizons overlie the eroded surface of the Browns Park Formation and are undissected by the north-south trending fault aligned with the west wall of the pit. The weak soil development indicates the undissected soil is probably not older than Holocene age, or less than 10,000 years.

Along the outlet valley forming the lower reach of Johnson Wash shown in Figure 3.1, colluvium mantled slopes grade to alluvial fills in the narrow valley bottom. At the head of the valley, at least three fill surfaces may be differentiated by their successively lower heights (ranging from a few feet to 20 ft [6 m] above the present stream channel); at least two such surfaces are present farther downstream. The channel is incised below these fill surfaces

and is on alluvium; however, a few bedrock exposures near present stream level suggest that the channel alluvium is, at most, a few feet (few meters) thick. The maximum thickness of the dissected alluvial fill is about 25 ft (7 m).

Soils on the surficial deposits were examined briefly at 10 places in the basin but are not described in detail. The soils either lack B horizons or have thin (roughly 4 inches [10 cm]) cambic B horizons that are siltier and redder than the underlying sandy alluvium and probably formed in patchy eolian deposits. The soils generally lack visible carbonate, although Stage I-II carbonate accumulations occur locally. Most of the soils probably are early to late Holocene, but those with stronger carbonate accumulations may be late Pleistocene. The presence of multiple surfaces with weak soils suggests that natural changes in precipitation and vegetation have caused alternating periods of landscape stability and erosion during Holocene time.

4.0 GEOLOGIC STABILITY

4.1 GEOMORPHIC STABILITY

The site is located in the upper drainage basin of Johnson Wash, a minor southward-flowing tributary of Lay Creek. From its northern divide to the Lay Creek junction, this drainage basin is about 5 mi (8 km) long and has a total area of about 4.3 square mi (11.1 square km). An elevational difference of about 230 ft (70 m) exists from the base of the tailings pile to the junction of Johnson Wash and Lay Creek. Total relief of the basin from Lay Creek to the drainage divide is about 760 ft (230 m).

Physiographically, the drainage basin may be divided into three parts. The northern headwaters include the dissected flank of a broad ridge underlain principally by the Fort Union Formation. In contrast, the rest of the basin is underlain by a sloping, bowl-like area in which many gullies join to form the main channel of Johnson Wash. These gullies drain not only the ridge to the north but also lower divides to the east and west.

The lower part of the basin includes the narrow, steep-sided outlet valley, 200 to 250 ft (60 to 75 m) deep, that connects the upper and central parts of the basin with Lay Creek. The northern mined area lies on the north edge of the central basin, downslope from the hilly area underlain by the Fort Union Formation. The western mined area lies on the western divide and adjacent slope of the central basin.

The central basin probably acquired its bowl-like shape because of large sediment yields from the surrounding, steeper hillsides where the numerous branch streams join. It appears that this sediment sometimes exceeded the carrying capacity of the trunk stream, causing temporary sediment storage as a thin alluvial fill. The narrow outlet valley, which gives an overall wine glass shape to the basin, is characteristic of basins that have been rejuvenated by the recent base-level fall of Lay Creek. Thus, the large-scale processes controlling the geomorphology of the Lay Creek basin are temporary sediment storage and flushing in the central basin and continuing incision due to base-level fall.

Exposures in the mine pits and stream banks show that the central and lower basin probably have experienced several cycles of recent (perhaps Holocene) erosion and landscape stability. The main drainages are now incised into the alluvium as gullies. However, previous episodes of gully filling are recorded by exposures in the pit walls where V-shaped cuts 10 to 20 ft (3 to 6 m) deep are filled with surficial deposits. The extensions of these former gullies cannot be traced across the ground surface away from the pits.

Present entrenchment of most of the drainage lines, possibly to near former maximum depths, suggests that the central and lower basins are now in a period of erosion. This erosion is being expressed primarily by headward

extension, branching, and deepening of gullies and by slumping along gully sides. In comparison, erosional lowering of interfluvies is likely to be minor during the next few hundred years.

The drainage basin of Johnson Wash contains old alluvium-filled gullies in the open pit mine area and alluvial terraces within the outlet valley to the south. These attest to at least two periods of channel incision followed by deposition. The present drainage channels of Johnson Wash are incised into the former alluvial fills. This sequence appears to be the result of periodic sediment storage within the basin followed by overall erosion, possibly linked to base level falls. Old channel fill deposits are shown in Figure 4.1. Filled V-shaped gullies are exposed in open pit mine exposures but do not connect with the current headward limits of the tributaries of upper Johnson Wash. The existence of the filled gullies, however, indicates that future erosion may result in headward migration of gullies to the north boundary of the drainage divide.

Several incised gullies extend westward from the upper reach of Johnson Wash to the edge of the tailings pile and overburden piles (Figure 4.1). The existing tailings pile lies on top of one of these gullies. Actively eroding knickpoints occur in each of the western gullies near its junction with the main wash. Except where gullies drain significant surface areas, the Browns Park Formation offers a relatively erosion-resistant surface to gully formation.

Tributary T5. This small gully heads in a bare, eroded soil area with numerous rills and shallow gullies. Surface runoff from the tailings pile flows across a dirt road to the gully head. The north segment of the gully contains an active knickpoint 4 ft (1.2 m) deep and 5 ft (1.5 m) wide, about 75 ft (23 m) upstream from the intersection with the main Johnson Wash channel. Recent erosion appears to have extended the knickpoint upstream 3 to 4 ft (1 to 1.2 m) in the past several years. Browns Park Formation bedrock occurs about 10 ft (3 m) below the land surface. The gully is actively growing toward the tailings pile along an old dirt road cut.

The south segment of Tributary T5 is slightly more vegetated than the rest of the gully. This segment is growing toward the dirt road along the tailings pile perimeter. An active knickpoint 2 ft (0.6 m) deep and 2 ft (0.6 m) wide occurs about 60 ft (18 m) from the lower end of the gully, but does not appear as active as the one in the north segment. The gully head next to the pile is deeply rilled and eroded and is actively eroding toward the tailings pile.

Tributary T6. This tributary gully to Johnson Wash is partially buried by the existing tailings pile. Examination of pre-tailings topographic maps shows that the original gully extended into the central portion of the pile area. The tributary heads at a washed out part of the tailings pile perimeter road. An active branch of the gully 2 ft (0.6 m) deep and 1.5 ft (0.5 m) wide cuts into Browns Park Formation bedrock and the overlying tailings, extending about 10 ft (3 m) into the tailings slope. Active headward erosion of 0.5 to 1 ft (0.2 to 0.3 m) has occurred within about 1 year's time. The rapid rate of erosion in this gully is

BASE MAP: (REF: USGS 7.5' LAY CO
TOPOGRAPHIC QUADRANGLE, 1969

FIGURE 4.1
CHANNEL FILL DEPOSITS AND MAJOR TRIBUTARIES OF
JOHNSON WASH, MAYBELL SITE NEAR MAYBELL, COLORADO

due to the high velocity of water coming off the steeply sloped tailings pile. The lower reach of the gully meanders in a well-vegetated channel with a recently deposited sand bed. The flat slope of this gully is indicative of the erosion resistance of the Browns Park Formation. The gully banks generally show little erosion. The active channel is incised within an older, larger channel. A small knickpoint occurs at the junction with the main Johnson Wash channel.

Tributary T7. This small gully does not reach the tailings pile, although it is actively eroding toward the pile. The channel is incised about 2.5 ft (0.8 m) deep and 4 to 5 ft (1.2 to 1.5 m) wide into the surficial soils up to the tailings pile perimeter road. Several knickpoints are cut about 1 ft (0.3 m) deep into Browns Park Formation bedrock about 150 ft (45 m) downstream of the road. The gully gradually deepens downstream with near-vertical walls.

Tributary T8. The head of this gully occurs at the tailings pile road, where numerous shallow swales and rills channel runoff into the wash. The gully does not intersect the tailings pile. The lower gully bed contains recently deposited sand. A major knickpoint 4 ft (1.2 m) deep and 4 ft (1.2 m) wide is incised into alluvium and bedrock about 500 ft (150 m) downstream of the road. Active erosion is evident from undercut tree roots and bare soil slopes. A sparse gravel layer occurs at the base of the knickpoint. Numerous smaller knickpoints 1 to 2 ft (0.3 to 0.6 m) deep occur upstream from the larger one. This gully is actively deepening the upper part of its channel and growing headward. An increase in channel width by lateral erosion appears to be occurring more slowly.

Tributary T9. This gully extends westward from Johnson Wash to a low ridge between the tailings and overburden piles. It drains a small subbasin near Johnson Pit. It is well-incised into alluvium and bedrock along the edge of the overburden pile. No lateral erosion toward the tailings pile is occurring.

Main channel of Johnson Wash. The present channel forms a meandering course within a wider floodplain bed cut into old channel fill alluvium. The extent of channel fill alluvium is shown in Figure 4.1. Distinct terraces of higher stream levels are present from a point near the south end of the tailings pile through the lower channel outlet to the high, level floodplain of Lay Creek. Net aggradation is present along most of the length of the channel. The present aggradational phase appears to represent the depositional part of a long-term erosion/deposition cycle within the Johnson Wash drainage basin. Terraces adjacent to the channel suggest at least two such cycles have occurred during Quaternary time.

An actively eroding knickpoint is present in the stream channel at about the midpoint of its reach through the hills south of the tailings pile (Figure 4.1). The channel upstream from the knickpoint contains a well-vegetated, sandy bed 50 to 100 ft (15 to 30 m) wide, shallowly incised by a 1- to 5-ft (0.3- to 1.5-m) wide, meandering, low-flow channel. This part of Johnson Wash is in an aggradational phase with sediment being received from gully erosion upstream

near the tailings pile. Except for high water flow events, this part of the channel appears to be stable. The only areas of active erosion are on the steep, unvegetated channel banks cut into parts of the terraces. These erosive areas do not affect erosion processes at the tailings pile.

The knickpoint in the channel is incised about 4 ft (1.2 m) into recent channel bed deposits, with a plunge pool below the lip incised an additional 3 ft (1 m). A densely packed, possibly cemented, gravel layer of clasts derived from Browns Park Formation deposits occurs at the base of the stream bed downstream from the knickpoint. This gravel layer may be close to the contact of the older alluvial fill and the underlying Browns Park Formation. The gravel layer forms a significant erosion-resistant barrier below the recent sandy channel deposits. Downtcutting within Johnson Wash appears to virtually stop once the gravel layer is reached.

The channel downstream from the knickpoint has a gravelly bed with little vegetation. The low-flow channel occupies the entire channel floor for several hundred feet (meters) downstream from the knickpoint, then gradually narrows to occupy a meandering, shallowly incised channel within a wider floodplain. The channel erodes during runoff events. Sediment from the knickpoint is being carried to the lower end of Johnson Wash.

Knickpoint migration is occurring but the exact rate is not known. Periods of significant water flow within the channel probably result in short periods of knickpoint erosion, with slower headward erosion occurring during low flow. Undercutting of a grass mat in the upper channel bed occurs at the lip of the knickpoint. About 1.5 ft (0.5 m) of channel deposits have been removed from beneath the overhanging grass mat. The current knickpoint is about 7000 ft (2100 m) from the edge of the tailings pile.

4.2 SEISMOTECTONIC STABILITY

4.2.1 Technical approach

The objectives and order of presentation of the seismic hazard analysis performed for this study are as follows:

4.2.2 Order of presentation of seismic analysis

- Previous studies are discussed and tables of probabilistic estimates of regional seismicity are presented.
- Epicentral compilations are discussed to characterize the instrumental and historic record.
- The ME for the province is determined.

- The effects of the MEs of other seismotectonic provinces in the region are discussed.
- Analysis of the recommended FE and the peak horizontal acceleration is discussed.
- The response of anomalies to regional seismicity is evaluated.
- An assessment is made of the age of the last fault movement on a segment that appears to reflect the seismic capability of the youngest and the largest fault system in the site region.
- Design earthquake is determined.

The technical analysis performed for this study involved a critical review of all the information developed during the investigation and a step-by-step approach to estimating seismic risk.

Based on the review of published and unpublished geologic data and the aerial-photo analysis, all mapped faults and aerial-photo lineaments within a 40-mi (65-km) radius of the site and the preparation of a map of faults and earthquake epicenters locations was compiled. The fault length/magnitude relationships of Bonilla et al. (1984) were used to determine the ME that each fault would be capable of producing if it were determined to be a capable fault. An on-site acceleration resulting from each fault was then calculated. These accelerations were then compared to the critical acceleration determined during the previous analysis. Any faults potentially capable of producing a larger on-site acceleration than the critical value were subjected to a detailed field investigation to determine if they are capable.

The maximum possible on-site acceleration resulting from earthquakes occurring in each of the remote seismotectonic provinces within the region of interest was determined from previous studies. A detailed analysis of individual faults within remote provinces was not performed, unless they lie within a 40-mile (65-km) radius of the site. A conservative approach was taken wherein the closest distance of the remote province from the site was first measured using published maps and literature to delineate province boundaries. The ME values for the remote provinces were estimated based on published studies and personal communications from researchers active in the area. The ME was then assumed to occur at the closest approach of each remote province to the site, and the resulting on-site acceleration was calculated.

The largest possible magnitude of FEs in the seismotectonic province within which the site is located (Uinta-Elkhead Province) was determined. This earthquake was then assumed to occur at a radial distance of 9 mi (15 km) from the site, and the resulting on-site acceleration was calculated using the acceleration/attenuation relationship of Campbell (1981).

The on-site accelerations resulting from the FE within the province containing the site and from the MEs at the closest approaches of each of the remote provinces were compared. The largest value was taken as the critical acceleration during the subsequent capable fault analysis.

The field investigation consisted of analysis of the seismic record for evidence of micro- or macroseismicity associated with the fault, close inspection of the mapped fault trace on aerial photography, detailed ground reconnaissance for evidence of Late Pleistocene or Holocene movements, and careful investigation of the indicated fault during the LSA aerial reconnaissance.

The highest calculated on-site acceleration of each capable fault would be recommended as the design acceleration value. The fault with the greatest acceleration would be designated as the controlling fault and the ME on the fault would be specified as the design earthquake. Because none of the faults were determined to be capable, the larger of the two acceleration values determined from the previous analysis (in this case the FE) is recommended as the design earthquake with the resulting design acceleration.

4.2.3 Previous studies

Probabilistic earthquake maps of the United States have been prepared by Algermissen et al. (1982) and by Liu and DeCapua (1975). Table 4.1 shows the resulting probabilistic values predicted for the region.

Table 4.1 Probabilistic estimates of maximum acceleration, velocity, and intensity in the site region

Source	Return period or probability	Maximum acceleration (g)	Maximum velocity (ft/s)	Maximum velocity (cm/s)	Magnitude or MMI (max)
Algermissen et al. (1982)	90% probability of not being exceeded in 10 years	< 0.04	0.07-0.10	2-3	--
Algermissen et al. (1982)	90% probability of not being exceeded in 50 years	0.04	0.13-0.20	4-6	--
Algermissen et al. (1982)	90% probability of not being exceeded in 250 years	0.07	0.20-0.33	6-10	M = 6.1
Liu and DeCapua (1975)	100 years	> 0.02			> IV

Liu and DeCapua (1975) estimated maximum intensities and accelerations for the Rocky Mountain region based on 100-year return intervals. They concluded

that the site region lies in an area with an expected intensity (MMI) of less than IV and an expected peak acceleration of 0.02 g. The map of Algermissen et al. (1982) shows the maximum seismicity value according to source areas that approximate the seismotectonic provinces. The source area indicated in that study includes most of the Uinta-Elkhead seismotectonic province, which contains the site as well as the Piceance Basin and White River Uplift to the south and most of the Wyoming Basin to the north. Table 4.2 shows the maximum earthquake of seismotectonic provinces recommended by previous studies. The estimated maximum magnitude, based on historical records from the source area, is $M=6.1$ with an average of one earthquake of intensity $MMI=V$ every 2.19 years. For the Washakie and Sand Wash Basin structures, a localized source area within the larger region and immediately north of the site, the Algermissen et al. (1982) study shows a maximum event of $M=6.1$ but only an average of one $MMI=V$ earthquake each 78 years (0.0127 events per year).

4.2.4 Epicentral compilation

An epicentral compilation was obtained from the NGDC/NOAA (NGDC/NOAA, 1986) earthquake data file to derive seismic parameters for the Maybell site. Table 4.3 presents the earthquakes of magnitude 4.0 or greater that have been located instrumentally since 1963; Table 4.4 shows the data for earthquakes of intensity III or greater prior to 1963.

A total of 114 events were listed within a 125-mi (200-km) radius of the site. However, only 21 of these events were instrumental recordings of $M \geq 4.0$, and 26 historic events were $MMI=III$ or greater. The two closest epicenters, at distances of 4 mi (6 km) and 21 mi (34 km), were historic preinstrumental events dated 1891 and 1942 with MMI of VI and III, respectively. These correspond to approximate magnitudes of $M=4.2$ and $M=3.2$ g, using a relationship of $M=0.355 (MMI) + 2.115$ based on linear regression analysis of data for the region (NGDC/NOAA, 1986).

The closest instrumentally recorded event was a 1973 event at a distance of 25 mi (40 km) with a magnitude of $M_b=5.4$, or $M=5.7$ at a distance of 51 mi (82 km). The hypocenters of earthquakes within a 40-mi (65-km) site radius are very shallow and range between 1.2 to 4.3 mi (2 to 7 km) in depth.

The largest known earthquake in Colorado and in the Middle Rocky Mountains occurred on November 7, 1882. The earthquake had an intensity of VIII and an approximate magnitude of $M=6.5$ (McGuire et al., 1982). The location of this earthquake was placed at 108° longitude and 40.5° latitude within 6 mi (10 km) south of the Maybell site. A recent study by Kirkham and Rogers (1986) has placed the event as probably in north central Colorado, in the northern Front Range or possibly in the southern Laramie Range. This study has assigned the event an intensity of $MMI=VII$ and magnitude of $6.2 \pm 0.3 M$. This conclusion was based primarily on a smaller, more locally felt aftershock on November 8, 1882, that occurred in the Front Range area. The new location

Table 4.2 Summary of maximum earthquakes recommended by previous studies

Seismotectonic province (cf)	Stone and Webster, 1986 (cf)Ms	Rowles et al., 1985 (cf)M _L	Martin et al., 1985 and MacDonald, 1986 (P)Ms	Thenhaus et al., 1982 (P)M _L	Algermissen et al., 1982 (P)M _L	Kirkham and Rogers, 1981 (P)M _L	Distance from site (mi) (km)		Resulting PHA from maximum event (Campbell, 1981) (g)
<u>Remote Provinces</u>									
Colorado Plateau	--	--	--	--	--	5.5 to 6.5	16	25	0.16
Western Mountain	--	--	--	--	--	6.0 to 6.5	16	25	0.16
N. Rio Grande Rift	--	--	--	--	--	6.0 to 7.0	50	80	0.13
Wyoming Basin	5.5 to 6.5	--	--	6.0	--	--	31	50	0.04
Western Uinta (ISB)	--	6.75 (FE = 6.5)	6.0	7.0	7.3	--	93	150	<0.02
<u>Site Province</u>									
Uinta-Elkhead	--	--	--	6.0	6.1	5.5 to 6.5	--	--	--

Notes:

ISB = Intermountain Seismic Belt.
(P) = probabilistic study.
(cf) = capable fault nearby.
FE = floating earthquake.
PHA = peak horizontal acceleration.

Table 4.3 Earthquakes of $M \geq 4.0$ since 1963^a in Maybell site region^b

Date			Time			Location		Site distance mi (km)/area	Depth		Magnitude				Intensity (MMI)
Yr	Mo	Day	Hr	Min	Sec	Lat(N)	Long(W)		(mi)	(km)	M_b	M_s	Other	Local	
1983	09	24	16	57	45.7	40.789	108.837	43 (70) (Uinta Fault near Green River Valley)	3	5	--	--	--	4.1	III
1966	07	06	05	47	08.2	40.1	108.9	50 (81) (vicinity Rangely oil field)	3 ^c	5 ^c	4.1	--	--	--	--
1970	04	21	08	53	52.4	40.1	108.9	50 (81) (vicinity Rangely oil field)	2 ^c	4 ^c	4.3	--	--	3.9	V
1970	04	21	15	05	47.5	40.09	108.898	51 (82) (vicinity Rangely oil field)	2 ^c	4 ^c	4.6	--	--	3.7	--
1973	05	17	16	--	--	39.79	108.37	51 (82) (vicinity Rangely oil field)	0 ^c	0 ^c	5.4	--	--	5.7	--
1967	02	15	03	28	03.6	40.1	109.072	58 (94) (vicinity Rangely oil field)	3 ^c	5 ^c	4.5	--	--	--	V
1971	03	18	09	08	59.4	40.705	106.97	61 (98) (Rio Grande Rift north of Steamboat)	6	10	4.4	--	--	--	V
1966	11	01	07	40	28.0	40.2	106.9	66 (107) (Rio Grande Rift south of Steamboat)	21	33	4.0	--	--	--	--
1977	03	03	17	50	28.0	41.242	107.147	71 (115) (Sierra Madre, Wyoming)	3	5	4.2	--	--	3.5	--
1969	09	10	21	00	00	39.406	107.948	76 (122) (Colorado River Valley)	0	0	5.3	--	--	--	--
1971	01	07	20	39	52.1	39.486	107.307	81 (131) (Glenwood, Colorado)	21	33	4.3	--	--	3.8	--
1975	01	30	14	48	40.3	39.27	108.646	89 (144) (North of Grand Junction, Colorado)	3	5	4.4	--	--	3.7	--
1977	09	24	11	16	48.4	39.309	107.311	93 (149) (Glenwood, Colorado)	3	5	4.0	--	--	3.0	--
1964	09	10	06	19	50.7	41.9	107.8	98 (158) (Rawlins, Wyoming)	21	33	4.1	--	--	--	--
1967	01	12	03	52	06.2	38.979	107.506	110 (177) (Crested Butte area)	21	33	4.4	--	--	--	--

Table 4.3 Earthquakes of $M \geq 4.0$ since 1963^a in Maybell site region^b (Concluded)

Date			Time			Location		Site distance mi (km)/area	Depth		Magnitude				Intensity
Yr	Mo	Day	Hr	Min	Sec	Lat(N)	Long(W)		(mi)	(km)	M _b	M _s	Other	Local	(MMI)
1971	11	12	09	30	44.6	38.914	108.678	114 (183) (Grand Junction, Colorado)	3	5	--	--	--	4.0	--
1973	08	06	21	47	52	41.9	106.8	118 (190) (East of Rawlins, Wyoming)	--	--	4.1	--	--	--	V
1965	05	30	17	31	04.1	39.4	106.3	122 (196) (Leadville, Colorado)	21	33	4.3	--	--	--	--
1963	09	02	17	40	15.4	39.6	110.1	122 (197) (Box Cliffs, Utah) (mining activities)	21°	33°	4.1	--	--	--	--
1966	04	03	16	21	33.5	39.3	106.4	122 (197) (Leadville, Colorado)	--	--	4.6	--	--	--	--
1977	09	30	10	19	21.0	40.518	110.436	122 (197) (Uinta Basin)	3	5	--	--	--	5.1	VI
1964	08	04	11	13	25.2	39.7	106.0	124 (200) (Climax, Colorado)	21	33	4.0	--	--	--	--

^aPrior to 1963, records are only for pre-instrument events.

^bRef. NGDC/NOAA, 1986.

^cAttributed to mining activities or oil field activities performed by Smith and Sbar (1974) and are not in seismic analysis.

Table 4.4 Historic earthquakes of MMI = III or greater in Maybell site region^a

Date			Time			Location		Site distance		Intensity
Yr	Mo	Day	Hr	Min	Sec	Lat(N)	Long(W)	mi (km)		(MMI)
1891	12	--	--	--	--	40.5	108.0	5 (8) Juniper Mountain		VI
1942	08	--	--	--	--	40.5	108.5	21 (34) Douglas Mountain		III
1895	03	22	--	--	--	40.5	107.1	53 (85) Steamboat Springs area		V
1955	02	10	17	30	--	40.4	106.9	63 (102) Steamboat Springs area		V
1956	02	12	03	--	--	40.3	109.3	65 (104) Uinta Basin		IV
1956	02	12	04	--	--	40.3	109.3	65 (104) Uinta Basin		IV
1906	12	21	16	10	--	39.6	107.6	68 (109) Glenwood Springs area		III
1946	04	03	02	05	--	39.8	107.1	71 (115) Glenwood Springs area		IV
1946	01	31	22	45	--	39.6	107.3	75 (121) Glenwood Springs area		IV
1920	12	29	02	50	--	39.5	107.5	76 (122) Glenwood Springs area		V
1920	12	30	09	50	--	39.5	107.5	76 (122) Glenwood Springs area		V
1920	12	30	17	50	--	39.5	107.5	76 (122) Glenwood Springs area		V
1889	01	15	--	--	--	39.5	107.3	81 (130) Glenwood Springs area		V
1910	07	26	01	30	--	41.5	109.3	93 (150) Rock Springs, Wyoming		V
1946	09	14	12	45	--	41.6	109.2	94 (152) Rock Springs, Wyoming		IV
1915	02	28	07	51	--	39.1	108.6	100 (161) Grand Junction, Colorado		III
1917	03	10	14	34	--	41.8	107.2	101 (163) Rawlins, Wyoming		III
1940	04	05	17	--	--	39.3	106.8	108 (173) Aspen, Colorado		III
1941	02	21	21	22	--	39.3	106.8	108 (173) Aspen, Colorado		IV

Table 4.4 Historic earthquakes of MMI = III or greater in Maybell site region* (Concluded)

Date			Time			Location		Site distance		Intensity
Yr	Mo	Day	Hr	Min	Sec	Lat(N)	Long(W)	mi (km)		(MMI)
1941	02	28	06	19	--	39.3	106.8	108 (173)	Aspen, Colorado	III
1954	01	23	04	--	--	41.1	106.2	108 (173)	Rocky Mountains	IV
1948	10	03	04	30	--	40.9	106.1	108 (174)	Rocky Mountains	IV
1960	10	17	16	--	--	39.2	106.9	110 (177)	Aspen, Colorado	V
1880	09	17	07	--	--	39.3	106.7	111 (179)	Aspen, Colorado	VI
1944	10	05	14	05	--	39.2	106.8	113 (182)	Aspen, Colorado	IV
1958	08	07	00	46	43	41.1	106.0	117 (189)	Rocky Mountains	IV

Note: All historic records reflect events which were primarily located near populated areas.

*Ref. NGDC/NOAA, 1986.

would place the event at a distance of about 140 mi (220 km) due east of the site in the Eastern Mountain seismotectonic province.

Another historical earthquake, in December 1891, has been located 5 mi (8 km) south of the Maybell site by NGDC/NOAA (NGDC/NOAA, 1986) at the same location as the 1882 event. It had an intensity of $\text{MMI} = \text{VI}$, which is approximately equivalent to a magnitude of $M = 4.2$ using the relationship described earlier in this section, or a magnitude of $M = 5.0$ using the relationship prescribed by Gutenberg and Richter (1956). Carl Von Hake (1987), reported that the epicenter was given a general accuracy of 1 to 2 degrees latitude and longitude (roughly 45 to 90 mi [75 to 150 km]). The event has not received the attention of the 1882 event and will not likely be reviewed for location.

4.2.5 Determination of floating earthquake magnitude

The ME that is considered the threshold for ground breakage is about $M = 6.5$. This has been established in the *Technical Approach Document* (DOE, 1989). It is based on the fault length/magnitude relationship of Bonilla et al. (1984) plate interiors.

The review of faults within the 40-mi (65-km) radius of the site region has indicated that fault rupture has not occurred within Quaternary time (the past 2,000,000 years), or at least in the last 500,000 years for recurring faults and in the last 35,000 years since initial faulting (see Section 4.2.8, Fault age assessment for Maybell site area). It follows that the FE magnitude cannot be within the range where ground breakage is likely. Therefore, the recommended maximum magnitude of the FE in the Uinta-Elkhead province is $M = 6.5$.

In accordance with seismic design procedures that have been adopted by the NRC for use where spectral response has not been developed, the $\text{FE} = 6.5$ event is assumed to occur at a radial distance of 9 mi (15 km) from the site. Using the constrained acceleration/attenuation relationship of Campbell (1981) results in a peak horizontal acceleration (PHA) (mean plus one standard deviation, or 84th percentile) of 0.27 g.

In the absence of known capable faults in the site area or a calculated ME from a remote seismotectonic province, or that are capable of producing higher accelerations at the site, the $\text{FE} = 6.5$ event will be designated as the design earthquake.

4.2.6 Effects of ME of other seismotectonic provinces in the region

Other seismotectonic provinces or subprovinces considered to be significant to the seismic hazard evaluation of the Maybell site include the following:

- Colorado Plateau.
- Western Mountain.
- Wyoming Basin.

Table 4.2 presents a summary of the recommended ME for each of these remote provinces from previous studies showing distances from the site with the resultant estimated PHA at the Maybell site. Two provinces outside the site region are included because of their elevated seismicity. These are the Rio Grande Rift zone and the Intermountain Seismic Belt. Both are north-south trending systems with known active faults.

4.2.7 Anomalous response to regional seismicity

Local areas near the site may respond to regional earthquakes with anomalously high intensity. For example, the 1977 earthquake near Duchesne, Utah, which had a maximum intensity of $MMI = VI$ at the epicenter, resulted in anomalously high intensities at Maybell, Colorado, of $MMI = V$ and at Meeker, Colorado, of $MMI = IV$, which are distances of 130 mi and 90 mi (210 km and 150 km) from the epicenter, respectively. Other locations within 62 mi (100 km) of the epicenter along the Utah-Colorado border were not affected by this earthquake ($MMI = II$ or less) (Coffman and Stover, 1979).

Kirkham (1987b) stated that such anomalous intensities are most likely due to the site-specific response of saturated alluvium in those areas and that they probably do not represent bedrock response at the site. Both the towns of Maybell and Meeker are situated on saturated floodplain deposits. For this reason, the response of the Maybell site to regional events will differ significantly from that of the town of Maybell.

4.2.8 Fault age assessment for Maybell site area

A separate study was made using geomorphic evidence for determining the age of last fault movement in the Maybell site area and to estimate the minimum time since displacement occurred. The findings of this assessment indicated that the soils are probably of Holocene age, and therefore too young to be used in the determination of a time period of 35,000 years for a single rupture, or 500,000 years for a recurring fault interval. However, based on the appearance of stability of the regional and local drainage, the evidence suggests that the last movements are no younger than Late Pleistocene and the faults are most likely noncapable.

An in-depth geomorphic study of stability of the areal drainage system and erosion rates would be required to refine this estimate but would not result in a significant reassessment of fault ages. For this reason, additional studies are not deemed necessary for the Maybell site.

4.2.9 Assessment of fault age by previous workers

Kirkham reported that Witkind, in an unpublished work, classified all faults in the Maybell area as pre-Quaternary with a low susceptibility to earthquakes (Kirkham, 1987b). Kirkham and Rogers (1978) updated this study and said the displacements were probably pre-Quaternary but listed a few faults that

appeared fresh and that should be studied further. These were faults south of Cross Mountain and the fault southwest of Craig. Further studies indicate that these faults are also noncapable. Hansen (1986b) listed three faults that exhibit Quaternary displacement but none are within the site region. In a personal communication, Hansen advised that very few faults could be closely dated but the finding of other Quaternary faults was a possibility (Hansen, 1987). Madol had not observed any Quaternary faults in his ongoing study in the Yampa River Basin (Madole, unpublished).

In personal communication, Kirkham reported that the scarps in the Maybell and Craig area were not examined on the ground but from aerial photographs (Kirkham, 1987a).

A previous worker, Spitzer (Spitzer, 1987) had examined the specific faults reported by Kirkham and Rogers (1978) and had not found the fresh scarps or any faults that appeared to be Quaternary (Spitzer, 1987). Spitzer (1987), however, had targeted the Lay Peak fault for extended investigation in a preliminary report on the Moffat County Dam sites at Juniper Mountain and Cross Mountain. The additional work performed for this study indicates that the Lay Peak fault is noncapable.

The analysis of all known fault groups within the 40-mi (65-km) site radius, presented in Section 2.4 (Seismotectonic Setting), resulted in the conclusion that the faults are noncapable.

4.2.10 Determination of design earthquake

The estimated on-site earthquake accelerations from remote source earthquakes are uniformly lower than the value of 0.27 g calculated for the FE at a radial distance of 9 mi (15 km). Therefore, site design parameters are not influenced by remote source earthquakes.

Because of the absence of the determination of a capable fault larger or closer than that defined for the FE, the FE is considered to establish the design parameter. The design earthquake for the Maybell site and the resultant parameters are as follows:

Design earthquake = $M=6.5$.
PHA = 0.27 g bedrock acceleration.
Duration of design event = 10 seconds.

5.0 GEOLOGIC SUITABILITY

5.1 GEOMORPHIC SUITABILITY

Fluvial processes of the most concern to long-term stability of the pile are gully formation and migration, stream channel erosion, sheetwash erosion, and the effects of base level changes. Present entrenchment of most of the drainage lines, possibly to near former maximum depths, suggests that the central and lower basins are now in a period of erosion. This erosion is being expressed primarily by headward extension, branching, and deepening of gullies and by slumping along gully sides. In comparison, erosional lowering of interfluvies is likely to be minor during the next few hundred years.

Long-term average erosion rates, such as the rate of 0.36 ft/1000 years (0.11 m/1000 years) for the Yampa River (Madole, unpublished), cannot be applied to small basins like that of Johnson Wash, although they do reflect the regional severity of erosion in a broad way. As noted above, evidence exists indicating changes in Quaternary erosion rates in both Lay Creek and the Yampa River. Work on the Yampa River upstream from Craig suggests that late Pleistocene incision has been very slow. While it is difficult to relate this finding to Holocene erosion cycles along Johnson Wash, it does suggest that base-level controls may favor relatively slow long-term erosion along Johnson Wash.

The existing tailings pile intersects the head of westward tributaries to Johnson Wash. Extensive ground disturbance in the central basin by mining resulted in decreasing vegetation and increased compaction of the soil, causing increased runoff that may have initiated the present phase of gullying. Before gullying, the central basin of Johnson Wash may have resembled Sugarloaf Basin to the east.

Tributary gullies T5 through T9 of Johnson Wash present hazardous geologic conditions for the tailings pile. As discussed in Section 4.1 (Geomorphologic Stability), Tributary T5 (Figure 4.1) contains recent, active knickpoints that are eroding headward toward the tailings pile. Rates of headward erosion of the knickpoints in the segments of Tributary T5 may be as high as 3 to 4 ft (1 to 1.2 m) per year. The heads of these knickpoints, adjacent to the tailings pile, are deeply rilled and eroded.

Tributary T6 (Figure 4.1) currently intersects the tailings pile and contains an actively eroding gully cut into the tailings and the underlying Browns Park Formation bedrock. Headward erosion appears to be occurring at a rate of at least 0.5 ft (0.2 m) per year. Instability of this tributary gully is indicated by a small, actively expanding knickpoint near the junction with the main channel of Johnson Wash.

Tributary gullies T7 and T8 (Figure 4.1) do not currently intersect the tailings pile but are actively eroding toward it. As discussed in Section 4.1 (Geomorphologic

Stability), these gullies contain several knickpoints that are cut into sandy soils and the underlying Browns Park Formation. Active erosion of the gully heads and sides is occurring. Tributary T7 is extending toward the southeast side of the tailings pile. Tributary T8 is incised deeply into erodible surficial deposits and contains a 4-ft (1.2-m)-deep knickpoint actively extending toward the tailings pile. These gullies are expected to reach the tailings pile within its proposed design life.

Tributary T9 does not currently intersect the tailings pile. Its head extends toward the low divide south of the pile. Development of side gullies to this tributary, which may erode toward the pile area, is probably within the proposed design life.

In the outlet valley, Johnson Wash appears to be near its past maximum depth, but it is unlikely that the soft Browns Park Formation would deter further valley deepening. On the 7.5-minute topographic map, contours across the channel are unevenly spaced, suggesting the existence of knickpoints separating channel reaches of differing gradient. On the other hand, some obvious knickpoints may not be significant. For example, the 3-ft (1-m) headcut near the former windmill appears to represent a local disruption in gradient associated with the gravel outcrop; this headcut does not seem likely to erode rapidly upstream. The channel conditions in the lower part of Johnson Wash are discussed in Section 4.1, Geomorphic Stability.

If a migration rate of 1.5 ft (0.5 m) per year is assumed for the Johnson Wash knickpoint (Figure 4.1), as previously discussed in Section 4.1, Geomorphic Stability, headward erosion would not reach the tailings pile for about 4660 years under the present climatic and hydrologic conditions. A change in conditions or a lowering of the local base level could result in more rapid knickpoint migration. Under any conditions, the erosion hazard to the tailings pile would be much greater from gullies adjacent to the pile than from erosion in the lower part of Johnson Wash.

Because the central basin is already gullied, the most important issues concern future gully growth and methods for restricting growth near the proposed embankment. The latter is primarily an engineering question. Nelson et al. (1983) suggest that on-site gullying can be prevented by regrading slopes, providing stable base levels for channels, covering the ground with coarser material, and improving vegetation.

Any modifications to the outlet valley of Johnson Wash would significantly affect erosion processes upstream near the tailings pile. The removal of large volumes of alluvium from the valley floor should be carefully considered with respect to the effects on stream processes and the indirect effects on the stability of the tailings site. Unless a stable base level is provided at the upstream end of the reach from which the alluvium is removed, preferably at some point in the narrow outlet valley, significant headcut migration and gully growth would result in the central basin. Any channel erosion downstream from

the base-level structure could tend to undercut it. At this time, no manmade changes are anticipated to the lower reach of Johnson Wash.

The following proposed design features will be incorporated to ensure geomorphic stability of the cell:

- A perimeter ditch will be constructed between the cell and the adjacent overburden pile on the west and southwest sides of the cell. The ditch will divert runoff through rechanneled Tributary T9 at a point 1000 ft (300 m) from the cell toe. The ditch shall be armored with erosion protection rock suitable for design flow where it lies within 200 ft (60 m) of the cell.
- Four existing tributaries at the southwest side of the cell, designated on Figure 4.1 of this attachment as T5 through T8, will be armored for design flow from a point at the 1 percent apron slope for a distance of at least 100 ft (30 m) in the bottom and 200 ft (60 m) on the side slopes. The armored section of the tributaries will be set back at least 50 ft (15 m) from the Johnson Wash to avoid damage from the greater design flow in that channel.
- The apron on the east side of the cell, in lieu of rock erosion protection, will be graded for sheet flow conditions on a slope not to exceed 5 percent to a minimum distance of 500 ft (150 m) from the toe of the cell.
- The runoff upland of the graded east side apron will be diverted from the northeast side of the cell through a reconstructed upper reach of Tributary T4 and angling southeasterly away from the east apron to meet the Johnson Wash channel. Erosion protection is not necessary since there is no potential for headcutting toward the cell.

5.2 OTHER GEOLOGIC PROCESSES

Grass and shrub vegetation currently control soil erosion. Moderate to severe surface erosion occurs on unvegetated slopes. Gully development appears more rapid in areas of sparse vegetation.

Wind erosion does not appear to be a process affecting site stability. No eolian dunes or erosional features are present. The soil surface is subject to moderate wind erosion only in unvegetated areas. A slow influx of eolian dust is occurring; however, this will not create adverse site effects.

No subsidence has been observed at the site. No geologic units subject to solutioning and collapse are present beneath the site. No underground mine workings are known to be present.

Several volcanic centers are situated in the region, localized along the margin of the Rio Grande Rift. Two areas are found within the 40-m (65-km) site radius: the Elkhead Mountains northwest of Craig, Colorado, and the Flat Top

Mountains in the White River Uplift, southeast of Craig. The ages of the eruptions and of the associated intrusive rocks range from Oligocene through Pliocene (Carey, 1955). The nearest vent to the site is Cedar Mountain, north of Craig, which is 20 mi (32 km) from the site.

These eruptions are the most recent known within this seismotectonic province. In the Rio Grande Rift Province, however, evidence exists of a Quaternary episode about 75 mi (125 km) southeast of the site (Kirkham and Rogers, 1981). The nearest heat flow anomalies to the Maybell site reported by Zoback and Zoback (1980) are near that episode.

The Juniper Hot Springs, about 6 mi (10 km) south of the tailings site, are the only thermal springs in the 40-mi (65-km) site radius. The springs are on a fault near Juniper Mountain, are only 91.4°F (33°C), and are isolated from any other known occurrence of thermal springs or volcanic activity (Pearl, 1980).

The potential for volcanic activity is considered very low under the present tectonic stress regime. No volcanic activity has occurred since the end of the Tertiary Period. Therefore, no reason exists to expect the occurrence of volcanic activity or any resulting adverse impact on site stability during the proposed 1000-year design life.

Mineral resources are discussed in Section 2.5, Mineral Deposits and Other Resources. Based on presently available information, future economic development of natural resources that could adversely impact the stability of the reclaimed tailings disposal site is not apparent.

5.3 SEISMIC SUITABILITY

Liquefaction is considered to be a potential hazard at the site due to the silty and sandy nature of the tailings in their present condition and the likelihood of saturation in the lower part of the pile. The design earthquake has sufficient energy to cause liquefaction given the proper soil and ground water conditions. Liquefaction potential is fully assessed in the geotechnical portion of this document.

Induced seismicity can theoretically occur as a result of various causes, including mining operations, oil and gas withdrawal, and reservoir loading.

Low-intensity seismic vibrations may be experienced periodically in the site area as a result of mining and oil and gas withdrawal in the surrounding region. However, site design to mitigate against the impact of the design earthquake should effectively mitigate against the low-intensity vibration as well.

The occurrence of numerous macroearthquakes ($M > 3.5$) has, in the past, been attributed to the injection of fluids at elevated pressures into the subsurface (Healey and Hoover, 1968); subsurface mining in high stress regions

(Smith and Sbar, 1974); and the reservoir impoundment of large volumes of water (Meade, 1982).

Withdrawal of hydrocarbons and fluid injection experiments conducted by the USGS triggered earthquakes near Rangely, Colorado, during the late 1960s and 1970s (Kirkham and Rogers, 1981). (See epicentral location near Rangely, Colorado, shown in Plate 1.) The largest of the induced earthquakes occurred approximately 70 mi (110 km) southwest of the Maybell site, and was recorded as a magnitude 4.6 event. Earthquakes could be started and stopped by the control of injected fluids (Kirkham and Rogers, 1981). Development of hydrocarbon resources much nearer the tailings pile in the Danforth Hills area has not resulted in induced seismicity. No macroearthquakes are shown on the 1986 NGDC/NOAA (NGDC/NOAA, 1986) earthquake data for northeastern Routt County, Colorado, a region of large-scale, active coal mining about 28 mi (45 km) southeast of the tailings site.

Martin et al. (1985) have related reservoir-induced seismicity to the following characteristics: (1) water depth in excess of 300 ft (92 m); (2) water volume in excess of 1,000,000 acre feet ($1.2 \times 10^9 \text{ m}^3$); and (3) active faults in the reservoir.

No reservoirs presently exist within the site region. Two reservoirs are proposed for the region, both on the Yampa River: one at Cedar Mountain and one at Juniper Mountain (Clifton, 1986). The highest of the several dam designs now being considered is 160 ft (50 m). The reservoir depths and volumes of the proposed dams do not meet the criteria for induced seismicity and no known seismic activity has taken place at either dam site. A preliminary seismicity study was conducted for both dam sites (Spitzer, 1987). The faults reported by Kirkham and Rogers (1978) were examined, and no evidence of recent movement was detected. However, tentative recommendations for final design studies were made.

Seismic design parameters for these dams were based on regional seismicity rather than on a specific design fault and an acceleration of about 0.10 g was recommended. The study concluded that faults at the two dam sites are not capable and would not cause reservoir-induced earthquakes (Spitzer, 1987).

Coal mining that may include significant blasting operations is proposed for an area south of Lay, Colorado, and could extend to within 10 mi (16 km) of the site (Clifton, 1986). The operation is contingent on economic conditions and is expected to be similar to the several large open-pit mining operations south of Craig, Colorado. No seismic events have been attributed to these sites.

5.4 EARTHQUAKE-INDUCED LANDSLIDE OR SUBSIDENCE HAZARD

The higher elevations in the site area are typically exposed bedrock consisting of slightly to moderately cemented sandstone of the Browns Park Formation. The slopes in the region are less than 15 percent and are well drained. No spring

runoff occurs within the site area. All natural slopes within the site valley are considered to be stable in the event of a design earthquake.

No oil or gas wells or underground mines are within the site area that might result in subsidence at the site as a result of mining or excessive pumping stress.

The open pit mine walls of the adjacent Rob Pit and Marge Pit, some on the order of 100 to 180 ft (30 to 55 m) deep and nearly vertical, could produce some minor sloughs in the event of a design earthquake but are not expected to impact the disposal site or affect geomorphic conditions beyond their present impact.

6.0 LIST OF CONTRIBUTORS

The following individuals contributed to the preparation of this remedial action plan.

Name	Contribution
R. Heydenburg	Document review
M. Hansen	Document coordination, document review
G. Lindsey	Site geologist
J. McBee	Site management
D. Thalley	Technical editing, document production and coordination
C. Slosberg, L. Keith	Text processing
B. Harvey, L. Wagner	Graphics

AIM

Association for Information and Image Management

1190 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

3 of 3

7.0 REFERENCES

- AEC (Atomic Energy Commission), U.S. Environmental Protection Agency, and Colorado Department of Health, 1974. "Report on Conditions of Uranium Mill Sites and Tailings Near Maybell, Colorado," USAEC, Grand Junction, Colorado.
- Algermissen et al. (S. T. Algermissen, D. M. Perkins, P. C. Thenhaus, S. L. Hanson, and B. L. Bender), 1982. *Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States*, U.S. Geological Survey, Open File Report 82-1033.
- Andrews, E. D., 1978. *Present and Potential Sediment Yields in the Yampa River Basin, Colorado and Wyoming*, U.S. Geological Survey, Water Resources Investigations 78-105, Bureau of Land Management, 1977, pp. D-46.
- Andrews et al. (J. T. Andrews, P. E. Carrara, F. B. King, and R. Struckenrath), 1975. "Holocene Environmental Changes in the Alpine Zone, Northern San Juan Mountains, Colorado: Evidence from Bog Stratigraphy and Palynology," in *Quaternary Research*, Vol. 5, pp. 173-197.
- Baars, D. L. and G. M. Stevenson, 1981. "Tectonic Evolution of Western Colorado and Eastern Utah," in *Western Slope Colorado*, eds. R. C. Epis and J. F. Callendar, New Mexico Geological Society Guidebook, 32nd Field Conference, pp. 105-112.
- Baker, R. G., 1983. "Holocene Vegetational History of the Western United States," in *Late-Quaternary Environments of the United States, Vol. 2; The Holocene*, ed. H. E. Wright, Jr., University of Minnesota Press, Minneapolis, Minnesota, pp. 109-128.
- Bergin, M. J., 1959. "Preliminary Geologic Map of the Maybell-Lay Area, Moffat County, Colorado," U.S. Geological Survey, Open File Report, Two Plates (no file number assigned).
- BLM (Bureau of Land Management), 1977. Aerial photographs 9-18-77, 24 CN, CO771, Series 4-13-13 through 4-13-23.
- Bonilla et al. (M. G. Bonilla, R. K. Mark, and J. J. Lienkamper), 1984. Statistical Relations Among Earthquake Magnitude, Surface Rupture Length and Surface Fault Displacement," in *Bulletin of the Seismological Society of America*, Vol. 74, No. 6, pp. 2379-2411.
- Boreck et al. (L. Boreck, C. Tremain, L. Sitowitz and T. D. Lovenson), 1981. "The Coal Bed Methane Potential of the Sand Wash Basin, Green River Coal Region, Colorado," Open File Report 81-6, Colorado Geological Survey Department of Natural Resources, Denver, Colorado.

- Bradley, R. S., 1976. *Precipitation History of the Rocky Mountain States: Boulder, Colorado*, Westview Press.
- Bright, R. C., 1966. "Pollen and Seed Stratigraphy of Swan Lake, Southeastern Idaho: Its Relation to Vegetational History and to Lake Bonneville History, *Tebiwa*, Vol. 9, pp. 1-47.
- Bucknam, R. C., and R. E. Anderson, 1979. "Estimation of Fault Scarp Ages from Scarp Height-Slope Angle Relationships," in *Geology*, Vol. 7, No. 1, pp. 11-14.
- Campbell, K. W., 1981. "Near-Source Attenuation of Peak Horizontal Acceleration," in *Bulletin of the Seismological Society of America*, Vol. 71, pp. 2039-2070.
- Carey, Byrl D., Jr., 1955. *The Elkhead Mountain Volcanic Field in Northwestern Colorado*, California Company for Rocky Mountain Association of Geologists and Intermountain Association for Petroleum Geologists.
- Carrara, P. E., 1980. "Surficial Geologic Map of the Vernal 1° x 2° Quadrangle, Colorado and Utah," U.S. Geological Survey, Miscellaneous Investigation Series, Map I-1204.
- Carrara et al. (P. E. Carrara, W. N. Mode, M. Rubin, and S. W. Robinson), 1984. "Deglaciation and Post-Glacial Timberline in the San Juan Mountains, Colorado," in *Quaternary Research*, Vol. 21, No. 1, p. 42-55.
- Case, Jim, 1986. Geologic Hazard Section, Geological Survey of Wyoming, personal communication to G. Lindsey, Sergeant, Hauskins, and Beckwith, Albuquerque, New Mexico, regarding Quaternary Faults in Baggs, Wyoming area, improperly mapped, August 13, 1986.
- Chenoweth, W. L., 1986a. "Geology and Production History of the Uranium Deposits in the Maybell, Colorado, Area," in *New Interpretations of Northwest Colorado Geology*.
- Chenoweth, W. L., 1986b. Personal communication, R. Gerald Lindsey, Technical Assistance Contractor, regarding faults mapped near Maybell site, December 22, 1986.
- Clark, M. M., 1971. *Solar Position Diagrams - Solar Altitude, Azimuth, and Time of Different Latitudes*, U.S. Geological Survey, Professional Paper 750-D, pp. 145-148.
- Clifton, Don, 1986. Moffat County Commissioner personal communication with G. Lindsey, Sergeant, Hauskins, and Beckwith, Albuquerque, New Mexico, regarding proposed dam sites and coal mines in Moffat County, December 4, 1986.

- Cluff, L. S., and D. B. Slemmons, 1972. *Wasatch Fault Zone - Features Defined by Low-Sun-Angle Photography*, Utah Geology Association, Publication No. 1, pp. G1-G9.
- Coffman, J. L., and C. W. Stover, 1979. "United States Earthquakes, 1977," National Oceanic and Atmospheric Administration and U.S. Geological Survey.
- Coffman et al. (J. L. Coffman, C. A. Von Hake, and C. W. Stover), 1982. *Earthquake History of the United States*, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Publication 41-1.
- Dames & Moore, 1975. "Report of Environmental Studies for Proposed Uranium Heap Leaching Project near Maybell, Colorado," unpublished report prepared by George C. Toland, Dames and Moore, Job Number 0822-081-06, for Union Carbide.
- Davis et al. (O. K. Davis, T. C. Sheppard, and S. Robertson), 1986. "Contrasting Climatic Histories for the Snake River Plain, Idaho, Resulting from Multiple Thermal Maxima," in *Quaternary Research*, Vol. 26, No. 3, pp. 321-339.
- DOE (U.S. Department of Energy), 1989. "Technical Approach Document," UMTRA-DOE/AL 050425.0002, Revision II, December 1989, Uranium Mill Tailings Remedial Action Project, Albuquerque, New Mexico.
- Dyni, John R., 1968. "Elk Springs Quadrangle, Moffat County, Colorado," U.S. Geological Survey MAP GQ-702.
- FBDU (Ford, Bacon & Davis Utah Inc.), 1981. *Engineering Assessment of Inactive Uranium Mill Tailings, Maybell Site, Maybell, Colorado*, DOE/UMT-0116, FBDU 360-11, UC 70, September 1981, prepared by FBDU, Salt Lake City, Utah, Contract No. DE-AC04-76GJ01658, for the U.S. Department of Energy, Albuquerque Operations Office, Uranium Mill Tailings Remedial Action Project Office, Albuquerque, New Mexico.
- Fritts, H. C., 1971. "Dendroclimatology and Dendroecology," *Quaternary Research*, Vol. 1, No. 4, pp. 419-449.
- Glass, C. E., and D. B. Slemmons, 1978. *State-of-the-Art for Assessing Earthquake Hazards in the United States, Report 11: Imagery in Earthquake Analysis*, U.S. Army Engineer Waterways Experiment Station, Miscellaneous Paper S-73-1, Vicksburg, Mississippi.
- Grutt, E. W., and J. F. Whalen, 1955. "Uranium in Northern Colorado and Southern Wyoming," published by Rocky Mountain Association of Geologists in *Geology of Northwest Colorado*.

- Gutenberg, B., and C. F. Richter, 1956. "Earthquake Magnitude, Intensity, Energy, and Acceleration," *Bulletin of the Seismological Society of America*, Vol. 46, No. 1, pp. 105-145.
- Hancock, E. T., 1925. *Geology and Coal Resource of the Axial and Monument Butte Quadrangles, Moffat County, Colorado*, U.S. Geological Survey, Bulletin 757.
- Hansen, W. R., 1987. Personal communication with Gerald Lindsey, Technical Assistance Contractor, regarding fault study, February 20, 1987.
- Hansen, W. R., 1986a. *Neogene Tectonics and Geomorphology of the Eastern Uinta Mountains in Utah, Colorado and Wyoming*, U.S. Geological Survey, Professional Paper 1356.
- Hansen, W. R., 1986b. "History of Faulting in the Eastern Uinta Mountains, Colorado, and Utah," in *New Interpretation of Northwest Colorado Geology*, published by Rocky Mountain Association of Geologists, Denver, Colorado.
- Hansen, W. R., 1985. "Drainage Development of the Green River Basin in Southwestern Wyoming and Its Bearing on Fish Biogeography, Neotectonics, and Paleoclimates," in *The Mountain Geologist*, Vol. 22, No. 4, pp. 192-204.
- Hansen, W. R., 1984. "Post-Laramide Tectonic History of the Eastern Uinta Mountains, Utah, Colorado, and Wyoming," in *The Mountain Geologist*, Vol. 21, No. 1, January, 1984, pp. 5-29.
- Healey, J. H., and Hoover, D. B., 1968. "Microearthquakes near the Rocky Mountain Arsenal Well, Denver, Colorado," Geological Society of America Special Paper 115.
- Heyman et al. (O. G. Heyman, P. W. Duntoon, and M. A. White-Heymon), 1986. "Laramide Deformation of the Uncompahgre Plateau - Geometry and Mechanisms," in *New Interpretations of Northwest Colorado Geology*, published by Rocky Mountain Association of Geologists, Denver, Colorado.
- Hintz, L. F., compiler, 1979. "Geologic Map of Utah," Utah Geological and Mineral survey.
- Hunt, C. B., 1967. *Physiography of the United States*, Chapter 13, "Rocky Mountains and Wyoming Basin," published by W. H. Freeman and Company, San Francisco, California.
- Irwin, C. D., 1986. "Upper Cretaceous and Tertiary Cross Section Moffat County, Colorado," in *New Interpretations of Northwest Colorado Geology*, published by Rocky Mountain Association of Geologists, Denver, Colorado.

- Izett, G. A., and R. E. Wilcox, 1982. "Map Showing Localities and Inferred Distributions of the Huckleberry Ridge, Mesa Falls, and Lava Creek Ash Beds in the Western United States and Southern Canada," U.S. Geological Survey, Miscellaneous Investigations Map I-1325, Scale 1:4,000,000.
- Izett et al. (G. A. Izett, J. G. Honey, and M. E. Brownfield), 1985. "Geologic Map of the Citadel Plateau Quadrangle, Moffat County, Colorado," U.S. Geological Survey, Map 1-1532.
- Keller et al. (G. R. Keller, L. W. Braile, and P. Morgan), 1979. "Crustal Structure, Geophysical Models, and Contemporary Tectonism of the Colorado Plateau," in *Tectonophysics*, Vol. 61, 1979, pp. 131-147, Elsevier-Scientific Publishing Company, Amsterdam, The Netherlands.
- Kirkham, Robert, 1987a. Personal communication with Mary Gillam, Technical Assistance Contractor, regarding evidence for suspected Quaternary faults, May 3, 1987.
- Kirkham, Robert, 1987b. Personal communication with Gerald Lindsey, Technical Assistance Contractor, regarding 1891 earthquake, July 6, 1987.
- Kirkham, R. M., and W. P. Rogers, 1986. "An Interpretation of the November 7, 1882 Colorado Earthquake," Colorado Geological Survey, Denver, Colorado, Open File Report 86-8.
- Kirkham, R. M., and W. P. Rogers, 1981. "Earthquake Potential in Colorado," Bulletin 43, Colorado Geological Survey, Department of Natural Resources, Denver, Colorado.
- Kirkham, R. M., and W. P. Rogers, 1978. *Earthquake Potential in Colorado—A Preliminary Evaluation*, Colorado Geological Survey, Open File Report 78-3.
- Knox, J. C., 1983. "Responses of Rivers to Holocene Climates," in H. E. Wright, Jr., *Late Quaternary Environments of the United States, Vol. 2, The Holocene*, University of Minnesota Press, Minneapolis, Minnesota, pp. 26-41.
- Krinitzsky, E. L., and F. K. Chang, 1977. *State-of-the-Art for Assessing Earthquake Hazards in the United States, Report 7: Specifying Peak Motions for Design Earthquakes*, U.S. Army Engineers Waterways Experiment Station, Miscellaneous Paper S-73-1, Vicksburg, Mississippi.
- Larson et al. (E. E. Larson, M. Ozima, and W. C. Bradley), 1975. "Late Cenozoic Basaltic Volcanism in Northwestern Colorado and Its Implications Concerning Tectonism and the Origin of the Colorado River System," in *Cenozoic History of the Southern Rocky Mountains*, ed. B. F. Curtis, Geological Society of America, Memoir 144, pp. 155-178.

- Liu, S. C., and N. J. DeCapua, 1975. "Microzonation of Rocky Mountain States," *Proceedings of the U.S. National Conference on Earthquake Engineering, Ann Arbor, Michigan*, Earthquake Engineering Research Institute, pp. 128-135.
- Luft, S. J., 1985. "Pitfall Tuff in the Browns Park Formation, North Colorado and Northeastern Utah," in *The Mountain Geologist*, Vol. 22, No. 3, pp. 110-127.
- MacDonald, R. B., 1986. "Seismic Considerations for Modifications Decision Analysis Steinaker Dam, Utah," U.S. Geological Survey Memorandum, unpublished, Denver Federal Center, August 26, 1986, Denver, Colorado.
- Madole, R. F., 1982. "Surficial Geologic Map of the Craig 1/2° x 1° Quadrangle, Moffat and Routt Counties, Colorado," U.S. Geological Survey Miscellaneous Investigations Series, Map I-1346.
- Madole, R. F., unpublished. "Yampa River Basin," manuscript September 8, 1986, to appear in *Quaternary Non-Glacial Geology of the Conterminous United States*, Geological Society of America, Decade of North American Geology Series.
- Madsen, D. B., and D. R. Curry, 1979. "Late Quaternary Glacial and Vegetation Changes, Little Cottonwood Canyon Area, Wasatch Mountains, Utah," in *Quaternary Research*, Vol 12, pp. 254-270.
- Maher, L. J., Jr., 1972. "Absolute Pollen Diagram of Redrock Lake, Boulder County, Colorado," in *Quaternary Research*, Vol. 2, pp. 531-553.
- Maher, L. J., Jr., 1961. "Pollen Analysis and Post-Glacial Vegetation History in the Animas Valley Region, Southern San Juan Mountains, Colorado," Ph.D. Dissertation, University of Minnesota, Minneapolis, Minnesota.
- Markgraf, V., and L. Scott, 1981. "Lower Timberline in Central Colorado During the Past 15,000 Years," in *Geology*, Vol. 9, pp. 231-234.
- Martin et al. (R. A. Martin, Jr., A. R. Nelson, R. R. Weisser, and J. Sullivan), 1985. "Seismotectonic Study for Taskeech Dam and Reservoir Site and Upper Stillwater Dam and Reservoir Site, Central Utah Project, Utah," Seismotectonic Report No. 85-2, published by U.S. Bureau of Reclamation, Seismotectonic Section, Denver, Colorado.
- McGuire et al. (Robin K. McGuire, A. Krusi, and S. D. Oahr), 1982. "The Colorado Earthquake of November 7, 1882: Size, Epicentral Location, Intensities, and Possible Causative Faults," in *The Mountain Geologist*, Vol. 19, No. 1, January, 1982, pp. 11-23.
- McKay, E. J., and M. J. Bergin, 1974. "Geologic Map of the Maybell Quadrangle, Moffat County, Colorado," U.S. Geological Survey Map GQ-1145.

- Meade, 1982. *State-of-the-Art for Assessing Earthquake Hazard in the United States: Report 19, The Evidence for Reservoir-Induced Macro-Earthquakes*, U.S. Army Engineer Waterways Experiment Station, Miscellaneous Paper S-74-1, Vicksburg, Mississippi.
- NGDC/NOAA (National Geophysical Data Center/National Oceanic and Atmospheric Administration), 1986. "Seismicity Map and Earthquake Data File for 320-km Radius of Maybell site, Colorado," prepared by NGDC/NOAA, Boulder, Colorado.
- Nakata et al. (J. K. Nakata, C. M. Wentworth and M. N. Machette), 1982. "A Quaternary Fault Map of the Basin and Range and Rio Grande Rift Provinces, Western U.S.," U.S. Geological Survey Open File Report 82-579.
- Nelson et al. (J. D. Nelson, R. L. Volpe, R. E. Wardwell, S. A. Schumm, and W. P. Staub), 1983. *Design Considerations for Long-term Stabilization of Uranium Mill Tailings Impoundments*, U.S. Nuclear Regulatory Commission, NUREG/CR-339, ORNL-5979, Washington, D.C.
- Ochs, A. M., and R. D. Cole, 1981. "Comparative Petrology of Tertiary Sandstones of Southern Piceance Creek Basin, Colorado," in *Western Slope Colorado*, eds. R. C. Epis and J. F. Callender, New Mexico Geological Society, 32nd Field Conference Guidebook, pp. 219-228.
- Osmond, John C., 1986. "Petroleum Geology of the Uinta Mountains-White River Uplift, Colorado and Utah," in *New Interpretations of Northwest Colorado Geology*, published by Rocky Mountain Association of Geologists, Denver, Colorado, pp. 213-222.
- Pearl, R. C., 1980. "Geothermal Resources of Colorado, 1980," Map Series 14, Colorado Geological Society.
- Peterson, K. L., and P. J. Mehringer, Jr., 1976. "Post-Glacial Timberline Fluctuations, La Plata Mountains, Southwestern Colorado," in *Arctic and Alpine Research*, Vol. 8, No. 3, pp. 275-288.
- Robinson, Charles S., and Associates, 1975. "Mineral Resource Maps, Moffat County, Colorado, Coal, Uranium, Geothermal Resources, and Metallic Minerals," U.S. Geological Survey Open File Report, 75-3.
- Roehler, H. W., 1987. Personal communication with Gerald Lindsey, Technical Assistance Contractor, regarding Wyoming Boundary Faults, January 30, 1987.
- Roehler, H. W., 1985. "Geologic Map of the Kinney Rim 30 x 60 Minute Quadrangle Wyoming and Colorado," U.S. Geological Survey, Map 1-1615.
- Rowles et al. (Peter D. Rowles, W. R. Hansen, Ogden Tweto, P. E. Carrara), 1985. "Geologic Map of the Vernal 1° x 2° Quadrangle, Colorado," U.S. Geological Survey, Map 1-1526.

- Rowles et al. (P. D. Rowles, J. R. Dyni, W. R. Hansen, and G. N. Pippingos), 1979. "Indian Water Canyon Quadrangle," U.S. Geological Survey, Map GQ-1516.
- Schumm, S. A., and R. J. Chorley, 1983. *Geomorphic Controls on the Management of Nuclear Waste*, U.S. Nuclear Regulatory Commission, NUREG/CR-3276RW, Washington, D.C.
- Slemmons, D. B., 1978. *State-of-the-Art for Assessing Earthquake Hazards in the United States, Report 6: Faults and Earthquake Magnitude*, U.S. Army Engineer Waterways Experiment Station, Miscellaneous Paper S-73-1, Vicksburg, Mississippi.
- Slemmons, D. B., 1969. "New Methods for Studying Regional Seismicity and Surface Faulting," in *Geoscience*, Vol. 10, Article 1, pp. 91-103.
- Smith, R. B. and M. L. Sbar, 1974. "Contemporary Tectonics and Seismicity of the Western United States with Emphasis on the Intermountain Seismic Belt," in Geological Society of America *Bulletin*, Vol. 85, August, 1974, pp. 1205-1218.
- Spitzer, R., 1987. Personal communication with G. Lindsey, Sergeant, Hauskins, and Beckwith, Albuquerque, New Mexico, regarding fault study for dam sites for Chen and Associates, June 15, 1987.
- Steele et al. (Timothy D. Steele, D. P. Bauer, D. A. Wentz and J. W. Warner), 1979. "The Yampa River Basin, Colorado and Wyoming, A Review of Expanded Coal-Resource Development and Its Impacts on Regional Water Resources," Water Resource Investigation 78-126, U.S. Geological Survey, Lakewood, Colorado.
- Stockton, C. W., and G. C. Jacoby, 1976. *Long-Term Surface-Water Supply and Streamflow Trends in the Upper Colorado River Basin, Based on Tree-Ring Analyses*, University of California, Los Angeles Institute for Geophysics and Planetary Physics, Lake Powell Research Project, Bulletin 18, Los Angeles, California.
- Stone, D. S., 1986. "Seismic and Borehole Evidence for Important Pre-Laramide Faulting along the Axial Arch in Northwest Colorado," in *New Interpretations of Northwest Colorado Geology*, published by Rocky Mountain Association of Geologists, Denver, Colorado.
- Stone and Webster (D. S. Stone and Webster Engineering Corporation), 1986. "Preliminary Design Concept for Sandstone Dam and Reservoir," for Wyoming Water Development Commission.
- Thenhaus et al. (P. C. Thenhaus, S. T. Algermissen, and D. M. Perkins), 1982. "A New Seismic Source Zone Map for the Conterminous U.S.," Geological Society of America, Vol. 14, No. 7, p. 630.

- Thompson, G. A., and M. L. Zoback, 1979. "Regional Geophysics of the Colorado Plateau," in *Tectonophysics*, Vol. 61, pp. 149-181.
- Tweto, O., 1980. "Summary of Laramide Orogeny in Colorado," in *Colorado Geology*, Rocky Mountain Association of Geologists, 1980 Symposium, Denver, Colorado, pp. 129-134.
- Tweto, O., 1979. *Geologic Map of Colorado*, U.S. Geological Survey in Cooperation with Geological Society of Colorado.
- Tweto, O., 1976. "Geologic Map of the Craig 1° x 2° Quadrangle, Northwestern Colorado," U.S. Geological Survey Map 1-972.
- Tweto, O., 1973. "Laramide (Late Cretaceous-Early Tertiary) Orogeny in the Southern Rocky Mountains," in *Cenozoic History of the Southern Rocky Mountains*, by the Geological Society of America, Inc., Memoir 144, Boulder, Colorado.
- URS Company, 1976. "Meteorology Affecting Uranium Tailings Near Maybell, Colorado," unpublished report prepared for Ford, Bacon & Davis Utah Inc., Salt Lake City, Utah.
- USGS (U.S. Geological Survey), 1976. Topographic Map of Maybell, Colorado Quadrangle. Published in Denver, Colorado.
- USGS (U.S. Geological Survey), 1969. Map of Lay, Colorado, Quadrangle. Published in Denver, Colorado.
- Von Hake, Carl, 1987. National Geophysical Data Center/National Oceanic and Atmospheric Administration, personal communication with G. Lindsey, Sergeant, Hauskins, and Beckwith, Albuquerque, New Mexico, on 1891 earthquake location, April, 1987.
- Waechter, N. B., and W. Johnson, 1986. "Pennsylvanian-Permian Paleo-structure and Stratigraphy as Interpreted from Seismic Data in the Piceance Basin, Northwest Colorado," in *New Interpretations of Northwest Colorado Geology*, by Rocky Mountain Association of Geologists, Denver, Colorado.
- Wallace R. E., 1982. "Patterns and Timing of Late Quaternary Faulting in the Great Basin Province and Relation to Some Regional Tectonic Features," in *Proceedings of the Chapman Conference*, Snowbird, Utah.
- Warner, L. A., 1980. "The Colorado Lineament," in *Colorado Geology*, eds. H. C. Kent and K. W. Porter, Rocky Mountain Association of Geologists, 1980 Symposium, Denver, Colorado, pp. 11-21.
- Wells, S. G. and T. W. Gardner, 1985. "Geomorphic Criteria for Selecting Stable Uranium Tailings Disposal Sites in New Mexico," Vol. I, Technical Report, New Mexico Energy Research and Development Institute, Santa Fe, New Mexico.

Zoback, M. L., and M. D. Zoback, 1980. "State of Stress in the Contiguous United States," in *Journal of Geophysical Research*, Vol. 85, pp. 6113-6156.

CODE OF FEDERAL REGULATIONS

10 CFR Part 100, *Reactor Site Criteria*, U.S. Nuclear Regulatory Commission (1993).

40 CFR Part 192, *Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings*, U.S. Environmental Protection Agency (1993).

FEDERAL REGISTER

52 FR 36000, *Standards for Remedial Actions at Inactive Uranium Processing Sites; Proposed Rule*, September 24, 1987.

**DATE
FILMED**

10/19/94

END